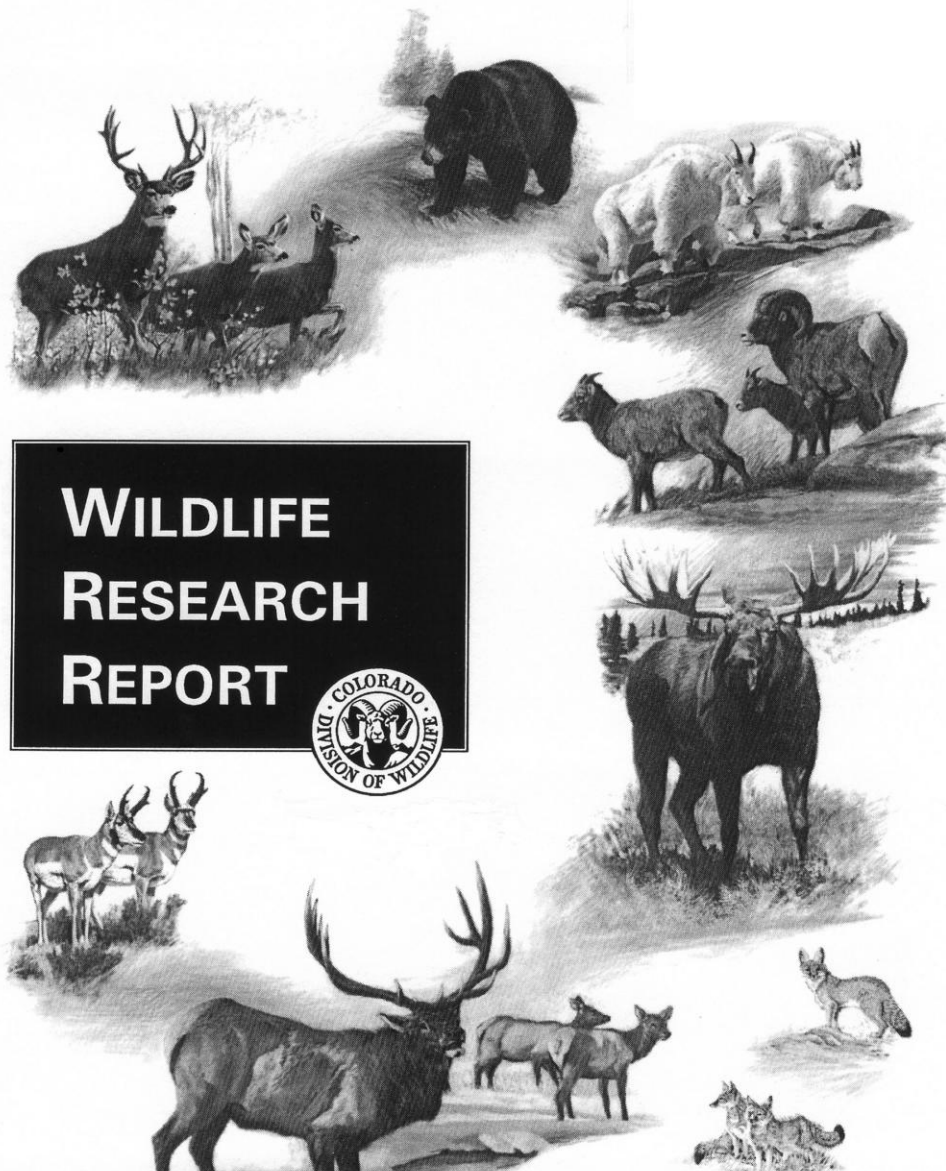
MAMMALS - JULY 2008



WILDLIFE RESEARCH REPORTS

JULY 2007 – JUNE 2008

MAMMALS PROGRAM

COLORADO DIVISION OF WILDLIFE
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Colorado Division of Wildlife
July 2007 – June 2008

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Colorado Division of Wildlife
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WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	0670	:	Lynx Conservation
Task No.:	1	:	Post-Release Monitoring of Lynx
		:	Reintroduced to Colorado
Federal Aid Project No.	N/A		

Period Covered: July 1, 2007 - June 30, 2008

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ABSTRACT

In an effort to establish a viable population of Canada lynx (*Lynx canadensis*) in Colorado, the Colorado Division of Wildlife (CDOW) initiated a reintroduction effort in 1997 with the first lynx released in February 1999. From 1999-2007, 218 wild-caught lynx from Canada and Alaska were released in Colorado. We documented survival, movement patterns, reproduction, and landscape habitat-use through aerial (n = 10,935) and satellite (n = 26,082) tracking. Most lynx remained near the core release area in southwestern Colorado. From 1999-August 2008, there were 112 mortalities of released adult lynx. Approximately 30.4% were either human-induced or likely human-induced through either collisions with vehicles or gunshot. Starvation and disease/illness accounted for 18.8% of the deaths while 36.6% of the deaths were from unknown causes. Of these mortalities, 26.8% occurred outside of Colorado. Monthly mortality rate was lower inside the study area than outside, and slightly higher for male than for female lynx, although 95% confidence intervals for sexes overlapped. Mortality was higher immediately after release (first month = 0.0368 [SE = 0.0140] inside the study area, and 0.1012 [SE = 0.0359] outside the study area), and then decreased according to a quadratic trend over time. Reproductive females had the smallest 90% utilization distribution home ranges ($\bar{x}$ = 75.2 km^2, SE = 15.9 km^2), followed by attending males ($\bar{x}$ = 102.5 km^2, SE = 39.7 km^2) and non-reproductive animals ($\bar{x}$ = 653.8 km^2, SE = 145.4 km^2). Reproduction was first documented in 2003 with subsequent successful reproduction in 2004, 2005 and 2006. No dens were documented in 2007 or 2008. From snow-tracking, the primary winter prey species (n = 548 kills) were snowshoe hare (*Lepus americanus*, annual $\bar{x}$ = 73.3%, SE = 4.7, n = 10) and red squirrel (*Tamiasciurus hudsonicus*, annual $\bar{x}$ = 18.2%, SE = 4.2, n = 10); other mammals and birds formed a minor part of the winter diet. Lynx use-density surfaces were generated to illustrate relative use of areas throughout Colorado. Within the areas of high use in southwestern Colorado, site-scale habitat use, documented through snow-tracking, supports mature

Engelmann spruce (*Picea engelmannii*)-subalpine fir (*Abies lasiocarpa*) forest stands with 42-65% canopy cover and 15-20% conifer understory cover as the most commonly used areas in southwestern Colorado. Little difference in aspect (slight preference for north-facing slopes), slope ($\bar{x}$ = 15.7°) or elevation ($\bar{x}$ = 3173 m) were detected for long beds, travel and kill sites (n = 1841). Den sites (n = 37) however, were located at higher elevations ($\bar{x}$ = 3354 m, SE = 31 m) on steeper ($\bar{x}$ = 30°, SE = 2°) and more commonly north-facing slopes with a dense understory of coarse woody debris. Two years of a study to evaluate snowshoe hare densities, demography and seasonal movement patterns among small and medium tree-sized lodgepole pine stands and mature spruce/fir stands have been completed in 2006-2008 and will continue through 2009 (see Appendix I of this report). Results to date have demonstrated that CDOW has developed lynx release protocols that ensure high initial post-release survival followed by high long-term survival, site fidelity, reproduction and recruitment of Colorado-born lynx into the Colorado breeding population. What is yet to be demonstrated is whether Colorado can support sufficient recruitment to offset annual mortality for a viable lynx population over time. Monitoring continues in an effort to document such viability.

WILDLIFE RESEARCH REPORT

POST RELEASE MONITORING OF LYNX (*LYNX CANADENSIS*) REINTRODUCED TO COLORADO

TANYA M. SHENK

P. N. OBJECTIVE

The initial post-release monitoring of Canada lynx (*Lynx canadensis*) reintroduced into Colorado will emphasize 5 primary objectives:

1. Assess and modify release protocols to ensure the highest probability of survival for each lynx released.
2. Obtain regular locations of released lynx to describe general movement patterns and habitats used by lynx.
3. Determine causes of mortality in reintroduced lynx.
4. Estimate survival of lynx reintroduced to Colorado.
5. Estimate reproduction of lynx reintroduced to Colorado.

Three additional objectives will be emphasized after lynx display site fidelity to an area:

6. Refine descriptions of habitats used by reintroduced lynx.
7. Refine descriptions of daily and overall movement patterns of reintroduced lynx.
8. Describe hunting habits and prey of reintroduced lynx.

Information gained to achieve these objectives will form a basis for the development of lynx conservation strategies in the southern Rocky Mountains.

SEGMENT OBJECTIVES

1. Complete winter 2007-08 field data collection on lynx habitat use at the landscape scale, hunting behavior, diet, mortalities, and movement patterns.
2. Complete winter 2007-08 lynx trapping field season to collar Colorado born lynx and re-collar adult lynx.
3. Complete spring 2008 field data on lynx reproduction.
4. Summarize and analyze data and publish information as Progress Reports, peer-reviewed manuscripts for appropriate scientific journals, or CDOW technical publications.
5. Complete the second year of field work to evaluate snowshoe hare (*Lepus americanus*) densities, demography and seasonal movement patterns among small and medium tree-sized lodgepole pine stands and mature spruce/fir stands (see Appendix I).

INTRODUCTION

The Canada lynx occurs throughout the boreal forests of northern North America. Colorado represents the southern-most historical distribution of lynx, where the species occupied the higher elevation, montane forests in the state. Little was known about the population dynamics or habitat use of this species in their southern distribution. Lynx were extirpated or reduced to a few animals in the state by the late 1970’s due, most likely, to predator control efforts such as poisoning and trapping. Given the isolation of Colorado to the nearest northern populations, the CDOW considered reintroduction as the only option to attempt to reestablish the species in the state.

A reintroduction effort was begun in 1997, with the first lynx released in Colorado in 1999. To date, 218 wild-caught lynx from Alaska and Canada have been released in southwestern Colorado. The goal of the Colorado lynx reintroduction program is to establish a self-sustaining, viable population of lynx in this state. Evaluation of incremental achievements necessary for establishing viable populations is an interim method of assessing if the reintroduction effort is progressing towards success. There are 7 critical criteria for achieving a viable population: 1) development of release protocols that lead to a high initial post-release survival of reintroduced animals, 2) long-term survival of lynx in Colorado, 3) development of site fidelity by the lynx to areas supporting good habitat in densities sufficient to breed, 4) reintroduced lynx must breed, 5) breeding must lead to reproduction of surviving kittens 6) lynx born in Colorado must reach breeding age and reproduce successfully, and 7) recruitment must equal or be greater than mortality over an extended period of time.

The post-release monitoring program for the reintroduced lynx has 2 primary goals. The first goal is to determine how many lynx remain in Colorado and their locations relative to each other. Given this information and knowing the sex of each individual, we can assess whether these lynx can form a breeding core from which a viable population might be established. From these data we can also describe general movement patterns and habitat use. The second primary goal of the monitoring program is to estimate survival of the reintroduced lynx and, where possible, determine causes of mortality for reintroduced lynx. Such information will help in assessing and modifying release protocols and management of lynx once they have been released to ensure their highest probability of survival.

Additional goals of the post-release monitoring program for lynx reintroduced to the southern Rocky Mountains included refining descriptions of habitat use and movement patterns and describing successful hunting habitat once lynx established home ranges that encompassed their preferred habitat. Specific objectives for the site-scale habitat data collection include: 1) describe and quantify site-scale habitat use by lynx reintroduced to Colorado, 2) compare site-scale habitat use among types of sites (e.g., kills vs. long-duration beds), and 3) compare habitat features at successful and unsuccessful snowshoe hare chases.

Documenting reproduction is critical to the success of the program and lynx are monitored intensively to document breeding, births, survival and recruitment of lynx born in Colorado. Site-scale habitat descriptions of den sites are also collected and compared to other sites used by lynx.

The program will also investigate the ecology of snowshoe hare in Colorado. A study comparing snowshoe hare densities among mature stands of Engelmann spruce (*Picea engelmannii*)/subalpine fir (*Abies lasiocarpa*), lodgepole pine (*Pinus contorta*) and Ponderosa pine (*Pinus ponderosa*) was completed in 2004 with highest hare densities found in Engelmann spruce/subalpine fir stands and no hares found in Ponderosa pine stands. A study to evaluate the importance of young, regenerating lodgepole pine and mature Engelmann spruce/subalpine fir stands in Colorado by examining density and demography of snowshoe hares that reside in each was initiated in 2005 and will continue through 2009 (see Appendix I).

Lynx is 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). Colorado is included in the federal listing as lynx habitat. Thus, an additional objective of the post-release monitoring program is to develop conservation strategies relevant to lynx in Colorado. To develop these conservation strategies, information specific to the ecology of the lynx in its southern Rocky Mountain range, such as habitat use, movement patterns, mortality factors, survival, and reproduction in Colorado is needed.

STUDY AREA

Byrne (1998) evaluated five areas within Colorado as potential lynx habitat based on (1) relative snowshoe hare densities (Bartmann and Byrne 2001), (2) road density, (3) size of area, (4) juxtaposition of habitats within the area, (5) historical records of lynx observations, and (6) public issues. Based on results from this analysis, the San Juan Mountains of southwestern Colorado were selected as the core reintroduction area, and where all lynx were reintroduced. Wild Canada lynx captured in Alaska, British Columbia, Manitoba, Quebec and Yukon were transported to Colorado and held at The Frisco Creek Wildlife Rehabilitation Center located within the reintroduction area prior to release.

Post-release monitoring efforts were focused in a 20,684 km^2 study area which included the core reintroduction area, release sites and surrounding high elevation sites (> 2,591 m). The area encompassed the southwest quadrant of Colorado and was bounded on the south by New Mexico, on the west by Utah, on the north by interstate highway 70, and on the east by the Sangre de Cristo Mountains (Figure 1). Southwestern Colorado is characterized by wide plateaus, river valleys, and rugged mountains that reach elevations over 4,200 m. Engelmann spruce/subalpine fir is the most widely distributed coniferous forest type within the study area. The lynx-established core area is roughly bounded by areas used by lynx in the Taylor Park/Collegiate Peak areas in central Colorado and includes areas of continuous use by lynx, including areas used during breeding and denning (Figure 1).

METHODS

REINTRODUCTION

Effort

Wild Canada lynx were captured in Alaska, British Columbia, Manitoba, Quebec and Yukon and transported to Colorado where they were held at the Frisco Creek Wildlife Rehabilitation Center prior to release. All lynx releases were conducted under the protocols found to maximize survival (see Shenk 2001). Estimated age, sex and body condition were ascertained and recorded for each lynx prior to release (see Wild 1999). Lynx were transported from the rehabilitation facility to their release site in individual cages. Specific release site locations were recorded in Universal Transverse Mercator (UTM) coordinates and identification of all lynx released at the same location, on the same day, was recorded. Behavior of the lynx on release and movement away from the release site were documented.

Movement, Distribution and Relative Use of Areas by Lynx

To monitor lynx movements and thus determine distribution and relative use of areas all released lynx were fitted with radio collars. All lynx released in 1999 were fitted with Telonics™ radio-collars. All lynx released since 1999, with the exception of 5 males released in spring 2000, were fitted with Sirtrack™ dual satellite/VHF radio-collars. These collars have a mortality indicator switch that operated on both the satellite and VHF mode. The satellite component of each collar was programmed to be active for 12 hours per week. The 12-hour active periods for individual collars were staggered throughout the week. Signals from the collars allowed for locations of the animals to be made via Argos, NASA, and NOAA satellites. The location information was processed by ServiceArgos and distributed to the CDOW through e-mail messages.

Datasets.-- To determine recent (post-reintroduction) movement and distribution of lynx reintroduced, born or initially trapped in Colorado and relative use of areas by these lynx, regular locations of lynx were collected through a combination of aerial and satellite tracking. Locations were recorded and general habitat descriptions for each aerial location was recorded. The first dataset of lynx locations included all locations obtained from daytime flights conducted with a Cessna 185 or similar aircraft to locate lynx by their VHF collar transmitters (hereafter aerial locations). VHF transmitters have been used on lynx since the first lynx were released in February 1999. The second type of lynx location data was collected via satellite from the satellite collar transmitters placed on the lynx (hereafter satellite locations). Satellite transmitter collars were first used for lynx in April 2000. These satellite collars also contained a VHF transmitter which also allowed locating lynx from the air or ground. All locations were recorded in Universal Transverse Mercator (UTM) coordinates using the CONUS NAD27 datum.

Flights to obtain lynx aerial locations were typically conducted on a weekly basis throughout most summer and winter months and twice a week during the den search field season (May 15 – June 30), depending on weather and availability of planes and pilots. Flights were typically concentrated in the high elevation (> 2700 m) southwest quadrant of Colorado which encompasses the core lynx release and research area (Figure 1). Flights during the den seasons were conducted to obtain locations on all female lynx within the state wearing an active VHF transmitter. VHF transmitters were outfitted with sufficient batteries to last 60 months. The satellite transmitters were designed to provide locations on a weekly basis with sufficient batteries to last for 18 months.

Lynx may not be exhibiting typical behavior or habitat use within the first few months after their release in Colorado. Therefore, a subset of each of the aerial and satellite datasets was created that eliminated the first 180 days (approximately 6 months) of locations obtained for each lynx immediately after their initial release. As a result, the truncated aerial location dataset contained lynx locations from September 1999 through March 2007 while the truncated satellite location dataset began October 2000 and extended through March 2007.

Accuracy of both aerial and satellite locations varied with the environmental conditions at the time the location was obtained. Accuracy of aerial locations was influenced by weather with accuracy ranging from 50 - 500 meters. Satellite location accuracy was also influenced by atmospheric conditions and position of the satellites. Satellite location accuracy ranged from 150 meters -10 km.

Movement and Distribution.-- To document all known lynx locations maps were generated with all aerial and satellite locations displayed. Due to lynx movements outside of Colorado, particularly into the states of New Mexico, Utah and Wyoming we further evaluated lynx use throughout those three states, as well as the data would allow. All individual lynx located at least once in these 3 states (non-truncated datasets) were identified and tallied for each year. To document consistency and known use of these states after the initial effect of being reintroduced was minimized (i.e., 180 days post-release), each individual lynx located at least once in these states from the truncated datasets were identified and tallied.

Relative Use.-- To document relative use of areas by lynx, 90% kernel use-density surfaces were calculated for truncated satellite and aerial lynx locations using the ArcGIS Spatial Analyst Kernel Density Tool. Due to differences in data collection frequency and accuracy between datasets, the truncated satellite and truncated aerial data were analyzed separately for generating the lynx use-density surfaces.

These use-density surfaces fit a smoothly curved surface over each lynx location. The surface value was highest at the location of the point and diminished with increasing distance from the point. A fixed kernel was used with a smoothing parameter of 5 km, reaching 0 at the search radius distance from the point. Only a circular neighborhood was possible. The volume under the surface equaled the total value for the point. The use-density at each output GIS raster cell was calculated by adding the values of all the kernel surfaces from all the lynx point locations that overlaid each raster cell center. The kernel function was based on the quadratic kernel function described in Silverman (1986, p. 76, equation 4.5). The use-density surfaces were calculated at 100 m resolution. To enhance graphic displays of higher use-density areas, density values representing single locations were not displayed.

Home Range

Annual home ranges were calculated as a 95% utilization distribution using a kernel home-range estimator for each lynx we had at least 30 locations for within a year. A year was defined as March 15 – March 14 of the following year. Locations used in the analyses were collected from September 1999 – January 2006 and all locations obtained for an individual during the first six months after its release were eliminated from any home range analyses as it was assumed movements of lynx initially post-release may not be representative of normal habitat use. Locations were obtained either through aerial VHF surveys or locations or the midpoint (ArcView Movement Extension) of all high quality (accuracy rating of 0-1km) satellite locations obtained within a single 24-hour period. All locations used within a single home range analysis were taken a minimum of 24 hours apart.

Home range estimates were classified as being for a reproductive or non-reproductive animal. A reproductive female was defined as one that had kittens with her; a reproductive male was defined as a male whose movement patterns overlapped that of a reproductive female. If a litter was lost within the defined year a home range described for a reproductive animal were estimated using only locations obtained while the kittens were still with the female.

Survival

Multi-state mark-recapture models were used to estimate monthly mortality rates and described in detail in Devineau et al. 2008 (*in review*). This approach accommodated missing data and allowed exploration of factors possibly affecting lynx survival such as sex, time spent in pre-release captivity, movement patterns, and origin.

Mortality Factors

When a mortality signal (75 beats per minute [bpm] vs. 50 bpm for the Telonics™ VHF transmitters, 20 bpm vs. 40 bpm for the Sirtrack™ VHF transmitters, 0 activity for Sirtrack™ PTT) was heard during either satellite, aerial or ground surveys, the location (UTM coordinates) was recorded. Ground crews then located and retrieved the carcass as soon as possible. The immediate area was searched for evidence of other predators and the carcass photographed in place before removal. Additionally, the mortality site was described and habitat associations and exact location were recorded. Any scat found near the dead lynx that appeared to be from the lynx was collected.

All carcasses were transported to the Colorado State University Veterinary Teaching Hospital (CSUVTH) for a post mortem exam to 1) determine the cause of death and document with evidence, 2) collect samples for a variety of research projects, and 3) archive samples for future reference (research or forensic). The gross necropsy and histology were performed by, or under the lead and direct supervision of a board certified veterinary pathologist. At least one research personnel from the CDOW involved with the lynx program was also present. The protocol followed standard procedures used for thorough post-mortem examination and sample collection for histopathology and diagnostic testing (see Shenk 1999 for details). Some additional data/samples were routinely collected for research, forensics, and archiving. Other data/samples were collected based on the circumstances of the death (e.g., photographs, video, radiographs, bullet recovery, samples for toxicology or other diagnostic tests, etc.).

From 1999–2004 the CDOW retained all samples and carcass remains with the exception of tissues in formalin for histopathology, brain for rabies exam, feces for parasitology, external parasites for ID, and other diagnostic samples. Since 2005 carcasses are disposed of at the CSUVTH with the exception of the lower canine, fecal samples, stomach content samples and tissue or bone marrow samples to be delivered by CDOW to the Center for Disease control for plague testing. The lower canine, from all carcasses, is sent to Matson Labs (Missoula, Montana) for aging and the fecal and stomach content samples are evaluated for diet.

Reproduction

Females were monitored for proximity to males during each breeding season. We defined a possible mating pair as any male and female documented within at least 1 km of each other in breeding season through either flight data or snow-tracking data. Females were then monitored for site fidelity to a given area during each denning period of May and June. Each female that exhibited stationary movement patterns in May or June were closely monitored to locate possible dens. Dens were found when field crews walked in on females that exhibited virtually no movement for at least 10 days from both aerial and ground telemetry.

Kittens found at den sites were weighed, sexed and photographed. Each kitten was uniquely marked by inserting a sterile passive integrated transponder (PIT, Biomark, Inc., Boise, Idaho, USA) tag subcutaneously between the shoulder blades. Time spent at the den was minimized to ensure the least amount of disturbance to the female and the kittens. Weight, PIT-tag number, sex and any distinguishing characteristics of each kitten was also recorded. Beginning in 2005, blood and saliva samples were collected and archived for genetic identification.

During the den site visits, den site location was recorded as UTM coordinates. General vegetation characteristics, elevation, weather, field personnel, time at the den, and behavioral responses of the kittens and female were also recorded. Once the females moved the kittens from the natal den area, den sites were visited again and site-specific habitat data were collected (see Habitat Use section below).

Captures

Captures were attempted for either lynx that were in poor body condition or lynx that needed to have their radio-collars replaced due to failed or failing batteries or to radio-collar kittens born in Colorado once they reached at least 10-months of age when they were nearly adult size. Methods of recapture included 1) trapping using a Tomahawk™ live trap baited with a rabbit and visual and scent lures, 2) calling in and darting lynx using a Dan-Inject CO_2 rifle, 3) custom box-traps modified from those designed by other lynx researchers (Kolbe et al. 2003) and 4) hounds trained to pursue felids were also used to tree lynx and then the lynx was darted while treed. Lynx were immobilized either with Telazol (3 mg/kg; modified from Poole et al. 1993 as recommended by M. Wild, DVM) or medetomidine (0.09mg/kg) and ketamine (3 mg/kg; as recommended by L. Wolfe, DVM)) administered intramuscularly (IM) with either an extendible pole-syringe or a pressurized syringe-dart fired from a Dan-Inject air rifle.

Immobilized lynx were monitored continuously for decreased respiration or hypothermia. If a lynx exhibited decreased respiration 2mg/kg of Dopram was administered under the tongue; if respiration was severely decreased, the animal was ventilated with a resuscitation bag. If medetomidine/ketamine were the immobilization drugs, the antagonist Atipamezole hydrochloride (Antisedan) was administered. Hypothermic (body temperature < 95^{o} F) animals were warmed with hand warmers and blankets.

While immobilized, lynx were fitted with replacement Sirtrack™ VHF/satellite collar and blood and hair samples were collected. Once an animal was processed, recovery was expedited by injecting the equivalent amount of the antagonist Antisedan IM as the amount of medetomidine given, if medetomodine/ketemine was used for immobilization. Lynx were then monitored while confined in the box-trap until they were sufficiently recovered to move safely on their own. No antagonist is available for Telezol so lynx anesthetized with this drug were monitored until the animal recovered on its own in the box-trap and then released. If captured and in poor body condition, lynx were anesthetized with either Telezol (2 mg/kg) or medetomodine/ketemine and returned to the Frisco Creek Wildlife Rehabilitation Center for treatment.

HABITAT USE

Gross habitat use was documented by recording canopy vegetation at aerial locations. More refined descriptions of habitat use by reintroduced lynx were obtained through following lynx tracks in the snow (i.e., snow-tracking) and site-scale habitat data collection conducted at sites found through this method to be used by lynx. See Shenk (2006) for detailed methodologies.

DIET AND HUNTING BEHAVIOR

Winter diet of reintroduced lynx was estimated by documenting successful kills through snow-tracking. Prey species from failed and successful hunting attempts were identified by either tracks or remains. Scat analysis also provided information on foods consumed. Scat samples were collected wherever found and labeled with location and individual lynx identification. Only part of the scat was collected (approximately 75%); the remainder was left in place in the event that the scat was being used by the animal as a territory mark. Site-scale habitat data collected for successful and unsuccessful snowshoe hare kills were compared.

SNOWSHOE HARE ECOLOGY

To further our understanding of snowshoe hare ecology in Colorado, a study was conducted comparing snowshoe hare densities among mature stands of Engelmann spruce/subalpine fir, lodgepole pine (*Pinus contorta*) and Ponderosa pine (*Pinus ponderosa*). The highest hare densities were found in Engelmann spruce/subalpine fir stands and no hares found in Ponderosa pine stands (Zahratka and Shenk 2008). A second study was initiated in 2005 to evaluate the importance of young, regenerating lodgepole pine and mature Engelmann spruce / subalpine fir stands in Colorado by examining density and demography of snowshoe hares that reside in each (Ivan 2005).

Specifically, this study was designed to evaluate small and medium lodgepole pine stands and large spruce/fir stands where the classes “small”, “medium”, and “large” refer to the diameter at breast height (dbh) of overstory trees as defined in the United States Forest Service R2VEG Database (small = 2.54–12.69 cm dbh, medium = 12.70–22.85 cm, and large = 22.86–40.64 cm dbh; J. Varner, United States Forest Service, personal communication). The study design was also developed to identify which of the numerous hare density-estimation procedures available perform accurately and consistently using an innovative, telemetry augmentation approach as a baseline. In addition, movement patterns and seasonal use of deciduous cover types such as riparian willow were assessed. Finally, the study was designed to further expound on the relationship between density, demography, and stand-type by examining how snowshoe hare density and demographic rates vary with specific vegetation, physical, and landscape characteristics of a stand.

RESULTS

REINTRODUCTION

Effort

From 1999 through 2006, 218 wild-caught lynx were reintroduced into southwestern Colorado (Table 1). No lynx were released in 2007 or 2008. All lynx were released with either VHF or dual VHF/satellite radio collars so they could be monitored for movement, reproduction and survival. The CDOW does not plan to release any additional lynx in 2009.

Movement Patterns and Distribution

Numerous travel corridors were used repeatedly by more than one lynx. These travel corridors include the Cochetopa Hills area for northerly movements, the Rio Grande Reservoir-Silverton-Lizardhead Pass for movements to the west, and southerly movements down the east side of Wolf Creek Pass to the southeast through the Conejos River Valley. Lynx appear to remain faithful to an area during winter months, and exhibit more extensive movements away from these areas in the summer.

A total of 10,935 aerial and 26,082 satellite locations were obtained from the 218 reintroduced lynx, radio-collared Colorado kittens (n = 14) and unmarked lynx captured in Colorado (n = 2) as of August 27, 2008. The majority of these locations were in Colorado (Figure 2). Some reintroduced lynx dispersed outside of Colorado into Arizona, Idaho, Iowa, Kansas, Montana, Nebraska, Nevada, New Mexico, South Dakota, Utah and Wyoming (Figure 2). The majority of surviving lynx from the reintroduction effort currently continue to use high elevation (> 2900 m), forested terrain in an area bounded on the south by New Mexico north to Independence Pass, west as far as Taylor Mesa and east to Monarch Pass. Most movements away from the Core Release Area were to the north.

Relative Use

The lynx use-density surfaces resulting from the fixed kernel analyses provided relative probabilities of finding lynx in areas throughout their distribution. A single use-density surface was calculated separately for both the aerial (n = 8058) and satellite truncated datasets (n = 16240).

All 218 lynx released in Colorado, all radio-collared kittens and 2 captured unmarked adults were located at least once in Colorado. The majority of these lynx remained in Colorado. The use-density surfaces within Colorado were displayed separately for both the aerial (Figure 3) and satellite truncated datasets (Figure 4). Of the total locations available in the truncated datasets used to generate the use-density surfaces, 7953 of the aerial locations and 13,241 of the satellite locations were in Colorado. Aerial and satellite use-density surfaces indicated similar high use-density areas. Satellite locations indicated broader spatial use by lynx because satellite collars provided more locations than flights.

The use-density surface for lynx use in Colorado indicates two primary areas of use. The first is the Core Research Area (see Figure 1) and a secondary core centered in the Collegiate Peaks Wilderness (Figures 1, 3 and 4). High use is also documented for 1) the area east of Dillon, on both the north and south sides of I70 and 2) the area north of Hwy 50 centered around Gunnison and then north to Crested Butte. These last 2 high use areas are smaller in extent than the 2 core areas.

Relative use-density surfaces were also generated for New Mexico, Wyoming and Utah and presented in detail in Shenk (2007).

Home Range

Reproductive females had the smallest 90% utilization distribution annual home ranges ($\bar{x}$ = 75.2 km^2, SE = 15.9 km^2, n = 19), followed by attending males ($\bar{x}$ = 102.5 km^2, SE = 39.7 km^2, n = 4). Non-reproductive females had the largest annual home ranges ($\bar{x}$ = 703.9 km^2, SE = 29.8 km^2, n = 32) followed by non-reproductive males ($\bar{x}$ = 387.0 km^2, SE = 73.5 km^2, n = 6). Combining all non-reproductive animals yielded a mean annual home range of 653.8 km^2 (SE = 145.4 km^2, n = 38).

Survival

Detailed analyses of lynx mortality was completed and described in Devineau et al. 2008 (*in review*). Monthly mortality rate was lower inside the study area than outside, and slightly higher for male than for female lynx, although 95% confidence intervals for sexes overlapped. Mortality was higher immediately after release (first month = 0.0368 [SE = 0.0140] inside the study area, and 0.1012 [SE = 0.0359] outside the study area), and then decreased according to a quadratic trend over time.

As of August 27, 2008, CDOW was actively monitoring/tracking 45 of the 106 lynx still possibly alive (Table 2). There are 62 lynx that we have not heard signals on since at least August 27, 2007 and these animals are classified as ‘missing’ (Table 2). One of these missing lynx is a mortality of unknown identity, thus only 61 are truly missing. Possible reasons for not locating these missing lynx include 1) long distance dispersal, beyond the areas currently being searched, 2) radio failure, or 3) destruction of the radio (e.g., run over by car). CDOW continues to search for all missing lynx during both aerial and ground searches. Two of the missing lynx released in 2000 are thought to have slipped their collars.

Mortality Factors

Of the total 218 adult lynx released, we have 112 known mortalities as of August 27, 2008 (Table 2). Starvation was a significant cause of mortality in the first year of releases only. The primary known causes of death included 30.4% human-induced deaths which were confirmed or probably caused by collisions with vehicles or gunshot (Table 3). Malnutrition and disease/illness accounted for 18.8% of the deaths. An additional 36.6% of known mortalities were from unknown causes.

Mortalities occurred throughout the areas through which lynx moved, with 26.8% occurring outside of Colorado. The out of state mortalities included 14 in New Mexico, 4 in Wyoming, Utah and Nebraska, and 1 each in Arizona, Kansas, Iowa and Montana (Figure 2, Table 4).

Reproduction

Reproduction was first documented in 2003 when 6 dens and a total of 16 kittens were found in the lynx Core Release Area in southwestern Colorado. Reproduction was also documented in 2004, 2005 and 2006. No dens were found in 2007 or 2008 (Table 5).

Field crews weighed, photographed, PIT-tagged the kittens and checked body condition. Beginning in 2005, we also collected blood samples from the kittens for genetic work in an attempt to confirm paternity Kittens were processed as quickly as possible (11-32 minutes) to minimize the time the kittens were without their mother. While working with the kittens the females remained nearby, often making themselves visible to the field crews. The females generally continued a low growling vocalization the entire time personnel were at the den. In all cases, the female returned to the den site once field crews left the area. At all dens the females appeared in excellent condition, as did the kittens. The kittens weighed from 270-500 grams. Lynx kittens weigh approximately 200 grams at birth and do not open their eyes until they are 10-17 days old.

The percent of tracked females found with litters in 2006 was lower (0.095) than in the 3 previous years (0.413, SE = 0.032, Table 5). However, all demographic and habitat characteristics measured at the 4 dens that were found in 2006 were comparable to all other dens found. Mean number of kittens per litter from 2003-2006 was 2.78 (SE = 0.05) and sex ratio of females to males was equal ($\bar{x}$ = 1.14, SE = 0.14). More details of reproduction in 2003-06 were presented in Shenk (2007).

Den Sites.-- A total of 37 dens were found from 2003-2006. All of the dens except one have been scattered throughout the high elevation areas of Colorado, south of I-70. In 2004, 1 den was found in southeastern Wyoming, near the Colorado border. Dens were located on steep ($\bar{x}_{slope} = 30^{o}$, SE=2^{o}), north-facing, high elevation ($\bar{x}$ = 3354 m, SE = 31 m) slopes. The dens were typically in Engelmann spruce/subalpine fir forests in areas of extensive downfall of coarse woody debris (Shenk 2006). All dens were located within the winter use areas used by the females. No dens were found in either 2007 or 2008 even though up to 34 adult females were monitored intensively during the denning period (Table 5).

Captures

Two adult lynx were captured in 2001 for collar replacement. One lynx was captured in a tomahawk live-trap, the other was treed by hounds and then anesthetized using a jab pole. Five adult lynx were captured in 2002; 3 were treed by hounds and 2 were captured in padded leghold traps. In 2004, 1 lynx was captured with a Belisle snare and 6 adult lynx were captured in box-traps. Trapping effort was substantially increased in winter and spring 2005 and 12 adult lynx were captured and re-collared. Eight reintroduced lynx were captured in winter and spring 2006. In 2007, 11 reintroduced adult lynx were captured and re-collared and an additional 10 in 2008. All lynx captured in Colorado from 2005-2008 were caught in box-traps.

In addition, as part of the collaring trapping effort, 14 Colorado-born kittens were captured and collared at approximately 10-months of age. Seven 2004-born kittens were collared in spring 2005, and 7, 2005-born kittens were collared in spring 2006. We were not successful at capturing and collaring any kittens born in 2006 in winter 2006-07. We did however, capture 2 adults (approximate age 2 years old) in winter 2006-07 that had no PIT-tags or radio collars. We assume these 2 lynx were from litters born in Colorado that were never found at dens (i.e., why there were no PIT-tags). All lynx captured for collaring or re-collaring were fitted with new Sirtrack ™ dual VHF/satellite collars and re-released at their capture locations.

Seven adult lynx were captured from March 1999-August 27, 2008 because they were in poor body condition (Table 6). Five of these lynx were successfully treated at the Frisco Creek Rehabilitation Center and re-released in the Core Release Area. One lynx, BC00F07, died from starvation and hypothermia within 1 day of capture at the rehabilitation center. Lynx QU04M07 died 3 days after capture at the rehabilitation center. Necropsy results documented starvation as the cause of death for this lynx that was precipitated by hydrocephalus and bronchopneumonia (unpublished data T. Spraker, CSUVTH).

Seven lynx were captured (either by CDOW personnel or conservation personnel in other states) because they were in atypical habitat outside the state of Colorado (Table 6). They were held at Frisco Creek Rehabilitation Center for a minimum of 3 weeks, fitted with new Sirtrack ™ dual VHF/satellite collars and re-released in the Core Release Area in Colorado. Five of these 7 lynx were still alive 6 months post-re-release but 3 had already dispersed out of Colorado and 1 stayed in Colorado through August 27, 2008. Two of these lynx died within 6 months of re-release: 1 died of starvation in Colorado and the other died of unknown causes in Nebraska. One lynx captured out of state and re-released currently remains in Colorado.

HABITAT USE

Landscape-scale daytime habitat use was documented from 9496 aerial locations of lynx collected from February 1999-June 30, 2007. Throughout the year Engelmann spruce - subalpine fir was the dominant cover used by lynx. A mix of Engelmann spruce, subalpine fir and aspen (*Populus tremuloides*) was the second most common cover type used throughout the year. Various riparian and riparian-mix areas were the third most common cover type where lynx were found during the daytime flights. Use of Engelmann spruce-subalpine fir forests and Engelmann spruce-subalpine fir-aspen forests was similar throughout the year. There was a trend in increased use of riparian areas beginning in July, peaking in November, and dropping off December through June.

Site-scale habitat data collected from snow-tracking efforts indicate Engelmann spruce and subalpine fir were also the most common forest stands used by lynx for all activities during winter in southwestern Colorado. Comparisons were made among sites used for long beds, dens, travel and where they made kills. Little difference in aspect, mean slope and mean elevation were detected for 3 of the 4 site types including long beds, travel and kills where lynx typically use gentler slopes ($\bar{x} = 15.7^{o}$) at an mean elevation of 3173 m, and varying aspects with a slight preference for north-facing slopes. See Shenk (2006) for more detailed analyses of habitat use.

DIET AND HUNTING BEHAVIOR

Winter diet of lynx was documented through detection of kills found through snow-tracking. Prey species from failed and successful hunting attempts were identified by either tracks or remains. Scat analysis also provided information on foods consumed. A total of 548 kills were located from February 1999-April 2008. We collected over 950 scat samples from February 1999-April 2008 that will be analyzed for content. In each winter, the most common prey item was snowshoe hare, followed by red squirrel (*Tamiusciurus hudsonicus*; Table 7). The percent of snowshoe hare kills found however, varied annually from a low of 55.56% in 1999 to a high of 90.77% in winter 2002-2003. An annual mean of 73.29% (SE = 4.67) snowshoe hare kills in the diet has been documented.

A comparison of percent overstory for successful and unsuccessful snowshoe hare chases indicated lynx were more successful at sites with slightly higher percent overstory, if the overstory species were Englemann spruce, subalpine fir or willow. Lynx were slightly less successful in areas of greater aspen overstory. This trend was repeated for percent understory at all 3 height categories except that higher aspen understory improved hunting success. Higher density of Engelmann spruce and subalpine fir increased hunting success while increased aspen density decreased hunting success.

SNOWSHOE HARE ECOLOGY

Two years of a 3-year study to evaluate snowshoe hare densities, demography and seasonal movement patterns among small and medium tree-sized lodgepole pine stands and mature spruce/fir stands have been completed and preliminary results presented (see Appendix I).

DISCUSSION

In an effort to establish a viable population of lynx in Colorado, CDOW initiated a reintroduction effort in 1997 with the first lynx released in winter 1999. From 1999 through spring 2007, 218 lynx were released in the Core Release Area.

Locations of each lynx were collected through aerial- or satellite-tracking to document movement patterns and to detect mortalities. Most lynx remain in the high elevation, forested areas in southwestern Colorado. The use-density surfaces for lynx use in Colorado indicate two primary areas of use. The first is the Core Research Area (see Figure 1) and a secondary core centered in the Collegiate Peaks Wilderness (Figures 1, 3, 4). High use is also documented for 1) the area east of Dillon, on both the north and south sides of I70 and 2) the area north of Hwy 50 centered around Gunnison and then north to Crested Butte. These last 2 high use areas are smaller in extent than the 2 core areas.

Dispersal movement patterns for lynx released in 2000 and subsequent years were similar to those of lynx released in 1999 (Shenk 2000). However, more animals released in 2000 and subsequent years remained within the Core Release Area than those released in 1999. This increased site fidelity may have been due to the presence of con-specifics in the area on release. Numerous travel corridors within Colorado have been used repeatedly by more than 1 lynx. These travel corridors include the Cochetopa Hills area for northerly movements, the Rio Grande Reservoir-Silverton-Lizardhead Pass for movements to the west, and southerly movements down the east side of Wolf Creek Pass to the southeast to the Conejos River Valley.

Lynx appear to remain faithful to an area during winter months, and exhibit more extensive movements away from these areas in the summer. Reproductive females had the smallest 90% utilization distribution home ranges ($\bar{x}$ = 75.2 km^2, SE = 15.9 km^2), followed by attending males ($\bar{x}$ = 102.5 km^2, SE = 39.7 km^2) and non-reproductive animals ($\bar{x}$ = 653.8 km^2, SE = 145.4 km^2). Most lynx currently being tracked are within the Core Release Area. During the summer months, lynx were documented to make extensive movements away from their winter use areas. Extensive summer movements away from areas used throughout the rest of the year have been documented in native lynx in Wyoming and Montana (Squires and Laurion 1999).

Current data collection methods used for the Colorado lynx reintroduction program were not specifically designed to address the reintroduced lynx movements or use of areas in other states. In particular, the core research and release area were in Colorado. Therefore, the number of aerial locations obtained would be far fewer in other states than in Colorado which would bias low the number of lynx and intensity of lynx use documented outside the state. In contrast, obtaining satellite locations is not biased by the location of the lynx. Satellite locations are, however, biased by the shorter time the satellite transmitters function, approximately 18 months versus 60 months for the VHF transmitters used to obtain the aerial locations. However, data collected to meet objectives of the lynx reintroduction program were used to provide information to help address the question of lynx use outside of Colorado. Due to the rarity of flights conducted outside Colorado, only use-density surfaces generated from satellite locations were used to document relative lynx use of areas in New Mexico, Utah and Wyoming.

New Mexico and Wyoming have been used continuously by lynx since the first year lynx were released in Colorado (1999) to the present. Lynx reintroduced in Colorado were first documented in Utah in 2000 and are still being documented there to date. In addition, all levels of lynx use-density documented throughout Colorado are also represented in New Mexico, Utah and Wyoming from none to the highest level of use (Shenk 2007). One den was found in Wyoming. Although no reproduction has been documented in New Mexico or Utah to date, documenting areas of the highest intensity of use and the continuous presence of lynx within these states for over six years does suggest the potential for year-round residency of lynx and reproduction in those states.

From 1999-August 2008, there were 112 mortalities of released adult lynx. Human-caused mortality factors are currently the highest causes of death with approximately 30.4% attributed to collisions with vehicles or gunshot. Starvation and disease/illness accounted for 18.8% of the deaths while 36.6% of the deaths were from unknown causes. Lynx mortalities were documented throughout all areas lynx used, including 30 (26.8%) occurring in other states (Figure 2, Table 3). Nearly half (14 of 30) of the out-of-state mortalities were documented in New Mexico. Monthly mortality rate was lower inside the study area than outside, and slightly higher for male than for female lynx, although 95% confidence intervals for sexes overlapped. Mortality was higher immediately after release (first month = 0.0368 [SE = 0.0140] inside the study area, and 0.1012 [SE = 0.0359] outside the study area), and then decreased according to a quadratic trend over time.

Reproduction is critical to achieving a self-sustaining viable population of lynx in Colorado. Reproduction was first documented from the 2003 reproduction season and again in 2004, 2005 and 2006. Lower reproduction occurred in 2006 (Table 5) but did include a Colorado-born female giving birth to 2 kittens, documenting the first recruitment of Colorado-born lynx into the Colorado breeding population. No reproduction was documented in 2007 or 2008. The cause of the decreased reproduction from 2006 - 08 is unknown. One possible explanation would be a decrease in prey abundance.

Additional reproduction is likely to have occurred in all years from females we were no longer tracking, and from Colorado-born lynx that have not been collared. The dens we find are more representative of the minimum number of litters and kittens in a reproduction season. To achieve a viable population of lynx, enough kittens need to be recruited into the population to offset the mortality that occurs in that year and hopefully even exceed the mortality rate to achieve an increasing population.

The use-density surfaces depict intensity of use by location. Why certain areas would be used more intensively than others should be explained by the quality of the habitat in those areas.

Characteristics of areas used by lynx, as documented through aerial locations and snow-tracking of lynx in the Colorado core research area, include mature Engelmann spruce-subalpine fir forest stands with 42-65% canopy cover and 15-20% conifer understory cover (Shenk 2006). Within these forest stand types, lynx appear to have a slight preference for north-facing, moderate slopes ($\bar{x}$ = 15.7°) at high elevations ($\bar{x}$ = 3173 m; Shenk 2006).

Snow-tracking of released lynx also provided information on hunting behavior and diet through documentation of kills, food caches, chases, and diet composition estimated through prey remains. The primary winter prey species (n = 548) were snowshoe hare (Table 7) with an annual $\bar{x}$ = 73.3% (SE = 4.7, n = 10) and red squirrel (annual $\bar{x}$ = 18.2%, SE = 4.2, n = 10). Thus, areas of good habitat must also support populations of snowshoe hare and red squirrel. In winter, lynx reintroduced to Colorado appear to be feeding on their preferred prey species, snowshoe hare and red squirrel in similar proportions as those reported for northern lynx during lows in the snowshoe hare cycle (Aubry et al. 1999). Environmental conditions in the springs and summers of 2003 and 2006 resulted in high cone crops during their following winters based on field observations, resulting in increased red squirrel abundance. This may partially explain the higher percent of red squirrel kills, and thus a lower percent of snowshoe hare kills, found in winters 2003-04 and 2006-07 (Table 7).

Caution must be used in interpreting the proportion of identified kills. Such a proportion ignores other food items that are consumed in their entirety and thus are biased towards larger prey and may not accurately represent the proportion of smaller prey items, such as microtines, in lynx winter diet. Through snow-tracking we have evidence that lynx are mousing and several of the fresh carcasses have yielded small mammals in the gut on necropsy. The summer diet of lynx has been documented to include less snowshoe hare and more alternative prey than in winter (Mowat et al., 1999). All evidence suggests reintroduced lynx are finding adequate food resources to survive.

Mowat et al. (1999) suggest lynx and snowshoe hare select similar habitats except that hares select more dense stands than lynx. Very dense understory limits hunting success of the lynx and provides refugia for hares. Given the high proportion of snowshoe hare in the lynx diet in Colorado, we might then assume the habitats used by reintroduced lynx also depict areas where snowshoes hare are abundant and available for capture by lynx in Colorado. From both aerial locations taken throughout the year and from the site-scale habitat data collected in winter, the most common areas used by lynx are in stands of Engelmann spruce and subalpine fir. This is in contrast to adjacent areas of Ponderosa pine, pinyon juniper, aspen and oakbrush. The lack of lodgepole pine in the areas used by the lynx may be more reflective of the limited amount of lodgepole pine in southwestern Colorado, the Core Release Area, rather than avoidance of this tree species.

Hodges (1999) summarized habitats used by snowshoe hare from 15 studies as areas of dense understory cover from shrubs, stands that are densely stocked, and stands at ages where branches have more lateral cover. Species composition and stand age appears to be less correlated with hare habitat use than is understory structure (Hodges 1999). The stands need to be old enough to provide dense cover and browse for the hares and cover for the lynx. In winter, the cover/browse needs to be tall enough to still provide browse and cover in average snow depths. Hares also use riparian areas and mature forests with understory. Site-scale habitat use documented for lynx in Colorado indicate lynx are most commonly using areas with Engelmann spruce understory present from the snow line to at least 1.5 m above the snow. The mean percent understory cover within the habitat plots is typically less than 15% regardless of understory species. However, if the understory species is willow, percent understory cover is typically double that, with mean number of shrubs per plot approximately 80, far greater than for any other understory species.

In winter, hares browse on small diameter woody stems (<0.25"), bark and needles. In summer, hares shift their diet to include forbs, grasses, and other succulents as well as continuing to browse on woody stems. This shift in diet may express itself in seasonal shifts in habitat use, using more or denser coniferous cover in winter than in summer. The increased use of riparian areas by lynx in Colorado from July to November may reflect a seasonal shift in hare habitat use in Colorado. Major (1989) suggested lynx hunted the edge of dense riparian willow stands. The use of these edge habitats may allow lynx to hunt hares that live in habitats normally too dense to hunt effectively. The use of riparian areas and riparian-Engelmann spruce-subalpine fir and riparian-aspen mixes documented in Colorado may stem from a similar hunting strategy. However, too little is known about habitat use by hares in Colorado to test this hypothesis at this time.

Lynx also require sufficient denning habitat. Denning habitat has been described by Koehler (1990) and Mowat et al. (1999) as areas having dense downed trees, roots, or dense live vegetation. We found this to be in true in Colorado as well (Shenk 2006). In addition, the dens used by reintroduced lynx were at high elevations and on steep north-facing slopes. All females that were documented with kittens denned in areas within their winter-use area.

SUMMARY

From results to date it can be concluded that CDOW developed release protocols that ensure high initial post-release survival of lynx, and on an individual level, lynx demonstrated they can survive long-term in areas of Colorado. We also documented that reintroduced lynx exhibited site fidelity, engaged in breeding behavior and produced kittens that were recruited into the Colorado breeding population. What is yet to be demonstrated is whether current conditions in Colorado can support the recruitment necessary to offset annual mortality in order to sustain the population. Monitoring of reintroduced lynx will continue in an effort to document such viability.

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Table 1. Number of wild-caught male (M) and female (F) Canada lynx (*Lynx canadensis*) from Alaska (AK) and Canada (BC = British Columbia, MB = Manitoba, QU = Quebec and YK = Yukon) released in southwestern Colorado per year from 1999–2006.

Year	%Released	Sex	State / Province of Origin					Total
			AK	BC	MB	QU	YK	
1999	19	F	13	5			4	22
		M	7	6			6	19
2000	25	F	6	9			20	35
		M	4	9			7	20
2003	15	F		10		7		17
		M		10	1	5		16
2004	17	F		7		10		17
		M		13		7		20
2005	17	F		4	3	8	3	18
		M		9		8	3	20
2006	6	F		4			3	7
		M		5			2	7
	Total		30	91	4	45	48	218

Table 2. Status of adult Canada lynx (*Lynx canadensis*) reintroduced to Colorado as of August 27, 2008.

Lynx	Females	Males	Unknown	TOTALS
Released	115	103		218
Known Dead	62	49	1	112
Possible Alive	53	54		106
Missing	27	35		61[a]
Monitoring/tracking	26	19		45

[a] 1 is unknown mortality

Table 3. Causes of death for all Canada lynx (*Lynx canadensis*) released into southwestern Colorado 1999-2006 as of August 27, 2008.

Cause of Death	Mortalities		
	Total (%)	In Colorado (%)	Outside Colorado (%)
Unknown	41 (36.6)	27 (32.91)	14 (46.7)
Gunshot	15 (13.4)	9 (11.0)	6 (20.0)
Hit by Vehicle	14 (12.5)	9 (11.0)	5 (16.7)
Starvation	11 (9.8)	10 (12.2)	1 (3.3)
Other Trauma	8 (7.1)	7 (8.5)	1 (3.3)
Plague	7 (6.3)	7 (8.5)	0 (0)
Probable Gunshot	5 (4.5)	4 (4.9)	1 (3.3)
Predation	5 (4.5)	5 (6.1)	0 (0)
Probable Predation	3 (2.7)	2 (2.4)	1 (3.3)
Illness	3 (2.7)	2 (2.4)	1 (3.3)
Total Mortalities	112	82 (73.2)	30 (26.8)

Table 4. Known lynx mortalities (*n* = 30) and causes of death documented by state outside of Colorado from February 1999 – August 27, 2008.

Lynx ID	State	Date Mortality Recorded	Cause of Death
AK99F8	New Mexico	7/30/1999	Starvation
Unknown	New Mexico	2000	Hit by Vehicle
AK99M11	New Mexico	1/27/2000	Unknown
YK99M06	New Mexico	6/19/2000	Probable Gunshot
AK99F13	New Mexico	6/22/2000	Unknown
YK00F04	New Mexico	4/20/2001	Gunshot
BC99M04	New Mexico	6/7/2002	Gunshot
QU05M01	New Mexico	8/22/2005	Unknown
QU04F05	New Mexico	8/26/2005	Hit by Vehicle
QU03F07	New Mexico	9/15/2005	Unknown
BC00M04	New Mexico	7/19/2006	Unknown
YK06F01	New Mexico	10/19/2006	Unknown
BC03M08	New Mexico	10/19/2006	Unknown
BC06F07	New Mexico	1/8/2007	Gunshot
AK99M06	Nebraska	11/16/1999	Gunshot
AK99M01	Nebraska	1/11/2005	Snared (Other Trauma)
QU05M08	Nebraska	10/1/2006	Unknown
MB05F02	Nebraska	2/13/2007	Gunshot
BC00F14	Wyoming	7/28/2004	Unknown
QU04F07	Wyoming	9/21/2004	Unknown
BC06M10	Wyoming	8/15/2006	Vehicle Collision
QU04F02	Wyoming	3/14/2007	Unknown
AK00M03	Utah	7/2/2001	Unknown
QU05M03	Utah	10/26/2005	Unknown
YK06M01	Utah	12/4/2006	Unknown
YK00F07	Utah	8/6/2007	Unknown
YK99F01	Arizona	9/15/2005	Gunshot
YK00M03	Kansas	9/30/2005	Vehicle Collision
YK05M03	Montana	11/8/2005	Unknown
YK05M02	Iowa	8/6/2007	Vehicle Collision

Table 5. Lynx reproduction summary statistics for 1999-2008. No reproduction was expected in 1999 because it was the first year of lynx releases and most animals were released after breeding season.

Year	Females Tracked	Dens Found in May/June	Percent Tracked Females with Kittens	Additional Litters Found in Winter	Mean Kittens/Litter (SE)	Total Kittens Found	Sex Ratio M/F (SE)
2000	9	0	0.0	0		0	
2001	25	0	0.0	0		0	
2002	21	0	0.0	0		0	
2003	17	6	0.353	0	2.67 (0.33)	16	1.0
2004	26	11	0.462	2	2.83 (0.24)	39	1.5
2005	40	17	0.425	1	2.88 (0.18)	50	0.8
2006	42	4	0.095	0	2.75 (0.47)	11	1.2
2007	34	0	0.0	0		0	
2008	28	0	0.0	0		0	
TOTAL						116	1.14 (0.14)

Table 6. Lynx captured because they were in poor body condition or were in atypical habitat and their fates 6 months post re-release and as of August 28, 2008.

Lynx ID	Date of Capture	State Where Captured	Reason For Capture	Date of Re-release	Status 6 Months Post Re-release	Current Status
BC99F6	3/25/1999	Colorado	Poor body condition	5/28/1999	Dead	Died 7/19/1999 in Colorado from vehicle collision
AK99M9	3/24/2000	Colorado	Poor body condition	5/3/2000	Missing	Last located 5/3/2000, collar failure
AK99F2	4/18/2000	Colorado	Poor body condition	5/22/2000	Alive in Colorado	Last located 7/30/2003 in Colorado
BC00F7	2/11/2001	Colorado	Poor body condition	N/A	Dead	Died at Rehab Center on 2/12/2001
BC00M13	3/21/2001	Wyoming	Poor body condition	4/24/2001	Alive in Colorado	Last located 10/26/2004 in Colorado
BC03M08	9/5/2003	Colorado	Poor body condition	1/1/2004	Alive in Colorado	Died in New Mexico of unknown causes 10/19/06
QU04M07	2/2/2006	Colorado	Poor body condition	N/A	Dead	Died at Rehab Center on 2/5/2006 from hydrocephalous and pneumonia
BC04M01	11/5/2004	Utah	Atypical habitat	12/5/2004	Alive in Colorado	In Colorado as of 8/27/2008
QU04F02	4/10/2005	Nebraska	Atypical habitat	5/7/2005	Alive in Wyoming	Died 3/14/2007 in Wyoming (good habitat) of unknown causes
QU05M08	11/25/2005	Wyoming	Atypical habitat	4/18/2006	Dead	Died of unknown causes in Nebraska 10/1/2006
QU04M04	12/5/2006	Utah	Atypical habitat	1/20/2007	Dead in Colorado	Died of starvation in Colorado, found 3/19/07
YK00F07	12/12/2006	Utah	Atypical habitat	1/20/2007	Alive in Utah	Died in Utah of unknown causes 8/6/2007
YK05M02	1/1/2007	Kansas	Atypical habitat	2/2/2007	Alive in Iowa	Died in Iowa from vehicle collision 8/6/2007
BC04M08	1/22/2007	Wyoming	Atypical habitat	2/15/2007	Alive in Colorado	Died in Colorado from gunshot 1/4/2008

Table 7. Number of kills found each winter field season through snow-tracking of lynx and percent composition of kills of the three primary prey species.

		Prey (%)			
Field Season	n	Snowshoe Hare	Red Squirrel	Cottontail	Other
1999	9	55.56	22.22	0	22.22
1999-2000	83	67.47	19.28	1.20	12.05
2000-2001	89	67.42	19.10	8.99	4.49
2001-2002	54	90.74	5.56	0	3.70
2002-2003	65	90.77	6.15	0	3.08
2003-2004	37	67.57	27.03	2.70	2.70
2004-2005	78	83.33	10.26	0	6.41
2005-2006	50	90.00	0.08	0	0.02
2006-2007	41	61.00	39.0	0	0
2007-2008	42	59.00	33.3	0	7.4
Total/Mean	548	73.29 (SE=4.7)	18.2 (SE=4.2)	1.29 (SE=0.95)	6.21 (SE=2.22)

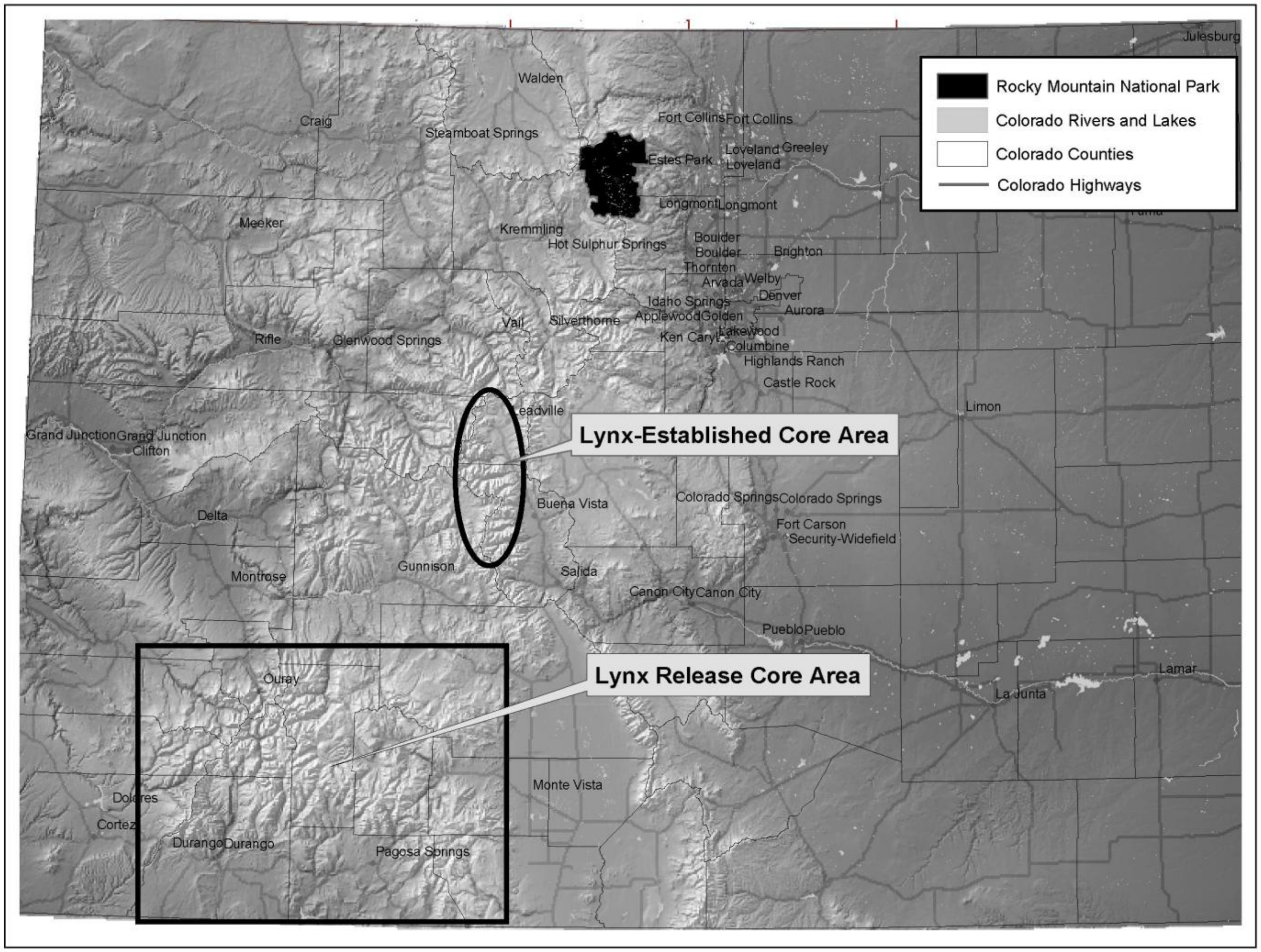

Figure 1. Lynx are monitored throughout Colorado and by satellite throughout the western United States. The lynx core release area, where all lynx were released, is located in southwestern Colorado. A lynx-established core use area has developed in the Taylor Park and Collegiate Peak area in central Colorado.

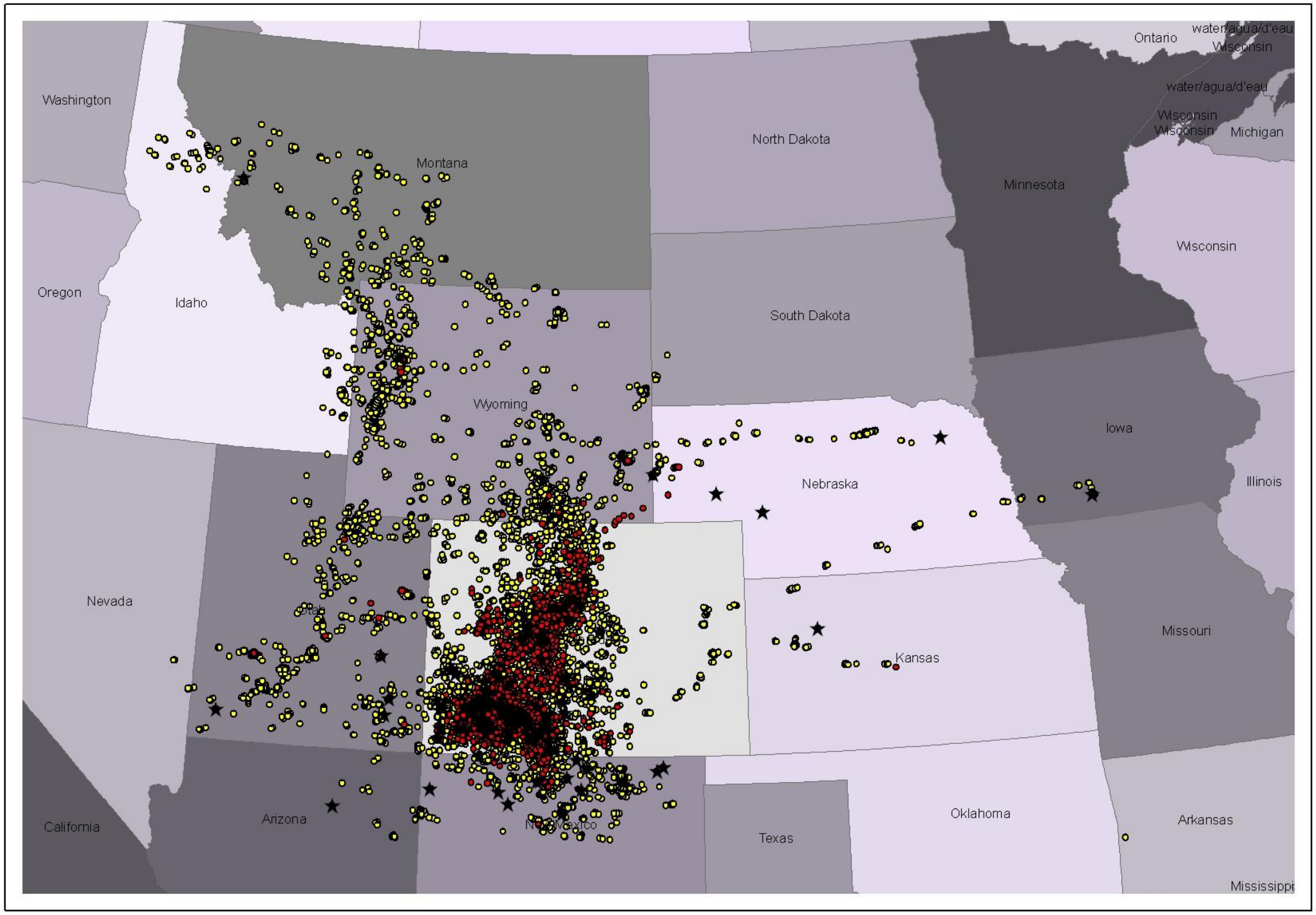

Figure 2. All documented lynx locations (non-truncated datasets) obtained from either aerial (red circles) or satellite (yellow circles) tracking from February 1999 through August 27, 2008. All known lynx mortality locations (n = 112) are displayed as black stars.

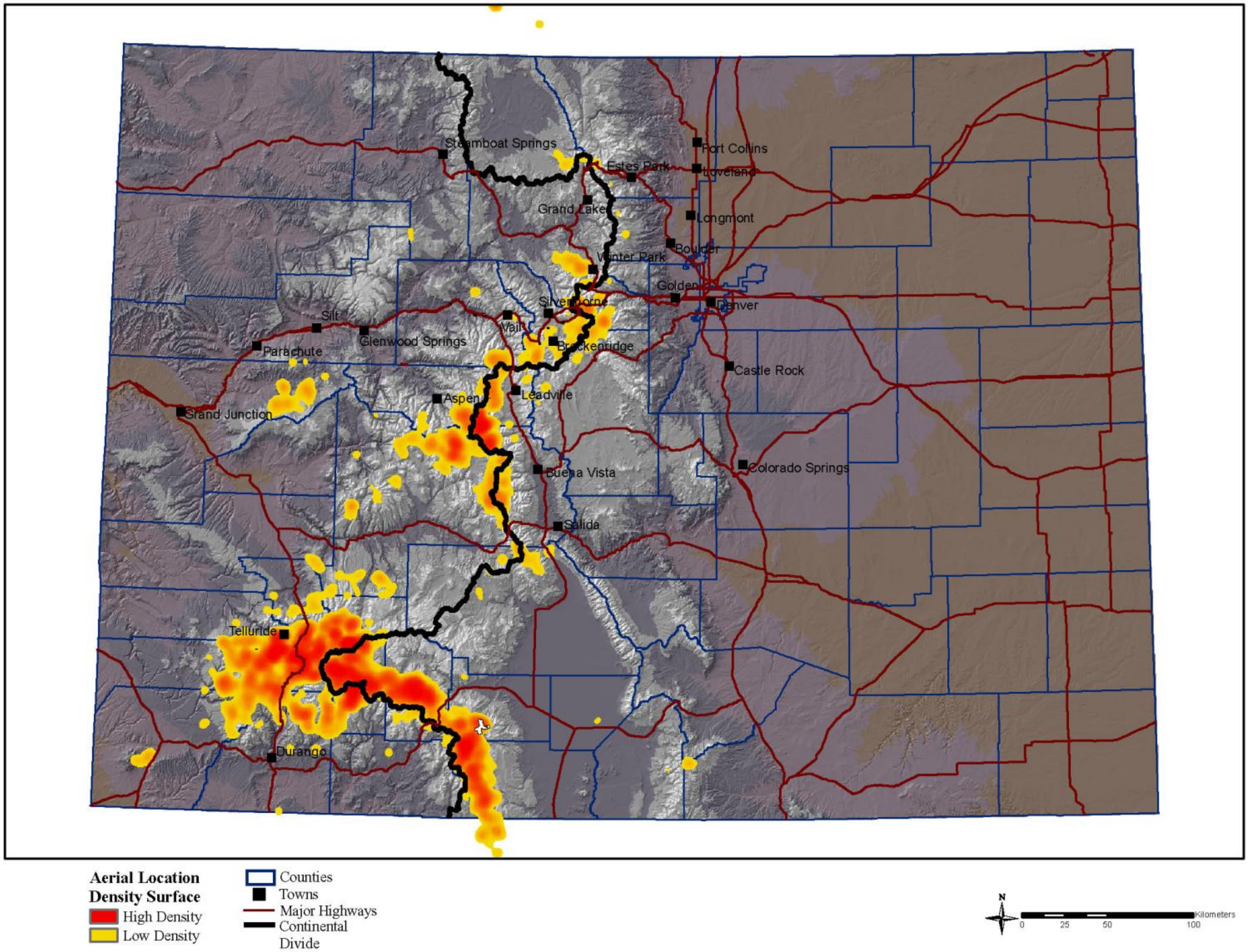

Figure 3. Use-density surface for lynx aerial locations (truncated dataset) in Colorado from September 1999-March 2007.

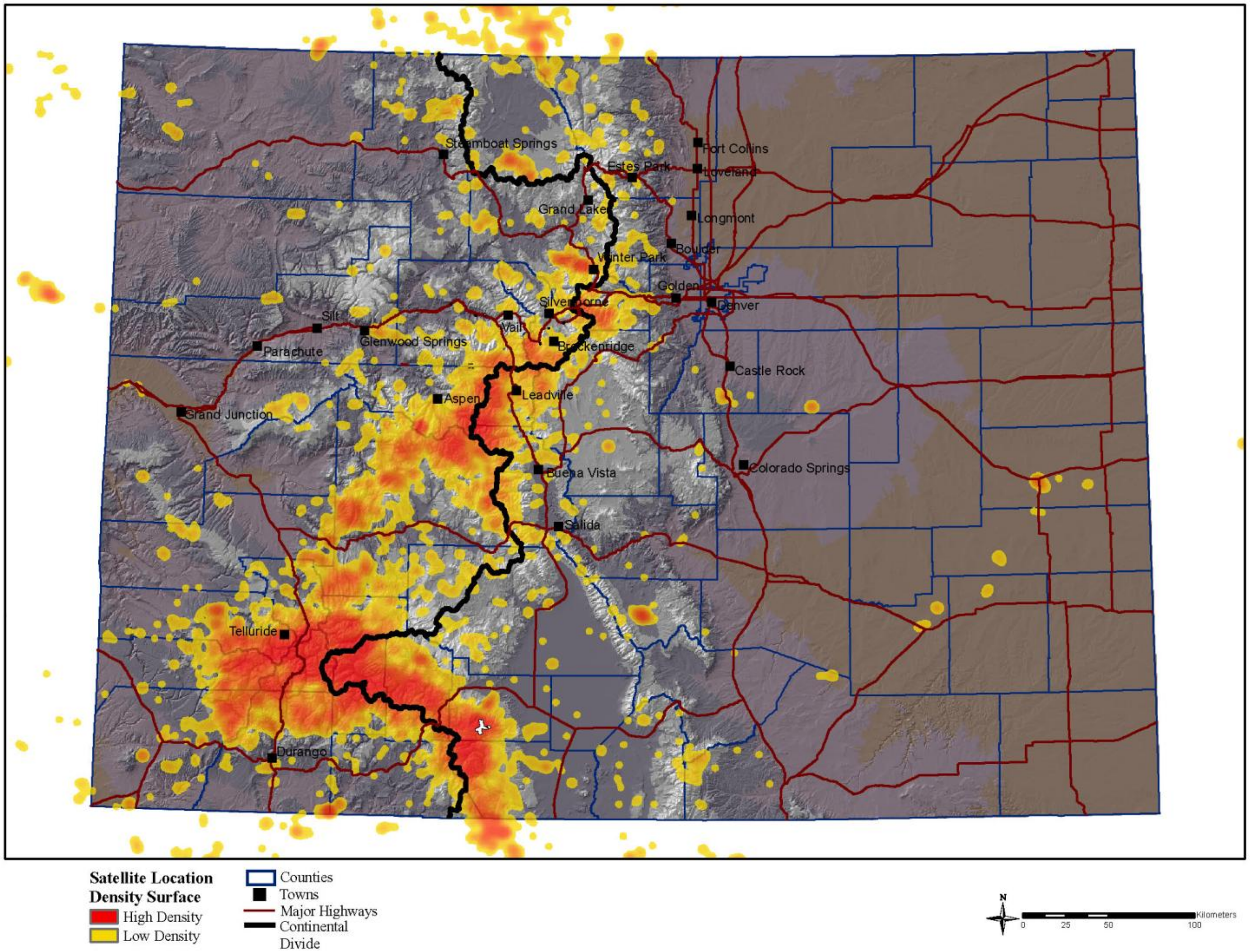

Figure 4. Use-density surface for lynx satellite locations (truncated dataset) in Colorado from September 1999-March 2007.

APPENDIX I

Colorado Division of Wildlife
July 2007 - June 2008

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	0670	:	Lynx Conservation
Task No.:	2	:	Density, Demography, and Seasonal Movements
		:	Of Snowshoe Hare in Colorado
Federal Aid Project No.	N/A		

Period Covered: July 1, 2007- June 30, 2008

Author: J. S. Ivan, Ph.D. Candidate, Colorado State University

Personnel: Dr. T. Shenk of CDOW and Dr. G. C. White of Colorado State University.

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

A program to reintroduce the threatened Canada lynx (*Lynx canadensis*) into Colorado was initiated in 1997. Analysis of scat collected from winter snow tracking indicates that snowshoe hares (*Lepus americanus*) comprise 65–90% of the winter diet of reintroduced lynx. Thus, existence of lynx in Colorado and success of the reintroduction hinge at least partly on maintaining adequate and widespread hare populations. Beginning in July 2006, I initiated a study to assess the relative value of 3 stand types for providing hare habitat in Colorado. These types include mature, uneven-aged spruce/fir forests, sapling lodgepole pine forests ("small lodgepole"), and pole-sized lodgepole pine forests ("medium lodgepole"). Estimates and comparisons of survival, recruitment, finite population growth rate, and maximum (late summer) and minimum (late winter) snowshoe hare densities for each stand will provide the metrics for assessing these stands.

Thus far, snowshoe hare densities on the study area are low compared to densities reported elsewhere. Within the study area, hare densities during summer were highest in small lodgepole stands, followed by mature spruce/fir and medium lodgepole, respectively. This pattern was consistent through the first 2 summers of this project, although absolute hare densities declined considerably in summer 2007. Hare density in small and medium lodgepole stands equalized during both winters of the project. However, as with summer, overall density was much lower during the second winter compared to the first.

Hare survival from summer to winter has been relatively high. However the single winter to summer estimate I have to date is quite low. Extension of this time series will help determine whether low winter to summer survival is typical or somehow related to the decline in density.

WILDIFE RESEARCH REPORT

DENSITY, DEMOGRAPHY, AND SEASONAL MOVEMENTS OF SNOWSHOE HARES IN COLORADO

JACOB S. IVAN

P. N. OBJECTIVE

Assess the relative value of 3 stand types (mature spruce/fir, sapling lodgepole, pole-sized lodgepole) that purportedly provide high quality hare habitat by estimating survival, recruitment, finite population growth rate, and maximum (late summer) and minimum (late winter) snowshoe hare densities for each type.

SEGMENT OBJECTIVES

1. Complete mark-recapture work across all replicate stands during late summer (mid-July through mid-September) and winter (mid-January through March).
2. Obtain daily telemetry locations on radio-tagged hares for 10 days immediately after capture periods, as well as monthly between primary trapping sessions.
3. Locate, retrieve, and refurbish radio tags as mortalities occur.
4. Summarize initial sampling efforts and provide initial density estimates for Progress Reports for Colorado Division of Wildlife (CDOW).

INTRODUCTION

NEED

A program to reintroduce the threatened Canada lynx (*Lynx canadensis*) into Colorado was initiated in 1997. Since that time, 218 lynx have been released in the state, and an extensive effort to determine their movements, habitat use, reproductive success, and food habits has ensued (Shenk 2005, Shenk 2007). Analysis of scat collected from winter snow tracking indicates that snowshoe hares (*Lepus americanus*) comprise 65–90% of the winter diet of reintroduced lynx (T. Shenk, Colorado Division of Wildlife, unpublished data). Thus, as in the far north where the intimate relationship between lynx and snowshoe hares has captured the attention of ecologists for decades, it appears that the existence of lynx in Colorado and success of the reintroduction effort may hinge on maintaining adequate and widespread populations of hares.

Colorado represents the extreme southern range limit for both lynx and snowshoe hares (Hodges 2000). At this latitude, habitat for each species is less widespread and more fragmented compared to the continuous expanse of boreal forest at the heart of lynx and hare ranges. Neither exhibits dramatic cycles as occur farther north, and typical lynx (≤2–3 lynx/100km^2; Aubry et al. 2000) and hare (≤1–2 hares/ha; Hodges 2000) densities in the southern part of their range correspond to cyclic lows form northern populations (2-30 lynx/100 km^2, 1–16 hares/ha; Aubry et al. 2000, Hodges 2000, Hodges et al. 2001).

Whereas extensive research on lynx-hare ecology has occurred in the boreal forests of Canada, literature regarding the ecology of these species in the southern portion of their range is relatively sparse. This scientific uncertainty is acknowledged in the "Canada Lynx Conservation Assessment and Strategy," a formal agreement between federal agencies intended to provide a consistent approach to lynx conservation on public lands in the lower 48 states (Ruediger et al. 2000). In fact, one of the explicit guiding principles of this document is to "retain future options…until more conclusive information concerning lynx management is developed." Thus, management recommendations in this agreement are decidedly conservative, especially with respect to timber management, and are applied broadly to cover all habitats thought to be of possible value to lynx and hare. Accurate identification and detailed description of lynx-hare habitat in the southern Rocky Mountains would permit more informed and refined management recommendations.

A commonality throughout the snowshoe hare literature, regardless of geographic location, is that hares are associated with dense understory vegetation that provides both browse and protection from elements and predators (Wolfe et al. 1982, Litvaitis et al. 1985, Hodges 2000, Homyack et al. 2003, Miller 2005). In western mountains, this understory can be provided by relatively young conifer stands regenerating after stand-replacing fires or timber harvest (Sullivan and Sullivan 1988, Koehler 1990a, Koehler 1990b, Bull et al. 2005) as well as mature, uneven-aged stands (Beauvais 1997, Griffin 2004). Hares may also take advantage of seasonally abundant browse and cover provided by deciduous, open habitats (e.g., riparian willow [*Salix* spp.], aspen [*Populus tremuloides*]; Wolff 1980, Miller 2005). In drier portions of hare range, such as Colorado, regenerating stands can be relatively sparse, and hares may be more associated with mesic, late-seral forest and/or riparian areas than with young stands (Ruggiero et al. 2000).

Numerous investigators have sought to determine the relative importance of these distinctly different habitat types with regards to snowshoe hare ecology. Most previous evaluations were based on hare density or abundance (Bull et al. 2005), indices to hare density and abundance (Wolfe et al. 1982, Koehler 1990a, Beauvais 1997, Miller 2005), survival (Bull et al. 2005), and/or habitat use (Dolbeer and Clark 1975). Each of these approaches provides insight into hare ecology, but taken singly, none provide a complete picture and may even be misleading. For example, extensive use of a particular habitat type may not accurately reflect the fitness it imparts on individuals, and density can be high even in "sink" habitats (Van Horne 1983). A more informative approach would be to measure density, survival, and habitat use simultaneously in addition to recruitment and population growth rate through time. Griffin (2004) employed such an approach and found that summer hare densities were consistently highest in young, dense stands. However, he also noted that only dense mature stands held as many hares in winter as in summer. Furthermore hare survival seemed to be higher in dense mature stands, and only dense mature stands were predicted (by matrix projection) to impart a mean positive population growth rate on hares. Griffin's (2004) study occurred in the relatively moist forests of Montana, which share many similarities but also many notable differences with Colorado forests including levels of fragmentation, species composition, elevation, and annual precipitation.

Density estimation is a key component in assessing the value of a particular stand type and is the common currency by which hare populations are compared across time and space. However, it can be a difficult metric to estimate accurately. Abundance estimation based on capture-recapture methods is a well-developed field (Otis et al. 1978, White et al. 1982), but is often too costly and labor intensive to be implemented on scales necessary to effectively monitor density over a biologically meaningful area. Also, density can be difficult to assess from grid-trapping efforts because it is often unclear how much area was effectively sampled by the grid (Williams et al. 2002:314). Alternate approaches can produce density estimates that differ by an order of magnitude even when calculated from the same data (Zahratka 2004). Indices such as pellet plot counts and distance sampling of pellet groups can be used to estimate density, but each of these has limitations as well (Krebs et al. 1987, Eriksson 2006).

The study outlined below is designed principally to evaluate the importance of young, regenerating lodgepole pine (*Pinus contorta*) and mature Engelmann spruce (*Picea engelmannii*)/ subalpine fir (*Abies lasiocarpa*) stands in Colorado by examining density and demography of snowshoe hares that reside in each. Secondarily, I intend to quantify movement between these stands and other seasonally available types (e.g., willow). My hope is that information gathered from this research will be drawn upon as managers make routine decisions, leading to landscapes that include stands capable of supporting abundant populations of hares. I assume that if management agencies focus on providing habitat, hares will persist. I will use mark-recapture techniques as data from such an approach can provide information on both density and demography. In the future, I will address the "effective trapping area" issue using a new approach that augments mark-recapture data with telemetry locations of animals using the grid. However, for this report I used one of the more popular, traditional techniques. I determined that 2 classes of young, regenerating lodgepole stands could both provide adequate hare habitat. Thus, in addition to older spruce/fir forests, I am sampling "small" (2.54-12.69 cm dbh) and "medium" (12.70-22.85 cm dbh) stands regenerating from clearcutting that took place 20 and 40 years ago, respectively (Figure 1). Additionally, medium lodgepole stands were pre-commercially thinned 20 years ago; small lodgepole stands have not yet been thinned.

Hypotheses

1) In general, snowshoe hare density in Colorado will be relatively low (≤0.5 hares/ha) compared to densities reported in northern boreal forests, even immediately post-breeding when an influx of juveniles will bolster hare numbers.
2) Snowshoe hare density will be consistently highest in small lodgepole pine stands, followed by large spruce/fir and medium lodgepole pine, respectively.
3) Survival will generally be highest in mature (large) spruce/fir stands followed by small and medium lodgepole pine, respectively.
4) Finite population growth rate will be consistently at or above 1.0 in mature spruce/fir stands with survival contributing most significantly to the growth rate. Finite growth rates for the lodgepole pine stands will be more variable.
5) Snowshoe hares will significantly shift their home ranges to make use of abundant food and cover provided by riparian willow (and/or aspen) habitats in summer.
6) Snowshoe hare density, survival, and recruitment will be highly correlated with understory cover and stem density.

STUDY AREA

The study area stretches from Taylor Park to Pitkin in central Colorado (Figure 2). Elevation ranges from 2700 m to 4000 m. Sagebrush (*Artemisia spp.*) dominates broad, low-lying valleys. Most montane areas are covered by even-aged, large-diameter lodgepole pine forests with sparse understory. Moist, north-facing slopes and areas near tree line are dominated by large-diameter Engelmann spruce/subalpine fir. Interspersed along streams and rivers are corridors of willow. Patches of aspen occur sporadically on southern exposures. This area was chosen over other potential study areas in the state because 1) it contained numerous examples of the 3 stand types of interest (more southern regions lack naturally occurring stands of lodgepole pine), 2) it was not subject to confounding effects of large-scale mountain pine beetle outbreak as were more northern stands, and 3) an adequate number of radio frequencies were available to support a large study with hundreds of radio-tagged individuals.

Within the study area I selected sample stands based on the following: Potential replicate stands were required to be 1) close enough geographically to minimize differences due to climate, weather, and topography, but are far enough apart to be considered independent, 2) adjacent to one or more riparian willow corridors, 3) within 1 km of an access road for logistical purposes, 4) of suitable size and shape to admit a 16.5-ha trapping grid, and 5) consistent in their management history (i.e., replicate lodgepole pine stands were clear-cut and/or thinned within 1-2 years of each other).

I queried the U.S. Forest Service R2VEG GIS database using the criteria listed above to initially develop a suite of potential sample stands. I further narrowed this suite after obtaining updated stand-level information from local USFS personnel (Art Haines, Silviculturalist, USFS Gunnison Ranger

District, personal communication). Finally, I ground-truthed potential stands and qualitatively assessed their representativeness and similarity to other potential replicates. Given the numerous constraints imposed, very few stands met all criteria. Thus, I was unable to randomly select sample stands from a population of suitable stands. Rather, I subjectively chose the "best" stands from among the handful that met my criteria. Small lodgepole stands rarely occur on the landscape in patches large enough to fit a full trapping grid. To accommodate this, I sampled 6 replicate small lodgepole stands (rather than 3) using half-sized trapping grids.

METHODS

Experimental Design/Procedures

Variables.--The response variables of interest for this project include stand-specific snowshoe hare density (D), apparent survival (ϕ), recruitment (f), finite population growth rate (λ), and a metric of seasonal movement. Density is the number of hares per unit area and is estimated using a conventional techniques in this report. The stand-specific demographic parameters will be estimated primarily from capture-mark-recapture methods. As such, apparent survival is defined as the probability that a marked animal alive and in the population at time i survives and is in the population at time $i + 1$. Apparent survival encompasses losses due to both death and emigration. Estimates of recruitment, population growth, and seasonal movement are forthcoming and not provided in this report.

Potential explanatory variables for snowshoe hare density, demographics, and movement include general species composition and structural stage of each stand in which response variables are measured. Additionally, stem density, horizontal cover, and canopy cover (to a lesser extent) are highly correlated with snowshoe hare abundance and habitat use (Wolfe et al. 1982, Litvaitis et al. 1985, Hodges 2000, Zahratka 2004, Miller 2005). Thus, I further characterized vegetation in each stand by measuring stem density by size class (1-7 cm, 7.1-10 cm, and >10 cm), percent canopy cover, percent horizontal cover of understory and basal area. Basal area is an easily obtainable metric that may be correlated with the other variables and is recorded routinely during timber cruises, whereas the others are not. Thus, it might prove a useful link for biologists designing management strategies for snowshoe hare. Additionally, I recorded physical covariates such as ambient temperature, precipitation, and snow depth at each stand during sampling. These metrics were not included in the current preliminary analyses, but will be used as covariates in future models.

Sampling.--All trapping and handling procedures have been approved by the Colorado State University Animal Care and Use Committee and filed with the Colorado Division of Wildlife. Snowshoe hares breed synchronously and generally exhibit 2 birth pulses in Colorado (although in some years, some individuals may have 3 litters), with the first pulse terminating approximately June 5–20 and the second approximately July 15–25 (Dolbeer 1972). To obtain a maximum density estimate, I began data collection on the first suite of sites immediately following the second birth pulse in late July. Along with a crew of 5 technicians, I deployed one 7×12 trapping grid (50-m spacing between traps; grid covers 16.5 ha) in the large spruce/fir and medium lodgepole stands within the first suite, along with 2 6×7 grids in 2 small lodgepole stands. Grid set up and trap deployment followed Griffin (2004) and Zahratka (2004). Grid locations and orientation within each stand were chosen subjectively to accommodate logistical constraints and to ensure that hares using the grid had ample opportunity to use adjacent riparian willow zones. As traps were deployed, they were locked open and "pre-baited" with apple slices, hay cubes, and commercial rabbit chow. Traps were pre-baited in this manner for a total of 3 nights to maximize capture rates when trapping began. This minimized the number of trap-nights needed to capture the desired number of animals which in turn minimized trap-related injuries and minimized problems with predators keying into trap lines. During pilot work in winter 2005, I observed low but increasing capture rates (<0.20) during the first 3 nights of trapping, with higher, more stable capture probabilities after 3 days (approximately 0.35–0.45). Thus 3 days of pre-baiting seemed reasonable.

Traps were set on the afternoon of the 4th day and checked early each morning and again in the evening on days 5–9. By checking traps in both morning and evening I prevented hares from being entrapped >13 hours, which should minimize capture stress. A crew of 2 people worked together on each grid to check traps and process captures as quickly as possible. All captured hares were coaxed out of the trap and into a dark handling bag by blowing quick shots of air on them from behind. Hares remained in the handling bag, physically restrained with their eyes covered, for the entire handling process. Each individual was aged, sexed, marked with a passive integrated transponder (PIT) tag and temporary ear mark (to track PIT tag retention), then released. Aging consisted of assigning each individual as either juvenile (<1 year old, <1000 g) or adult (≥1 year old, ≥1000 g) based on weight. This criterion is accurate through the end of September at which point juveniles are difficult to distinguish from adults (K. Hodges, University of British Columbia; P. Griffin, University of Montana, personal communication). After the first day of trapping, all captured hares were scanned for a PIT tag prior to any handling and those already marked were recorded and immediately released. Traps and bait were completely removed from the grid on day 10.

In addition to PIT tags and ear marks, I radio collared up to 10 hares captured on each grid with a 28-g mortality-sensing transmitter (BioTrack, LTD) to facilitate unbiased density estimation as well as assessment of seasonal movements. I expected heterogeneity in snowshoe hare movements and use of the grid area, with potential bias surfacing due to location at which a hare is captured (e.g., hares captured on the edge of a grid may use the grid area differently than those captured at the center), and differential behavioral responses to trapping (e.g., young individuals may have lower capture probabilities and thus may be more likely to be captured on later occasions). To guard against the first potential bias, I randomly selected a starting trap location each morning and ran the grid systematically from that point. Thus, the first several hares encountered (and collared) were as likely to be from the inner part of the grid as from the edge. To protect against the second potential source of bias, I refrained from deploying the final 3 collars until days 4 and 5 of the trapping session.

Immediately following the removal of traps, the field crew began work locating each radio-collared hare 1–2 times per day for 10 days. Most locations were obtained by triangulation from relatively close proximity, but some were obtained by "homing" on a signal (Samuel and Fuller 1996, Griffin 2004) taking care not to push hares while approaching them. Because hares are largely nocturnal (Keith 1964, Mech et al. 1966, Foresman and Pearson 1999), I made an effort to conduct telemetry work at various times of the night (safety and logistics permitting) and day to gather a representative sample of locations for each hare.

Crews gathered telemetry locations for radio-collared hares on the initial suite of sites for 10 days. Then the 10−day trapping procedure and 8 to 10−day telemetry work were repeated on the grids comprising suites 2 and 3(Figure 3). The entire process was repeated during the winter when densities should have been at a minimum. Thus, during the period covered by this report, sampling occurred from July 16 – September 14 and from January 20 – March 24, 2008. Sampling occurred across similar dates during FY06/07 and will continue during FY08/09. During the interim between intensive trapping and telemetry work, monthly telemetry checks were conducted from the air to track mortalities and facilitate retrieval of collars from dead hares. Telemetry work also occurred during "pre-baiting" days after the initial summer sampling session to determine which hares were still alive and immediately available to be sampled by the grid during the ensuing trapping period.

Vegetation sampling at each stand commenced in June 2008 and is nearly finished. I followed protocols established through previous snowshoe hare and lynx work in Colorado (Zahratka 2004, T.

Shenk, Colorado Division of Wildlife, personal communication). Specifically, on each of the 12 live-trapping grids, I laid out 5 $\times$ 5 grids (3-m spacing) of vegetation sampling points centered on 15 of the 84 trap locations (Figure 4; 9 points were sampled on each of the ½-sized small lodgepole stands). At each of the 25 vegetation sampling points, I recorded canopy cover (present or absent) using a densitometer. I quantified downed coarse wood along the center transect of the 25-point grid following Brown (1974). From the centerpoint (i.e., trap location) I measured 1) distance to the nearest woody stem 1.0–7.0 cm, 7.1–10.0 cm, and >10.0 cm in diameter at heights of 0.1 m and 1.0 m above the ground (to capture both summer and winter stem density; Barbour et al. 1999), 2) horizontal cover in 0.5-m increments above the ground up to 2 m (Nudds 1977), 3) basal area, and 4) slope.

Data Analysis

Density, Survival, and Population Growth.--I analyzed mark-recapture data in a robust design framework (Williams et al. 2002:523-554) treating summer and winter sampling occasions as primary periods, and the 5-day trapping sessions within each as secondary periods. As such, I assumed hare populations were demographically and geographically closed during the short 5-day mark-recapture sampling periods, but were open to immigration, emigration, births, and deaths between these occasions. I specified the Pradel Robust Design data type in Program MARK (White and Burnham 1999) and chose the Huggins closed capture model (Huggins 1989, 1991) to obtain abundance estimates for each grid from the secondary periods. I obtained estimates of apparent survival ($\hat{\phi}_i$) between each primary period. I employed a technique known as ½ Mean Maxmimum Distance Moved (MMDM; Wilson and Anderson 1985) to calculate the effective area trapped and obtain a density estimate for each grid from each secondary period. Future density analyses will employ a new estimator that employs telemetry data to correct for bias (Ivan 2005). I used Akaike's Information Criterion corrected for small sample size (AICc; Burnham and Anderson 1998) to select appropriate models from alternatives that included all 8 closed capture models (Otis et al. 1978) in combination with models that allowed survival to be constant, vary with time, and/or vary with stand type.

RESULTS AND DISCUSSION

I captured 30 hares 73 times during July-September 2007. I captured 48 hares 71 times during January-March 2008. During summer, density estimates have thus far followed hypotheses 1) and 2) above (Figure 5). Specifically, hare densities were clearly highest in small lodgepole stands and quite low in medium lodgepole stands. Spruce/fir was intermediate in density. This pattern remained consistent between summer 2006 to summer 2007, although the absolute density of hares dropped considerably during summer 2007. Why this decline occurred is unclear, although disease outbreak, natural population cycles, and response to increased predation due to lynx reintroduction are possibilities. Note that even the highest densities recorded here correspond to low estimates observed in other parts of hare range (Hodges 2000).

Hare densities tend to equalize in lodgepole stands during winter (Figure 5). I submit that the interplay between food, cover, and snow depth provides a plausible explanation for this pattern. Medium lodgepole stands apparently provide very little forage/cover for hares during summer as the canopy in these stands is generally ≥1 meter off the ground. However, in winter, accumulated snow may make that canopy available again to hares. Conversely, small lodgepole stands provide abundant food and cover during summer, but accumulated snow during winter brings hares closer to the crowns of the young trees, which then provide less cover. Spruce/fir stands probably provide adequate access to both food and cover during both summer and winter due to their uneven-aged, multi-layered structure. Like the summer estimates, density during the second winter was much lower than during the first winter.

Hare survival from the first sampling season into the first winter was relatively high (Figure 6). However, survival from the first winter to the second summer declined drastically. Survival from the second summer to the second winter was again quite high. Whether this pattern is typical is unclear. Survival from winter to summer is commonly lower than from summer to winter. However, the low survival from the first winter to second summer is coincident with the dramatic decline in hare density observed on spruce/fir and small lodgepole grids. Thus, low survival for this period is possibly reflective of, or maybe even a driver for, the decline in density. Extension of the time series and a breakdown of survival by stand type should provide more evidence for one or the other of these explanations.

SUMMARY

- Snowshoe hare densities on my study sites appear to be relatively low compared to densities reported elsewhere. Densities during summer were highest in small lodgepole stands, followed by spruce/fir and medium lodgepole.
- During winter, densities equalize in lodgepole stands, possibly due to the interplay between snow depth and canopy height in small and medium lodgepole pine.
- Hare density declined considerably beginning in summer 2007.
- Summer to winter hare survival has been consistently high thus far in the study, but the lone winter to summer survival estimate is quite low. It is unclear whether winter to summer survival is typically this low or whether that estimate is related to coincident drop in density.

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Ken Wilson (CSU), Bill Romme (CSU), Paul Doherty (CSU), Dave Freddy (CDOW), Chad Bishop (CDOW), and Paul Lukacs (CDOW) provided helpful insight on the design of this study. We appreciate the invaluable logistical support provided by Mike Jackson (USFS), Art Haines (USFS), Jake Spritzer (USFS), Kerry Spetter (USFS), Margie Michaels (CDOW), Gabriele Engler (USGS), Dana Winkelman (USGS), Brandon Diamond (CDOW), Chris Parmeter (CDOW), Kathaleen Crane (CDOW), Lisa Wolfe (CDOW), and Laurie Baeten (CDOW). Jim Gammonley (CDOW), Dave Freddy (CDOW), Chad Bishop (CDOW), Jack Vayhinger (CDOW), Brandon Diamond (CDOW) assisted with trucks and equipment. The following hardy individuals collected the hard-won data presented in this report: Braden Burkholder, Matt Cuzzocreo, Brian Gerber, Belita Marine, Adam Behney, Pete Lundberg, Katie Yale, Britta Shielke, Cory VanStratt, Mike Watrobka, Meredith Goss, Sidra Blake, Keith Rutz, Rob Saltmarsh, Jennie Sinclair, Evan Wilson, Mat Levine, Matt Strauser, Greg Davidson, Leah Yandow, Renae Sattler, and Caylen Cummins. Funding was provided by the Colorado Division of Wildlife.

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Prepared by ____

Jacob S. Ivan, Graduate Student, Colorado State University

Figure 1. Purported high quality snowshoe hare habitat in Colorado. From left to right: small lodgepole pine, medium lodgepole pine, and large Engelmann spruce/subalpine fir.

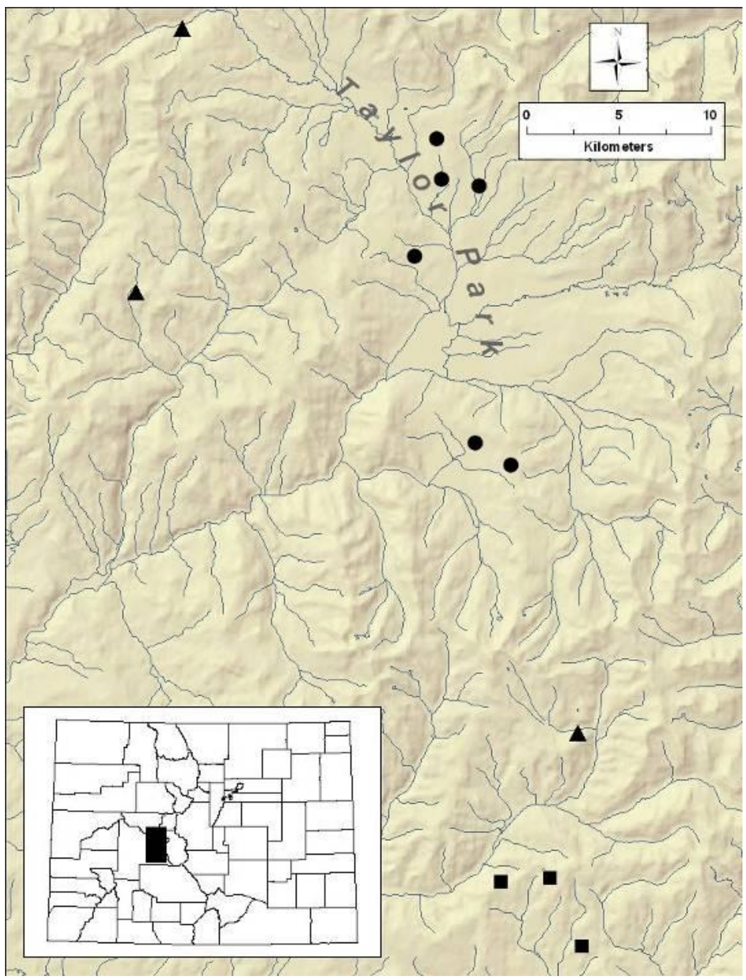

Figure 2. Study area near Taylor Park and Pitkin, Colorado including medium lodgepole (squares), small lodgepole (circles), and spruce/fir (triangles) stands selected for mark-recapture sampling.

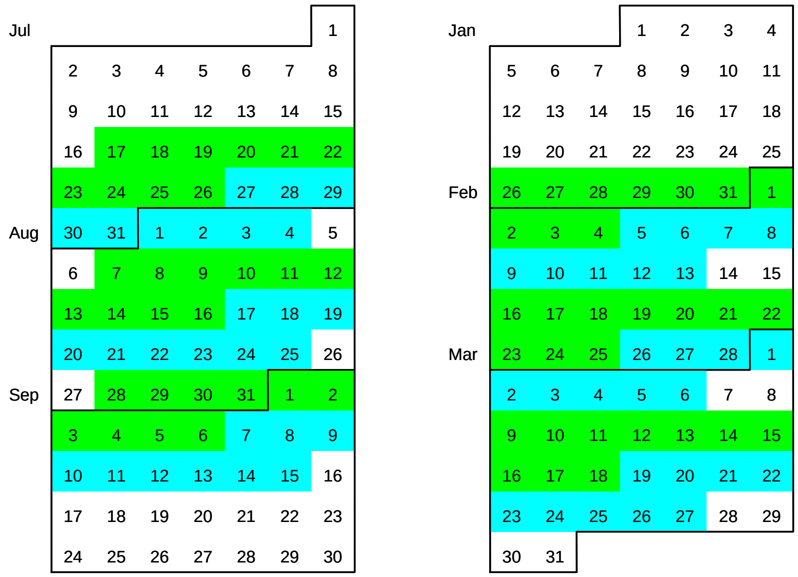

Figure 3. Approximate annual data collection schedule for trapping (■) and telemetry (■). Dates and weeks changed depending on calendar year and pay schedule. During telemetry work, the 6-person crew was divided into 2 teams, only one of which worked at any given time. Monthly locations on radio-collared hares were also collected in the interim between the intensive sampling periods indicated here.

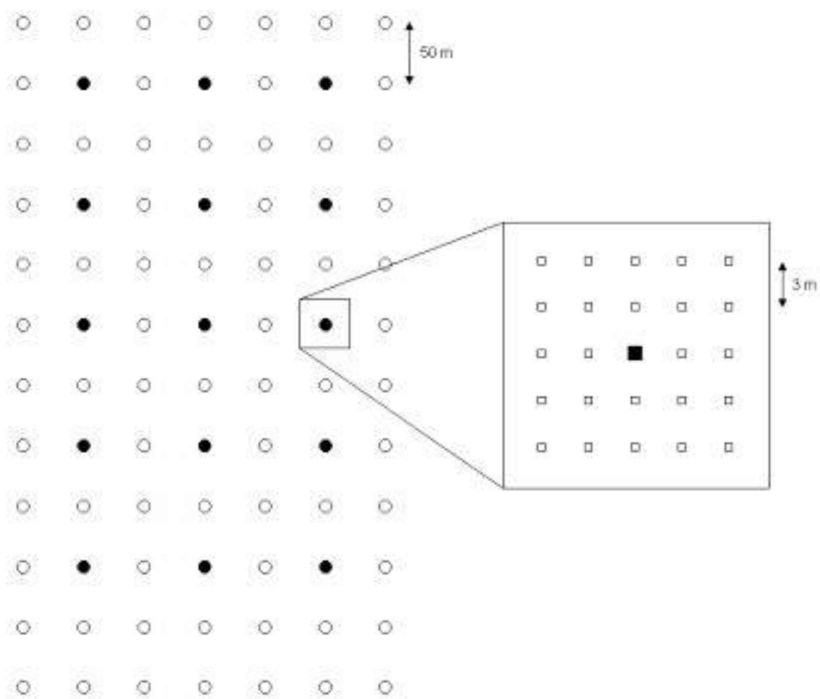

Figure 4. 15 trap locations (•) on 7 × 12 trapping grid where vegetation was sampled by measuring stem density, horizontal cover, downed woody material, and basal area. Additionally, the 25-point grid superimposed on each of the 15 trap locations (inset) was used to quantify canopy covert).

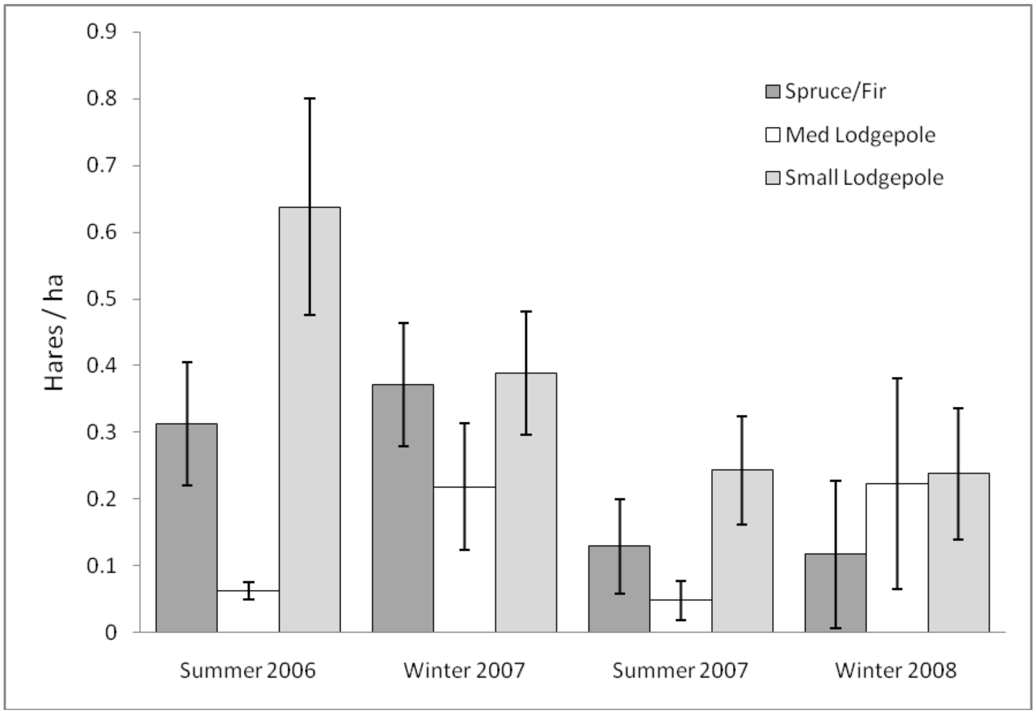

Figure 5. Snowshoe hare density and 95% confidence intervals in 3 types of stands in central Colorado as determined by ½ mean maximum distance moved, summer 2006 through winter 2008.

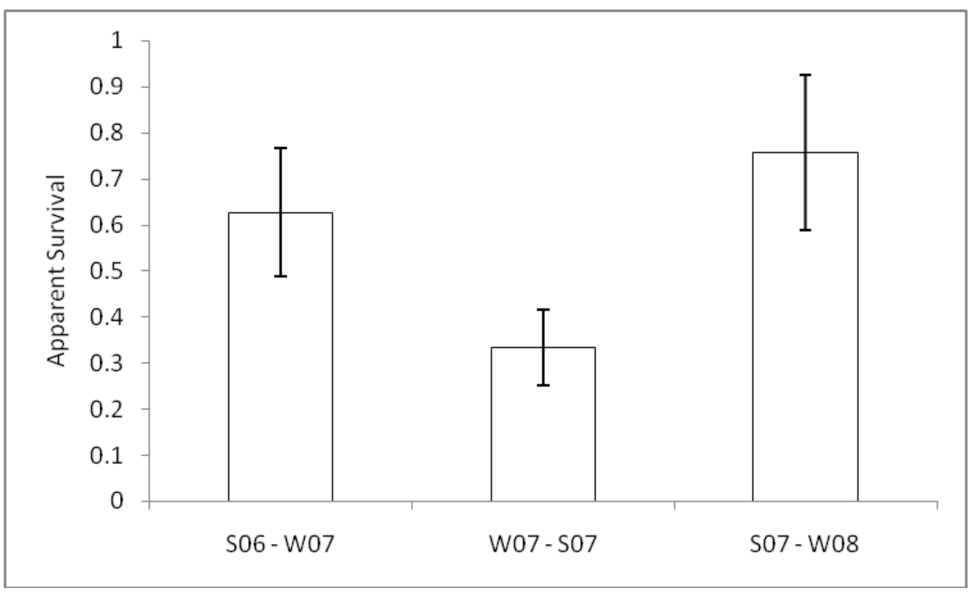

Figure 6. Snowshoe hare survival and 95% confidence intervals across summer (S) and winter (W) sampling seasons in central Colorado as determined by mark-recapture, 2006-2008.

Colorado Division of Wildlife
July 2007 – June 2008

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	3001	:	Deer Conservation
Task No.:	4	:	Effect of Nutrition and Habitat Enhancements
		:	On Mule Deer Recruitment and Survival Rates
Federal Aid Project No.	W-185-R		

Period Covered: July 1, 2007 – June 30, 2008

Authors: C. J. Bishop, G. C. White, D. J. Freddy, and B. E. Watkins

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

We measured mule deer (*Odocoileus hemionus*) population parameters in response to a nutrition enhancement treatment to evaluate the relative importance of habitat quality as a limiting factor of mule deer in western Colorado during November 2000 – January 2005. The nutrition enhancement treatment increased survival of fetuses to the yearling age class by 0.14–0.20 depending on year and fawn sex; 95% confidence intervals slightly overlapped 0. Averaged across sexes and years, survival of treatment fetuses to the yearling age class was 0.447 (SE = 0.0519), whereas survival of control fetuses to the yearling age class was 0.271 (SE = 0.0418). The treatment caused fetal to yearling survival to increase by 0.177 (SE = 0.0818, 95% CI: 0.0163, 0.3370). The nutrition treatment also had a positive effect on annual adult female survival. Survival of adult females receiving the treatment ($\hat{S}$ = 0.879, SE = 0.0206) was higher than survival of control adult females ($\hat{S}$ = 0.833, SE = 0.0253). Our estimate of the population rate of change, $\hat{\lambda}$, was 1.165 (SE = 0.0358) for treatment deer and 1.033 (SE = 0.0380) for control deer. The nutrition treatment caused $\hat{\lambda}$ to increase by 0.133 (SE = 0.0428). We documented food limitation in the Uncompahgre deer population because survival of fawns and adult females increased considerably in response to enhanced nutrition. Our results provide a foundation for focusing deer management efforts on improving habitat quality in western Colorado pinyon-juniper (*Pinus edulis-Juniperus osteosperma*) ecosystems with corresponding research efforts to quantify the effects of habitat manipulations on deer performance. During 2007–08, we published one paper from this research in the Journal of Wildlife Management (JWM 72(5):1085–1093), we had another paper accepted for publication in Journal of Wildlife Management, and we had one paper accepted for publication in Wildlife Monographs pending suitable revision. The lead principal investigator published a Dissertation to complete requirements for a Ph.D. at Colorado State University. We previously published a manuscript on the effectiveness of vaginal implant transmitters (VITs) for capturing newborn fawns from specific adult females (Bishop et al. 2007). As a follow-up to this component of our research, we worked with Advanced Telemetry Systems (ATS, Isanti, MN) to develop a VIT with modified retention wings. The modified VIT will be ready for field-testing in 2009.

WILDLIFE RESEARCH REPORT

EFFECT OF NUTRITION AND HABITAT ENHANCEMENTS ON MULE DEER RECRUITMENT AND SURVIVAL RATES

CHAD J. BISHOP, GARY C. WHITE, DAVID J. FREDDY, AND BRUCE E. WATKINS

P. N. OBJECTIVE

To determine experimentally whether enhancing mule deer nutrition during winter and early spring via supplementation increases fetal survival, neonatal survival, overwinter fawn survival, or ultimately, population productivity.

SEGMENT OBJECTIVES

1. Publish manuscripts in peer-reviewed scientific journals.
2. Publish dissertation as part of Ph.D. requirements at Colorado State University

INTRODUCTION

Mule deer (*Odocoileus hemionus*) numbers apparently declined during the 1990s throughout much of the West, and have clearly decreased since the peak population levels documented during the 1940s–1960s (Unsworth et al. 1999, Gill et al. 2001). Biologists and sportsmen alike have concerns as to what factors may be responsible for declining population trends. Although previous and current research indicates multiple interacting factors are responsible, habitat and predation have typically received the focus of attention. A number of studies have evaluated whether predator control increases deer survival, yet results are highly variable (Connolly 1981, Ballard et al. 2001). Together, predator control studies with adequate rigor and statistical power indicate predation effects on mule deer are variable as a result of time-specific and site-specific factors. Studies which have demonstrated deer population responses to predator control treatments have failed to determine whether predation is ultimately more limiting than habitat when considering long term population changes. Numerous research studies have evaluated mule deer habitat quality, but virtually no studies have documented population responses to habitat improvements. In many areas where declining deer numbers are of concern, predation is common yet habitat quality appears to have declined. The question remains as to whether predation, habitat, or some other factor is more limiting to mule deer in these situations, and whether habitat quality can be improved for the benefit of deer. It may also be that no single factor is responsible for observed deer declines, and a more comprehensive understanding of multi-factor interactions is needed.

We designed and implemented a field experiment where we measured deer population responses to a nutrition enhancement treatment to further understand the causative factors underlying observed deer population dynamics. We conducted the study on the Uncompahgre Plateau in southwest Colorado, where several predator species were present in abundant numbers: coyotes (*Canis latrans*), mountain lions (*Felis concolor*), and bears (*Ursus americanus*). In addition to predation, myriad diseases in combination have proximately affected survival of the Uncompahgre deer population (Pojar and Bowden 2004, B. E. Watkins, Colorado Division of Wildlife, unpublished data). Predator numbers were not manipulated in any manner during the course of the study. All factors were left constant with the exception of deer nutrition. Deer nutrition was enhanced by providing supplemental feed to deer occupying a treatment area during winter. We measured December fawn recruitment and overwinter fawn survival in response to the treatment to determine whether deer nutrition was ultimately more limiting than predation or disease. A second phase of research was initiated in 2005 to quantify deer population parameters in response to manipulations of pinyon-juniper (*Pinus edulis-Juniperus osteosperma*) habitat (Bergman et al. 2007). The objective of this research is to determine whether habitat can be effectively improved for mule deer by introducing disturbance into late-seral pinyon-juniper stands.

STUDY AREA

We non-randomly selected two experimental units (A–B) within mule deer winter range on the Uncompahgre Plateau (Figure 1) to facilitate a cross-over experimental design for evaluating the effects of enhanced deer nutrition during winter on annual population performance. Unit A received a nutrition enhancement treatment during the first 2 winters of research (2000 – 2002) while Unit B served as a control unit. During winters 2002–03 and 2003–04, Unit B received the treatment while Unit A served as the control. In late April and May, prior to fawning, deer from the winter range experimental units migrated to summer range. We defined the summer range study area by movements of the radio-collared deer captured on winter range; summer range encompassed >1000 mi^2 covering the southern portion of the Uncompahgre Plateau and adjacent San Juan Mountains (Figure 2). Winter range elevations ranged from 1830 m (6000 ft) in Shavano Valley to 2318 m (7600 ft) adjacent to the Dry Creek Rim above Shavano Valley. Winter range habitat was dominated by pinyon-juniper with interspersed sagebrush adjacent to agricultural fields in the Shavano and Uncompahgre Valleys. Summer range elevations occupied by deer ranged from 1891 m (6200 ft) in the Uncompahgre Valley to 3538 m (11,600 ft) in Imogene Basin southwest of Ouray, CO. Summer range habitats were dominated by spruce-subalpine fir (*Picea* spp.-*Abies lasiocarpa*), aspen (*Populus tremuloides*), sagebrush, ponderosa pine (*Pinus ponderosa*), Gambel oak (*Quercus gambelii*), and to a lesser extent, pinyon-juniper at lower elevations. Bishop et al. (2005) provide a detailed study area description.

METHODS

Refer to Bishop et al. (2005) or Bishop (2007) for field methodology employed during 2000–2005. During fiscal year 2007–08, we had 1 paper published and 2 papers accepted for publication in peer-reviewed scientific journals. Thus, our primary research efforts were focused on preparation of manuscripts for publication. We completed and published a paper in Journal of Wildlife Management focused on mule deer sibling dependence in context of fetal and neonatal survival analyses. In this paper, we also presented a likelihood function for estimating fetal survival when the fates of some fetuses are unknown. We spent much of the year preparing and submitting a manuscript to Wildlife Monographs. This particular publication documents the effect of enhanced nutrition on all aspects of mule deer productivity, survival, and population rate of change. Finally, we prepared and submitted a manuscript documenting the utility of serum thyroid hormone concentrations for evaluating mule deer body condition in late winter with this manuscript accepted for publication following two substantive revisions. The principal investigator also published his Ph.D. dissertation.

A component of this project was an evaluation of vaginal implant transmitters (VITs) as a tool for locating neonatal mule deer fawns from targeted adult females (Bishop et al. 2007). To build on this research, we worked with Advanced Telemetry Systems (ATS, Isanti, MN) to develop a VIT with modified retention wings during 2007–08. We intend to evaluate the modified VIT in conjunction with ongoing mule deer energy development research in northwest Colorado.

RESULTS AND DISCUSSION

A comprehensive presentation and discussion of all results from this study is provided by Bishop (2007) and is not repeated here. These results and conclusions are being systematically published in peer-reviewed journals. The following manuscripts were published in 2007 and 2008 (abstracts are provided in Appendix I):

Bishop, C. J. 2007. Effect of enhanced nutrition during winter on the Uncompahgre Plateau mule deer population. Dissertation, Colorado State University, Fort Collins, USA.

Bishop, C. J., D. J. Freddy, G. C. White, B. E. Watkins, T. R. Stephenson, and L. L. Wolfe. 2007. Using vaginal implant transmitters to aid in capture of mule deer neonates. Journal of Wildlife Management 71:945–954.

Bishop, C. J., G. C. White, and P. M. Lukacs. 2008. Evaluating dependence among mule deer siblings in fetal and neonatal survival analyses. Journal of Wildlife Management 72:1085–1093.

Schultheiss, P. C., H. Van Campen, T. R. Spraker, C. J. Bishop, L. L. Wolfe, and B. Podell. 2007. Malignant catarrhal fever associated with ovine herpesvirus-2 in free-ranging mule deer in Colorado. Journal of Wildlife Diseases 43:533–537.

The following manuscripts were accepted for publication in 2008 and will most likely be published in 2009 (abstracts are provided in Appendix II):

Bishop, C. J., B. E. Watkins, L. L. Wolfe, D. J. Freddy, and G. C. White. 2009. Evaluating mule deer body condition using serum thyroid hormone concentrations. Journal of Wildlife Management: In press.

Bishop, C. J., G. C. White, D. J. Freddy, B. E. Watkins, and T. R. Stephenson. 2009. Effect of enhanced nutrition on mule deer population rate of change. Wildlife Monographs: in review. (Manuscript has been tentatively accepted pending suitable revision).

We intend to pursue several additional manuscripts as time allows, listed below in order of priority.

1. Evaluating dependence of fates among mule deer siblings in Colorado, Idaho, and Montana. Journal of Wildlife Management.
2. Bovine viral diarrhea isolation and seroprevalence in a free-ranging mule deer (*Odocoileus hemionus*) population in southwest Colorado. Journal of Wildlife Diseases.
3. Spatial patterns in mortality causes of neonatal mule deer across a land use gradient in southwest Colorado. Journal of Wildlife Management.
4. Evaluation of mule deer age and sex ratios as a response variable in field research. Journal of Wildlife Management.

SUMMARY

Enhanced winter nutrition of free-ranging deer caused an increase in both fetus-neonate survival and overwinter fawn survival, resulting in higher yearling recruitment. Overwinter adult female survival increased as a result of the nutrition treatment, and therefore annual survival was higher among treatment than control adult females. Combining all parameter estimates into a deterministic population model, the treatment population indicated an exceptionally high rate of increase while the control population was stable and indicative of the overall Uncompahgre deer population during 2000–2004. The nutrition enhancement treatment was artificial in the sense that we applied it only to test whether habitat quality was ultimately more limiting than predation or other factors. Our results to do not provide support for managing deer populations with nutrition supplements because our treatment delivery approach could not

be applied to a large number of animals over a large area. Rather, our results provide a foundation for focusing deer management efforts on improving habitat quality in western Colorado pinyon-juniper ecosystems with corresponding research efforts to quantify the effects of habitat manipulations on deer.

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Bishop, C. J. 2007. Effect of enhanced nutrition during winter on the Uncompahgre Plateau mule deer population. Dissertation, Colorado State University, Fort Collins, USA.

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Prepared by ______________________
Chad J. Bishop, Wildlife Researcher

Year	Unit A	Unit B
2000-01	**Treatment**	Control
2001-02	**Treatment**	Control
2002-03	Control	**Treatment**
2003-04	Control	**Treatment**

Figure 1. Schematic representation of experimental units and nutrition enhancement treatment allocation. Units A and B were located in winter range habitat on the Uncompahgre Plateau in southwest Colorado. The nutrition enhancement cross-over design encompassed 4 years.

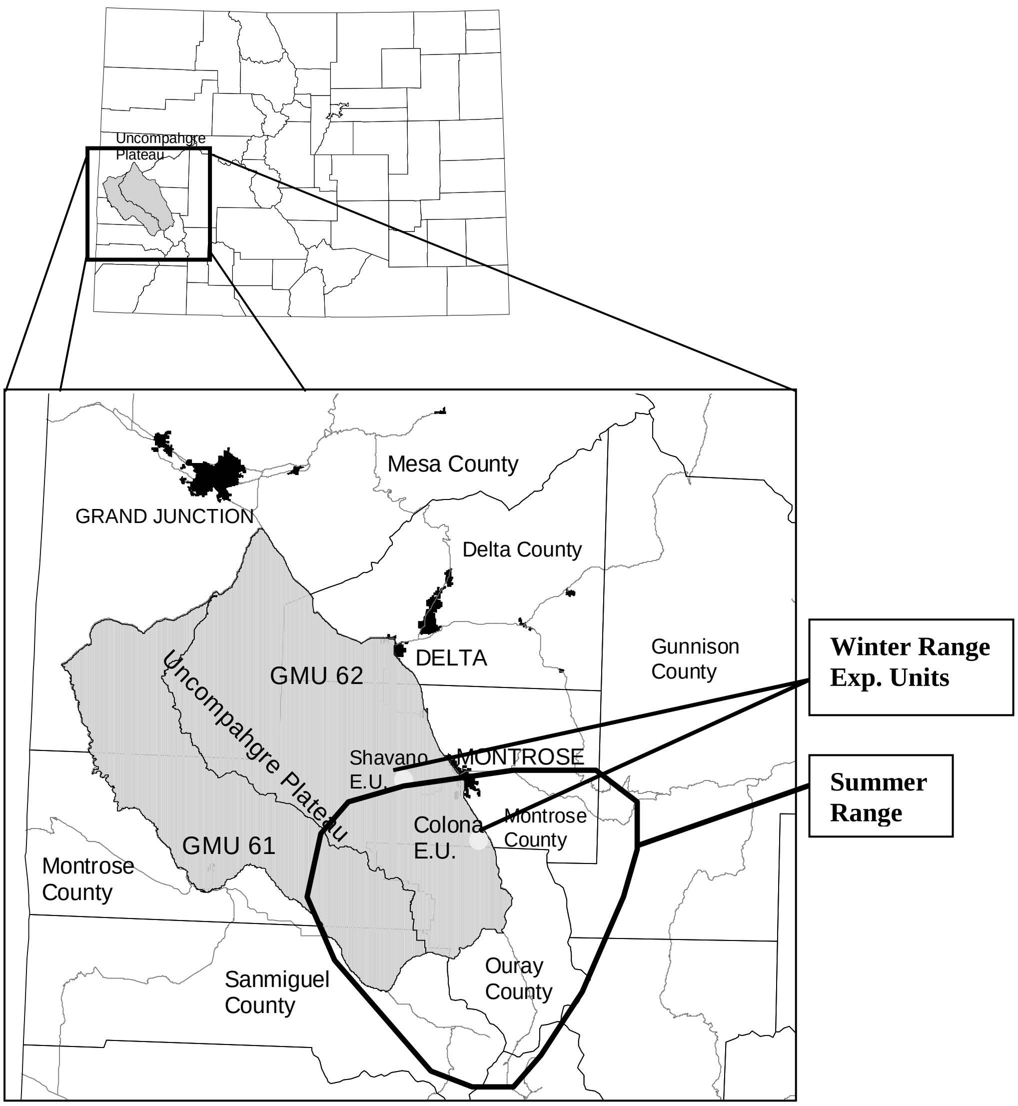

Figure 2. Location of Colona and Shavano (Units A and B) experimental units on the Uncompahgre Plateau, southwest Colorado; and location of the summer range study area encompassing the southern Uncompahgre Plateau and adjacent San Juan Mountains.

APPENDIX I – PUBLISHED PROJECT PAPERS

The following Colorado State University dissertation (referenced here by Abstract) was published in 2007.

EFFECT OF ENHANCED NUTRITION DURING WINTER ON THE UNCOMPAHGRE PLATEAU MULE DEER POPULATION

CHAD J. BISHOP

ABSTRACT

Mule deer (*Odocoileus hemionus*) populations declined across much of the West during the 1990s, prompting state wildlife agencies to explore mule deer limiting factors. The greatest concern of agencies and sportsmen was whether declining habitat quality, predation, or both were responsible for the observed declines. In Colorado, the Uncompahgre Plateau mule deer population received the most attention because of a steep population decline from the 1980s through the late 1990s. Biologists hypothesized that poor quality of the pinyon (*Pinus edulis*) and juniper (*Juniperus osteosperma*) winter range was the primary cause of the observed decline. In contrast, many of the Colorado Division of Wildlife's (CDOW) constituents hypothesized that high predation rates were keeping the mule deer herd below nutritional carrying capacity. These hypotheses represented very different paradigms of population limitation. Perhaps more importantly, the competing views suggested that CDOW should pursue one of two very different management strategies: 1) implement habitat improvements in the pinyon-juniper winter range, or 2) implement efforts to reduce predator populations, particularly coyote (*Canis latrans*) populations. Information was needed to guide the decision process. I therefore evaluated the effect of enhanced nutrition during winter on the Uncompahgre deer population as a way to evaluate the importance of habitat quality versus that of predation.

I conducted a field study incorporating a crossover experimental design to quantify the effect of enhanced nutrition on fetal, neonatal, overwinter fawn, and annual adult doe survival rates. I captured and radio-collared samples of deer in 2 experimental units (EUs) on winter range. I delivered the nutrition treatment to deer occupying one EU (treatment) and did not administer the treatment to deer in the other EU (control). Established field techniques were not sufficient to allow me to quantify the effect of the treatment on fetal and neonatal survival. I therefore pursued an exploration of vaginal implant transmitters as a mechanism to capture necessary samples of newborn fawns on summer range exclusively from radio-collared does that occupied the winter range EUs (Chapter 1). This effort allowed me to estimate fetal and neonatal survival as a function of the treatment. In broad terms, I demonstrated that direct estimates of fetal and neonatal survival may be obtained from previously marked female mule deer in free-ranging populations, thus expanding opportunities for conducting field experiments.

I encountered additional challenges with estimation of fetal and neonatal survival. First, I was unable to determine the fate of all fetuses that I documented in utero. I therefore developed a likelihood function for estimating fetal survival when the fates of some fetuses are unknown (Chapter 2). Second, a majority of my fetal and neonatal samples were comprised of siblings, indicating my data were potentially overdispersed. Overdispersion causes sample variances to be underestimated and requires a variance inflation factor, c. To estimate c, I compared theoretical variance estimates with empirical variance estimates obtained from bootstrap analyses of the data (Chapter 2). I found little evidence of overdispersion in my fetal survival data, and I found modest overdispersion in my neonatal sample data ($\hat{c} = 1.25$). Although some overdispersion was detected, my results indicated that fates of sibling mule deer neonates may often be independent even though they have the same dam and use the environment similarly. I discuss reasons for this in Chapter 2.

After resolving issues with fetal and neonatal survival estimation, I quantified the effect of the nutrition enhancement treatment on fetal, neonatal, overwinter fawn, and annual adult doe survival (Chapter 3). I then used these parameter estimates, along with estimated fecundity rates, in an age-structured, deterministic population model to estimate the effect of the treatment on the population rate of change, $\hat{\lambda}$. The treatment caused $\hat{\lambda}$ to increase by an average of 0.133 (SD = 0.0168) during the 3 years of my study. I documented density dependence in the Uncompahgre deer population because survival of fawns and does increased considerably in response to enhanced nutrition. I found strong evidence that coyote predation of ≥6-month-old fawns and adult does was compensatory. Finally, I found that winter range habitat quality was a limiting factor of the Uncompahgre Plateau deer population.

I completed my principal study objectives in the first 3 chapters of the dissertation. However, my research afforded the opportunity to evaluate the utility of serum thyroid hormones in mule deer as an index to body condition (Chapter 4). Concentrations of total thyroxine (T4) and free T4 (FT4) were substantially higher in treatment deer than control deer. I also found that serum thyroid hormones were highly correlated with estimated body fat in mule deer during late winter. Concentrations of T4 and FT4 could be useful for evaluating relative condition of different deer groups or populations, and for roughly estimating body fat of individual animals during late winter.

In summary, I demonstrated that winter range habitat quality was ultimately limiting the Uncompahgre mule deer population. Observed predation was primarily compensatory, particularly of ≥6-month-old fawns and adult does. My findings indicate that CDOW should evaluate habitat treatments in late-seral pinyon-juniper habitat as a means to increase habitat productivity for mule deer.

Citation: Bishop, C. J. 2007. Effect of enhanced nutrition during winter on the Uncompahgre Plateau mule deer population. Dissertation, Colorado State University, Fort Collins, USA.

The following manuscript (referenced here by Abstract) was published in the Journal of Wildlife Management in 2007.

USING VAGINAL IMPLANT TRANSMITTERS TO AID IN CAPTURE OF MULE DEER NEONATES

CHAD J. BISHOP, DAVID J. FREDDY, GARY C. WHITE, BRUCE E. WATKINS, THOMAS R. STEPHENSON, AND LISA L. WOLFE

ABSTRACT

Estimating survival of the offspring of marked female ungulates has proven difficult in free-ranging populations yet could improve our understanding of factors that limit populations. We evaluated the feasibility and efficiency of capturing large samples (i.e., >80/year) of neonate mule deer (*Odocoileus hemionus*) exclusively from free-ranging, marked adult does using vaginal implant transmitters (VITs, n = 154) and repeated locations of radio-collared does without VITs. We also evaluated the effectiveness of VITs, when used in conjunction with in utero fetal counts, for obtaining direct estimates of fetal survival. During 2003 and 2004, after we placed VIT batteries on a 12-hour duty cycle to lower electronic failure rates, the proportion that shed ≤3 days prepartum or during parturition was 0.623 (SE = 0.0456), and the proportion of VITs shed only during parturition was 0.447 (SE = 0.0468). Our neonate capture success rate was 0.880 (SE = 0.0359) from does with VITs shed ≤3 days prepartum or during parturition and 0.307 (SE = 0.0235) from radio-collared does without VITs or whose implants failed to function properly. Using a combination of techniques, we captured 275 neonates and found 21 stillborns during 2002–2004. We accounted for all fetuses at birth (i.e., live or stillborn) from 78 of the 147 does (0.531, SE = 0.0413) having winter fetal counts, and this rate was heavily dependent on VIT retention success. Deer that shed VITs prepartum were larger than deer that retained VITs to parturition, indicating a need to develop variable-sized VITs that may be fitted individually to deer in the field. We demonstrated that direct estimates of fetal and neonatal survival may be obtained from previously marked female mule deer in free-ranging populations, thus expanding opportunities for conducting field experiments. Survival estimates using VITs lacked bias that is typically associated with other neonate capture techniques. However, current vaginal implant failure rates, and overall expense, limit broad applicability of the technique.

Citation: Bishop, C. J., D. J. Freddy, G. C. White, B. E. Watkins, T. R. Stephenson, and L. L. Wolfe. 2007. Using vaginal implant transmitters to aid in capture of mule deer neonates. Journal of Wildlife Management 71:945–954.

The following manuscript (referenced here by Abstract) was published in the Journal of Wildlife Management in 2008.

EVALUATING DEPENDENCE AMONG MULE DEER SIBLINGS IN FETAL AND NEONATAL SURVIVAL ANALYSES

CHAD J. BISHOP, GARY C. WHITE, AND PAUL M. LUKACS

ABSTRACT

The assumption of independent sample units is potentially violated in survival analyses where siblings comprise a high proportion of the sample. Violation of the independence assumption causes sample data to be overdispersed relative to a binomial model, which leads to underestimates of sampling variances. A variance inflation factor, *c*, is therefore required to obtain appropriate estimates of variances. We evaluated overdispersion in fetal and neonatal mule deer (*Odocoileus hemionus*) datasets where more than half of the sample units were comprised of siblings. We developed a likelihood function for estimating fetal survival when the fates of some fetuses are unknown, and we used several variations of the binomial model to estimate neonatal survival. We compared theoretical variance estimates obtained from these analyses with empirical variance estimates obtained from data bootstrap analyses to estimate the overdisperion parameter, *c*. Our estimates of *c* for fetal survival ranged from 0.678 to 1.118, which indicate little to no evidence of overdispersion. For neonatal survival, 3 different models indicated that $\hat{c}$ ranged from 1.1 to 1.4 and averaged 1.24–1.26, providing evidence of limited overdispersion (i.e., limited sibling dependence). Our results indicate that fates of sibling mule deer fetuses and neonates may often be independent even though they have the same dam. Predation tends to act independently on sibling neonates because of dam-neonate behavioral adaptations. The effect of maternal characteristics on sibling fate dependence is less straightforward and may vary by circumstance. We recommend that future neonatal survival studies incorporate additional sampling intensity to accommodate modest overdispersion (i.e., $\hat{c}$ = 1.25), which would facilitate a corresponding $\hat{c}$ adjustment in a model selection analysis using quasi-likelihood without a reduction in power. Our computational approach could be used to evaluate sample unit dependence in other studies where fates of individually marked siblings are monitored.

Citation: Bishop, C. J., G. C. White, and P. M. Lukacs. 2008. Evaluating dependence among mule deer siblings in fetal and neonatal survival analyses. Journal of Wildlife Management 72:1085–1093.

The following manuscript (referenced here by Abstract) was published in the Journal of Wildlife Diseases in 2007:

MALIGNANT CATARRHAL FEVER ASSOCIATED WITH OVINE HERPESVIRUS-2 IN FREE-RANGING MULE DEER IN COLORADO

PATRICIA C. SCHULTHEISS, HANA VAN CAMPEN, TERRY R. SPRAKER, CHAD J. BISHOP, LISA L. WOLFE, AND BRENDAN PODELL

ABSTRACT

Malignant catarrhal fever (MCF) was diagnosed in 4 free-ranging mule deer (*Odocoileus hemionus*) in January and February of 2003. Diagnosis was based on typical histologic lesions of lymphocytic vasculitis and PCR identification of ovine herpesvirus-2 (OHV-2) viral genetic sequences in formalin fixed tissues. The animals were from the Uncompahgre Plateau of southwestern Colorado. Deer from these herds occasionally resided in close proximity to domestic sheep *(Ovis aries)*, the reservoir host of OHV-2, in agricultural valleys adjacent to their winter range. These cases indicate that fatal OHV-2 associated MCF can occur in free-ranging mule deer exposed to domestic sheep that overlap their range.

Citation: Schultheiss, P. C., H. Van Campen, T. R. Spraker, C. J. Bishop, L. L. Wolfe, and B. Podell. 2007. Malignant catarrhal fever associated with ovine herpesvirus-2 in free-ranging mule deer in Colorado. Journal of Wildlife Diseases 43:533–537.

APPENDIX II

PROJECT PAPERS ACCEPTED FOR PUBLICATION

The following manuscript (referenced here by Abstract) was accepted for publication by the Journal of Wildlife Management during 2008 but has not yet been published.

EVALUATING MULE DEER BODY CONDITION USING SERUM THYROID HORMONE CONCENTRATIONS

CHAD J. BISHOP, BRUCE E. WATKINS, LISA L. WOLFE, D. J. FREDDY, AND GARY C. WHITE

ABSTRACT

Body condition of ungulates is a determinant of fecundity and survival rates. Ultrasonography and body condition scoring techniques allow reliable estimation of body fat but may not be feasible to employ in some circumstances. A reliable blood chemistry index for assessing relative condition of different ungulate populations or groups would be useful in ongoing population monitoring programs. We provided a nutrition supplement (treatment) to a group of free-ranging mule deer (*Odocoileus hemionus*) during 2 consecutive winters in southwest Colorado. In late February each year, we evaluated whether percent body fat and serum concentrations of total thyroxine (T4), total triiodothyronine (T3), free T4 (FT4), and free T3 (FT3) were higher among treatment deer than an adjacent group of deer that did not receive the treatment (control). As a corroborative analysis, we modeled body fat as a function of thyroid hormone concentrations and morphometric variables. Estimated body fat of treatment deer averaged 12.3% (SE = 0.327), whereas estimated body fat of control deer averaged 7.0% (SE = 0.333), during the 2 winters of study. Concentrations of T4 and FT4 averaged 48.07 nmol/l (SE = 3.80) and 12.61 pmol/l (SE = 1.04) higher, respectively, in treatment deer than control deer. Our optimal model of estimated body fat included T4, $T4^2$, FT4, and deer chest girth ($\%\hat{Fat} = -4.8015 - 0.0946 \times T4 + 0.000603 \times T4^2 + 0.1474 \times FT4 + 0.1426 \times \text{chest girth}$, $R^2 = 0.609$). Serum thyroid hormones effectively discerned treatment deer from control deer and were related to estimated body fat. Ultrasound and body condition scoring should be used to estimate body fat whenever possible. However, in cases where only a blood sample can be obtained, we documented potential utility of T4 and FT4 during late winter for evaluating relative body condition of mule deer.

The following manuscript (referenced here by Abstract) was tentatively accepted for publication by Wildlife Monographs during 2008 and is still in the revision stage.

EFFECT OF ENHANCED NUTRITION ON MULE DEER POPULATION RATE OF CHANGE

CHAD J. BISHOP, GARY C. WHITE, DAVID J. FREDDY, BRUCE E. WATKINS, AND THOMAS R. STEPHENSON

ABSTRACT

Concerns over declining mule deer (*Odocoileus hemionus*) populations during the 1990s prompted research efforts to identify and understand key limiting factors of deer. Similar to past deer decline incidents, a top priority of state wildlife agencies was to evaluate the relative importance of habitat and predation. We therefore evaluated the effect of enhanced nutrition of deer during winter and spring on fecundity and survival rates using a life table response experiment involving free-ranging mule deer on the Uncompahgre Plateau in southwest Colorado. The nutrition enhancement treatment represented an instantaneous increase in nutritional carrying capacity of a pinyon (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*) winter range, and was intended to simulate optimum habitat quality. Prior studies on the Uncompahgre Plateau indicated predation and disease were the most common proximate causes of deer mortality. By manipulating nutrition and leaving natural predation unaltered, we determined whether habitat quality was ultimately a critical factor limiting the deer population. We measured fetal, neonatal, and overwinter fawn survival, and annual adult female survival, which we then used to estimate population rate of change as a function of enhanced nutrition. Pregnancy and fetal rates were high for all deer, regardless of the nutrition treatment. Fetal and neonatal survival rates were higher among deer that received the nutrition enhancement treatment than deer that served as experimental controls. Overwinter fawn survival increased for treatment deer by 0.16–0.31 depending on year and fawn sex, and none of the 95% confidence intervals associated with the effect overlapped 0. Nutrition enhancement increased survival of fetuses to the yearling age class by 0.14–0.20 depending on year and fawn sex, although 95% confidence intervals slightly overlapped 0. Annual survival of adult females receiving the treatment ($\hat{S}$ = 0.879, SE = 0.0206) was higher than survival of control adult females ($\hat{S}$ = 0.833, SE = 0.0253). Our estimate of the population rate of change, $\hat{\lambda}$, was 1.165 (SE = 0.0358) for treatment deer and 1.033 (SE = 0.0380) for control deer. The nutrition treatment caused $\hat{\lambda}$ to increase by 0.133 (SE = 0.0428). We documented density dependence in the Uncompahgre deer population because survival of fawns and adult females increased considerably in response to enhanced nutrition. We found strong evidence that coyote (*Canis latrans*) predation of ≥6-month-old fawns and adult females was compensatory. Our results demonstrate that observed coyote predation, by itself, is not useful for evaluating whether coyotes are negatively impacting a deer population. We also found evidence that mountain lion (*Puma concolor*) predation was compensatory. Disease mortality was not compensatory among adult females. We found that winter range habitat quality was a limiting factor of the Uncompahgre Plateau mule deer population. Therefore, we recommend evaluating habitat treatments for deer that are designed to set-back succession and increase productivity of late-seral pinyon-juniper habitats that presently dominate the winter range.

Colorado Division of Wildlife
July 2007 – June 2008

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of 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, 2007 - June 30, 2008

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

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, 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 CDOW, L. Carpenter - Wildlife Management Institute, D. Felix, L. Felix - Olathe Spray Service, P. Johnston, M. Keech, R. Swisher, S. Swisher - Quicksilver Air

ABSTRACT

We completed the third year of a multi-year, multi-area study to assess the impacts of landscape level winter range habitat improvement efforts on mule deer population performance. This study is occurring on the Uncompahgre Plateau and in adjacent valleys in southwestern Colorado. Data collection and analysis for this third year were consistent with that of the pilot study and first two years of the study. We measured over-winter fawn survival and total deer density on 4 annual study areas, as well as on a fifth variable area that had previously not been involved in the study. Additionally, on 2 of the study areas we estimated body condition of does. 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, but tended to be above published long term averages (mean survival rate of 0.63 (0.04 SE)). However, survival rates for the third year of the study were lower than all previous years, which were consistent with observed patterns throughout the state, likely stemming from harsher winter conditions. Preliminary evidence continues to suggest that areas that have received habitat treatments have higher fawn survival. However, based on estimates of total body fat for adult female deer, there was no apparent distinction between treatment and reference study areas. Point estimates of deer density on the 5 study areas during the winter of 2007-2008 varied from estimates colleted during the winters of 2005-2006 and 2006-2007. However, general mule deer density estimates have followed a consistent trend between all winters of the study with no major annual change observed.

WILDLIFE RESEARCH REPORT

EVALUATION OF WINTER RANGE HABITAT TREATMENTS ON OVER-WINTER SURVIVAL AND BODY CONDITION OF MULE DEER

ERIC J. BERGMAN

P.N. OBJECTIVE

To experimentally assess whether mechanical/chemical treatments of native habitat vegetation will increase over-winter mule deer fawn survival, adult doe body condition, and localized deer densities on the Uncompahgre Plateau in southwest Colorado.

SEGMENT OBJECTIVES

1. Capture and radio-collar the minimum necessary sample (n=25) of 6 month-old fawns between November and early-January in each of 5 study areas.
2. Measure over-winter fawn survival from mid-December through mid-June.
3. Estimate late-winter deer densities in each study area via helicopter resighting of marked deer.
4. Capture and sample a minimum number of adult female deer (n=30) to estimate late-winter body condition in 2 study areas.

INTRODUCTION

A common trend among many terrestrial, mammalian systems is a tendency to cycle between population highs and lows (Jedrzejewska and Jedrzejewski 1998, Krebs et al. 2001, Clutton-Brock and Pemberton 2004). While the true cause of these cycles is likely a merger of habitat quality, weather, disease, predation, sport hunting, competition and community population dynamics, it is often necessary or intriguing for wildlife managers and ecologists to identify the primary limiting factor to population growth. Without exception, mule deer populations have also demonstrated a tendency to show large fluctuations. Several dramatic declines have been observed since the turn of the 19th century (Connolly 1981, Gill 2001, Hurley and Zager 2004). However, only one period of increase, a general trend during the 1940's and 1950's, has been noted. The most recent and pressing decline took place during the 1990's (Unsworth et al. 1999). Colorado has not escaped these tendencies, with certain parts of the state experiencing population declines by as much as 50% between the 1960's and present time (Gill 2001, B. Watkins personal communication). Primarily due to the value of mule deer as a big game hunting species, wildlife managers' challenges are two-fold: understanding the underlying causes of mule deer population change and managing populations to dampen the effects of these fluctuations.

In Colorado, the role of habitat as the limiting factor for mule deer populations was recently tested. Specifically, the role of forage quality and quantity on over-winter fawn survival was tested using a treatment/reference cross-over design with *ad libitum* pelleted food supplements as a substitute for instantaneous high quality habitat improvements (Bishop 2007). The primary hypothesis behind this research concerned the interaction between predation and nutrition. If supplemental forage treatments improved over-winter fawn survival (i.e. if predation did not prevent an increase), then it could be concluded that over-winter nutrition was the primary limiting factor on populations. As such, preliminary evidence suggests that nutrition enhancement treatments increased fawn survival by as much as 20% (C.J. Bishop, personal communication). This research effectively identified some of the underlying processes in mule deer population regulation, but did not test the effectiveness of acceptable habitat management techniques. Due to the undesirable effects of feeding wildlife (e.g. artificially elevating density, increased potential for disease transmission and cost), a more appropriate technique for achieving a high quality nutrition enhancement needs to be assessed.

Based on this past research and the above mentioned objectives, we designed and initiated a multi-year, multi-area study to assess the impacts of landscape level winter range treatments on mule deer population performance. This study is being conducted on the Uncompahgre Plateau and adjacent valleys in southwestern Colorado. Due to the active habitat treatment history in this area, the Uncompahgre Plateau stood out as the most opportune place for addressing these issues. Additionally, there are several tracts from 2 state wildlife areas that are located in key locations, thereby allowing additional habitat treatments to occur on the level and schedule necessary of this project. To assess the impacts of habitat treatments on mule deer in these areas, we are measuring over-winter fawn survival, mule deer density and late winter body condition.

In addition to the above mentioned objectives, the opportunity to explore deer/elk interactions, as well as predator-prey dynamics is available in our study areas. As part of a pilot study to assess these interactions, we distributed elk GPS collars across the south end of the Uncompahgre Plateau where the density of radio-marked deer and mountain lions is highest (Alldredge et al. 2008). Preliminary data will give basic information regarding elk distribution throughout the year, which can then be compared to similar data for deer and the spatial distribution of mountain lion kill sites.

STUDY AREA

At the onset of this study (Bergman et al. 2005), we identified 2 pairs of treatment/reference study areas, stratified into historically known high and low deer density areas. The selection process for these pairs of experimental units followed several strict guidelines:

1) Treatment/reference units could not be further than 10km apart, but needed to have adequate buffer to minimize the movement of animals between the treatment and reference areas.
2) Reference study areas could not have received any mechanical treatment during the past 30 years.
3) Strata were defined by winter range type (all experimental units had to be in pinyon/juniper winter range) and deer density.
4) Treatment units needed to have received mechanical treatment in the past, but also had to be capable of receiving further treatments during the study period.

Each winter a 5th study area is added to increase the level of inference that can be drawn from this study. For each of the 4 winters that will cover the study period, this 5th study area shifts between 4 randomly selected areas. The treatment history on each of these additional study areas varies, but is representative of what can be expected of typical winter-range treatments. During the second winter of this study, this 5th study area fell on the Colona Tract (~5km^2) of Billy Creek State Wildlife Area (approximately 15km south of Montrose, CO). The treatment history of Colona Tract is primarily composed of brush mowing and chemical control of weeds and dry land fertilization of preferred species.

The high density treatment area is located on the Billy Creek tract of Billy Creek State Wildlife Area (approximately 20km south of Montrose, CO). The high density reference area is located around Beaton Creek (approximately 15km south of Montrose, CO and approximately 5km north of Billy Creek State Wildlife Area). Both of the high density study areas are located in GMU 65 (DAU D-40). The low density treatment area is located on Peach Orchard Point, on/near Escalante State Wildlife Area (approximately 25km southwest of Delta, CO). The low density reference area is located on Sowbelly and Tatum draws (approximately 25km west of Delta, CO and approximately 8km from Peach Orchard Point). Both of the low density study areas are located in GMU 62 (DAU D-19). Shavano Valley was also located in GMU 62 (DAU D-19) to the west of Montrose, CO.

METHODS

Twenty-five mule deer fawns were captured and radio-collared in each of the 5 study areas. Fawns were captured via baited drop-nets (Ramsey 1968, Schmidt et al. 1978, Bartmann et al. 1992) and helicopter net-gunning (Barrett et al. 1982, van Reenen 1982) between mid-November and late-December. Ten adult female elk were captured via helicopter net-gunning during this same period. Fawns were fitted with radio collars made of vinyl belting and equipped with mortality sensors, which after remaining motionless for 4 hours, increase the pulse rate of received signals. To make fawn collars temporary, one end of the collar was cut in half and reattached using rubber surgical tubing; fawns shed the collars after approximately 6 months. Elk were collared with either permanent VHF collars or temporary GPS collars that were fitted with timed blow-off devices.

On a daily basis, from December through May, we monitored the radioed fawns in order to document live/death status. This allowed us to determine accurately the date of death and estimate the proximate cause of death. Daily monitoring was done from the ground to maximize efficient collection of mortalities and assessment of cause specific mortality. Weekly aerial telemetry flights were conducted to insure that all deer were heard at least once a week, allowing weekly survival estimates for each study area.

Additionally, throughout the winter field season and as part of a related pilot field study, investigations of mountain lion GPS clusters were conducted (see Alldredge et al. 2008).

To estimate body composition, an additional 30 adult female deer were captured via helicopter net-gunning and fitted with temporary radio-collars, also having mortality sensors, in late-February within each of the 2 high density study areas. For body condition work, we relied on methods that employed the use of ultrasonography to estimate total body fat (Stephenson et al. 1998, Cook 2000, Stephenson et al. 2002). Blood samples were also collected for endocrinology and pregnancy tests.

During late winter (early-March) we estimated deer density on each of our study areas. Helicopter based mark-resight techniques were used for density estimation (Gill 1969, Bartmann et al. 1986, Kufeld et al. 1980, Freddy et al. 2004).

Preliminary survival analyses were conducted on the first two years of data. In addition to including individual covariates (fawn sex and mass), we explored the role of habitat treatment history on survival. Due to the preliminary nature of these analyses and the ongoing status of the habitat treatment work, we did not attempt to rank individual study areas. Rather, our analyses were conducted such that areas were included and compared using three different approaches. With the first approach, areas were included individually and a unique survival rate was calculated for each area. The second approach allowed for 3 levels of habitat treatment intensity (untreated, single treatment or ongoing treatments). The final approach did not attempt to segregate treated areas by treatment history. Rather, any area with any treatment history was treated similarly, resulting in a unique survival rates being calculated for untreated (reference) areas and a different, unique survival rate being calculated for all other areas.

All survival models were conducted in program MARK (White and Burnham 1999). Known-fate models were tested using the logit link function. All models are compared using Akaike's Information Criterion corrected for small sample size (Burnham and Anderson 2003).

RESULTS AND DISCUSSION

With the exception of one study area, minimum desired sample sizes were met in all study areas for all components of this research (n = 25 fawns per area for survival work, n = 30 adult females in two areas for body condition assessment). Minimum desired sample size for fawn survival was not met in one study area (McKenzie Buttes) due to radio-collar failure. Capture related mortalities occurred on 2 of 183 occasions (1.01%, 2 adult females). Four fawns died of unknown causes within 1week of capture and were censored from the survival analysis. Mean mass of all fawns was 35.8 kg and the observed sex ratio for the sample was 54 males to 68 females (Table. 1). The sex of one fawn was inadvertently not recorded.

Estimates of fawn survival collected during this study have been above average compared to results from other research throughout the west, as well as on the Uncompahgre Plateau. Across our 5 study areas, estimated survival rates ranged between 0.36 (0.13 SE) and 0.79 (0.08 SE), with a mean survival rate of 0.63 (0.04 SE) (Table 2). While these rates are lower than those measured during previous winters, they remain higher than long term averages reported in the literature (Unsworth et al. 1999). Of note, winter conditions across the state of Colorado were harsher than those observed over the past decade and survival rates are expected to have been negatively affected throughout the state. During the previous years of this study, survival rates in our low-density study areas have been higher than expected. While rates in those areas continued to be higher than those observed in our high-density areas, they also appeared to have been negatively affected by harsher winter conditions.

Preliminary survival models indicate that the individual parameter most influencing over-winter fawn survival continues to be fawn mass (Table 3). Fawn sex did not appear to add much additional strength or support to any given model. Of particular interest to this study is that models incorporating study area treatment level were among the top performing models for the entire suite of models run. However, the most supported model did not take treatment history into account. At this time, we speculate that deviation from the previous year's best performing model is primarily driven by a single study area (McKenzie Butte) where observed survival rates were quite low, despite being classified as a treatment area. The average elevation for this particular study area was higher than that of nearby study areas, likely exacerbating that harsher winter conditions observed across all areas. When run with a yearly effect, survival models were not improved and consistently under-performed less complex models. The variable nature of model results between years highlights the preliminary nature of these analyses and is ultimately linked to not having collected all of the necessary data. As the study progresses and more study areas are included, a treatment intensity effect is likely to be detected if it exists.

Late winter body condition estimates for adult females during the winter of 2007-2008 were again higher than those collected during previous winters on the Uncompahgre Plateau (Bishop 2007 and C.J. Bishop, personal communication). In light of the harsher winter that was observed this past year, this result was counter intuitive. While point estimates of total percent body fat were higher in the treatment area (Billy Creek) than in the reference area (Buckhorn), there was no apparent statistical distinction between our study areas. This lack of distinction was also observed in the levels of the T3 hormone, but not in the T4 hormone (nmol/l) (Table 4). Of particular note, pregnancy rates, based on PSPB, were numerically lower than those observed in earlier years. Past rates ranged between 90% and 95%, whereas rates for this past winter were 80% (Buckhorn) and 87% (Billy Creek). Of note, body condition estimates were collected in the Sowbelly study areas during the first year of the study, but were later replaced by estimates in the Buckhorn study area as estimates from Buckhorn were deemed to be a more realistic and practical comparison to those that have been continuously collected in the Billy Creek study area.

Density estimates were collected during March for all five study areas (Figure 1). No major modifications were made to the methodology, although the total number of marked animals in Billy Creek and Buckhorn increased. As such, the precision of estimates for these two areas improved. No major shifts in deer density were observed in Billy Creek, Peach Orchard or Sowbelly. The total number of deer observed and the overall estimated density for Buckhorn showed a marked increase. This shift was likely due to annual variation in deer distribution with deer having shifted down in elevation due to harsher conditions at the upper end of winter range. However, under this scenario, a similar shift in distribution would have been expected to occur in the Billy Creek study area as winter conditions between these two study areas were very similar.

SUMMARY

Survival rates for mule deer fawns across our study areas averaged 63% with a measured high of 79% and measured low of 36%. Overall body condition parameter estimates for late-winter adult female deer were moderate to high, which did not coincide with the harsher winter conditions that were observed throughout deer winter range in Colorado. However, pregnancy rates did appear to be lower, which may be explained by winter conditions. Evidence of higher deer survival in treatment areas was observed, but we do not have enough data to draw strong conclusions at this preliminary stage. Estimates of total deer density across our study areas continue to be in line with historical estimates. Precision of density estimates have improved with modification to techniques and additional years of data collection will be needed to determine if habitat treatment effects can potentially be detected.

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Table 1. Mean mass (n) and sex of mule deer fawns captured on the Uncompahgre Plateau from late-November through early-January of each year, 2005-2006, 2006-2007 and 2007-2008. All fawns were captured by baited drop-nets or helicopter net-gunning. Mass is reported in kg.

Area	Year	Males	Females	Total
Billy Creek	2005	37.1 (14)	32.0 (11)	34.9 (25)
Buckhorn	2005	37.4 (11)	35.0 (15)	36.0 (26)
Shavano	2005	39.4 (11)	37.2 (14)	38.2 (25)
Peach Orchard	2005	37.0 (11)	35.3 (14)	36.1 (25)
Sowbelly	2005	37.1 (16)	34.2 (9)	36.1 (25)
Billy Creek	2006	38.3 (12)	34.4 (12)	36.5 (25)
Buckhorn	2006	36.7 (10)	34.7 (15)	35.5(25)
Colona	2006	38.1 (12)	32.5 (12)	35.4 (24)
Peach Orchard	2006	37.0 (13)	35.5 (12)	36.3 (25)
Sowbelly	2006	44.3 (8)	35.5 (15)	38.7 (25)
Billy Creek	2007	36.0 (13)	36.3 (12)	36.1 (25)
Buckhorn	2007	37.8 (6)	34.8 (18)	35.5 (25)
McKenzie	2007	36.8 (15)	34.3 (8)	36.0 (23)
Peach Orchard	2007	37.3 (9)	33.5 (16)	34.9 (25)
Sowbelly	2007	38.6 (11)	35.1 (14)	36.7 (25)

Table 2. Over-winter mule deer fawn survival rates for study areas across the Uncompahgre Plateau, for the first three winters of the study. Billy Creek, Peach Orchard, Colona, Shavano and McKenzie Buttes represent treatment areas. Buckhorn and Sowbelly are reference areas. Peach Orchard and Sowbelly are considered low-density study areas. Deer reflected by the category ‘Other’ represent deer that were captured on transition range, with the hope that they would migrate onto the Sowbelly study area, but alternatively migrated into an area not formally designated as a study area.

	2005-2006	2006-2007	2007-2008
Area	$\hat{S}$ (S.E.)	$\hat{S}$ (S.E.)	$\hat{S}$ (S.E.)
Billy Creek	0.83 (0.76)	0.72 (0.09)	0.71 (0.09)
Buckhorn	0.76 (0.88)	0.63 (0.10)	0.59 (0.10)
Colona	N.A.	0.68 (0.09)	N.A.
Shavano	0.76 (0.85)	N.A.	N.A.
McKenzie Buttes	N.A.	N.A.	0.61 (0.11)
Peach Orchard	0.88 (0.65)	0.92 (0.05)	0.79 (0.08)
Sowbelly	1.00 (0.00)	0.88 (0.07)	0.70 (0.19)
Other	0.83 (1.08)	N.A.	0.36 (0.13)

Table 3. Preliminary survival model results for radio collared fawns on the Uncompahgre Plateau for the winters of 2005-2006, 2006-2007 and 2007-2008.

Model	AICc	ΔAICc	ω_i
Area + Mass	811.953	0.000	0.371
Treatment Type + Mass	812.781	0.827	0.245
Area + Mass + Sex	813.926	1.972	0.138
Treatment/Reference + Mass	814.576	2.623	0.100
Treatment Type + Mass + Sex	814.619	2.665	0.098
Treatment/Reference + Sex + Mass	816.276	4.322	0.043
Area	822.177	10.224	0.002
Area + Sex	823.065	11.112	0.001
Treatment Type	826.542	14.589	0.000
Constant	826.768	14.815	0.000
Treatment Type + Sex	827.363	15.410	0.000
Treatment/Reference	828.525	16.571	0.000
Treatment/Reference + Sex + Mass	829.661	17.708	0.000

Table 4. Late-winter body condition estimates for female adult mule deer on the Uncompahgre Plateau in 2 study areas each year, 2005-2006 and 2006-2007. Sample sizes were 30 does in each area. Mean T3 and T4 samples are reported in nmol/l. Parameters marked with an asterisk designate a significant difference between areas at the 0.05 level.

Year	Parameter	Billy Creek	Buckhorn	Sowbelly
	% Body Fat	8.80% (2.02)	N.A.	9.81% (2.88)
2005-2006	T3*	1.12 (0.28)	N.A.	1.41 (0.51)
	T4	70.69 (20.94)	N.A.	79.97 (15.80)
	% Body Fat	7.61% (1.94)	7.03% (1.80)	N.A.
2006-2007	T3	1.55 (0.53)	1.42 (0.31)	N.A.
	T4	88.23 (19.53)	78.07 (22.34)	N.A.
	% Body Fat	8.09% (1.10)	7.20% (1.69)	N.A.
2007-2008	T3	1.17 (0.28)	1.17 (0.56)	N.A.
	T4*	94.30 (20.7)	56.20 (23.30)	N.A.

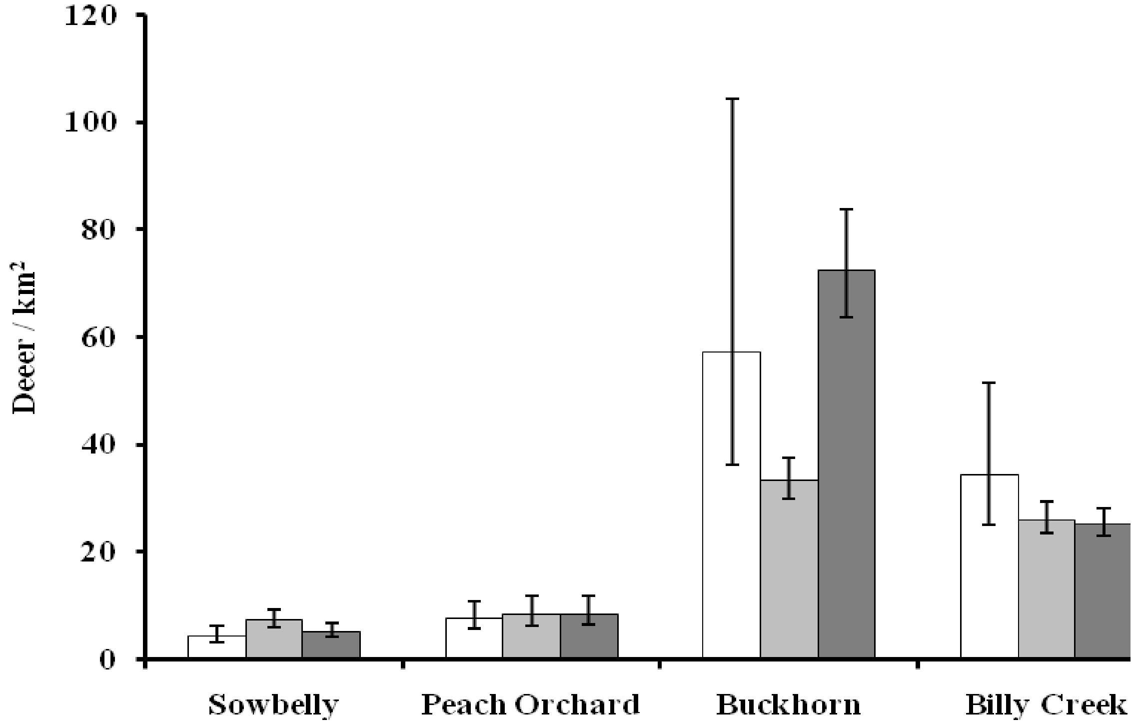

Figure 1. Mule deer density estimates for the 4 permanent study areas. Clear boxes reflect data from the 2005-2006 winter, light grey boxes reflect data from the 2006-2007 winter and dark grey boxes reflect data from the 2007-2008 winter. Error bars represent the 95% confidence intervals for density estimates.

Colorado Division of Wildlife
July 2007 – June 2008

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of 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 – Stage I, Objective 5; Patterns of Mule Deer Distribution and Movements
Federal Aid Project No.	W-185-R		

Period Covered: July 1, 2007 – June 30, 2008

Authors: C. R. Anderson and D. J. Freddy

Personnel: J. Broderick, B. deVergie, D. Finley, L. Gepfert, C. Harty, K. Kaal, L. Kelly, S. Lockwood, R. Velarde, CDOW; R. Swisher, Quicksilver Air, Inc. Project support received from Federal Aid in Wildlife Restoration, Colorado Mule Deer Association, Colorado Oil and Gas Conservation Commission, Williams Production LMT Co., EnCana Corp., and Shell Petroleum.

ABSTRACT

We propose to experimentally evaluate habitat treatments that may rehabilitate the landscape to benefit mule deer (*Odocoileus hemionus*) and to evaluate human-activity management alternatives to reduce the disturbance of energy development impacts on mule deer. 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 within the state. Assessments of potential study areas, resource inventory maps, and tentative study plan outlines were presented to potential agency and industry cooperators. Sufficient funding was secured to initiate a pilot study allowing refinement of study area selection based on distribution of GPS collared deer, address logistics of deer captures and collaring efforts, and begin addressing one of the six proposed objectives by monitoring deer movements from GPS locations in 5 study areas representing varying levels of energy development. We attached GPS collars collecting 5 fixes/day to 75 adult female mule deer (15/study area) in January, 2008 to document deer movements and habitat use patterns among 5 deer winter ranges exposed to varying levels of energy development. Over-winter survival of adult females was 90% (64 of 71) and typical for adult female mule deer in the western US. Data analyses of mule deer habitat use patterns will begin once GPS collars are recovered in February, 2009. These data will provide deer behavior information under existing conditions and serve as pre-treatment comparisons to future

conditions following habitat treatments and/or improved development practices. Additional funding has become available to initiate the full study proposal (see Appendix I) beginning November 2008, which will provide for evaluation of changes in body condition, fawn survival, and deer densities relative to improved habitat treatments and energy development practices. This project will require additional funding commitments and cooperative agreements beyond spring 2010 from private industry, the BLM, and the CDOW to assess if sustainable mule deer populations can persist within a highly disturbed landscape following implementation of beneficial habitat treatments and development practices.

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

STAGE I, OBJECTIVE 5: PATTERNS OF MULE DEER DISTRIBUTION & MOVEMENTS

CHARLES R. ANDERSON, JR. AND DAVID J. FREDDY

P. N. OBJECTIVES

1. To determine experimentally whether enhancing mule deer habitat conditions on winter and/or transition range elicits behavioral responses, improves body condition, increases overwinter 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, over-winter fawn survival, and winter range mule deer densities.

SEGMENT OBJECTIVES

3. Assess the logistics capturing and collaring mule deer via helicopter net-gunning in 5 winter herd segments of the Piceance Basin, Colorado.
4. Improve delineation and identify degree of separation of winter range study sites based on deer distribution and movements from GPS collars collecting 5 fixes/day.
5. Monitor survival of adult female mule deer by daily ground tracking and bi-weekly aerial tracking.
6. Summarize data and present information in an annual Job Progress Report.

INTRODUCTION

Anderson and Freddy (2007) 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. Much of the rationale for conducting the long-term research is presented in Appendix I. However, this progress report, beginning as of January 2008, focuses only on Objective 5 of the research proposal (Appendix I): monitoring distribution, movements, and habitat selection patterns of adult female mule deer on 5 potential segments of winter range in relation to varying levels of natural gas development, experimental modifications in energy developmental practices, and potential habitat improvement treatments. Long-term funding and support had not been secured to simultaneously address all 6 proposed study objectives on 5 potential winter range segments, but preliminary funding and support had been established to begin to address mule deer movement patterns relative to current natural gas development activities in the Piceance Basin. This initial effort during FY07-08 provided key information to 1) document movement patterns and degree of spatial separation of deer among potential experimental control and treatment sites, 2) help refine study area boundaries, 3) begin documenting deer spatial use in proposed experimental control and treatment areas prior to implementing habitat or development improvements, and 4) provide an assessment of deer capture logistics and operational success of improved versions of GPS and VHF radio-telemetry collars. Monitoring spatial use patterns of deer is planned for at least 5 years as part of the forthcoming major study so that this first year of data acquisition establishes the foundation for long-term data acquisition process. Once longer term financial and administrative commitments have been established, we will incorporate the additional objectives into a revised study plan to achieve our overall goal of developing approaches to provide for energy extraction in a manner that maintains viable mule deer populations for future recreational and ecological purposes. We recently acquired the necessary funding to allow for the complete study proposal to be initiated by fall 2008 and continue through spring 2010.

STUDY AREA

The Piceance Basin 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 also exhibits one of the highest natural gas reserves in North America (Fig. 1). Historically, mule deer numbers on winter range were estimated between 15,000-22,000 (Bartmann 1975), and the current number of well pads (Appendix I: Fig.1) and projected number of gas wells in the Piceance Basin over the next 20 years is about 400 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 1675 m to 2285 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 (*Crysothamnus* 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 coming from spring snow melt.

In our initial proposal, we outlined 6 potential study sites exhibiting varying winter deer densities and varying levels of energy development activity to provide control and treatment experimental units for evaluating improved habitat and development treatments (Appendix I: Table 1, Fig. 2). Ultimately, 1 of the 6 proposed study sites was omitted partly due to funding limitations and ultimately because the omitted area (Crooked Wash) offered limited opportunity to examine habitat improvements due to dry moisture conditions inhibiting success of habitat treatments and future energy development in the area appeared unlikely due to extensive previous development precluding evaluations of improved development practices. The remaining 5 areas were maintained and North Ridge will serve as a temporal control area offering evaluations of annual variation in parameter estimates due to non-development factors from an undeveloped area, and Story/Sprague Gulch (formerly referred to as Story/Willow Creek) and Yellow Creek will serve as spatial control areas to the 2 treatment areas (Magnolia and Ryan Gulch, respectively), providing spatial comparisons from geographically and vegetatively similar areas exposed to minor levels of energy development compared to extensively developed areas receiving improved habitat and/or development treatments. Because the progression and extent of energy development in the future is currently unknown (to CDOW, at least), North Ridge may also serve as a spatial control area to Magnolia or possibly Ryan Gulch should the Story/Sprague Gulch or Yellow Creek study areas become developed in the future.

METHODS

Tasks addressed this fiscal year included deer capture and collaring efforts, monitoring adult female mule deer survival, and downloading and plotting GPS location data monthly from a segment of the sample fitted with downloadable GPS collars (24 of 75 deer total). We employed helicopter net-gunning techniques (Barrett et al. 1982, van Reenen 1982) to capture 15 adult female mule deer in each of 5 study areas (75 deer total). Once netted, deer were hobbled, blind folded, fitted with GPS collars, and released. Five deer in 4 of the 5 study areas and 4 deer in the Yellow Creek study area were fitted with remotely downloadable GPS collars (GPS-4400S; Lotek Wireless, Newmarket, Ontario, Canada) and the remaining deer in each area were fitted with store-on-board GPS collars (G2110B; Advanced Telemetry Systems, Isanti, MN, USA). To insure GPS fixes for at least 1 year, both collar types were programmed to attempt a fix every 5 hours and the fix schedule for store-on-board collars was reduced to attempt a fix every 23 hours July-October. Mule deer mortality monitoring consisted of ground tracking deer daily and aerial monitoring deer approximately every 2 weeks from fixed-wing aircraft. Once a mortality signal was detected, deer were located and necropsied to attempt determination of cause of death. We collected GPS locations from the 24 downloadable collars monthly via ground tracking, if possible, or using fixed-wing aircraft.

RESULTS AND DISSCUSSION

Deer Captures

We captured and GPS collared 4 yearling and 71 adult female mule deer (15 deer/study area) from January 10-12, 2008 (Fig. 2). No significant injuries were noted during captures. In planning future capture efforts for adult female mule deer, we will anticipate about 25 captures/day/helicopter.

Deer Mortalities

We identified 1 yearling and 7 adult female mule deer mortalities from January-June, 2008 (Table 1). Although winter severity was relatively high this past winter, adult female survival (90%, n = 71) was typical of mule deer populations under normal winter conditions in the western US (Unsworth et al. 1999). Cause of mortality was determined for 4 of the 8 mortalities documented and varied between coyote predation, malnutrition, and vehicle collision (Table 1). Although the other 4 mortalities were undetermined due to timing of carcass inspection, winter severity was likely a factor given 3 of the 4 mortalities occurred during late May (Table 1).

GPS Data Collection and Deer Distribution

GPS data downloads and collars retrieved from mortalities suggested collars were generally functioning as expected, but a few issues were noted that may warrant future attention. GPS location acquisition rates were high (>90%) for all collars except 1 where intermittent acquisition failures were common (Lotek GPS_4400S; 58% acquisition rate). The single collar exhibiting a low acquisition rate is acceptable relative to the 31 other collars exhibiting high acquisition rates, but the malfunctioning collar will be returned for evaluation once retrieved to potentially enhance collar performance in the future. We noted that false mortality signals (a mortality signal for an active deer) occurred for short durations (1 to a few days) on several occasions during winter monitoring, and we will increase the inactive time period to activate the mortality switch from 4 to 8 hours for future collar orders to try to address this problem. In addition, consultation with collar manufacturers will be conducted in an attempt to address the problem of inactive mortality signals occurring while deer are active. Another, more significant problem was noted when we unsuccessfully attempted to remotely detonate drop-off mechanisms on a few occasions (Lotek collars). The 20 Lotek collars currently in use will require remote detonation for retrieval in February, 2009, but the apparent unreliability of this device may require additional efforts to successfully retrieve the collars. We should consider the feasibility of using helicopter net-gunning to retrieve Lotek collars during capture efforts scheduled for late February, 2009, assuming attempts to remotely detonate drop-off mechanisms fail.

Monthly downloads and collars retrieved from mortalities yielded GPS movement and distribution data from 32 individuals during winter (Fig. 3), 28 during the spring transition period (Fig. 4), and 24 during early summer (Fig. 5). Observed winter deer distribution (Fig. 3) reasonably followed apriori expectations (Appendix I; Fig. 2) with minor differences in study area boundaries, as defined by deer use, except for the Story/Sprague study area, where wintering deer were distributed farther east than expected (see Bartmann et al. 1992); this change in distribution may be due to changes in habitat conditions and/or potential increases in other ungulate populations (e.g., elk). Of the 32 deer monitored during winter, no interchange between winter herd segments was noted, but a few individuals traveled beyond areas of interest relative to control and treatment experimental units addressing energy development (Fig. 3B). These movements can be addressed by either censoring those data or applying a covariate to the analyses. Based on the winter deer distribution data documented since January and the level of energy development activity present in April, 2008, we provide preliminary study area boundaries (Fig. 3) for future monitoring efforts to address experimental control (North Ridge, Yellow Creek, and Story/Sprague Gulch) and treatment (Ryan Gulch and Magnolia) areas addressing mule deer responses to beneficial habitat treatments and/or development activities. More specific boundaries will be assigned once data are analyzed from the remaining 43 collars scheduled for retrieval in February, 2009. During the spring transition period, deer from North Ridge and the northern half of Magnolia generally moved east, deer from southern Magnolia, Yellow Creek, and Ryan Gulch moved south, and the Story/Sprague Gulch deer moved relatively short distances south and east (Fig. 4). As expected, summer deer distribution was more widely scattered than during winter with deer distributions radiating from the Piceance Basin to the northeast, east, southeast, and south generally following wintering deer from North Ridge, Magnolia-north, Story/Sprague Gulch, and Magnolia-south, Ryan Gulch, Yellow Creek.

FUTURE PLANS

Funding has been recently secured to initiate the complete study proposal (Appendix I) beginning fall 2008 and continuing spring 2010. To address the other 5 study objectives outlined in Appendix I, we will attach VHF collars to 50 fawns/study area, increase our GPS sample to 20 GPS collared does/study area, measure body condition of 30 does/study area, and add 10 VHF collared does/study area to enhance mark-resight estimates. The period covered will represent existing development conditions or the pretreatment period and allow estimates of mule deer population parameters relative to current development practices and habitat conditions. Additional funding and cooperative agreements will be necessary to manipulate habitat conditions to benefit mule deer and modify development practices to enhance mule deer condition and survival on winter ranges exposed to energy development. We optimistically 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.

LITERATURE CITED

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Prepared by ________________________
Charles R. Anderson, Wildlife Researcher

Table 1. Mortalities of GPS collared yearling and adult female mule deer in the Piceance Basin, Colorado, January-June, 2008.

Deer ID	Study area	Mortality date	Age class	Apparent cause
150.194	Story/Sprague Gulch	1/19/08	Young adult	Undetermined
150.235	Magnolia	4/9/08	Young adult	Coyote predation
219.159	Ryan Gulch	4/25/08	Yearling	Vehicle collision
150.094	North Ridge	5/4/08	Young adult	Coyote predation
219.149	Story/Sprague Gulch	5/23/08	Old adult	Malnutrition
150.275	Ryan Gulch	5/24/08	Young adult	Undetermined
216.706	North Ridge	5/25/08	Old adult	Undetermined
217.615	Magnolia	5/28/08	Young adult	Undetermined

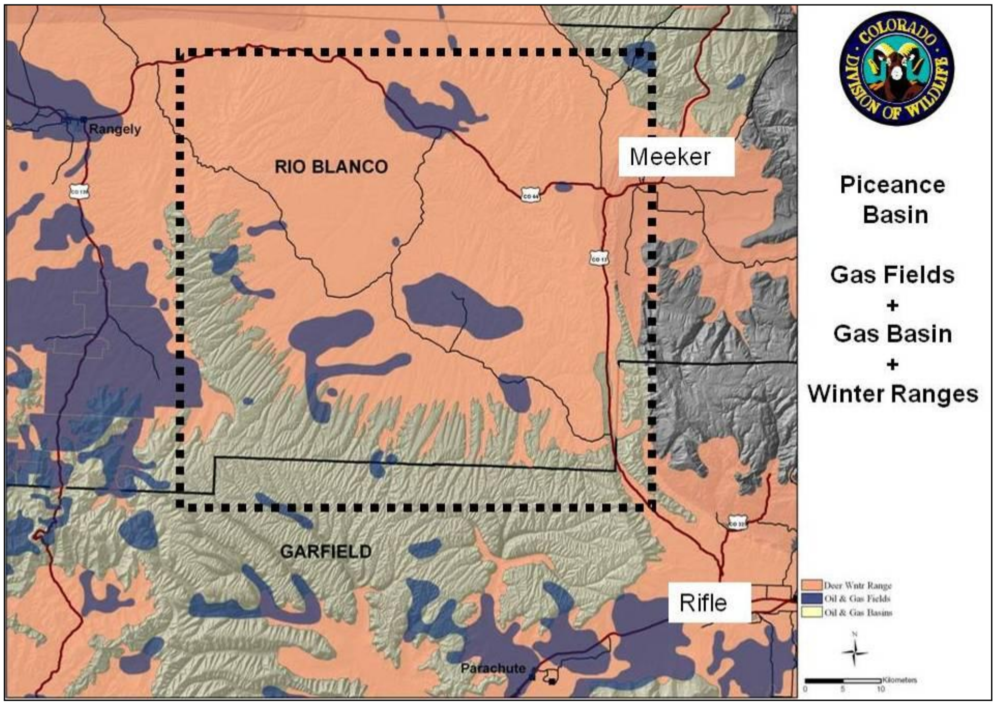

Figure 1. Piceance Basin project area (dashed line) relative to mule deer winter range, oil and gas fields, and the oil and gas basin.

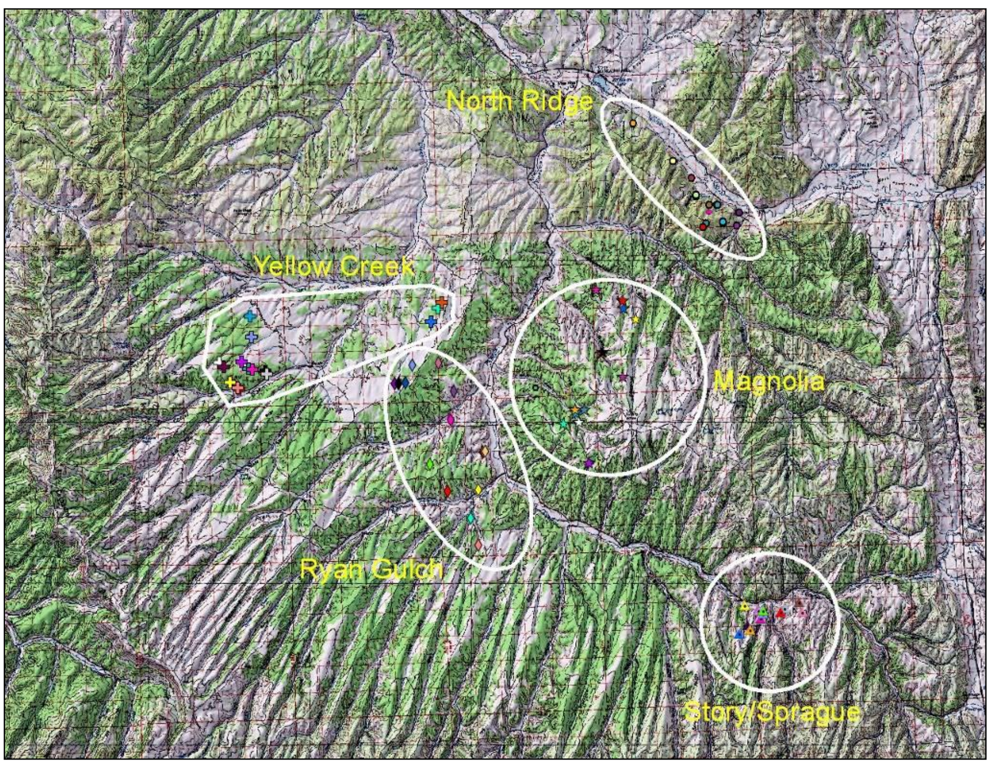

Figure 2. Capture locations by study area (solid lines) of GPS collared adult female mule deer in the Piceance Basin, Colorado, January 10-12, 2008.

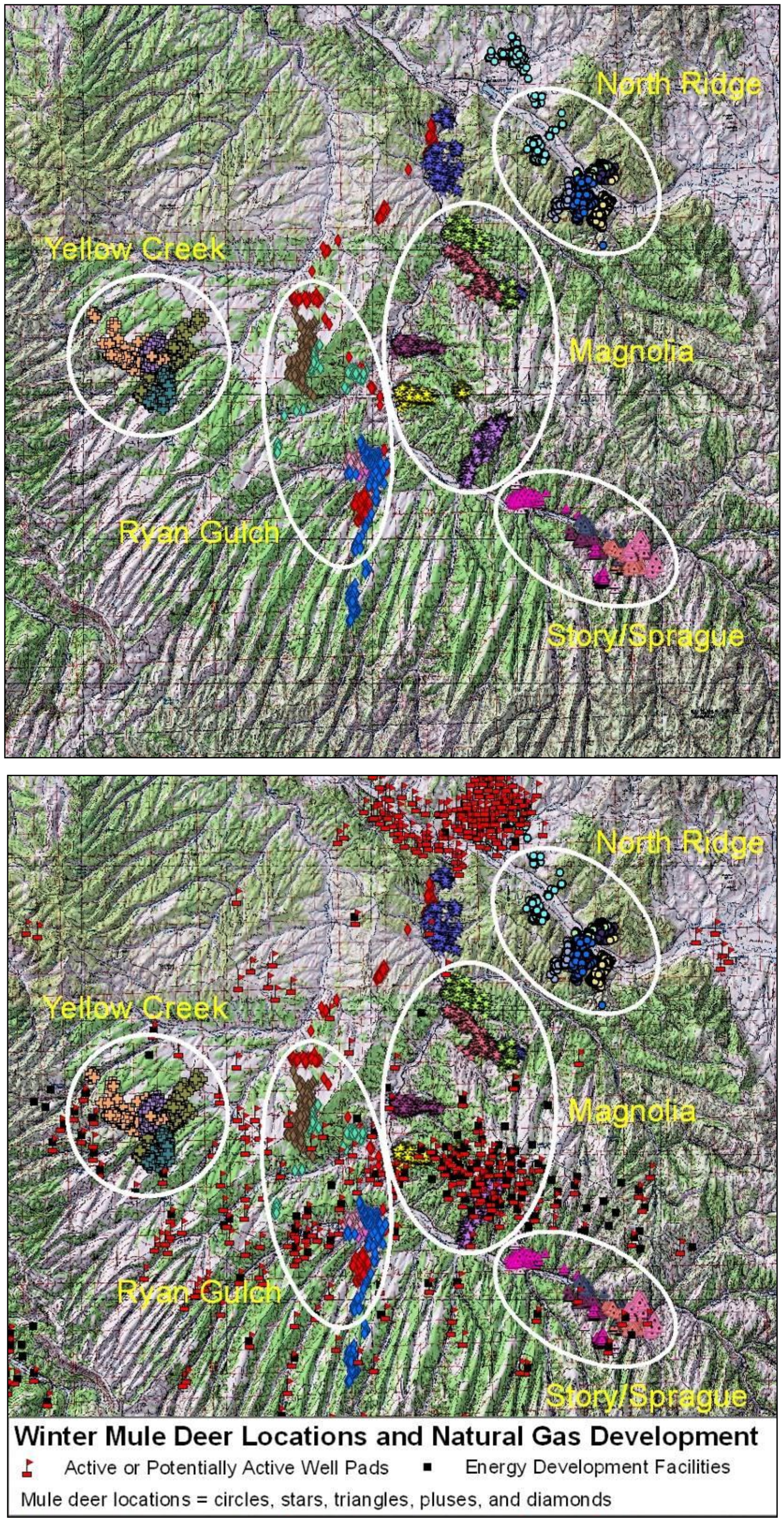

Figure 3. Mule deer GPS locations by preliminary study area boundary (solid lines) excluding (top) and including (bottom) active will pads and energy development facilities (as of April, 2008) in the Piceance Basin, Colorado, January—April, 2008.

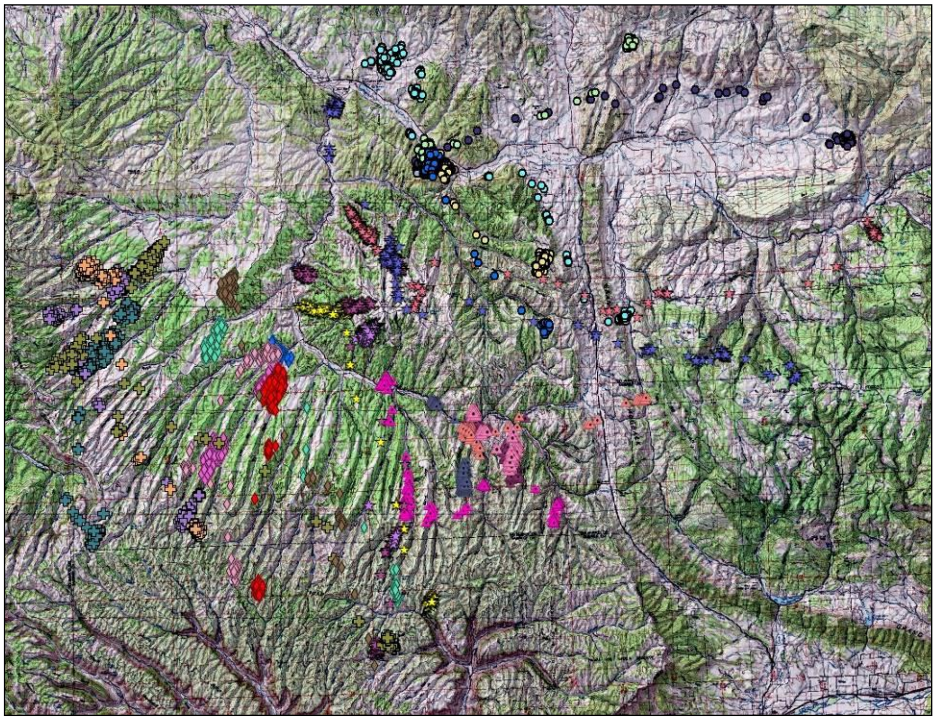

Figure 4. GPS locations of Piceance Basin mule deer during the spring transition period (April—May, 2008). Capture study site: circles = North Ridge, stars = Magnolia, triangles = Story/Sprague Gulch, diamonds = Ryan Gulch, pluses = Yellow Creek.

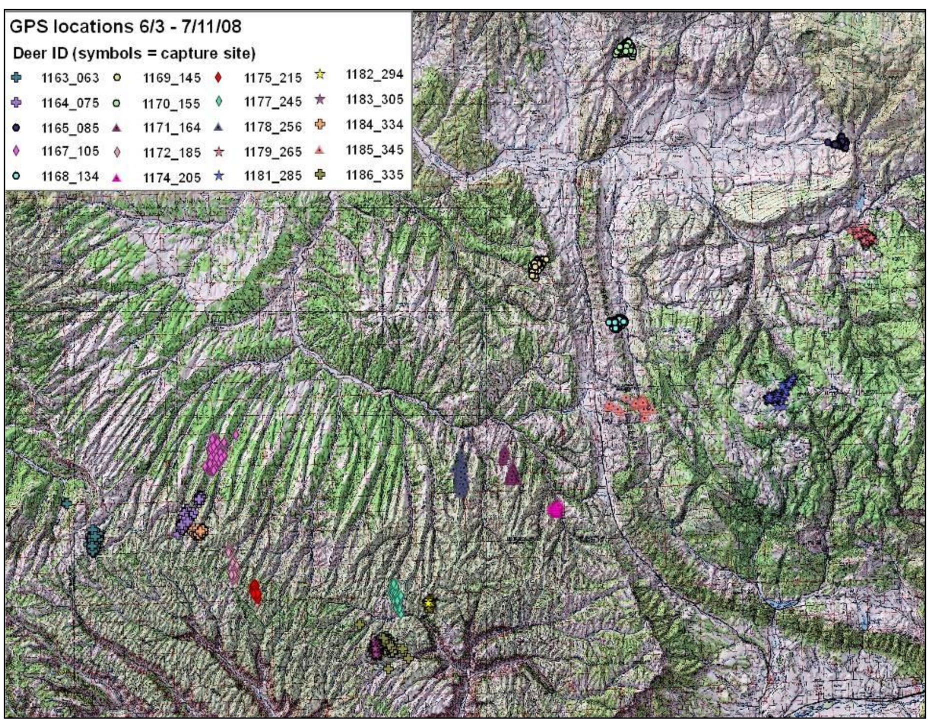

Figure 5. Summer range GPS locations of Piceance Basin mule deer, June—July, 2008. Capture study site: circles = North Ridge, stars = Magnolia, triangles = Story/Sprague Gulch, diamonds = Ryan Gulch, pluses = Yellow Creek.

APPENDIX I

PROGRAM NARRATIVE STUDY PLAN
FOR MAMMALS RESEARCH
FY 2007-08 – FY 2012-13

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

STAGE I, OBJECTIVE 5: PATTERNS OF MULE DEER DISTRIBUTION & MOVEMENTS

A Research Study Plan submitted by:

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D.J. Freddy, Mammals Research Leader, Colorado Division of Wildlife

A. Need

Extraction of natural gas from areas throughout western Colorado has raised concerns among many public stakeholders and the Colorado Division of Wildlife 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 by converting native habitat vegetation to 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 and the subsequent need for developing 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 deer populations. Thus, research documenting these impacts 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 supports one of the largest migratory mule deer populations in North America and also exhibits one of the highest natural gas reserves in North America. Projected energy development throughout northwest Colorado within the next 20 years is projected to be about 15,000 wells, many of which will occur in the Piceance Basin. The Piceance Basin (including the White River gas field immediately to the north) currently supports about 400 active gas well pads, 250 permits for development within the next year, and 200 energy development facilities (Colorado Oil and Gas Conservation Commission; Fig. 1). Wintering mule deer population segments in or immediately adjacent to the Piceance Basin include: Crooked Wash along the White River on the north edge of the Basin, North Ridge between Dry Fork of Piceance Creek and the White River in the northeastern portion of the Basin, Yellow Creek along Yellow Creek in the western portion of the Basin, Ryan Gulch between Ryan Gulch and Dry Gulch in the southwestern portion of the Basin, Magnolia north and east of Piceance Creek in the central portion of the Basin, and Story/Willow Creek between Willow Creek and Story Gulch in the southern portion of the Basin. Each of these wintering population segments has received varying levels of development, from little-no development in Story/Willow Creek and North Ridge, light development in Yellow Creek, and relatively high development in Ryan Gulch, Crooked Wash, and

Magnolia segments (Fig. 2). Due to advances in resource extraction technology and the increased demand for natural gas, future development and extraction activities will likely focus on natural gas fields previously developed and expand into adjacent areas where previously identified oil shale reserves and natural gas basins provide additional resource extraction opportunities. Because of the variation in the geology relative to gas reserves in the area and the juxtaposition of differing mule deer winter herd segments, several opportunities are available to address different, but related, questions relative to natural gas extraction methods and mitigation efforts relative to mule deer habitat use patterns.

Past Research

The Piceance Basin has been the location of numerous research investigations conducted by the Colorado Division of Wildlife, Colorado State University, and others which addressed various aspects of mule deer ecology and management beginning in the 1970s and continuing through the mid 1990s. Previous investigations of Piceance Basin mule deer addressed food habits (Hansen and Dearden 1975, Hubbard and Hansen 1976, Gibbs 1978, Bartmann 1983), physiology (Bartmann 1986, Torbit et al. 1988), development of management techniques (Freddy and Bowden 1983b, Garrott and White 1984a, Lee et al. 1985, White and Bartmann 1994), efficacy of population sampling methods (Freddy and Bowden 1983a, Bartmann et al. 1986, 1987, White et al. 1989), and population dynamics (White and Bartmann 1983, 1998, Garrott and White 1984b, Lee 1984, Garrott et al. 1987, White et al. 1987, Bartmann et al. 1992). Previous investigations of mule deer habitat use patterns in the Piceance Basin (Garrott et al. 1987) suggested fall migration consistently occurred during November, but spring migration varied likely due to winter severity and body condition, where rapid migration was evident when deer were leaving winter range in good condition and delayed migration was indicative of deer transitioning from winter range in relatively poor condition. Garrott et al. (1987) also noted strong fidelity to seasonal ranges, that deer shifted from north to south slopes as winter severity increased, and that irrigated and fertilized hay meadows served as important transition areas during fall and spring migration periods. Bartmann et al. (1992) manipulated deer densities to demonstrate compensatory mortality in the Piceance Basin mule deer population, where overwinter fawn survival varied inversely with density and adult female survival remained relatively constant; fawn mortality rather than reproduction appeared to be the major process driving the density-dependent mechanism. White and Bartmann (1998) reduced deer densities by 75% in their treatment area and reported 16% higher overwinter fawn survival and fawn body mass averaging 0.8 kg higher than the control area, whereas adult female survival was comparable between areas supporting previous findings (Bartmann et al. 1992).

Empirical evidence of mule deer population response to habitat manipulations is currently limited, largely due to the logistical and financial difficulty in conducting long-term research sufficient to address this relationship. Density dependent relationships have been demonstrated (e.g., Bartmann et al. 1992) and habitat quality rather than proximate mortality factors (e.g., predation) appear to be the driving factor (Bartmann et al. 1992, Hurley and Zager 2004, Bishop et al. 2005). Bishop et al. (2005), however, demonstrated enhanced population performance in supplementally fed, free-ranging deer to simulate high quality habitat, and reported 18% higher fawn survival (fetus to yearling; fetus-neonate = 0.127, overwinter = 0.240) and adult females averaged 5.5% more body fat, but reproduction and adult female survival were similar between treatment and control groups. Bergman et al. (2005, 2006) are currently investigating mule deer population response to habitat treatments in western Colorado, which will likely provide insight into our approach of addressing habitat treatments in response to energy development as this study progresses.

Currently, research addressing mule deer activity in response to natural gas development is limited to one study from the Pinedale anticline in Wyoming (Sawyer et al. 2006). Sawyer et al. (2006) examined changes in distribution before and during development of a natural gas field, and observed shifts in mule deer habitat use away from well pads (2.7-3.7 km) within 1 year of development which continued throughout the study, suggesting indirect habitat loss may be substantially larger than direct habitat loss and presumably results in deer using lower quality habitats that may ultimately lead to population decline. Mule deer habitat in Pinedale was much less topographically and vegetatively diverse than the Piceance Basin, however, and mule deer may respond differently where the habitat affords a higher degree of security cover.

Mule Deer Response to Habitat Treatments and Changes in Development Practices

Our primary goal of this study is to develop approaches to provide for energy extraction in a manner that maintains viable mule deer populations for future recreational and ecological purposes. This may be accomplished by restoring or enhancing habitat conditions on or adjacent to disturbed sites and by modifying development practices. Mitigating developed sites following disturbance requires reseeding or planting native vegetation, control of noxious weeds, and demonstrating success of mitigation efforts. Because mule deer are primarily browsers, shrub establishment will be essential, but shrub establishment is difficult and takes time for reemergence. Mule deer response to winter range mitigation efforts on disturbed sites will require relatively long-term monitoring to determine success of habitat treatments. More rapid habitat, and thus mule deer, responses can be expected from treating mule deer habitat adjacent to developed areas and by irrigating and fertilizing hay meadows adjacent to winter ranges (Garrott et al. 1987). Improving habitat conditions for or reverting succession of shrub communities using roller-chopping, hydro-axing, or fire can improve forage quality, and increasing forage quality and quantity by irrigating and fertilizing hay fields can improve mule deer body condition at critical times when transitioning to and from winter range. In addition to habitat treatments, mule deer may also benefit from modification in development practices that reduce human disturbance. Development practices that concentrate activities and/or minimize human disturbance will most likely minimize detrimental impacts to mule deer populations. Energy development practices that may be informative to investigate include directional versus non-directional drilling, piping versus trucking condensate from well pads, remotely versus directly monitoring gas wells, closing access roads following development, shifting from noisy diesel to quieter natural gas motors, and phased/clustered development where sections of deer winter range are developed while others remain undisturbed until development and mitigation are completed in developed sections. Determining the response of mule deer to specific development practices will require collaboration with the developer, and the specific conditions of the site being developed will dictate which development practices can feasibly be evaluated. Encana and Exxon-Mobile are the primary energy companies controlling natural gas development in the Piceance Basin (Fig. 3).

Mule Deer Response to Energy Development

Mule deer may negatively respond to energy development from direct reduction in forage availability from development activities, from indirect reduction of forage quality and quantity by shifting their distribution away from development activity to less preferred habitats, from negative physiological responses where deer maintain fidelity in areas exposed to development activities or from a combination of these factors. Depending on the extent and concentration of development, deer may also be able to adjust to development activities without population level impacts, and other factors (e.g., winter severity, drought, habitat succession, predation) also contribute to fluctuations in population performance/trajectory over time. Ultimately, reproduction and survival drive population performance and, based on past research, focusing on fawn survival and recruitment appear to be the most influential parameters given the density dependent nature of these factors versus the apparent density independent nature of adult female survival and reproduction. Documenting proximate factors influencing fawn survival will also be useful and thus changes in distribution, deer density, body condition, and specific mortality factors should also be monitored. Comparing changes in mule deer population parameters relative to energy development will require that undeveloped control areas are monitored and pre-development data are collected to determine whether or not and to what extent development versus environmental factors may be contributing. This will be challenging given development already in place and the unpredictability of future development that may occur. Large scale impacts from energy development may be detectable by comparing mule deer population parameters from undeveloped sites to developed sites, but natural variation due to geographic differences will be unaccounted for and add error to comparisons. Our ability to examine mule deer response to habitat mitigation and/or beneficial development practices will be better suited for demonstrating cause-effect relationships by allowing controlled experimental designs where habitat manipulation or modifying human behavior (i.e., development practices) provide the treatments for examining positive responses in mule deer population parameters.

B. Objective

The primary objectives for the long-term research proposal are as follows:

1. Determine if winter range and riparian vegetation responds positively to habitat treatments;
2. Determine if fawn and yearling survival is positively influenced by winter range habitat treatments;
3. Determine if fawn and yearling survival is positively influenced by irrigating and fertilizing hay meadows adjacent to winter ranges;
4. Determine if modification of development practices positively influences mule deer population performance;
5. Determine if habitat treatments, changes in development practices, or natural gas development results in distributional shifts on mule deer winter range;
6. Determine if habitat treatments, changes in development practices, or natural gas development results in changing mule deer densities on winter range.

The specific objective of this study plan is to address objective 5:

Determine if habitat treatments, changes in development practices, or natural gas development result in distributional shifts on mule deer winter range in the Piceance Basin.

The primary working hypotheses for the long-term research proposal are as follows:

a. Landscape level habitat treatments do not influence forage quantity and quality;
b. Fawn and yearling survival are not influenced by winter range habitat treatments;
c. Fawn and yearling survival are not influenced by modification of development practices;
d. Mid-winter deer density does not fluctuate in response to habitat treatments, changes in development practices, or natural gas development;
e. Mule deer habitat selection does not change in response to habitat treatments, changes in development practices, or natural gas development.

The specific working hypothesis of this study plan is:

Mule deer habitat selection does not change in response to habitat treatments, changes in development practices, or natural gas development.

C. Expected Results

Due to the extensive energy development that is projected to occur over the next 20 years throughout much of the mule deer winter range in the northern Rocky Mountains of the western US, innovative approaches to energy development and mitigation methods are essential to sustain viable mule deer populations in the region. Impacts from development and conversely success of mitigation efforts are often assumed but rarely demonstrated, and these assumptions can only be confirmed by application of well designed research efforts conducted over sufficiently long time periods to measure responses. As a first step toward this effort, we propose to address mule deer habitat selection patterns relative to varying levels natural gas development and associated human activity and ultimately address mule distributional responses to habitat and development modifications anticipated to be beneficial to mule deer. This project will require coordination and cooperation between Colorado Division of Wildlife, land management agencies, and the major energy companies developing the Piceance Basin. We anticipate this partnership will benefit mule deer populations and foster the evolution of wildlife management and energy development practices that are compatible with other wildlife and human values associated with maintaining functional ecosystems over the long term.

D. Approach

1. Experimental Approach

a. *Experimental Units*

Because of the varying levels of development and deer densities relative to differing winter population segments in the Piceance Basin, different experimental areas (i.e., mule deer winter ranges) are uniquely suited for addressing mule deer habitat selection patterns relative to varying levels of energy development. Experimental designs monitoring mule deer responses to treatment (e.g., habitat mitigation, modified development practices) and control areas are necessary to differentiate cause-effect relationships from development versus environmental factors. Suitable control areas require that little or no previous development has occurred and that no development occurs during the experimental time frame. Ideally, both temporal and spatial control areas would be monitored to make valid comparisons to developed and subsequently mitigated sites; temporal controls provide measures of natural variability in mule deer population parameters over time and spatial controls provide measures of variability due to differences in geography. Once spatial and temporal variation is accounted for, inferences can be made relative to development disturbance or mitigation effects on mule deer.

The North Ridge, Story/Willow Creek, and Yellow Creek deer population segment areas (Fig. 2) currently exhibit little to no development, but it is currently unknown whether or not these areas will be developed in the future; there is potential for future oil shale development in the Story/Willow Creek and Yellow Creek deer areas. North Ridge appears least likely to be developed because it is outside of the current oil shale lease area and only a few natural gas wells have historically been drilled on or adjacent to the area, whereas some development is currently occurring and likely to increase in the Story/Willow Creek and Yellow Creek areas. Thus, North Ridge would appear best suited as a temporal control site for comparison to other developed winter ranges within the Piceance Basin and may also serve as a geographic control for the Crooked Wash deer population segment located immediately north and adjacent to the Piceance Basin (*as of Dec. 2007, the Crooked Wash site ranks 6th in study priority and will not be sampled in the initial year due to limited funding*). The Story/Willow Creek and Yellow Creek deer may provide spatial controls for the Magnolia and Ryan Gulch deer population segments, respectively, but future development potential in these areas is unknown. If these areas become developed in the future (either for oil shale or natural gas), they would provide BACI (Before-After-Control-Impact) type comparisons strengthening our inference of development impacts on mule deer habitat selection patterns.

Magnolia, Crooked Wash, and Ryan Gulch deer areas have historically received relatively high development activity and currently exhibit moderate-high development, and appear likely to be developed extensively in the future based on the gas development layers currently available (Colorado Oil and Gas Conservation Commission; Fig. 1). Pretreatment data in these areas will be represented by parameters associated with developed sites and the measured response will be in the form of habitat treatments and/or differing development practices, which will be measured in comparison to the control sites.

We propose including 3 control sites (1 temporal/spatial control and 2 spatial controls) and 3 treatment sites to investigate mule deer response to habitat and/or development treatments (e.g., directional versus non-directional drilling, piping versus trucking condensate, etc.) across a range of deer densities (Table 1). We would strive to split high intensity extraction study sites into 2 halves with one half serving as the ‘control’ [standard development] and one half serving as the ‘treatment’ [improved development approach or improved habitat] (e.g., see Magnolia in Fig. 2). The above scenario addresses the potential for establishing control and treatment sites for evaluating shifts in mule deer habitat use patterns in response to habitat treatments and/or development treatments, and may allow larger scale comparisons in mule deer habitat use patterns relative to varying levels of energy development to be compared among experimental areas. Modified versions of the proposed design could be implemented depending on the level of funding available and the degree to which industry is willing to collaborate with this effort.

We consider 3 study sites, likely North Ridge, Magnolia, and Ryan Gulch, as the minimum number of study sites necessary to adequately address the objectives of this project; the additional proposed study areas will allow increased flexibility in the questions that are addressed and increase our inference relative to mule deer responses to habitat treatments and modifications of development practices. Furthermore, if we are not able to evaluate potential for mitigating industrial operation and/or habitat improvements, this study would likely only have the potential to document negative impacts of intense energy extraction practices on mule deer.

Table 1. Relative density of natural gas wells and mule deer and experimental designation for potential study sites in the Piceanace Basin, Colorado, for addressing mule deer response to natural gas development practices and habitat mitigation.

	Relative density			Experimental
Study area	Inactive wells	Active wells	Mule deer	designation
North Ridge	Very low	None	High	Temporal/spatial control
Crooked Wash[a]	High	High	High	Treatment
Story/Willow Creek	Low	Low	Moderate	Spatial control
Magnolia	High	High	Moderate	Treatment
Yellow Creek	Moderate	Low	Low	Spatial control
Ryan Gulch	High	Moderate	Low	Treatment

[a] As of Dec. 2007, for the initial research effort, the Crooked Wash study site ranks 6th in priority and will not be sampled due to limited funding.

b. *Response Variables*

To determine if habitat treatments or development practices elicit a shift in habitat use patterns, we will examine changes in Resource Selection Probability Functions (RSPF; Sawyer et al. 2006) pre- and post-habitat treatments, between areas exhibiting differing development practices, and compare RSPFs between developed and non-developed sites. Population level models for each study area will be compared to assess similarities and differences in habitat selection patterns relative to differing levels of energy development. We suggest relevant habitat attributes associated with mule deer response to habitat treatments and development practices include slope, aspect, elevation, habitat type, road density, distance to well pad, and development activity. Definition for development activity would vary depending on the development treatment investigated. For example, if the development treatment were applied to examine fluid collection systems, the variable would be coded 1 or 0 depending on whether they were present or absent and the RSPF would be estimated relative to this effect. In another example, well pad visitation rate may be the variable of interest and the RSPF would be estimated for a continuous effect of increasing road traffic to well pads.

2. Sample Size / Power Calculations

We anticipate 20 GPS collars per experimental area will be sufficient to provide population level inference based on similar studies with ungulates (Millspaugh and Marzluff 2001) for addressing adult female mule deer habitat selection patterns for each study site.

3. Procedures

a). *Capture and Handling Methods*

A total of 120 adult female mule deer will be captured and GPS-collared (20/study area assuming 6 study sites, 100 deer during initial FY07-08 for 5 study sites). Helicopter net-gunning (Barrett et al. 1982, van Reenen 1982) will be used to complete the necessary sample in January 2008 and a combination of helicopter net-gunning and drop netting will be used during March of subsequent years.

b). *Monitoring Habitat Use Patterns*

Habitat use patterns on treatment and control sites will be evaluated applying the Resource Selection Probability Function (RSPF) approach of Sawyer et al. (2006), where resource selection is estimated using the relative frequency or absolute probability of use as a function of the predictor variables. This approach will consists of 5 basic steps including (1) estimate the relative frequency of use (an empirical estimate of probability of use) for a large number of sampling units for each GPS collared deer (20/study area), (2) use the relative frequency as the response variable in a multiple regression analysis to model the probability of use for each deer as a function of predictor variables, (3) develop a population level model from the individual deer models for each experimental area, (4) map predictions from each model annually to examine changes in habitat use patterns over time relative to treatment effects, and (5) compare population level model coefficients between treatment and control sites to examine differences in resource selection among non-developed, developed, and mitigated sites. Relative frequency of use for each deer will be estimated by counting the number of deer locations that occur within 100-m radii circular sampling units (representing habitat attributes) systematically sampled throughout each study area; 200-m-wide sample unit should be small enough to detect changes in deer movements and large enough to provide multiple locations for estimating use probability functions.

c). *Habitat Manipulations*

The purpose of habitat manipulation would be 2-fold: 1) replace forage lost directly to surface destruction associated with gas pad/road/infrastructure development through rehabilitation of these areas, and 2) enhance suitable undisturbed vegetation. In both situations, the goal would be to provide habitats/vegetation having enhanced nutritional value to mule deer during fall (pre-winter) and spring (post-winter) migrations and during the critical winter period in order to improve body condition of deer and enhance their probability of survival. Placement of such habitat treatments would need to be evaluated and planned based on identification of priority areas within the Piceance Basin, in general, and specifically within experimental study sites. Opportunities within study sites would, in part, be dependent on cooperation of Energy Corporations, BLM, and private land owners, and site specific potentials that realistically can only be specifically determined after commitments are made in choosing experimental sites.

We envision the potential to utilize a full-suite of habitat improvement options. These could include: enhancing existing sagebrush areas using combinations of herbicide, nitrogen fertilizer, chopping-mowing, reseeding with grasses-forbs, and in some cases reseeding with suitable sagebrush species; enhancing mountain brush habitats through burning, hydroaxing, and reseeding; enhancing pinyon-juniper habitats through hydroaxing, burning, and reseeding. Site specific situations could require using advanced mulching, seeding, and irrigation options to effectively rehabilitate sites. In all cases, we would attempt to layout experimental habitat improvements to facilitate evaluation of success both from the standpoint of vegetation rehabilitation and use by mule deer.

Past research and monitoring of radio-collared mule deer in the Piceance Basin documented the high use and importance of cultivated hay fields along Piceance Creek. We envision considerable potential to improve management of hayfields to specifically address the needs of deer, especially during post-fall and pre-spring migrations of deer into and out of the Piceance Basin. The potential to manage hayfields for deer will be dependent on options to own or lease fee-title property and water rights. There may be nearly 10,000 acres of suitable hayfields located along Piceance, Ryan, Black Sulphur and Yellow creeks. In general, we believe that hayfields using more efficient irrigation practices and planted with suitable varieties of alfalfa developed to be grazed more so than for traditional hay production and suitable to alkaline soils would offer high potential to enhance nutrition of deer at key periods of the year. We also could see potential to establish hayfields with appropriate varieties of cool-season grasses (bluegrass for example) that could be managed for high nutritional quality through annual burning, mowing, grazing, and irrigation practices. Such cool season grass fields could provide 'green' forage for deer both during spring 'green-up' and fall 're-green' periods, especially if limited irrigation could be applied. The specific design and layout of reformed hayfield management would require considerable planning involving the expertise of NRCS or University Extension programs and considerable cost (potentially millions of dollars) for fee title ownership of land and water rights, mechanical preparation of hayfields and irrigation systems, and annual management practices once fields were established.

d) *Evaluation of Development Practices*

We anticipate options for industry to alter extraction practices that would reduce and/or concentrate human activity and benefit deer by increasing the relative 'security' of existing or improved habitats for deer. Options could include: multi-well versus single-well drilling platforms to reduce well pad density; piping instead of trucking well-condensate; road closures that minimize where traffic occurs; time of day restrictions; remote well-monitoring, or other options that industry may be able to offer. The key to evaluating any of these industrial-human activity options would be to create experimental comparisons using 'control' areas [current practices] versus 'treatment' areas [improved practices]. Which alternative practices are tested and in which potential study sites involved will depend upon cooperation from industry. Ideally, energy corporations would cooperate among themselves, the BLM, and with Division of Wildlife to help develop the best possible experimental design among extraction lease areas.

e). *Statistical Analyses*

Following Sawyer et al. (2006) for estimating Resource Selection Probability Functions, we will obtain population–level models for each experimental area by first estimating coefficients for each GPS-collared deer. A negative binomial distribution will be used to fit the following general linear model (GLM):

$$\ln(E[r_i]) = \ln(total) + \beta_0 + \beta_1 X_1 + \ldots + \beta_p X_p,$$

where r_i is the number of locations for a GPS-collared deer within sampling unit i ($i = 1, 2, \ldots, r$), *total* is the total number of locations for that deer within each experimental unit, β_o is the intercept term, $\beta_1, \ldots, \beta_p$ are unknown coefficients for habitat variables $X_1, \ldots, X_p$, and $E[.]$ denotes the expected value. We will estimate coefficients for the population–level model for each experimental unit following:

$$\hat{\bar{\beta}}_k = \frac{1}{n}\sum_{j=1}^{n} \hat{\beta}_{kj},$$

where $\hat{\beta}_{kj}$ is the estimate of coefficient *k* for individual *j* (*j* = 1,…,n) and the variance will be estimated applying the variation among individual model coefficients. To compare habitat use patterns between areas and over treatment effects, we will map predicted probabilities of use for each study area by season. Differences ($P < 0.05$) between population level model coefficients will be compared between study areas using a *t*-test.

4. Project Schedule

FY2007-08	Pretreatment/Revised Program Narrative Study Plan	9/1/2007
FY2008-09	Pretreatment/Progress Report (PR)	8/1/2008
FY2009-10	Habitat and/or Development Treatments/PR	8/1/2009
FY2010-11	Habitat-and/or Development Treatments/PR	8/1/2010
FY2011-12	Monitor Deer Response/Progress Report Project Status Evaluation	8/1/2011
FY2012-13	Monitor Deer Response/Progress Report	8/1/2012
FY2013-14	Monitor Deer Response/Progress Report	8/1/2013
FY2014-15	Monitor Deer Response/Progress Report Project Status Evaluation	8/1/2014
FY2015-16	Monitor Deer Response/Progress Report	8/1/2015
FY2016-17	Monitor Deer Response/Progress Report	8/1/2016
FY2017-18	Monitor Deer Response/Completion Report	8/1/2017
FY2018-19	Prepare and submit peer-reviewed publications	8/1/2018

5. Annual Cost Estimates

Estimating mule deer resource selection probability functions and implementing small scale habitat improvements are costly endeavors involving the purchase of specialized GPS radio-collars, helicopter flight hours for deer capture/collaring, machinery to physically alter the habitat, and personnel to adequately perform day-to-day data collection. If large scale habitat treatments are needed or desired, funding in addition to the estimates below will be required as habitat treatments cost $300 to $1,000/acre depending on the most appropriate treatment for a locale. Key to evaluating mule deer responses to habitat and/or development treatments will be sufficient and steady funding over a time horizon (minimum of 5-year commitments over the 10 year study period) that allows for meaningful biological responses to occur and be measured.

Cost estimates per year (2007 dollars for objective #5):

GPS Equipment Costs:	$200,000
Helicopter Capture Costs:	$ 70,000
12 months TFTE:	$ 30,000
Vehicle support:	$ 20,000
Other field operations and equipment:	$ 15,000
Total:	$335,000

6. Personnel

Charles R. Anderson, Jr., Wildlife Researcher, Project Leader, Colorado Division of Wildlife
David J. Freddy, Mammals Research Leader, Colorado Division of Wildlife

E. Location of Work

The proposed research will take place in or adjacent to the Piceance Basin of northwest Colorado, primarily within Game Management Unit 22 of the White River mule deer DAU D-7, west and southwest of Meeker, Colorado (Fig. 2).

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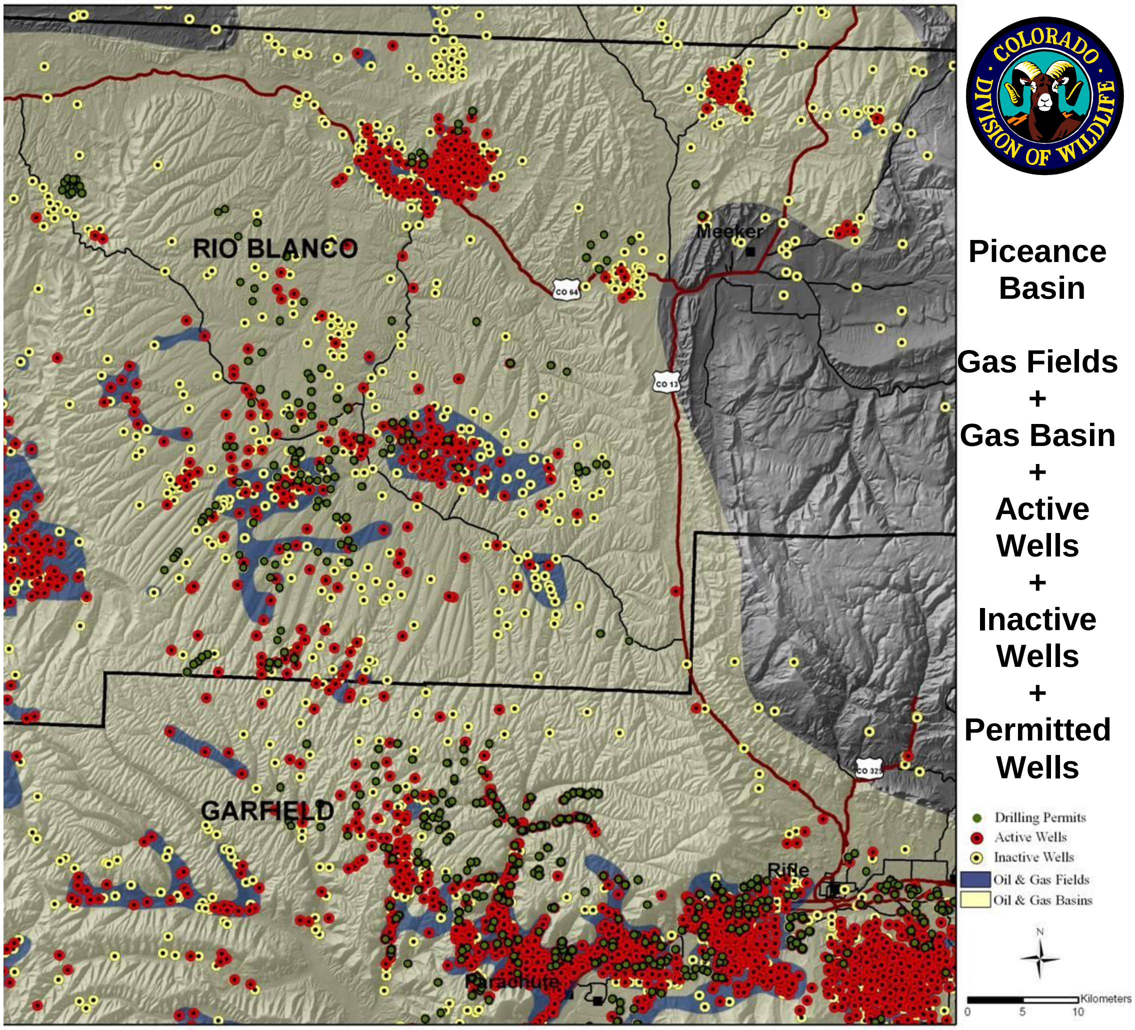

Figure 1. Natural gas development in the Piceance Basin, Colorado, July 2007.

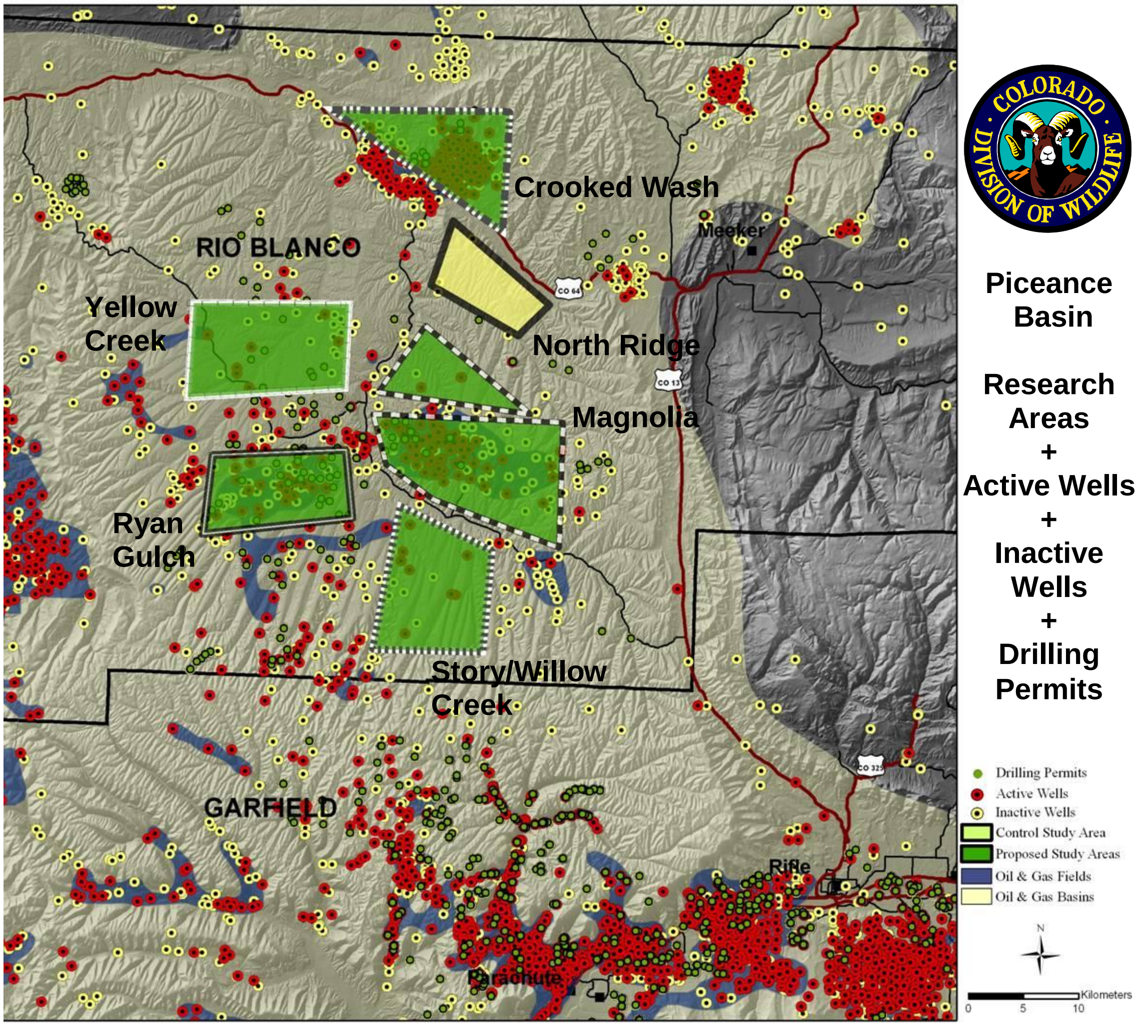

Figure 2. Proposed mule deer study sites relative to natural gas development in the Piceance Basin, Colorado, July 2007.

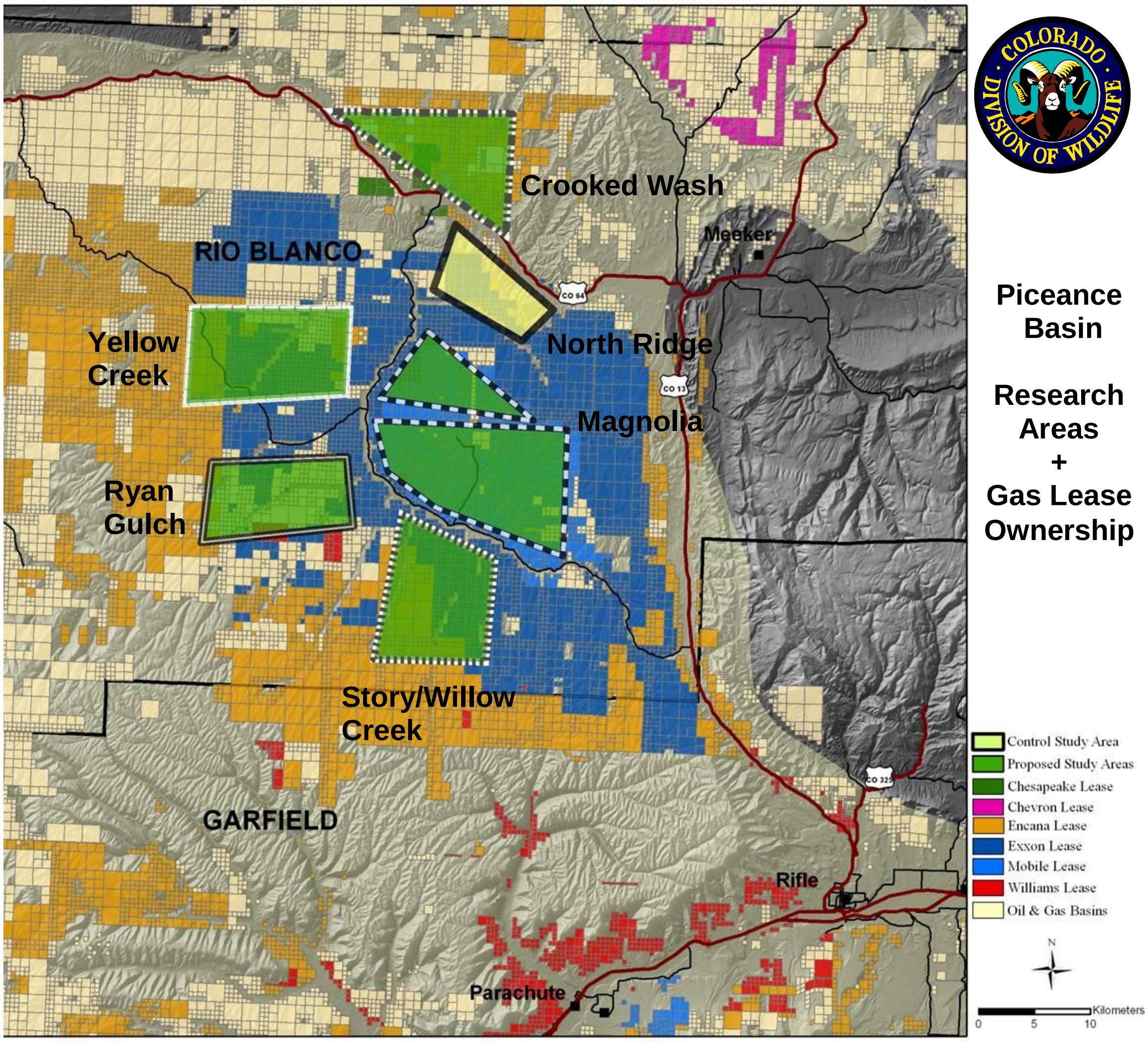

Figure 3. Proposed mule deer study sites relative to the primary energy companies controlling natural gas leases in the Piceance Basin, Colorado, July 2007.

Colorado Division of Wildlife
July 2007 – June 2008

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	3001	:	Deer Conservation
Task No.:	3	:	Pilot Evaluation of Predator-Prey Dynamics On the Uncompahgre Plateau
Federal Aid Project No.	W-185-R		

Period Covered: July 1, 2007 - June 30, 2008

Authors: M.W. Alldredge, E.J. Bergman, C.J. Bishop, K.A. Logan, D.J. Freddy

Personnel: B. Dunne, V. Yovovich, E. Phillips, M. Schuette

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

In an attempt to address predator-prey dynamics, we initiated a pilot study to evaluate cougar predation relative to prey distribution across the southern half of the Uncompahgre Plateau in southwestern Colorado. As part of ongoing mule deer and cougar research in this area, we estimated cougar kill rates and prey selection by sampling different sized clusters of cougar GPS locations across the landscape. Cluster size ranged from 1 location to >30 locations/cluster. In the vicinity of each sampled cluster, we searched for cougar prey items to determine whether a kill had occurred and to classify prey by species and age. This field effort was primarily focused in areas with extensive historical mule deer population and winter range distribution data. Simultaneously, a pilot effort to collect distribution and movement data of elk over this same geographic area was conducted. As predicted, cougar kill sites were associated with deer and elk distribution. The greatest density of kill sites occurred across mid-upper elevation deer winter range where overlap of wintering elk and deer was greatest. We investigated 462 clusters during this pilot study. Kill probability increased as cluster size increased ($\hat{\beta}$ = 0.353, SE = 0.0706). Kill probability exceeded 0.9 with ≥ 10 locations/cluster and approached 1 with ≥ 15 locations/cluster. The probability of a kill was high if a cougar spent >2 days in the same general area, and a kill was essentially certain if a cougar spent >3 days in the same general area. There was some probability of a kill at clusters that comprised only 1 location, indicating that isolated cougar locations may periodically be associated with kills and should not be ruled out when using GPS location data to address cougar prey utilization. Our estimates of kill probability are conservative because the estimates assume detection probability was 1, which is unlikely. Cougars killed adult deer, fawn deer, adult elk, and calf elk in roughly equal proportions. Each prey class comprised 0.22–0.24 of the total kill. Kill composition varied as a function of percent vegetative cover and elevation. Future research should evaluate detection probability, which underlies the interpretation of cougar kill rates.

WILDLIFE RESEARCH REPORT

PILOT EVALUATION OF PREDATOR-PREY DYNAMICS ON THE UNCOMPAHGRE PLATEAU

MATHEW W. ALLDREDGE, ERIC J. BERGMAN, CHAD J. BISHOP, KENNETH A. LOGAN, AND DAVID J. FREDDY

P.N. OBJECTIVE

To assess if a sampling based approach to collecting cougar predation data can efficiently result in unbiased data. To make a pilot assessment of how cougar kills are spatially distributed over prey winter range.

SEGMENT OBJECTIVES

1. Use and evaluate the efficiency of a GPS collar, GIS and statistical sampling based approach to investigate potential cougar kill sites.
2. Estimate mule deer density on three study areas and extrapolate results onto surrounding mule deer range.
3. Overlay locations of 5 elk, collected via GPS collars, on mule deer winter range boundaries to gain preliminary information as to how much spatial overlap occurs between the species and to determine where cougar kills occur in relation to the mule deer and elk space use.

INTRODUCTION

Predator prey interactions have always been a topic of interest for wildlife managers and ecologists. However, due to the complexities of studying natural systems, behavioral theories pertaining to the subject are often developed in invertebrate, aquatic or small mammal systems, often under controlled laboratory conditions (Mathews et al. 2006, Schmitz 2006, Werner and Peacor 2006). Similarly, many models are developed within theoretical frameworks (Keeling et al. 2000, Mitchell and Lima 2002). While developing theories under these conditions is almost inherently necessary, their subsequent transition to free ranging systems is not frequent (Ryall and Fahrig 2006). Of the free ranging systems where theories are developed and tested, most deal with avian species (Lima and Bednekoff 1999, Roth et al. 2006), where as application to large mammalian systems is less frequent. Of the mammalian predator prey systems that have been studied, most have been conducted in preservation/park settings that largely exclude human influence (Kunkel and Pletscher 1999, Kunkel et al. 1999, Krebs et al. 2001, Creel and Creel 2002, Mao et al. 2005, Wilmers et al. 2006,). Additionally, due to the small number of large scale studies that have been conducted, the ability of managers to draw inference to separate systems (i.e. different species or different ecosystems) is limited. While this existing body of work is invaluable, extrapolation of theories to large mammalian systems could be limited and basing wildlife management decisions on this information may be tenuous.

Due to the value of mule deer, elk and cougars as recreationally hunted species in Colorado, there is much interest in understanding the nature and relationship between the population dynamics of these species. However, resulting from the dearth of information pertaining to the interactions of these 3 species, a vast array of opinions and theories pertaining to their impacts on each other have been propagated. As a management agency, the Colorado Division of Wildlife is responsible for supporting or refuting claims with biological data that were collected in a scientifically unbiased manner. To date, these data are largely unavailable.

Currently, the opportunity to develop a predator prey study exists on the Uncompahgre Plateau in southwestern Colorado. Two large scale research programs, independently studying cougar and mule deer, are underway in the same geographic area. Thus, the initial framework to study a top carnivore, and what are thought to be its primary prey species, is in place. However, to date there is little or no information pertaining to elk distribution or population dynamics in this area. The addition of elk spatial data will allow us to assess the feasibility of developing a full study addressing the influence and interactions of cougars, mule deer, and elk.

STUDY AREA

This pilot study was conducted on the southern half of the Uncompahgre Plateau in southwestern Colorado, near Montrose, Colorado (Figure 1). The study area was defined by the existing boundary for the ongoing cougar research project with prey populations being monitored only in the eastern half of the cougar study area.

METHODS

Capture and Handling Methods

As part of completed, as well as ongoing mule deer research, approximately 75 adult female mule deer were marked with VHF radio collars in the area of interest (Bishop et al. 2005). Additionally, 25 mule deer fawns were captured and radio-collared within the eastern portion of the study area between late-November and late-December 2006 as part of the ongoing mule deer research (Bergman et al. 2005; capture protocols previously approved by CDOW ACUC). All mule deer were captured with baited drop-nets (Ramsey 1968, Schmidt et al. 1978, Bartmann et al. 1992) or via helicopter net-gunning (Barrett et al. 1982, van Reenen 1982). As part of the ongoing cougar research project, 19 cougars (15 female, 4 male) were outfitted with GPS collars that allowed on-demand data download interaction with researchers. Cougars were captured primarily via pursuit by dogs as well as in live traps (Logan 2005, capture protocols previously approved by CDOW ACUC). As part of this pilot study, adult female elk (9) were captured via helicopter net-gunning during late-December/January 2006-07 with 5 adult females fitted with drop-off GPS/VHF collars and 4 adult females fitted with VHF permanent collars. Elk were captured on the eastern portion of the study area, directly overlapping areas including radio collared mule deer and cougar. Sample sizes for elk reflected an estimate of what we believed to be an adequate number of elk to provide an initial estimation of elk spatial use in the study area.

Ungulate Survival and Location Monitoring

On a daily basis, from December through May, we monitored radioed fawns and adult female deer and elk in order to document live/death status. This allowed us to determine accurately the date of death and estimate the proximate cause of death. For animals not heard from the ground, we conducted weekly flights to assess live/death status. Detailed locations of GPS collared elk became available when self-actuating mechanisms caused the GPS collars to drop-off elk in September 2007. Elk GPS collars collected locations every 30 minutes.

Identification of Cougar GPS Location Clusters

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 provide a sound sampling frame from which statistical inference could be made about clusters that are not physically investigated. GPS collars collected locations 4 times/day to reflect time periods when cougars are both active and inactive (00:00, 6:00, 12:00 and 19:00).

The clustering routine was designed to identify clusters in five unique selection sets in order to identify clusters containing two or more points, those that contained missing GPS locations, and those that were represented by single points. 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.

The initial step was to prepare data files for ARCGIS. The main priority was to number all downloaded GPS lat-long location records consecutively to provide a time stamp that could be used in the program. Failed locations were numbered within the data files to maintain the proper time step (i.e. two locations that were separated by a missing location were time stamped in such a way that the clustering algorithm recognized that a missing location existed between the records). At this point data files were imported to ARCGIS and coordinates converted to UTMs.

The initial selection set of clusters (S_1) were based on clusters consisting of two or more points within a specified distance and time interval. Working with temporal and spatial variables simultaneously is difficult, so we chose to create an association matrix of the combined variables. The units for time were based on GPS locations so that the time between consecutive downloads was one. Cougar locations are attempted 4 times a day, so that one day consisted of 4 time-steps. The association matrix was then constructed as

$$A_{ij} = \frac{1}{e^{d_{\max}/d_{ij}}}\left(1-\left|\frac{t_i - t_j}{t_{\max}}\right|\right)$$

where A_{ij} was the association in time and space between points i and j, d_{max} was the maximum distance between two points to be considered a cluster, d_{ij} was the distance between points i and j, t_{max} was the maximum number of time steps between points to be considered in a cluster, and t_i and t_j were the times for locations i and j. This formula weighted the distance between two locations heavier than the time between two locations. It also caused the association A_{ij} to be negative for any locations that were outside the temporal window (separated by more time-steps than t_{max}). The association between two locations within the specified time interval was greatest for those locations that were spatially closer together. So, the largest value in the association matrix corresponded to the 2 points that were spatially the closest and within the time interval. Initially, d_{max} was set at 200 m and t_{max} was set at 16 time steps [4 DAYS] .

The initial cluster was selected by choosing the 2 points with the largest association value from the association matrix. The distance was checked to verify that the points were within the specified maximum distance, d_{max}, and if so, the centroid of the two points was calculated. An association vector $\overrightarrow{A_c}$ was made by calculating the association among the centroid and all other points using the above formula. If all values in $\overrightarrow{A_c}$ were negative, then no points were within the specified time interval, so no additional points were added to the cluster. Then the greatest association value A_{cmax} was selected from $\overrightarrow{A_c}$ and the distance from the centroid to the point corresponding to A_{cmax} was compared to d_{max}. If the distance was less than d_{max} then the point was added to the cluster and a new centroid was calculated using all cluster points and a new vector $\overrightarrow{A_c}$ was constructed using the new centroid. This procedure was repeated until no additional points were added to the cluster because either no points were within the specified time interval or the distance from the centroid to all points was greater than d_{max}.

After each cluster was constructed these points were omitted from the association matrix and a new cluster was started by again selecting the greatest value from the matrix and verifying that the distance between points was less than d_{max}. Points were again added to this cluster as previously described. This entire procedure was repeated until no 2 locations met the temporal or spatial criteria.

All clusters were given a unique identifier, which was based on the animal identification and the Julian date. This completed the selection set for clusters with two or more locations, which were likely to have a high probability of being a kill site.

Additional selection sets were constructed from the remaining points as single location clusters. However, not all locations are equal, so the remaining selection sets were created based on whether points were associated with missing locations and based on distance between consecutive locations. The second selection set (S_2) of clusters was created from any 2 points that were within a distance d_{miss}, and were separated by 1 or more missing locations. The cluster was considered to be the area within the distance d_{max} of each of the known locations (2 areas make up the cluster, and d_{miss} was initially set at 500 m).

The final 2 cluster selection sets consisted of consecutive points that were within the ranges d_{max} to d_2 (S_3) and d_2 to d_3 (S_4). To construct these selection sets, the distance between consecutive points was examined and if the distance was within the range d_{max} to d_2 (500 m) then the initial point was added as a cluster to the set S_3, or if the distance was within the range d_2 to d_3 (1000 m) then the initial point was added as a cluster to the set S_4. These single-point clusters were assumed to have radius d_{max}.

Points not used in selection sets S_1 through S_4 were then used in a final selection set S_5. These points represented larger movements between consecutive locations and thus were thought to have low probabilities of being associated with a kill site, although these points could be associated with use of small prey items, or kill sites where a cougar was physically disturbed away from a kill site. These single-point clusters were also assumed to have radius d_{max}.

Sampling of Cougar GPS Location Clusters

A primary objective of the pilot study was to determine the probability that a given cluster represented a cougar feeding site. Specifically, to evaluate cougar feeding sites as a function of the cluster association matrix. Using the clustering algorithm described above, we attempt to classify each sampled cluster as a cougar feeding site (1) or not a feeding site (0). We expected a high proportion of S_1 clusters to represent cougar feeding sites. Conversely, we expected a moderate proportion of S2 and S3 clusters, and a low proportion of S4 and S5 clusters, to represent cougar feeding sites. A secondary objective of the pilot study was to gather preliminary biological data regarding cougar prey utilization, primarily with respect to deer and elk. The secondary objective was most efficiently accomplished by sampling S_1 clusters with greater intensity than other clusters. We therefore structured our sampling approach to allow adequate estimation of the proportion of clusters that were cougar feeding sites for each cluster set, while more intensively sampling S_1 clusters than all others.

With no previous evidence to indicate similarities among individuals based on sex, age, or parental status, sampling was stratified by each individual cougar. GPS collars were downloaded once a month for each cougar and data were analyzed through the clustering algorithm. Clusters within 2 weeks of the download date were selected for the sampling frame, making the maximum time between the predation event and sampling about 1 month by the time field technicians could get to and assess evidence at each cluster site. Clusters were randomly chosen from each selection set for each individual cougar every month in the following manner: S_1 = 2 clusters, S_2 = 1 cluster, S_3 = 1 cluster, and S_4 and S_5 = 1 cluster on alternating months. Five clusters were sampled each month for each cougar, for a total of 30 clusters per cougar from 1 November 2006, to 15 July 2008. As time allowed, additional clusters were sampled from the selection sets.

Our approach forced constant sampling of each cluster set over time regardless of the frequency of clusters within a given set. This prevented a scenario where nearly all sampled clusters in a given month were from sets, S_3, S_4 and/or S_5 (i.e., low probability of finding feeding sites). Our assessment of prey utilization depended on relatively constant detection of cougar feeding sites over time to avoid bias.

However, for each cluster set, the true proportion of clusters representing feeding sites may possibly change over time corresponding to changes in cougar use of feeding sites. If the GPS download data indicated major changes in set-specific cluster frequencies over the sampling period, we maintained the ability to use a proportional-allocation sampling approach if needed.

Assuming a binomial distribution and 0.90 of S_1 clusters represented cougar feeding sites, our approach enabled us to estimate the true proportion with a 95% confidence interval of +/– 0.07. Assuming 0.5 of S_2 clusters represented cougar feeding sites, we were able to estimate the true proportion with a 95% confidence interval of +/– 0.17. Assuming 0.3 of S_3 clusters represented feeding sites, we were be able to estimate the true proportion with a 95% confidence interval of +/– 0.15. Finally, assuming 0.1 of S_4 and S_5 clusters represented feeding sites, we were able to estimate the true proportion with a 95% confidence interval of +/– 0.10. These precision levels were deemed acceptable for the pilot study, and should facilitate development of an optimal sampling scheme in future years for evaluating cougar prey utilization from GPS cluster-location data. Finally, regarding our secondary objective of collecting preliminary prey use data, we were able to estimate the overall proportion of kill sites represented by deer (or the proportion of kill sites represented by elk) with a 95% confidence interval of +/– 0.05 (Anderson and Lindzey 2003, Logan 2005).

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 inspecting 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, then we expanded our searches to a minimum of 50 m radius around each waypoint. The 20 m and 50 m radius search areas resulted in overlapping view fields of individual waypoints, and took up to 7 hours to complete, depending upon the number of waypoints, topography, and vegetation type and density associated with a cluster. 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.

Estimating Deer, Elk, and Cougar Distributions

We examine locations, movements, and kernel home ranges of mule deer, elk, and cougars for spatial overlap and time synchrony using ArcGIS. Our initial analyses are descriptive and should provide insight into patterns of cougar movements and feeding sites in relation to major ungulate species. Based on past observations, we did not expect deer distributions to fluctuate greatly during the winter. However, we did expect elk distributions to fluctuate depending on weather and time. We anticipated being able to generate correlations between species of prey killed by cougars and the relative presence of prey within cougar home ranges.

Cougar GPS Cluster Analysis

We estimated the probability of locating cougar prey items (i.e., cougar kills) at GPS location clusters using logistic regression in SAS (PROC LOGISTIC; SAS Institute, Cary, NC). We modeled cougar kills as a function of cluster type (S1, S2,…, S5), cluster size (no. locations/cluster), cougar status (adult female with cubs, adult female without cubs, adult male), and season when cluster was investigated (winter, spring, summer, fall). We then analyzed kill composition using a generalized logits model (i.e., multinomial logistic regression) in SAS (PROC LOGISTIC). For this analysis, we used only clusters where prey items were found (i.e., kills). Kill composition was divided into 5 categories: adult deer, fawn deer, adult elk, calf elk, and other (i.e., porcupine, coyote, turkey, unknown). We modeled kill composition as a function of cluster type, cluster size, cougar status, season when kill occurred, elevation, and percent vegetative cover. We used Akaike's information criterion adjusted for sample size (AIC_c) to select among candidate models in both modeling analyses (Burnham and Anderson 2002).

Hypothesis Testing

Our preliminary sampling effort of cougar clusters and ungulate distributions provided estimates of cougar kill rates and proportions of deer and elk killed. As data collection continues, we intend to address whether 1) cougar prey mass is positively related to cougar mass (i.e., male cougars kill larger prey than female cougars), 2) cougars prey on deer and elk in proportion to availability (i.e., no selection for prey species), 3) cougars prey on sex or ages of deer or elk populations in proportion to availability (i.e., no selection for prey age classes), 4) cougars alter their use of prey among seasons of the year (i.e., prey-switch between deer and elk, or between juvenile and adult), and 5) maternal cougar home ranges include the highest available densities of ungulate prey.

RESULTS AND DISCUSSION

Mule Deer Distribution

As expected, over the course of the winter, mule deer movements occurred at too fine of spatial and temporal scales to be detected without more intense repeated sampling. However, as they relate to the pilot study, the data gathered are adequate for making basic summaries. Mule deer density appeared to be highly variable across a gradient of winter range (density estimates ranged between 19 and 109 deer/km^2 , Figure 1) (Bergman et al. 2008). Relative to the entire Uncompahgre Plateau, the estimates tended to be high, confirming historical information and further justifying the decision to conduct pilot work in this area. Of particular interest in regards to spatial overlap between cougar kill sites and mule deer winter range, the majority of located kill sites were higher in elevation than the greatest concentrations of mule deer. The exception to this trend occurred on the southern most portion of deer winter range where the majority of kill sites were composed of mule deer. As discussed below, an apparent explanation for this may be linked to elk distribution as this area also appeared to be the area of greatest overlap between mule deer and elk. To improve future efforts, several key steps would need to be taken. Mule deer density estimates are relatively course for the majority of winter range included in this pilot study. With the exception of three polygons, deer density estimates were extrapolated from surrounding areas. Furthermore, estimates of deer density for the 3 areas were not collected during the same year and therefore include annual variation. To accurately reflect the conditions, albeit still at a course level, encountered by cougars as they move across mule deer winter range, density estimates should minimally be collected on all segments of winter range on an annual basis. While fine scale movements of deer (i.e. daily movements within winter range) were not incorporated in this study, such data likely would not be hugely beneficial. Fine scale data would be of greatest interest if the focus of the study were shifted to analyze/describe fine scale hunting behavior of individual cougars.

Elk Movement and Distribution

Elk GPS collar data confirmed our initial expectations that elk movements during winter months were more dynamic than those of deer. The four elk collared with VHF collars left the study area of interest after 7 months and collecting repeated aerial locations was not deemed worthwhile as they were not in areas with radio marked deer or cougar. However, elk did appear to be highly individualistic in regards to space use and movement during winter months. Two elk appeared to concentrate locations over a relatively large geographic area (>75 km^2) during the winter months, but restricted movements to stay within these areas. The other 3 elk appeared to utilize relatively small spatial areas (9-10 km^2) for 1-2 week periods before making slightly longer movements (10+ km) to new concentration areas. Plotting known locations for cougar kill sites on elk spatial data suggested that cougar kill sites had a strong correlation to elk distribution (Fig. 2). Based on the more dynamic nature of elk movement during winter, future efforts to map elk distributions and densities would be better met by saturating the area of interest with GPS collared elk. Annual density estimates, collected via helicopter, would likely only be valid for a relatively short time period (2-4 weeks) due to elk movement and thus making it difficult to track cougar space use and predation patterns in a realistic prey context. By outfitting a large number of elk with GPS collars, resource selection functions for the elk in the area of interest could be built around habitat and elevation selection patterns. Due the large amount of data collected by GPS collars, resource selection functions could justifiably be built at 2-4 week intervals.

Kill Probability Associated with Cougar GPS Clusters

We investigated 462 clusters during this pilot study (195 S1 clusters, 33 S2 clusters, 71 S3 clusters, 73 S4 clusters, 90 S5 clusters). The probability of locating cougar kills at GPS location clusters varied as a function of cluster type, cluster size, cougar status, and season (Table 1). As expected, S1 clusters were far more likely to be associated with cougar kills than S2–S5 clusters (Figure 3). The probability of a kill at an S1 cluster was 0.505 (95% CI: 0.435, 0.575), whereas kill probability was ≤ 0.12 at all other cluster types. There was some probability of a kill at S4 and S5 clusters, indicating that isolated cougar locations may periodically be associated with kills and should not be ruled out when using GPS location data to address cougar prey utilization. Kill probability increased as cluster size increased ($\hat{\beta}$ = 0.353, SE = 0.0706). Kill probability exceeded 0.9 with ≥ 10 locations/cluster and approached 1 with ≥ 15 locations/cluster (Figure 4). Thus, the probability of a kill was high if a cougar spent >2 days in the same general area, and a kill was essentially certain if a cougar spent >3 days in the same general area. Models receiving the most weight also provided evidence of interactions between cluster size and cougar status and between cluster size and season. The cluster size × cougar status interaction occurred because smaller cluster sizes were more likely to be associated with kills for female cougars than male cougars (Figure 5). For example, female cougars with ≥ 10 locations/cluster indicated a near-certain kill, whereas male cougars with 10 locations/cluster indicated only 0.571 probability of a kill (95% CI: 0.267, 0.830). Adult males were more likely to spend multiple days in an area without a kill than were adult females. The cluster size × season interaction occurred because larger cluster sizes during summer were less likely to indicate a kill than during other seasons (Figure 6). Perhaps cougars were more likely to remain sedentary without a kill nearby during summer months when energetic demands were lower. This result should be interpreted with caution, however, because we collected less data during summer than during other seasons.

Our primary reason for including season in the analysis was to evaluate possible differences in detection probability. We expected kills to be difficult to detect during winter and possibly spring months when carcasses and sign would be periodically covered by snow. However, our results did not support this hypothesis, but instead suggested that kills may have been the most difficult to detect during summer. Kills may be difficult to detect in summer range habitats because of extensive foliage or increases in scavenging by bears and/or coyotes. Regardless, carcass detection probability is a significant issue that underlies our entire analysis. That is, it is difficult to fully interpret our findings above without an adequate understanding of detection probability. For example, our summer results could reflect reduced carcass detection probability during summer, or they could reflect changes in cougar behavior during summer as compared to other months. A key point is that our estimates of kill probability for different cluster types and sizes are minimum estimates because these estimates assume detection probability was 1, which is unlikely. Detection probability should be addressed in subsequent research.

Cougar Kill Composition

Cougars killed adult deer, fawn deer, adult elk, and calf elk in nearly equal proportions (Figure 7). Each prey class comprised 0.22–0.24 of the total kill. Kill composition varied as a function of percent vegetative cover and elevation (Table 2). Adult elk were more likely to be killed in areas with little cover whereas calf elk, adult deer, and other species were more likely to be taken in habitats with heavier cover

(Figure 8). Adult elk and adult deer were more likely to be killed at lower elevations whereas calf elk and other species were more likely to be killed at higher elevations (Figure 9). Unexpectedly, kill composition did not vary in response to cluster type or cluster size (Figure 10). Kill composition could be biased if S1 clusters, or larger cluster sizes, were associated with larger prey items, because it would suggest that larger prey may be more easily detected. However, given that kills of different sized prey occurred in roughly equal probabilities across all cluster sizes, restricting sampling to larger clusters would not necessarily bias kill composition estimates, at least for ungulates. Efficiency would be gained in the field by sampling larger clusters because they are more likely to be associated with kills. Additional data collection will be necessary to determine whether this preliminary finding is valid. Also, we urge caution interpreting this result because it is not biologically intuitive and would lead to biased kill composition data if proven incorrect.

SUMMARY

Over the past 2 years we have collected data on elk and deer distributions in conjunction with cougar predation data across the southern half of the Uncompahgre Plateau. Part of this effort included the development and implementation of a sampling based approach to estimate cougar kill rates and prey selection from GPS location data. Based on this effort we were able to randomly sample clusters of cougar GPS locations in relation to cluster type/size, which presumably correlates to prey selection and handling time.

Mule deer and elk distributions on winter range were as expected with mule deer utilizing lower elevations and elk utilizing both lower and higher elevations with an area of overlap between the two species across deer winter range. Interestingly, cougar kill sites for mule deer generally occurred at mid-elevations within the range of overlap for deer and elk. Cougar kill sites for elk occurred at all elevations characteristic of elk distribution.

As expected, cougar clusters with a large number of points had a high probability of being associated with a predation event and those with few points had a lower probability, especially single point clusters that are spatially distinct from other points. However, evidence of predation was identified at some of the spatially distinct single point clusters, indicating that these types of clusters are important in accurately describing cougar diet composition and predator/prey interactions. The association between cluster size and the probability of a cougar kill was related to season and cougar sex, with larger clusters being less predictive of a kill during summer and for males. Cougars killed elk and deer in approximately equal proportions and killed fawns/calves in equal proportion to adults for both deer and elk. Other prey items that could be detected at GPS locations comprised less than 10% of cougar diets.

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Table 1. Model selection results, based on Akaike's Information Criterion with small sample size correction (AIC_c), of an analysis evaluating the probability of locating cougar prey items (i.e., cougar kills) at GPS location clusters. We modeled cougar kills as a function of cluster type (type; S1, S2,…, S5), cluster size (size; no. GPS locations/cluster), cougar age and sex status (status), and season when cluster was investigated (season; spring, summer, fall, winter).

Model	No. Parameters	AIC_c	Delta AIC_c	Model Weight
Type size season size×season	12	365.61	0.00	0.615
Type size status season size×status size×season	16	367.84	2.22	0.202
Type size status season size×season	14	369.68	4.07	0.081
Type size	6	370.75	5.13	0.047
Type size season	9	371.80	6.19	0.028
Size status season size×status size×season	12	373.04	7.42	0.015
Size season size×season	8	374.80	9.19	0.006
Type size status season	11	375.71	10.10	0.004
Size status season size×season	10	378.87	13.25	0.001
Size status size×status	6	380.07	14.46	0.000

Table 2. Model selection results, based on Akaike's Information Criterion with small sample size correction (AIC_c), of an analysis evaluating cougar kill composition at GPS location clusters. We modeled kill composition as a function of cluster type (type; S1, S2,…, S5), cluster size (size; no. GPS locations/cluster), cougar age and sex status (status), season when kill occurred (season; spring, summer, fall, winter), elevation (elev), and percent vegetative cover (cover).

Model	No. Parameters	AIC_c	Delta AIC_c	Model Weight
Elevation cover	12	347.81	0.00	0.926
Elevation cover status	20	353.25	5.45	0.061
Cover	8	356.35	8.54	0.013
Elevation	8	366.44	18.64	0.000
Size elevation	12	371.41	23.60	0.000
Status	12	385.84	38.04	0.000
Status season size elevation cover	36	386.30	38.49	0.000
Size	8	386.47	38.67	0.000
Season	16	389.36	41.55	0.000
Status season size elevation	32	399.07	51.27	0.000

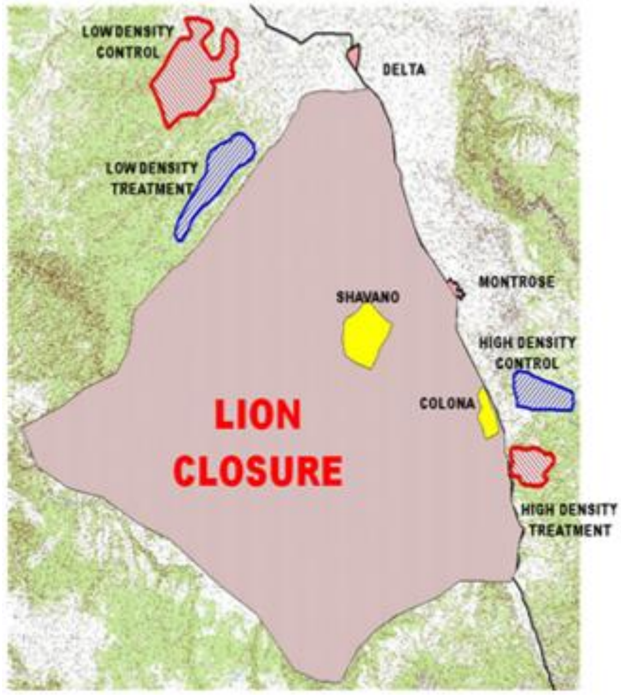

Figure 1. Location of pilot predator-prey research on the Uncompahgre Plateau, southwest Colorado. Ongoing deer research study areas are reflected by red and blue polygons with hash marks, as well as by solid yellow polygons. The ongoing lion research study area is designated by the large red polygon.

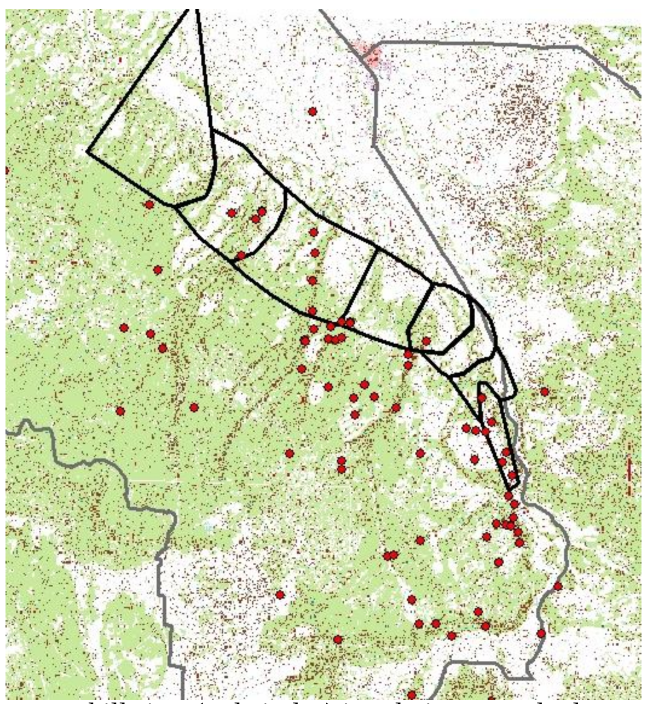

Figure 2. Distribution of cougar kill sites (red circles) in relation to mule deer winter range on the southeast portion of the Uncompahgre Plateau, Colorado. Black polygons represent segments of mule deer winter range where density estimates were either estimated or extrapolated to by surrounding areas on which estimates were measured. Gray lines represent Game Management Unit boundaries as designated by the Colorado Division of Wildlife.

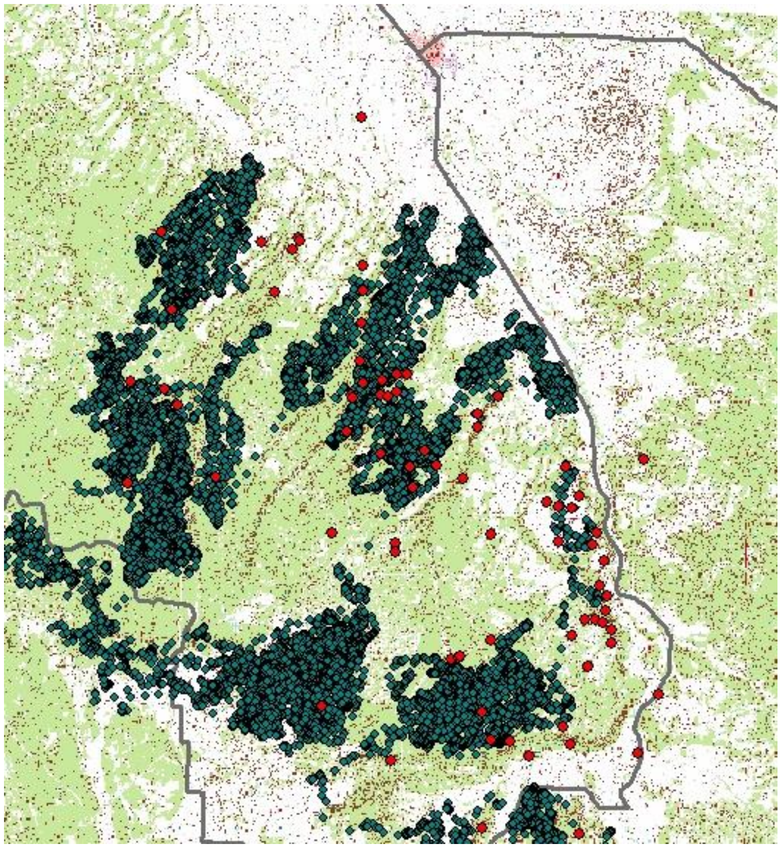

Figure 3. Distribution of cougar kill sites (red circles) in relation to GPS collar locations for 5 elk (black circles) on the southeast portion of the Uncompahgre Plateau, Colorado. Gray lines represent Game Management Unit boundaries as designated by the Colorado Division of Wildlife.

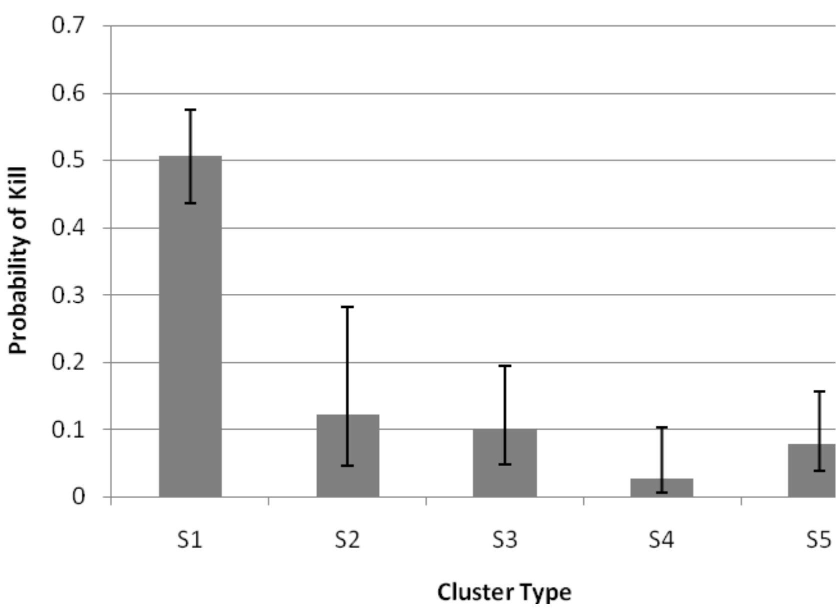

Figure 4. Probability of a cougar kill at different types of GPS location clusters (with 95% CIs), Uncompahgre Plateau, Colorado, 2006–2008. Refer to the Methods section for a detailed explanation of cluster types.

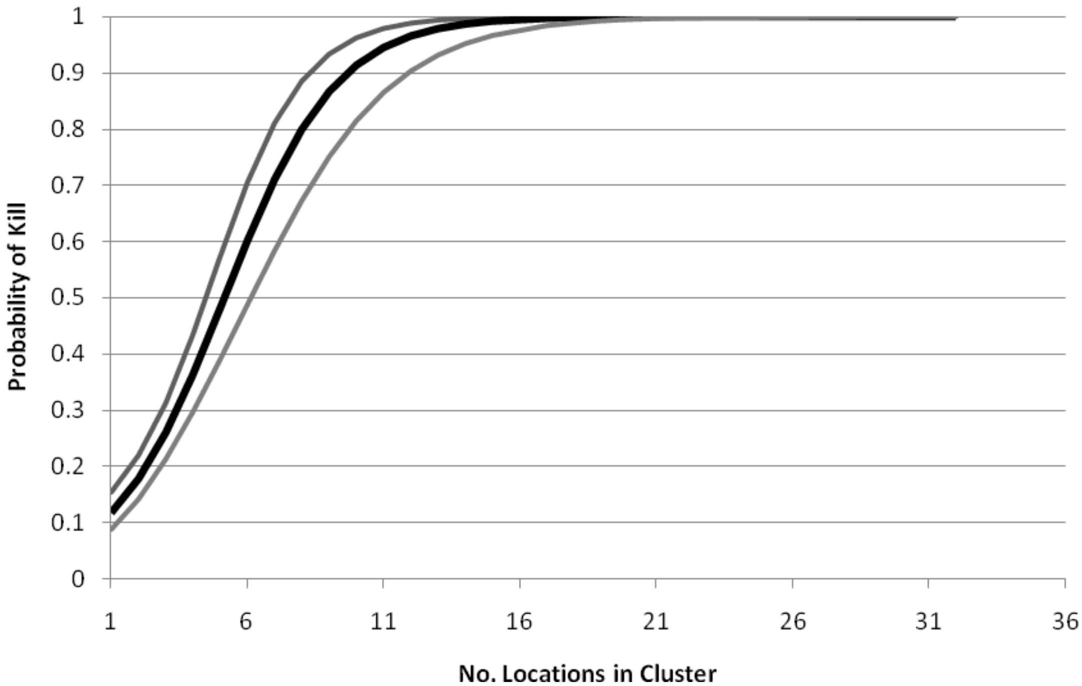

Figure 5. Probability of a cougar kill as a function of the number of locations in a GPS cluster (with 95% CI), Uncompahgre Plateau, Colorado, 2006–2008.

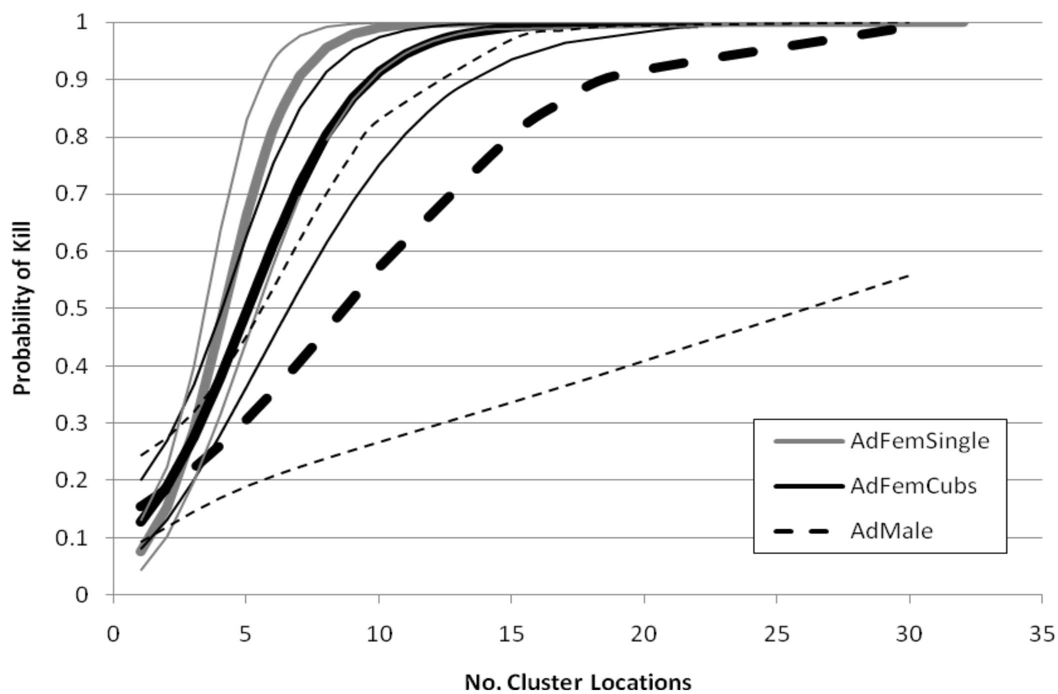

Figure 6. Probability of a cougar kill at GPS location clusters relative to sex and reproduction status (with 95% CIs), Uncompahgre Plateau, Colorado, 2006–2008. Cougar status was defined as single adult female (AdFemSingle), adult female with cubs (AdFemCubs), or adult male (AdMale).

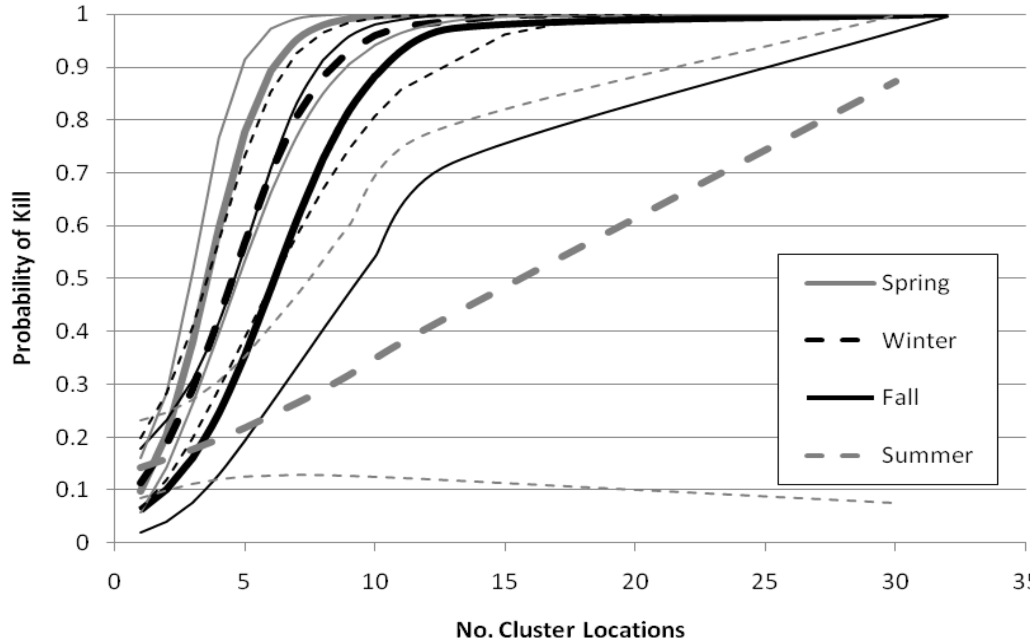

Figure 7. Probability of a cougar kill at GPS location clusters by season (with 95% CIs), Uncompahgre Plateau, Colorado, 2006–2008.

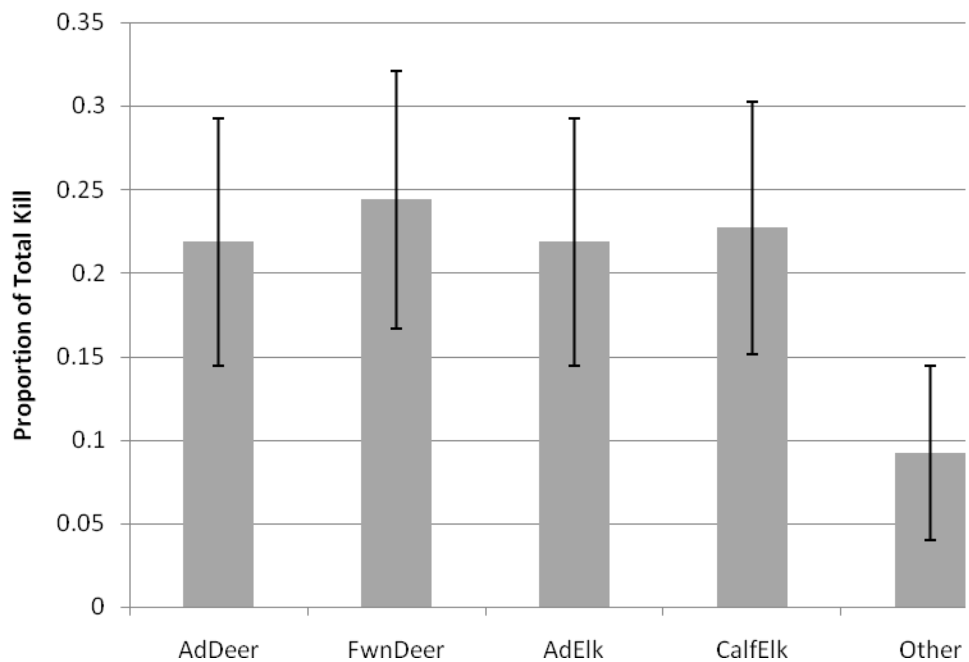

Figure 8. Prey composition of cougar kills (with 95% CIs) on the Uncompahgre Plateau, Colorado, 2006–2008. Prey items included adult deer (AdDeer), ≥ 6-month-old fawn deer (FwnDeer), adult elk (AdElk), calf elk (CalfElk), and other species (e.g., porcupine, turkey, coyote).

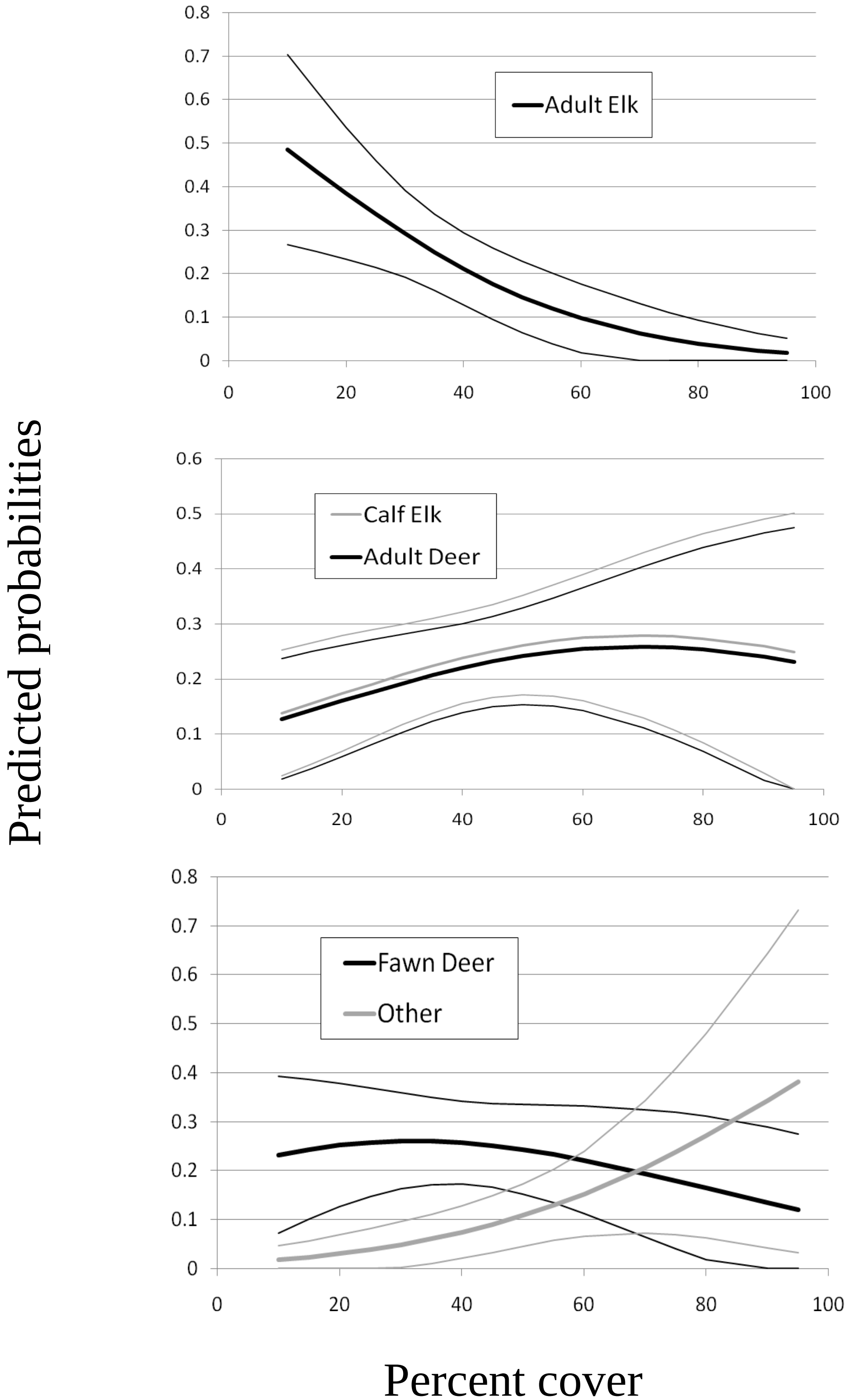

Figure 9. Predicted prey composition of cougar kills as a function of vegetative cover (with 95% CIs), Uncompahgre Plateau, Colorado, 2006–2008.

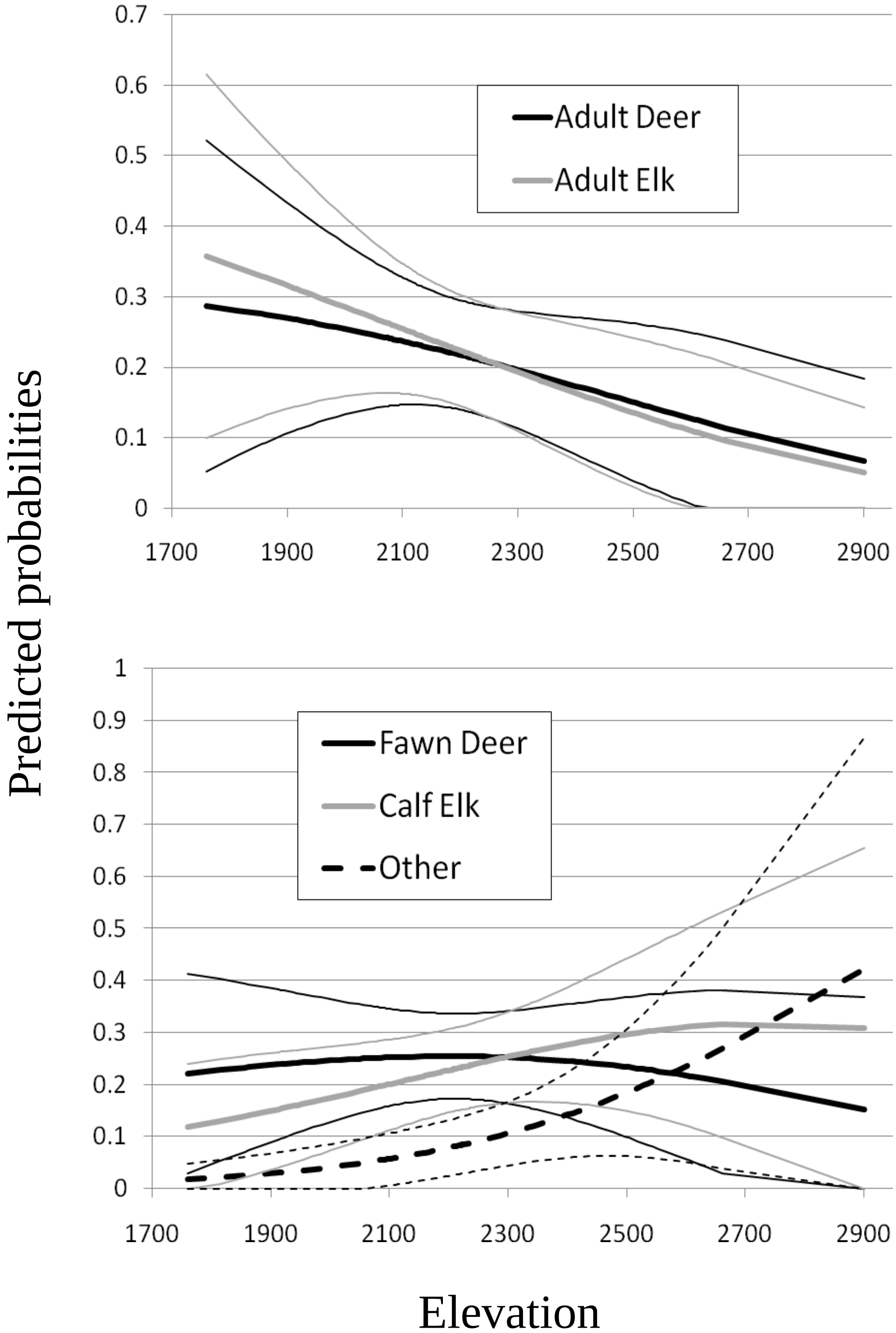

Figure 10. Predicted prey composition of cougar kills as a function of elevation (m) (with 95% CIs), Uncompahgre Plateau, Colorado, 2006–2008.

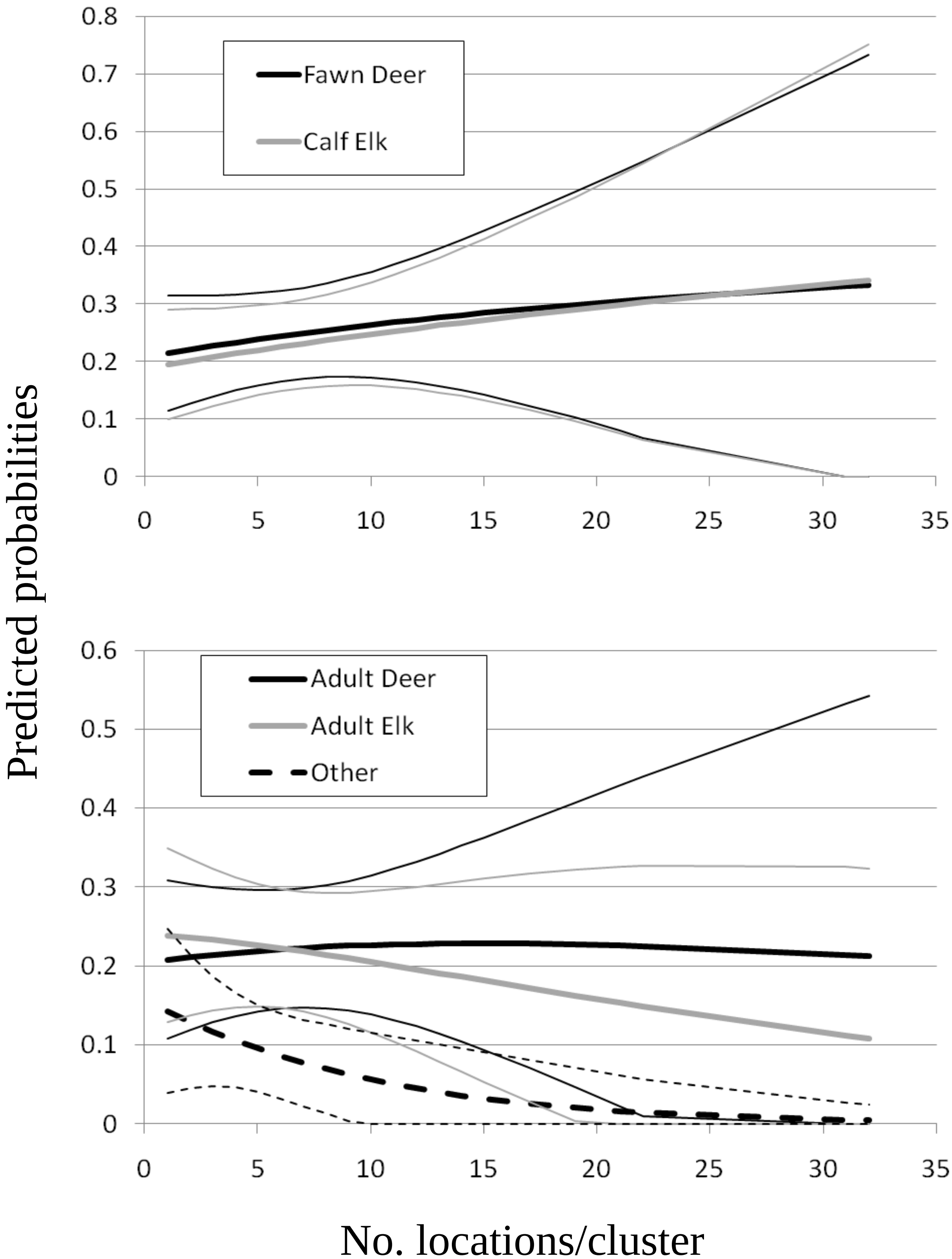

Figure 11. Predicted prey composition of cougar kills as a function of the number of locations comprising a GPS location cluster (with 95% CIs), Uncompahgre Plateau, Colorado, 2006–2008.

Colorado Division of Wildlife
July 2007 −June 2008

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	3003	:	Predatory Mammals Conservation
Task No.:	1	:	Puma Population Structure and Vital Rates
		:	On the Uncompahgre Plateau
Federal Aid Project No.	N/A		

Period covered: July 1, 2007−June 30, 2008

Author: K. A. Logan.

Personnel: K. Logan, B. Bavin, B. Dunne, J. Timmer, V. Yovovich, S. Waters, K. Crane, T. Mathieson, M. Caddy, and T. Bonacquista of CDOW; S. Young, and J. McNamara of U.S.D.A. Wildlife Services; volunteers and cooperators including: private landowners, Bureau of Land Management, Colorado State Parks, Colorado State University and U.S. Forest Service, with supplemental financial support received in previous years from The Howard G. Buffett Foundation and Safari Club International Foundation.

ABSTRACT

Research continued on puma population characteristics and dynamics on the Uncompahgre Plateau. All capture efforts in 2007-08 resulted in a total of 41 puma captures (9 adult females [1 adult female captured 3 times], 6 adult males [1 adult male captured 2 times], 1 subadult male, and 21 cubs [4 of them captured twice each]). Two adults, 4 subadults, and 16 cubs were captured for the first time. As of July 2008, there were 18 adults, 1 subadult, and 4 cubs marked with active radio-collars. Efforts to capture, sample, and mark pumas with the use of trained dogs extended from November 19, 2007 to April 24, 2008. Those efforts resulted in 77 search days, 217-218 puma tracks detected, 49 pursuits, and 20 puma captures. In 2007-08, capture efforts with ungulate carcasses and cage traps resulted in 1 adult male being captured twice. One cub was captured for the first time with dogs, and 15 cubs were caught the first time by hand. Capture and search efforts from November 2007 through March 2008 enabled us to estimate a minimum of 33 independent pumas detected on the Uncompahgre Plateau study area during that time, including 21 females and 12 males. Preliminary puma population parameters estimated during the past 3.7 years of research, included: population sex and age structure, reproduction rates, and survival rates. Data on puma reproduction rates included: average litter size = 2.810 ± 0.9808 *SD*, n = 21; average birth interval (mo.) = 17.969 ± 4.748 *SD*, n = 13; average proportion of adult females producing cubs each year = 0.65 ± 0.0586 *SD*, n = 12-13 females for 3 yr.; secondary sex ratio = 33:26, consistent with 1:1; and average gestation length (day) = 91.188 ± 2.3443 *SD*. Puma births occurred March through September. Survival rates for both adult and subadult pumas in this *reference period* appear to be high, and might reflect the relatively small samples of individual pumas in each age-stage and sex and years. Cub survival ranged from 0.50 (Kaplan-Meier procedure) to 0.56 (binomial model). The main cause of

mortality in the adults and cubs is caused by male pumas. A puma population model was developed for researchers and wildlife managers to assess scenarios of puma harvest management strategies. Results from a set of scenarios and attendant models are presented. Only 1 puma family with a radio-collared mother and cub could be monitored during the winter to assess association distances during aerial locations. The aggregate data gathered during the past 3 winters generally indicate that mothers were usually within 520 m of their cubs during the day. Preliminary comparisons between our current puma research on the Uncompahgre Plateau (3.7 years duration) and results of the Anderson et al. (1992) puma research on the plateau (7 years duration 1981-1988) were made where appropriate. Proposed work includes: continuing to quantify puma population characteristics and vital rates, with an emphasis on increasing sample sizes on radio-monitored adults, subadults, and cubs, and developing a study plan for the next 6 years of research, which will include the *treatment period*. We will collaborate with colleagues to assess puma health and model and map puma habitat.

WILDLIFE RESEARCH REPORT

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

KENNETH A. LOGAN

P. N. OBJECTIVE

Quantify puma population sex and age structure; estimate puma population vital rates, including: reproduction rates of females, age-stage survival rates, and immigration and emigration rates; quantify agent-specific mortality rates; begin puma population modeling process; and plan for the remaining 6 years of the Uncompahgre Plateau Puma Project— all to improve the Colorado Division of Wildlife's (CDOW) model-based approach to managing pumas in Colorado.

SEGMENT OBJECTIVES

1. Continue gathering data on puma population sex and age structure.
2. Continue gathering data for estimates of puma reproduction rates.
3. Continue gathering data to estimate puma sex and age-stage survival rates.
4. Continue gathering data to estimate agent-specific mortality rates.
5. Develop a puma population model and parameter estimates useful for guiding decisions about the hunting treatment phase of this project, and for the Data Analysis Unit puma management planning process performed by CDOW biologists and managers.
6. Gather data on spatial relationships of puma mothers to their cubs during the Colorado puma hunting season as a preliminary assessment of the vulnerability of puma mothers to sport-hunting harvest.
7. Develop a study plan for remaining 6 years of puma population research on the Uncompahgre Plateau Study Area.
8. Evaluate other data sources that could come from this research that can be developed into other puma research relevant to CDOW biologists and managers.

INTRODUCTION

Colorado Division of Wildlife managers need reliable information on puma biology and ecology in Colorado to develop sound management strategies that address diverse public values and the CDOW objective of actively managing puma while "achieving healthy, self-sustaining populations"(CDOW 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 CDOW's wildlife managers and biologists. In addition, we consulted with other agencies, organizations, and interested publics either directly or through other CDOW employees. In general, CDOW 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 CDOW 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 CDOW to achieve its strategic goal in puma management (Fig.1).

Management issues identified by managers translate into researchable objectives, requiring descriptive studies and field experiments. 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/radio-collared pumas. Those objectives include:

Describe and quantify puma population sex and age structure.

Estimate puma population vital rates, including: reproduction rates, age-stage-specific survival rates, emigration rates, immigration rates.

Estimate agent-specific mortality rates.

Improve the CDOW's model-based management approaches with Colorado-specific data from objectives 1—3. Consider other useful models.

Concurrently with the tasks associated with the objectives above, significant progress will be made toward a 5th objective, which will initially be subject to *pilot study*— develop methods that yield reliable estimates of population abundance (i.e., numbers and density) and attendant annual population growth rates, such as, direct mark-recapture, and DNA genotype capture-recapture.

A descriptive 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 a 5-year *reference period* (i.e., absence of recreational hunting) to allow puma life history traits to interact with the main habitat factors that appear to influence puma population growth (e.g., prey availability and vulnerability, Pierce et al. 2000, Logan and Sweanor 2001). Contingent upon results in the *reference period*, a subsequent 5-year *treatment period* is planned. The *treatment period* will involve the use of controlled recreational hunting to manage 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. Recreational puma hunting management in Colorado Data Analysis Units (DAUs) is guided by a model to estimate allowable harvest quotas 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). Basic model parameters are: puma population density, sex and age structure, and annual population growth rate. Parameter estimates 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 □ include population density, sex and age structure, female age-at-first-breeding, reproduction rates, sex- and age-specific survival, immigration and emigration.

   H_1: 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 $\lambda = 1.15$.

2. The key assumption is that the CDOW can manage puma population growth through recreational hunting: for a stable puma population hunting removes the annual increment of population growth (i.e., from current judgments on population density, structure, and □. Puma harvest rate formulations for DAUs assumes 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).

   H_2: 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 decline of the harvest-age segment of the population by the beginning of the next hunting season.

3. 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).

   H_3: Total mortality of an estimated 16% or greater of the harvestable population with greater than 45% females will cause a decline in the abundance of harvest-age pumas (i.e., adults and subadults).

Considering limitations (i.e., methods, number of years, assumption violations) to the Colorado-specific studies on puma densities cited above (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 CDOW assumes density ranges of 2.0—4.6 puma/100 km^2 to extrapolate to 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 capture, mark, re-capture techniques developed and refined during the study to estimate the puma population, the following will be tested:

H_4: 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**—**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.

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.

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 CDOW managers, will help those managers to biologically support and adapt puma management based on Colorado-specific estimated puma population characteristics, parameters, and dynamics.
3. Methods for estimating puma abundance (e.g., capture-mark-recapture) of known reliability will allow managers to "ground truth" 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 require development of reliable monitoring techniques based on capture-mark-recapture methods and models. Potential methods include direct and DNA genotype capture-recapture, and assessments of harvest sex and age structure. Study plans to develop and test feasible field and analytical methods will be developed in the future after we have learned 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. This information 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. 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 pinon-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. There are cattle and domestic sheep raised on summer ranges on the study area. Year-round human residents live 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 well accessible for puma research efforts. A detailed description of the Uncompahgre Plateau is in Pojar and Bowden (2004).

METHODS

Reference and Experimental Treatment Periods

This research is structured in two 5-year periods: a *reference period* (years 1—5) and a *treatment period* (years 6—10). The *reference period* is expected to cause a population increase phase. The *treatment period* will involve structured puma management strategies. In both phases, puma population structure, and vital rates will be quantified, and some management assumptions and hypotheses regarding population dynamics and effects of harvest will be tested. Contingent upon results of pilot studies, we will also estimate puma numbers, population growth rates, evaluate enumeration methods, and test other hypotheses (Logan 2004).

The *reference period*, without recreational puma hunting as a major limiting factor, is consistent with the natural history of the current puma species in North America which evolved life history traits during the past 10,000—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 evolution in western North America for the past 100 years. Hence, the *reference period*, years 1—5, will provide conditions where individual puma in this population (of estimated sex and age structure) express life history traits interacting with the environment without recreational hunting as a limiting factor. Theoretically, the main limiting factors will be catchable prey abundance (Pierce et al. 2000, Logan and Sweanor 2001). This should allow researchers to understand basic system dynamics *before* the treatment (i.e., controlled recreational hunting). In the *reference period*, all puma in the study area will be protected, except for individual puma that might be involved in depredation on livestock or human safety incidents. In addition, all radio-collared and ear-tagged puma that range in a buffer zone, that includes the northern halves of GMUs 61 and 62, will be protected from recreational hunting.

The *reference period* will allow researchers to quantify baseline demographic data on the puma population to estimate parameters for the CDOW's model-based approach to puma management. Moreover, it will allow researchers to develop and test puma enumeration methods when population growth is known to be in one direction— increasing. Without the hunting closure, pilot data for enumeration methods could be confounded by not knowing if the population was increasing, declining, or stable. The *reference period* will also facilitate other operational needs (because hunters will not be killing the animals) including the marking of a large proportion of the puma population for capture-mark-recapture estimates, and the gathering of movement data from GPS-collared puma to help formalize exact sampling designs for enumeration methods.

During the *treatment period*, years 6—10, experimentally structured recreational puma hunting will occur 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 CDOW's objectives of manipulating natural tendencies of puma populations, particularly survival, to maintain either population stability or increase and population suppression (CDOW, Draft L-DAU Plans, 2004). Theoretically, puma survival will be influenced mainly by recreational hunting, which will be quantified by agent-specific mortality rates of radio-collared puma. For managers, demonstrating that they can manage puma populations with hunting and achieve the CDOW strategic objective of managing for a healthy, self- sustainable puma population state-wide is important.

Dynamics of the puma population may be manipulated (i.e., increase and decline phases) 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), enumeration methods, and puma—prey interactions (i.e., lines of research identified in the Colorado Research Program, Fig. 1). The killing of tagged and collared puma during the *treatment period* will not hamper operational needs (as it would during the start-up years), because by the beginning of this period, a large majority of independent puma in the population will be marked, and sampling schemes will be formalized.

Puma 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 puma 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 CDOW if they perceive that an individual puma may be a threat to public safety.

Field Methods

Puma Capture: Realizing that puma live at low densities and capturing puma is difficult, as a starting point, our logistical aim will be 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 is to provide more quantitative and precise estimates of puma demographics than were achieved in earlier Colorado puma studies. This relatively large number of puma might represent the large majority of the puma population on the study area, and will provide the basic data for age- and sex-specific reproductive rates, survival rates, agent-specific mortality rates, emigration rates, and movement data pertinent to sampling designs for various projects.

Assuming that the puma population density on the study area is relatively low at the beginning of this study— about 1 adult/100 km^2 and the sex ratio is equal (Anderson et al. 1992, Logan and Sweanor 2001:167), then there might be 22 adults, 11 males and 11 females. Also assuming that the total population contains 10% subadults and 34% cubs (Logan and Sweanor 2001), then there might be 4 subadults and 13 cubs with equal sex ratios in a total population of 39 puma. If we achieve our logistical aim in the first 1—2 years (recognizing that the population might grow), then we should be able to quantify population characteristics and vital rates for a majority of the puma population in those years and build upon the tagged number in each subsequent year. Thus, our inferences will pertain to the large majority of the puma population, if not the population on the study area, instead of a relatively small sample of it. We anticipate it may take 2 years to mark the large majority of puma in the population. In addition, the study area is large and will require some time to learn to access it efficiently.

Puma capture and handling procedures have been approved by the CDOW Animal Care and Use Committee (file #08-2004). All captured puma will be examined thoroughly to ascertain sex and describe physical condition and diagnostic markings. Age of adult puma will be 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 puma will be estimated initially based on dental and physical characteristics of known-age puma (Logan and Sweanor unpubl. data). Body measurements recorded for each puma will include at a minimum: mass, pinna length, hind foot length, plantar pad dimensions. Tissue collections will include: 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) and fecal DNA for genotyping tests of field gathered samples. Universal Transverse Mercator Grid Coordinates on each captured puma will be fixed via Global Positioning System (GPS, North American Datum 27).

Puma will be captured year-round using 4 methods: trained dogs, cage traps, foot-hold snares, and by hand (for small cubs). Capture efforts with dogs will be conducted mainly during the winter when snow facilitates thorough searches for puma tracks and the ability of dogs to follow puma scent. The study area will be searched systematically multiple times per year by four-wheel-drive trucks, all-terrain vehicles, snow-mobiles, walking, and possibly horse- or mule-back. When puma tracks ≤1 day old are detected, trained dogs will be released to pursue puma to capture.

Puma usually climb trees to take refuge from the dogs. Adult and subadult puma captured for the first time or requiring a change in telemetry collar will be immobilized with Telazol (tiletamine hydrochloride/zolazepam hydrochloride) dosed at 5 mg/kg estimated body mass (Lisa Wolfe, DVM, CDOW, attending veterinarian, pers. comm.). Immobilizing agent will be 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 will be deployed beneath the puma to catch it in case it falls from the tree. A researcher will climb the tree, fix a Y-rope to two legs of the puma and lower the cat to the ground with an attached climbing rope. Once the puma is on the ground, its head will be covered, its legs tethered, and vital signs monitored (Logan et al. 1986). (Normal signs: pulse ~70—80 bpm, respiration ~20 bpm, capillary refill time ≤2 sec., rectal temperature ~101°F average, range = 95—104°F) (Kreeger 1996).

A cage trap will be used to capture adults, subadults, and large cubs when puma can be lured into the trap using road-killed or puma-killed ungulates (Sweanor et al. 2008). Efficiency of the trap might be enhanced by using an automated digital call box that emits puma vocalizations (Wildlife Technologies, Manchester, NH). A cage trap will be set only if a target puma scavenges on the lure (i.e., an unmarked puma, or a puma requiring a collar change). Researchers will continuously monitor the set cage trap from about 1 km distance by using VHF beacons on the cage and door. This allows researchers to be at the cage to handle captured puma within 30 minutes. Puma will be immobilized with Telazol injected into the caudal thigh muscles with a pole syringe. Immobilized puma will be restrained and monitored as described above. If non-target animals are caught in the cage trap, we will open the door and allow the animal to leave the trap.

Foot-hold snares will be used to capture adults, subadults, and large cubs only when safe snare sites at puma kills can be located as described by Logan et al. (1999). Snares set at puma kills will be monitored continuously with VHF beacons on the snares from about 1 km distance. We will not set snares at sites where tracks indicate that other mammals (e.g., deer, elk, bear, bighorn sheep, livestock) are also active. Puma will be immobilized with Telazol injected into the caudal thigh with a pole syringe. Vital signs will be monitored during the handling procedures. Efficiency of snares might also be enhanced with the use of an automated call box with puma or prey vocalizations.

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

Marking, Global Positioning System- and Radio-telemetry: Puma do not possess easily identifiable natural marking, such as tigers (see Karanth and Nichols 1998, 2002), therefore, the capture, marking, and GPS- or VHF- collaring of individual puma is essential to a number of project objectives, including estimating vital rates and gathering movement data on puma to formalize designs for developing and testing enumeration methods. Adult, subadult, and cub puma will be marked 3 ways: GPS/VHF- or VHF-collar, ear-tag, and tattoo. The identification number tattooed in the pinna is permanent and cannot be lost unless the pinna is severed. A colored (bright yellow or orange), numbered rectangular (5 cm x 1.5 cm) ear-tag (Allflex USA, Inc., DFW Airport, TX) will be inserted into each pinna to facilitate individual identification during direct recaptures. Cubs ≤10 weeks old will be ear-tagged in only one pinna.

Locations of GPS- and VHF-collared puma will be fixed about once per week (as flight schedules and weather allow) from light fixed-wing aircraft (e.g., Cessna 182) fitted with radio signal receiving equipment (Logan and Sweanor 2001). This monitoring will enable researchers to find GPS-collared puma to acquire remote GPS location reports from the ground, monitor the status (i.e., live or dead) of individual puma, and to recover carcasses for necropsy. It will also provide simultaneous location data on mothers and cubs. GPS- and VHF-collared puma will be located from the ground opportunistically using hand-held yagi antenna. At least 3 bearings on peak aural signals will be mapped to fix locations and estimate location error around locations (Logan and Sweanor 2001). Aerial and ground locations will be plotted on 7.5 minute USGS maps (NAD 27) and UTMs along with location attributes will be recorded on standard forms. GPS locations will be mapped using GIS software.

Adult and subadult female pumas will be fitted with GPS collars (approximately 400 g each, Lotek Wireless, Canada). Initially, GPS-collars will be 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 puma will provide precise, quantitative data on puma movements mainly to provide data to formalize study designs, to test assumptions for capture-mark-recapture methods for this project, and to assess the relevance of puma DAU boundaries. The GPS-collars also will provide 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 predation frequency on mule deer and elk.

Subadult male pumas will be fitted initially with conventional VHF collars (Lotek, LMRT-3, ~400 g each) with expansion joints fastened to the collars, which allows the collar to expand to the average adult male neck circumference (~46 cm). If subadult male puma reach adulthood on the study area, we will recapture them and fit them with GPS collars.

VHF radio transmitters on GPS collars will enable researchers to find those pumas on the ground in real time to acquire remote GPS data reports, facilitate recaptures for re-collaring, and to check on their reproductive and physical status. VHF transmitters on GPS- and VHF-collars will have a mortality mode set to alert researchers when puma have been immobile for 3 to 24 hours so that dead puma can be found to quantify survival rates and agent-specific mortality rates by gender and age.

We will attempt to collar all cubs in observed litters with small VHF transmitter mounted on an expandable collar (Wildlife Materials, Murphysboro, Illinois, HLPM-2160, ~50g, or Telonics, Inc., Mesa, Arizona MOD 210, ~100g,) when cubs weigh 2.3―11 kg (5―25 lb). Cubs with mass ≥11 kg can still wear these small expandable collars until they are about 12 months old. Cubs approaching the age of independence (~11―14 mo. old) may be fit with Lotek LMRT-3 VHF collars (~400 g) with expansion links. Cubs will be recaptured to replace collars as necessary. Monitoring radio-collared cubs allow quantification of survival rates and agent-specific mortality rates (Logan and Sweanor 2001).

Capture-Mark-Recapture: Capture-mark-recapture methods will be evaluated initially as a pilot study. Capturing and marking puma is time consuming, and would lengthen the time to thoroughly search the study area for capturing and marking puma during capture-recapture occasions needed for population estimation. Therefore, we will capture and mark pumas prior to performing capture-recapture or re-sight occasions using methods such as houndsmen teams. In addition, by marking puma before capture-recapture occasions begin, we will have opportunities to capture female puma at different stages of their reproductive status, and thus reduce the chance that mothers in a stage with suckling cubs and small activity areas are not detected and marked on the study area. After cubs are weaned, the mothers' activity area expands (Logan and Sweanor 2001). The probability of females having suckling cubs in winter is naturally small; that season exhibits the lowest rate of births (Logan and Sweanor 2001). Capture-recapture occasions to estimate the population of independent puma may not begin until we have a large majority of the puma population sampled and marked. Occasions performed at that time will be viewed as a pilot study allowing us to examine the logistics of the field methods, the extent to which model assumptions are met, performance of field methods (e.g., detection differences by sex or life stage as revealed by GPS data on collared puma), and precision of capture-recapture models used to estimate the puma population.

Analytical Methods

Population Characteristics: Population characteristics each year will be 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 known as kittens) (Logan and Sweanor 2001). When data allow, age categories may be further partitioned into months (for cubs and subadults) or years (for adults).

Reproductive Rates: Reproductive rates will be 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 puma (Murphy et al. 1998).

Survival and Agent-specific Mortality Rates: Radio-collared puma will provide known fate data which can be used to estimate survival rates for each age stage using the Kaplan-Meier procedure to staggered entry (Pollock et al. 1989), binomial survival model (Williams et al. 2001:343-344), or analyzed in program MARK (White and Burnham 1999, Cooch and White 2004). Agent-specific mortality rates can be analyzed using proportions and Trent and Rongstad procedures (Micromort software, Heisey and Fuller 1985). Cub survival curves for each gender will be plotted with survival rate on age in months (Logan and Sweanor 2001:119).

Population Estimates: Capture-recapture models will be evaluated initially as a pilot study to estimate the parameters of primary interest― absolute numbers of independent puma (i.e., number of adult and subadult puma present in the survey area) and puma density (i.e., number of independent puma/100 km^2) each winter― December through March― when snow facilitates detection and capture of puma, provided that we meet model assumptions. The December―March period also corresponds with Colorado's puma hunting season. The population of interest is independent puma (i.e., adults and subadults) because those are the puma that can be legally killed by recreational hunters. Furthermore, adults comprise the breeding segment of the population and subadults are non-breeders that are potential recruits into the adult population in ≤1 year. Thus, the sampling unit is the individual independent puma (~≥1 yr. old).

Basic assumptions for closed capture-recapture models are: (1) the population is closed; (2) animals do not lose their marks during the interval; (3) all marks are correctly noted and recorded at each trapping occasion; (4) each animal has a constant and equal probability of capture on each capture occasion. Open population models allow the assumption of closure to be relaxed (Otis et al. 1978, White et al. 1982, Pollock et al. 1990). The robust design is a combination of closed and open models; thus, assumptions are a combination of the assumptions for closed and open population methods (Kendall 2001).

To analyze capture-recapture data, closed, open, and the robust design models are available in program MARK. Akaike's Information Criterion will be used to select the most parsimonious models based on AICc score ranks and the difference in AIC (ΔAIC) between models (Burnham and Anderson 1998). MARK results also include estimates of abundance.

Because the precision of estimates for small populations is sensitive to the probability of capture (White et al. 1982, Pollock et al. 1990), our operational goal will be to achieve capture probabilities of ≥0.4 for each animal per capture occasion (see Results and Discussion, Segment Objective 7).

In addition, behavior, movements, survival and mortality of GPS- and VHF-collared puma will allow direct biological examinations of assumptions of geographic and demographic closure (White et al. 1982) and variation in capture probability of individual puma and puma classes (i.e., adult females, adult males, subadult females, subadult males). If capture probabilities vary by puma class, we will examine if data stratification is necessary or possible (depending upon sample size). For example, we might expect the larger home ranges of male puma to expose them to more search routes, thus, this may increase their probability of capture. If the assumption of demographic closure cannot be satisfied, then open population models and the robust design would be more appropriate (Pollock et al. 1990, Williams et al. 2001). Collared puma will allow us to determine the number of marked puma present in the search area each capture-recapture occasion. Furthermore, GPS locations (4 fixes/day) on individual puma will provide data on the probability that puma may temporarily move out of and back into the survey area between capture occasions. Unmarked puma that are subsequently GPS-collared should provide such information, too.

ArcView geographic information system software will be used to map and analyze puma locations, movements, and home ranges. It will also be used to map and quantify attributes of the study area and sampling frames.

Rate of Population Increase: Finite rates of increase ($\lambda = N_{t+1}/N_t$) between consecutive years and average annual rates of increase *(r)* for 3- to 5-year periods and levels of precision will be calculated (Caughley 1978, Van Ballenberghe 1983) and plotted.

Functional Relationships: Graphical methods will be used to examine functional relationships among puma population parameters. Linear regression procedures and coefficients of determination can 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, can also be used to test for monotonic relationships between puma abundance and other parameters of interest (Conover 1999). Statistical analyses will be performed using SYSTAT and SAS software.

RESULTS AND DISCUSSION

Segment Objective 1

Field research to quantify puma population structure, vital rates, and causes of mortality for this report extended from August 2007 to July 2008. Our searches to detect puma presence covered the entire study area. We made 41 puma captures during the period (9 adult females [1 adult female captured 3 times], 6 adult males [1 adult male captured 2 times], 1 subadult male, and 21 cubs [4 of them captured twice each]), resulting in 2 adults (1 female, 1 male), 4 subadults (2 females, 2 males), and 16 cubs (7 females, 9 males) captured for the first time in 2007-08.

Trained dogs were used as our main method to capture, sample, and mark adult and subadult pumas from November 19, 2007 to April 24, 2008. Those efforts resulted in 77 search days, 217-218 puma tracks detected, 49 pursuits, and 20 puma captures (Table 1). Puma capture efforts (i.e., search days) with dogs in this period was similar to our efforts in the 3 previous winters (Table 2). But, the frequency of tracks encountered and pursuits increased over the 3 previous periods. Our capture rate declined slightly probably due to our ability to identify radio-collared pumas associated with tracks (see later), thus, negating the need to capture the pumas directly with dogs. Seven adult and subadult pumas were captured for the first time (Table 3). This includes 1 adult female puma that could not be handled for safety reasons (Tables 4). One large cub, and 1 adult female were each recaptured twice, but could not be handled for safety reasons. One GPS-collared male puma was visually observed in association with an adult female puma we recaptured with dogs, but the male puma was not be bayed by the dogs (Table 4). The age structure of independent pumas captured for the first time continues to suggest that we have been studying a relatively young age-structured puma population that is increasing in the current *reference period* (Figure 2).

Our puma capture efforts using ungulate carcasses and cage traps extended from August 7, 2007 to July 15, 2008. We used 59 road-killed mule deer, 1 road-killed elk, and 1 puma-killed mule deer as bait at 15 different sites to capture one adult male puma 2 times (Tables 5). The puma-killed deer was used as bait at another site after puma F30 abandoned the carcass after we set a camera trap at her cache to obtain photos of the number of marked cubs in her family to confirm survival data. Pumas scavenged 11 of 60 (18.3%) of the ungulate carcasses used for bait. This was slightly lower than results of the last 2 years (i.e., 20%, 22.5%). Other carnivores that used the ungulate baits included: black bear, coyote, and bobcat.

Recaptures of 11 to 12 individual marked pumas were made 17 times with the use of dogs and cage traps; GPS/VHF collars were replaced as needed (Table 6). This included puma M27 (which wore a non-functional GPS collar) that was treed twice north of the study area by a puma hunter (Stan Garvey, Nucla) using dogs. The hunter reported the observation of the tagged animal (including, ear-tag number, and a visible hole in the GPS unit battery box), dates, and locations to principal investigator K. Logan. One recapture was of puma cub M44 (offspring of F7) made by Wildlife Services personnel responding to puma depredation on domestic sheep on the study area. The Wildlife Service houndsman released dogs on the puma tracks, and subsequently treed M44 and shot him to control the depredation. In another instance, a researcher visually observed a GPS-collared male puma in association with puma F23 as we pursued both pumas with dogs. Neither of the pumas had functioning GPS collars at the time. The GPS-collared male puma was either M27 or M29, as those 2 adult males were the only GPS-collared males that ranged in that area. The dogs treed F23, but they did not bay the male puma to enable us to obtain exact identity.

We also captured 16 cubs (9 male:7 female) for the first time (Table 7). Seven cubs were radio-collared, including zero to 2 cubs collared in each of 7 litters (Appendix A). One 18 kg female cub was treed by our trained dogs, and immobilized with a pole syringe for safe handling. The other 15 cubs were handled without anesthetics at their nurseries when they were 28 to 40 days old. The litters were produced in May (3), June (2), and July (2).

In addition to our direct puma captures, we identified 11 previously marked adult pumas that we detected 34 times initially by snow-tracking (Table 8). Upon detecting puma tracks that were roughly aged at 1 to 2 days 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. GPS data from pumas with functional GPS collars provided confirmatory information about movements of pumas. If GPS data indicated that the puma moved through the area at the time the tracks were made in snow, then we ruled the data were confirmatory. A large majority (i.e., 70%) of confirmatory data is a combination of radio-telemetry and GPS data. One snow track was assigned to a male puma only using GPS data, apparently because he had moved sufficiently far enough away so we did not receive radio signals at the time we found his tracks. If the GPS data did not indicate movement through the area, but the puma probably had sufficient time between fixes to foray to the tracks from proximate GPS locations, then we decided the GPS data were inconclusive. None of the GPS data clearly indicated that an individual puma could not have been the one we initially identified by radio-telemetry.

In one instance, principal investigator K. Logan visually observed puma F25 attack a mule deer after following up her tracks with radio-telemetry. If we could not identify a collared puma in association with 1-day-old puma tracks, then we released the dogs in attempt to capture the puma. 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 radio- or GPS-collars. This approach would also be useful in a rigorous mark-recapture effort where radio-collared pumas are available.

Our search efforts throughout the study area also revealed the presence of at least 9 other independent females and 1 independent male. We could separate the activity of these pumas from the GPS- and VHF- collared pumas in time and space. Moreover, females in association with cubs of different counts and sizes enabled us to separate 5 adult females followed by 1 to 3 medium-to-large-size cubs. One adult female with 1 large dependent cub was treed, but could not be handled safely. She initially treed, which provided us with an excellent visual observation; but, she left the tree and escaped into a system of sink holes that were too unstable (i.e., dangerous) for researchers to enter. Another adult female with 2 medium-size cubs was pursued with dogs, but was not captured. It was the same situation with another adult female with 2 to 3 medium-size cubs in a different area. The tracks we found of the other pumas were too old to pursue (i.e., probability of capture with the dogs was negligible).

Our search and capture efforts during November 2007 through April 2008 enabled us to estimate a minimum count of 33 independent pumas detected on the Uncompahgre Plateau study area, up from a minimum count of 24 independent pumas during the November 2006 to May 2007 period. This estimate was based on the number of known radio-collared pumas, the observation of one non-collared puma, and detection of tracks of suspected non-collared pumas on the study area (explained previously). In addition to the independent pumas, we also counted a minimum of 20 to 21 cubs. The sex and age structure of the minimum puma count is in Table 9. Of the 33 independent pumas, 23−24 (70−73%) were marked and 9−10 (27−30%) were assumed to be unmarked animals. Of the expected unmarked pumas, 8−9 were females and 1 was male, which might reflect lower detection rates of females. There appears to be variation in puma numbers on the west and east slopes of the study area. The west slope count includes 12 independent pumas (8 females, 4 males). The east slope count includes 21 independent pumas (13 females, 8 males). We used the minimum puma count and population structure in an effort to develop puma population models to simulate expected puma population dynamics in the remainder of the *reference period* and expected results of harvest management for the *treatment period* on the Uncompahgre Plateau Puma Project. Moreover, the models can be used by CODOW wildlife managers and biologists as a tool to explore expected outcomes of puma harvest management strategies in Colorado (see Segment Objective 5).

Anderson et al. (1992) studied pumas on the east slope of the Uncompahgre Plateau (i.e., GMU 62) during 1981 to 1988. Sport-hunting was banned during that study to investigate an "unexploited" puma population (Anderson et al. 1992:5). As our current effort results in larger samples and progresses in time through the *reference* and *treatment* periods, similarities and differences in results of the 2 research efforts, now separated by more than 15 years, should illuminate reliable knowledge for puma management in Colorado. Our current puma research on the Uncompahgre Plateau has been underway for 3.7 years (compared to 7 years of Anderson et al. 1992). Our data analysis at this stage of the research is not by any means exhaustive or complete because we are still in the intensive data-gathering phase, yet, our data allows some preliminary comparisons with Anderson's (1992) completed work.

In the Anderson et al. (1992) study, the average capture effort with dogs was 91.1 days per winter (range = 32 to 136, n = 7) resulting in an average capture effort of 13.9 days per puma. Of 189 pursuits of pumas, 110 (58%) were successful (either of radio-collared or non-collared animals). Anderson et al. (1992) focused on capturing pumas >27 kg in body mass while avoiding pumas <27 kg in mass. They captured 47 pumas with dogs for an average capture rate of 13.9 days per puma. Eight other pumas, all female cubs ≤ 7 months old, were caught in steel leg-hold traps by trappers, and were added to the study animal population. Two other cubs were killed by the dogs. In total, Anderson et al. (1992) captured 57 pumas, of which 49 were radio-collared.

So far, in our 4 winters, the average effort to capture pumas with dogs is 78.8 days (range = 77 to 82). Of 172 pursuits, 70 (41%) were successful. We captured 38 individual pumas their first time with dogs (i.e., does not include dog-aided recaptures), yielding an average capture rate of 8.3 days per capture (i.e., 315 days/38 captures). Other capture efforts and results between the 2 studies are not comparable, because Anderson et al. (1992) did not routinely attempt to capture pumas using cage traps or capture cubs at nurseries like we are. In our current effort, we captured, sampled, and marked 90 pumas. Of those animals, 74 were radio-collared, allowing us to monitor fates of pumas in all sexes and age stages, including: 15 adult females, 11 adult males, 2 subadult females, 5 subadult males, 25 female cubs, 22 male cubs (some individuals occur in more than one age-stage). To date, this represents the largest number of individual pumas sampled for population data in Colorado.

Mass recorded by Anderson et al. (1992:86) for pumas having an estimated age ≥24 months, averaged 61.6 kg for 8 males, (*SD* = 5.7, range = 51.8 to 70.8) and 44.5 kg for 14 females (*SD* = 3.6, range = 38.5 to 49.9). So far in our current study, mass for pumas ≥24 months old averaged 59.4 kg for 11 males (*SD* = 7.42, range 40 to 68 kg) and 38.4 kg for 14 females (*SD* = 4.29, range = 31 to 46). Sexual dimorphism is evident in pumas, and has been described for the species throughout its range (Young and Goldman 1946). Sexual dimorphism in puma has been explained as a potential result of sexual selection (Logan and Sweanor 2001:109).

<u>Segment Objective 2</u>

During the past 3.7 years of this work we compiled data on puma reproduction that was not previously available on pumas in Colorado. We examined 59 cubs from 21 litters aged 29 to 42 days old where we were reasonably sure that we counted all the cubs at the nurseries (Appendix A). The distribution of puma births by month indicate puma births extending from March into September, with 26 of 28 births occurring May through September (Fig. 3).The secondary sex ratio was 33:26 for 21 litters where all the cubs were sexed. This ratio was not significantly different from 1:1, ($X^2 = 0.8305 < 3.841$, $\alpha = 0.05$, 1 d.f.). An equal sex ratio at birth is characteristic of other puma populations in North America (Robinette et al. 1961, Logan and Sweanor 2001:69-70). The mean (±*SD*) and extremes of litter sizes were 2.810 (±0.9808), 1−4 (Table 10). In addition, 13 birth intervals for 8 different female pumas averaged 17.969 months (*SD* = 4.748), and ranged from 11.7 to 23.9 months (Table 10). During the past 3 biological years (i.e., 2005-06 to 2007-08) when we radio-monitored 12, 13, and 12 adult female pumas respectively, the proportion of adult females that produced cubs each year were 0.67, 0.69, and 0.58, with a mean ± *SD* of 0.65 ± 0.0586. Based on observations (from GPS and radio-telemetry data) of associations between 7 mothers and putative sires, 8 estimated gestation periods averaged 91.188 days (*SD* = 2.3443), which is consistent with average puma gestation reported in the technical literature on puma (i.e., mean ± *SD* = 91.9 ± 4.1, Anderson 1983:33, mean = 91.5 ± 4.0 Logan and Sweanor 2001:414).

Anderson et al. (1992:47) reported of "17 postnatal litters about 10-240 days in estimated age from 12 individual females, the mean (±SD) and extremes of litter sizes were 2.41 ± 0.8, 1-4". "Because most postnatal young were not handled, their sex ratio is unknown" (Anderson et al.1992:48). In addition, because cubs were first observed at older ages, it is likely that some post-natal mortality had occurred. This is one explanation for smaller litters observed by Anderson et al. (1992).

Anderson et al. (1992:47-48) found 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. Data on our 28 litters adds to Anderson's data (Fig. 2), and indicates puma births in Colorado occurring in every month except January and November (so far). Our data suggests that the majority of puma breeding activity occurs February through June. Anderson's observation of two 12-month birth intervals for one female (Anderson et al. 1992:48) is at the low range of our observations (see previously).

Segment Objective 3 & 4

From December 8, 2004 (capture and collaring of the first adult puma M1) to July 31, 2008, we radio-monitored 11 adult male and 15 adult female pumas to quantify survival and agent-specific mortality rates (Table 11). One adult male is known to have died. M4 was about 37 to 45 months old when he was killed by an unidentified male puma along the southeast boundary of the study area. We lost contact with 3 adult males apparently due to GPS/VHF collar failure: M1, M27, and M29. Direct observations in the field during January 2008 indicated that M27 was alive, and M29 might also be alive. Three adult females are known to have died. F50 was about 29 to 31 months old when she died apparently of natural causes (exact agent could not be identified). Two adult females, F54 and F30, were killed by other pumas. F54 was killed at about 49 months old by a male puma on the southern boundary of the study area while apparently in direct competition for a fawn mule deer. F30 was apparently killed by a puma of unknown sex and for unknown circumstances when she was about 60 months old. Both females died as a result of fatal bites to the head.

Preliminary estimates of adult puma survival rates indicate relatively high survival in this *reference period* (i.e., with no sport-hunting) (Table 12). Survival rates were estimated using the Kaplan-Meier procedure to staggered entry of animals (Pollock et al. 1989) for the past 2 annual and hunting season periods when samples were ≥ 5 animals in each sex category. The survival rates reflect zero male deaths, and all 3 adult females that occurred in those periods. We need to increase the number of radio-monitored adult males to obtain more realistic survival rates (i.e., other than 1.0). The adult age structure, as indicated in Figure 4, is indicative of high survival rates during the past 4 winters without sport-hunting mortality. Research in New Mexico on a non-hunted puma population also indicated higher survival rates for adult male than adult female pumas, with the major cause of death being aggression by male pumas (n = 8 years; Logan and Sweanor 2001:127-138).

We have radio-monitored 7 subadult pumas, 5 males and 2 females (Table 13). None of those died while we were monitoring them in the subadult age stage. F23 has become a breeding adult on the study area. M5 dispersed from his natal area and the study area at about 13 months old and went to the northwest slope of the Uncompahgre Plateau where he established an adult territory. M49 was orphaned at 9 months old when his mother F50 died. He dispersed from his natal area and the study area to the northeast slope of the Uncompahgre Plateau, but shed his expandable radio-collar at a fresh elk kill when he was about 15 months old. Puma M11 became a subadult at 13 months old and dispersed from his natal area at 14 months old. He moved to the Dolores River valley between Stapletone and Stoner, Colorado by December 14, 2006. He was legally killed by a puma hunter on December 12, 2007 when he was 30 months old, in the adult age-stage. We need to increase our efforts to acquire larger samples of male and female radio-monitored subadult pumas to acquire more realistic estimates of their survival (i.e., other than 1.0).

Contact was lost with 2 subadult males and 1 subadult female. F52 dispersed from the study area before we lost track of her in the area of the Black Canyon of the Gunnison in mid-May 2007. We lost track of M31 seven days after he was captured in April 2006. He might have dispersed from the study area. Efforts to locate him by flying over and around the study area have not been successful. M69 emigrated from the study area in spring 2008 when he was about 16 to 20 months old. We monitored him in the Beaton Creek area east of the Uncompahgre River for awhile until we lost contact with him in April 2008. In addition to the subadults discussed previously, a non-marked female puma about 18 to 24 months old was killed by a vehicle November 4, 2006 on highway 550 (between Colona and Ridgway), which forms the southeast boundary of our study area. The female appeared to be in good health (41 kg), was not pregnant, and was not lactating.

Anderson et al. (1992) found that all 9 radio-collared male pumas dispersed from their natal areas, and 2 of 6 radio-collared females did not disperse from their natal areas (A. E. Anderson, Sep. 1993, errata for Anderson et al. 1992:61). Mean ± *SD* and range of dispersal distances (km) for 8 males, aged 10 to 13 months old at dispersal, were 86.2 ± 51.3, 23 to 151. For 4 females, aged 11 to 31 months old at dispersal, mean ± *SD* and range of dispersal distances (km) were 37.0 ± 15.3, 17 to 54 (Anderson et al. 1992:63).

Although we have observed 3 male pumas disperse from natal areas, and no females disperse, our current research is too short in duration and samples too small yet to make meaningful comparisons with Anderson's earlier effort, particularly regarding offspring dispersal rates, distances moved, and philopatry. Dispersal and philopatry have been explained as life history strategies in pumas that assist gene flow, colonization, population maintenance, and individual survival and reproductive success (Logan and Sweanor 2001). Thus, such strategies would be expected to be conserved, and expressed in puma populations in different locations and at different times. In addition, because puma emigration and immigration (i.e., via dispersal) have been shown to be important processes in puma population dynamics (Sweanor et al. 2000), we need larger samples and longer research duration in this study to estimate those parameters.

A preliminary estimate of puma cub survival was made with 38 cubs (21 males, 17 females) that we marked (n = 31 were radio-collared) at nurseries when they were 26 to 42 days old. Only cubs that died of natural causes were used (i.e., 3 capture-related deaths were excluded). All cubs were born from May 2005 to July 2007. Cubs that died included 13 that were radio-collared at nurseries and 3 non-collared cubs that apparently disappeared from families because they were not subsequently observed or track counts indicated attrition in cubs. For the Kaplan-Meier procedure to staggered entry of animals (Pollock et al. 1989), the maximum survival period was assumed to be 365 days (i.e., 12 months) to coincide with the time that puma cubs would usually be expected to become independent from their mothers (Logan and Sweanor 2001). Otherwise, cubs were right censored if they reached independence, or we lost contact before then. Dates that bracketed the deaths or disappearances of cubs were used to estimate minim and maximum survival rates. Maximum estimated cub survival using the Kaplan-Meier procedure was 0.4998 (SE = 0.2499). The estimated minimum survival rate was practically the same, 0.4993 (SE = 0.2498). Cub survival estimated with a binomial model (Williams et al. 2001) was 0.5789 ± 0.1570 (95% C.I.). In order to improve the reliability of puma cub survival data, we will make an effort to increase the number of radio-collared cubs that are monitored.

The major natural cause of death in cubs, where cause could be determined, was infanticide and cannibalism by male pumas (Appendix A). Male-caused infanticide and cannibalism, along with aggression-caused mortality in adult (indicated previously) and subadult pumas (Logan and Sweanor 2001) has also been a dominant mortality factor in other puma populations in North America (Logan and Sweanor 2001:115-136). Such male puma behavior has been theorized for being a strong selective force in shaping the evolution of behavioral tactics and life history strategies in pumas (Logan and Sweanor 2001).

The current closure on sport-hunting on the study area and protection of marked pumas from sport-harvest on the buffer area on the northern portion of the Uncompahgre Plateau for the *reference period* appears to be operating, so far. None of the adult or subadult pumas wearing functional GPS- or VHF-collars have died due to human causes. This reference condition enables us to quantify puma population structure, survival rates, and agent-specific mortality rates of pumas in the absence of direct human-caused mortality factors related to sport-hunting, and allow comparisons with the *treatment period* when hunting of pumas on the study area resumes.

Anderson et al. (1992:50) reported on the fates of 21 radio-collared pumas (11 < 24 months old, 10 ≥ 24 months old) from a total of 49 in his previous study which was intended to "assess the effects of sport-hunting on an unexploited population" (Anderson et al. 1992:5). They found 19 (90%) of those pumas died due to human causes, attributed to: legal kill outside the study area (7), capture-related (6), predator management (3), illegal kill (2), and suspected predacide (1). Other causes of mortality included, intraspecies strife (1) and disease (1). Actual age-stage and annual survival rates and agent-specific mortality rates from our current effort cannot be clearly compared with the Anderson et al. (1992:53) data set because they pooled data for male and female pumas in seemingly arbitrary age stages that overlapped puma life history stages (i.e., cubs, subadults, adults). The Anderson et al. (1992:53) estimated survival rates with the Kaplan-Meier procedure (Pollock et al. 1989) for 20 male and 22 female pumas were: 12-24 month old = 0.642; 24-36 months old = 0.692, 36 to 48 months old = 0.917, and 48-60 months old = 0.800. Actual sample sizes within each age-stage were not given. There were no quantitative data allowing estimation of survival and agent-specific mortality for cubs less than 12 months old.

Segment Objective 5

Cumulative data gathered during the past 3.7 years on the Uncompahgre Plateau Puma Project allowed a minimum count of pumas on the Uncompahgre Plateau Study area, and attendant estimates of population structure, reproduction rates, and survival rates. Those data positioned this project to begin puma population modeling efforts. Such modeling processes are useful for CDOW Mammals Researchers to design the treatment phase of this research project and provide CDOW wildlife biologists and managers with tools to assess current puma harvest management assumptions (previously in Testing Assumptions and Hypotheses) and other conceptual and proposed puma management approaches.

A deterministic, discrete time model was developed and created on *Excel* (Microsoft Office software 2007) by principal investigator K. Logan and CDOW Biometrician P. Lukacs. The model structure has 3 age stages recognized in puma population biology (Logan and Sweanor 2001)− adult, subadult, and juvenile− and which are consistent with parameters we are estimating in this research and available in the technical literature on puma populations:

Adult: $N_{AFt+1} = (S_F*N_{AFt} + S_{SF}*N_{SFt})(1-H_{AFt+1})$

$N_{AMt+1} = (S_M*N_{AMt} + S_{SM}*N_{SMt})(1-H_{AMt+1})$

Subadult: $N_{SFt+1} = ((rS_{JF}*N_{Jt})(1-H_{SFt+1}))PI_F/E_F$

$N_{SMt+1} = (((1-r)S_{JM}*N_{Jt})(1-H_{SMt+1}))PI_M/E_M$

Juvenile: $N_{Jt+1} = RN_{AFt+1}$

The model terms are:

N_{AFt+1} = Number of adult females at year t+1.
N_{AMt+1} = Number of adult males at year t+1.
N_{SFt+1} = Number of subadult females at year t+1.
N_{SMt+1} = Number of subadult males at year t+1.
N_{Jt+1} = Number of juveniles at year t+1.
S = Survival rate for each specified sex and age stage.
H = Proportion of the harvest rate comprised by each sex and age stage (e.g., 0.28 harvest rate * 0.40 adult females).
PI/E = Ratio of progeny + immigrants/emigrants.
R = Reproductive rate for adult females (i.e., average number of cubs per female per year).

r = Proportion of the subadult population that is female (e.g., 0.5; 1-0.5 = proportion of males).

These basic assumptions pertain to the use of this model. Expected puma population projections and annual rates of increase (i.e., lambda) generated by the model are conditional on the assigned puma population structure and demographic estimates that parameterize the model. The model structure does not include density dependence, and thus, should not be used to project population trends beyond 10 years. In reality, density dependence probably operates in puma population dynamics, with competition for food expected to regulate independent (i.e., adults and subadults) female density and competition for mates expected to regulate independent male density (Logan and Sweanor 2001). The model structure also assumes that puma harvest is strongly additive mortality, an assumption that is consistent with the current observed adult and subadult (i.e., harvest-age pumas) puma survival rates in the *reference period* and for adult pumas in other non-hunted puma populations (Logan and Sweanor 2001).

We used this model to simulate puma population dynamics to examine a set of scenarios that pertain to current CDOW puma management assumptions and to consider the puma research and management direction for the *treatment period*. Furthermore, we modeled the potential population impact of the historical puma harvest on the study area prior to the current puma research (i.e., 1994-2003). We parameterized the model with data gathered on the pumas on the study area during the past 3.7 years. The starting population was the *minimum count* of pumas and attendant estimated sex and age structure made during November 2007 to March 2008 (Table 9). We assumed that all individuals were present in the population during that entire period. No mortalities of independent pumas were detected. But, one radio-collared subadult male emigrated by March 19, 2008.

Population parameters included: estimated rates of reproduction and sex and age-stage specific survival, which included data to July 2008 (Table 14). Some sex and age-stage specific estimates of survival (i.e., adult male, subadult male, subadult female) came from the literature (Table 14), because our current sample sizes (i.e., number of individuals and years) were not adequate for realistic estimates (i.e., estimates from our data were 1.0 for adult males and subadults). We did not use actual rates in the literature where estimates involved the pooling of data on sexes and age stages, and where sample sizes for age stages were not presented (e.g., Anderson et al. 1992). In addition, the ratio of progeny and immigrant recruits to emigrants as a model input was from the literature, because such data is scarce and does not exist for Colorado (all references in Table 14). We preferred using the population characteristics and parameter estimates gathered in the current study, because this is the puma population we intend to manipulate in the *treatment period* to test CDOW puma management strategies.

Results of our modeling efforts are presented in Appendix B. This constitutes the first time that current CDOW puma harvest assumptions have been evaluated by using Colorado-specific population data, and thus, is considered to be preliminary. Expected estimates of population growth were generally consistent with the CDOW puma harvest management assumptions that were previously developed from data in the puma population literature to manage for a stable-to-increasing population and for a declining puma population. The results demonstrated the importance of female survival to population dynamics. As more quantitative population data is gathered and the puma population is manipulated during the *treatment period*, population dynamics can be evaluated further. Results from the model evaluating the historical puma mortality on the study area during 1994 to 2003 indicate the expected outcome is that the puma population on the study area would decline during the treatment years.

<u>Segment Objective 6</u>

To investigate the potential that puma hunters might detect puma mothers away from their cubs, we continued gathering data on spatial associations of puma mothers and their cubs during the puma hunting season, which extends from November through March each winter in Colorado. Female pumas are fair game in Colorado, unless they are accompanied by 1 or more cubs. Mothers that are caught away from their cubs could be legally harvested. Such incidents would result in cubs being orphaned. Orphaned cubs that ≤ 6 months old could have a survival rate (to the subadult stage) of < 0.05. Orphaned cubs 7 to 12 months old might have a survival rate (to the subadult stage) of about 0.7 (K. Logan, unpublished data).

We monitored only 1 puma family with a radio-collared mother and cub from November 13, 2007 to February 14, 2008 during 8 airplane flights (Table 16).To assess whether mothers were apart or in close association with cubs, we considered error in aerial locations. We recovered 7 puma radiocollars that we located from the airplane and then fixed the actual locations of collars on the ground with GPS. Range of location error was 20 to 520 m (mean = 282.86, *SD* = 164.75). We decided to use distances greater than the extreme high range of location error (520 m) as the metric to decide if puma mothers might be detected away from their cubs by hunters. Five of 8 (62%) of the observations located the mother and cub ≤500 m apart, within the extreme margin of location error. In aggregate, the data for the past 3 winters include 136 observations for 1−5 families per winter (Table 15), and generally indicate that puma mothers are more likely to be within 520 m of their cubs during the day in winter. An effort will be made to increase the number of radio-collared family members in subsequent winters. In addition, we will examine variation in mother-cub association distances on an individual female basis.

Anderson et al. (1992:70-71) recorded 69 instances of simultaneous aerial locations of 7 pairs of puma mothers and dependent young. They reported that mothers and young were together in 21 (30.4%) of those instances, and they were 1 to 2.2 km apart in 48 (69.6%) of those instances.

Segment Objective 7

Principal investigator K. Logan developed 6 drafts study plans pertaining to the next 6 years of puma research on the Uncompahgre Plateau. Three of the drafts were circulated for internal review to obtain comments from CDOW Mammals Research Leader D. Freddy, Carnivore Biologist J. Apker, Area 18 Biologist B. Banulis, Southwest Regional Biologist S. Wait, and Area 18 Wildlife Manager R. Del Piccolo. The planning process involved modeling puma population scenarios (previously in Segment Objective 5) and modeling mark-recapture scenarios in MARK (Cooch and White 2004) with CDOW Biometrician P. Lukacs. The mark-recapture modeling process enabled consideration of effects of puma population size and individual detection rates on the ability to detect changes in puma population abundance that might result from the hunting treatment. Results of the MARK simulations applied to a scenario with 3 capture occasions and puma population abundances that varied from 25 to 50 animals indicated that individual detection rates would need to be 0.4 or greater to be able to detect changes in puma abundance (Table 16). The study plan is expected to be completed in September 2008, with a decision on a course to proceed with the remainder of the research soon thereafter.

Segment Objective 8

Data from 23 (7 male, 23 female) GPS-collared pumas, totaling over 31 thousand GPS locations (Table 17) are currently being used in a collaborative study of puma prey use on the Uncompahgre Plateau, carried out by CDOW Mammals Research staff. Plans to use these and other data subsequently gathered, include habitat modeling and mapping for pumas in the western U.S. in collaboration with colleagues at Colorado State University (CSU), and descriptive information on puma behavior in relation to human development on the Uncompahgre Plateau.

We are currently collaborating with Dr. Sue VandeWoude and Dr. Kevin Crooks, and post-doctoral and graduate students at CSU to develop a pilot study titled: *Puma concolor immune health—Relationship to management paradigms and disease.* Tissue samples (i.e., blood, saliva, feces) from pumas we capture are collected and shipped to the Department of Microbiology, Immunology, and Pathology at CSU for analyses. That project will be expanded to *The effects of urban fragmentation and landscape connectivity on disease prevalence and transmission in North American felids*. A description of that project and incomplete results on infectious disease surveillance on 27 pumas (16 female, 11 male) sampled on the Uncompahgre Plateau are presented in Appendix C.

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 3.7 years of effort, 90 pumas have been captured, sampled, marked, and released. Of those, 74 pumas were radio-collared, allowing us to monitor fates of pumas in sexes and age stages, including: 15 adult females, 11 adult males, 2 subadult females, 5 subadult males, 25 female cubs, 22 male cubs. As of July 2008, we were monitoring 18 adults, 1 subadult, and 4 cubs with active radio-collars. Data from the marked animals are used to quantify puma population characteristics and vital rates in a *reference* situation (i.e., without sport-hunting off-take). During November 2007 through March 2008 a minimum estimate of 33 independent pumas were detected on the Uncompahgre Plateau study area, up from 24 the previous winter, with estimates of sex and age structure. Our efforts to quantify puma population characteristics and vital rates positioned us to begin puma population model development, and to use modeling scenarios to assess potential directions for the remainder of the puma research on the Uncompahgre Plateau. Moreover, our data and model provide tools useful to CDOW wildlife biologists and managers for assessing effects of puma harvest strategies. A study plan for the remainder of the research has been in development and should be completed in September 2008. To improve data on puma population vital rates, attention will be given to increasing sample sizes on radio-collared adult males, subadults, and cubs. Furthermore, data from 23 GPS –collared pumas, totaling over 31 thousand GPS locations enables collaboration on investigations of puma use of prey, puma-human relations on the Uncompahgre Plateau, and puma habitat modeling and mapping with colleagues. All of these efforts should enhance the Colorado puma research and management programs.

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Table 1. Summary of puma capture efforts with dogs from November 19, 2007 to April 24, 2008, Uncompahgre Plateau, Colorado.

Month	No. Search Days	No. & type of puma tracks found[a]	No. & type of pumas pursued	No. & I.D. or type of pumas captured
November	5	20 tracks: 9 male, 8 female, 3 cub	1 pursuit: 1 male	1 puma recaptured: M55 (not handled).
December	18	32 tracks: 13-15 male, 10-12 female, 7 cub	5 pursuits: 1 male, 2 females, 2 cubs	4 pumas captured 5 times: M32 recaptured (not handled), F25 recaptured (faulty GPS collar changed), cub F57 recaptured twice (not handled), cub M44 recaptured by Wildlife Services & killed for depredation on domestic sheep.
January	18	69 tracks: 23-27 male, 22-26 female, 20 cub	5 pursuits: 2 males, 3 females	5 pumas captured: M69 & M71 (handled & marked for the first time), F16 recaptured (faulty GPS collar changed), F2 recaptured (faulty GPS collar changed), F70 (handled & marked for the first time).
February	20	64-65 tracks: 14-15 male, 30-31 female, 19-20 cub	21 pursuits: 9 males, 9 females, 3 cubs	5 pumas captured 7 times: M73 (handled & marked for the first time), F23 recaptured 3 times (could not be handled safely first 2 times, faulty GPS collar changed the 3rd time), F72 (handled & marked for the first time), 1 radio-collared male puma was visually observed in association with F23 while pursuing a female & male puma with dogs on 2-25-08, but he could not be treed to handle (either M27 or M29, both with non-functional GPS collars), 1 unmarked adult female captured (could not be handled safely).
March	11	17 tracks: 5-6 male, 9-10 female, 2 cub	11 pursuits: 3-4 males, 4-5 females, 3 cubs	2 pumas captured: F74 (handled & marked for the first time), F75 (handled & marked for the first time).
April	5	15 tracks: 1 male, 6 female, 8 cub	6 pursuits: 2 females, 4 cubs	0 pumas captured
TOTALS	77	217-218 tracks: 65-73 male, 85-93 female, 59-60 cub	49 pursuits: 16-17 males, 20-21 females, 12 cubs	20 captures of 17 individuals: 7 independent pumas and 1 cub were captured for the 1st time- M69, F70, M71, F72, M73, cub F74, F75, & 1 unmarked adult female (not handled).

[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] Pumas are not handled for a variety of safety reasons: tree to dangerous to climb for researchers, puma treed near river, creek or cliff, puma might fall from tree after drug induction.

Table 2. Summary of puma capture efforts with dogs, December 2004 to April 2008, 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 77/7 = 11.00 day/capture

Table 3. Adult and subadult pumas captured for the first time, sampled, tagged, and released from January 2008 to March 2008, Uncompahgre Plateau, Colorado.

Puma I.D.	Sex	Estimated Age (mo.)	Mass (kg)	Capture date	Capture method	Location
M69	M	14-18	42	01-11-08	Dogs	Dolores Creek
F70	F	33	39	01-14-08	Dogs	Dolores Creek
M71	M	24	55	01-29-08	Dogs	East Fork Dry Creek
F72	F	24	43	02-12-08	Dogs	Loghill Mesa
M73	M	49	60	02-21-08	Dogs	North fork Cottonwood Creek
F74	F	8-9	18	03-12-08	Dogs	North fork Cottonwood Creek
F75	F	41	39	03-26-08	Dogs	Cottonwood Creek

Table 4. Pumas that were captured and observed with aid of dogs, but were not handled at that time for safety or other reasons, December 2007 to February 2008, Uncompahgre Plateau, Colorado.

Puma sex	Age stage or months	Capture date	Location	Comments
F57	7	12-03-07	Caterwauler Canyon	F57 was previously marked at the nursery when about 35 days old; born ~April 16, 2007. F57 was recaptured high in a tree, too dangerous to attempt to handle her to fit an expandable radio-collar.
F57	8	12-19-07	Loghill Mesa	F57 was recaptured in a tree that did not allow safe immobilization to handle her to fit an expandable radio-collar.
Female	adult	02-01-08	Cottonwood Canyon	Unmarked female was bayed high in a tree out of range of dart gun. The puma left the tree, but escaped into deep system of sink holes too unstable for any research team member to enter.
F23	49	02-19-08	Big Bucktail Canyon	F23 was recaptured in a tree too dangerous to handle her to change the non-functioning GPS collar she wore.
F23	49	02-20-08	San Miguel Canyon	F23 was recaptured again in a tree too dangerous to handle her to change the non-functioning GPS collar she wore. She was safely recaptured and handled on 02-25-08, and was fit with a new GPS collar.
M27 or M29	78 107	02-25-08	Big Bucktail Canyon	A radio-collared male puma was visually observed in association with puma F23 when she & a male puma were pursued with dogs. The male puma was either M27 or M29, both of which had over-lapping home ranges in that area, and both had non-functional GPS collars. But, the male puma could not be treed for absolute identity or for handling.

Table 5. Summary of puma capture efforts with ungulate road-kill baits, puma kills, and cage traps from August 7, 2007 to July 15, 2008, Uncompahgre Plateau, Colorado.[a]

Month	No. of Sites	Carnivore activity & capture effort results[b]
August	3	No puma activity detected. One deer carcass scavenged by a black bear.
September	4	No puma activity detected. Deer carcasses scavenged by skunk, bobcat, & black bear.
October	12	Deer carcasses scavenged by male pumas M55 (10-2 to 3-07) and M29 (10-19 to 22-07). Puma M51 walked ~4 m from a deer carcass, but did not feed. An unknown female puma scavenged on a deer carcass 10-16-07; two cage traps were set and monitored for 2 days, but puma did not return. Deer carcasses were also scavenged by bobcat, coyote, and black bear.
November	3	An unknown female puma walked past a deer carcass on 11-1&2-07, but did not feed. An unknown female puma walked past another deer carcass on 11-4-07, but did not feed. An unknown male puma walked past a deer carcass on 11-14-07, but did not feed. Deer carcasses were scavenged by bobcat and coyote.
December	2	No puma activity detected.
March	3	Unknown male puma scavenged a deer carcass 3-15 to 17-08; two cage traps set and monitored 3-18 &19-08, but puma did not return. Unknown male puma (possibly same as above) scavenged deer carcass 3-23 to 24-08; cage trap set and monitored 3-25 to 27-08, but puma did not return.
April	5	Male puma M6 recaptured 4-12-08. He had shed his non-functional GPS collar; we fit him with a new one. An unknown female puma scavenged a deer carcass on ~4-10-08, but did not return. A deer carcass was visited by unknown male & a female pumas; one or both scavenged 4-16-08. Two cage traps were set and monitored 4-17 to 19-08, but the pumas did not return. An unknown male puma scavenged a deer carcass 4-19 or 20-08. Cage trap set and monitored 4-21 to 25-08, but the puma did not return. An unknown female puma scavenged a deer carcass 4-23-08. Cage trap was set and monitored 4-23 to 25-08, but the puma did not return. Another unknown female puma walked past a deer carcass without feeding.
July	1	Puma M6 was recaptured 7-15-08; his non-functional GPS collar was replaced with a VHF collar. This was the same bait site and cage trap where we recaptured M6 on 4-8-08.

[a] We used 59 road-killed mule deer, 1 road-killed elk, and 1 puma-killed mule deer (abandoned by F30 and used as bait) at 15 different sites. Of the road-killed ungulate baits, 11 of 60 (18.3%) were scavenged by pumas.
[b] One adult male puma, M6, was recaptured twice.

Table 6. Pumas recaptured with dogs, cage traps, or visually observed, November 2007 to July 2008, Uncompahgre Plateau, Colorado.

Puma I.D.	Recapture Date	Mass (kg)	Estimated Age (mo.)	Capture Method	Process
M55	11-28-07	Observed	42	Dogs	None
M27	12-02-07	Observed	76	Dogs	None, treed in E. fork Tabeguache Cr. by outfitter Stan Garvey, Nucla, CO
F25	12-03-07	45	102	Dogs	Changed GPS collar
F57	12-03-07	Observed	7.5	Dogs	None
M44	12-05-07	50	15.5	Dogs	Shot by Wildlife Services for depredation on domestic sheep
M32	12-12-07	Observed	76	Dogs	None
F57	12-19-07	Observed	8	Dogs	None
F16	01-01-08	43	59	Dogs	Changed GPS collar
F2	01-08-08	42	85	Dogs	Changed GPS collar
M27	01-22-08	Observed	77	Dogs	None, treed in Johnson Cr. by outfitter Stan Garvey, Nucla, CO
F25	01-26-08	Observed	103	Visual observation of F25 attacking a mule deer after detecting tracks on snow, then snow- & radio-tracking	None
F23	02-19-08	Observed	42	Dogs	None
F23	02-20-08	Observed	42	Dogs	None
F23	02-25-08	Observed	42	Dogs	Changed GPS collar
M27 or M29	02-25-08	Observed	78 107	Visually observed while pursued by dogs	None
M6	04-12-08	67	74	Cage	GPS collar
M6	07-15-08	63	77	Cage	VHF collar

Table 7. Puma cubs sampled June 2007 to August 2008 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)
F74[b]	F	June 1, 2007	267	18	F75	32
M76	M	May 19, 2008	30	2.0	F2	89
M77	M	"	"	2.3	"	"
F78	F	"	"	1.2	"	"
M79	M	"	"	2.2	"	"
F80	F	May 23, 2008	40	1.1	F23	45
F81	F	"	"	2.8	"	"
M82	M	May 29, 2008	37	2.8	F8	58
M83	M	"	"	2.5	"	"
M84	M	June 5, 2008	36	2.6	F70	38
F85	F	"	"	1.8	"	"
F86	F	"	"	2.0	"	"
M87	M	July 3, 2008	28	1.9	F3	83
M88	M	"	"	1.8	"	"
F89	F	"	"	1.7	"	"
M90	M	July 9, 2008	36	2.1	F72	29

[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 with mother only with radio-telemetry.

[b] This unmarked female cub was captured on 03-12-08 in association with an unmarked adult female puma. The adult female puma, F75, was captured and marked 03-26-08 with cub F74 in association.

Table 8. Pumas detected by tracks and identified by radio-telemetry, GPS-collar fixes, and visual observation.

Puma I.D.[a]	Date detected	Estimated Age of Tracks on Snow (days)	Type of Identification-Radio-telemetry (VHF) and/or GPS fixes, Visual Observation
M55	12/2/07	2	GPS
M51	12/3/07	1	VHF & GPS
F3	12/6/07	1	VHF & GPS
M55	12/15/07	1	VHF & GPS
M55	12/18/07	1	VHF (GPS inconclusive)
F7	12/28/07	1	VHF & GPS
M51	12/28/07	1	VHF & GPS
M51	1/3/08	1	VHF
M51	1/10/08	1	VHF & GPS
F2	1/11/08	1	VHF & GPS
F16 & cubs	1/15/08	2	VHF & GPS
M51	1/17/08	1	VHF & GPS
F16	1/17/08	2	VHF & GPS
F25	1/17/08	2	VHF & GPS
F16 & cubs	1/18/08	1	VHF & GPS
F25 & cub F57	1/18/08	1	VHF & GPS
F16 & cubs	1/22/08	1	VHF & GPS
F16 & cubs	1/24/08	1	VHF & GPS
F25 & cub F57	1/26/08	1	VHF & GPS & visual of F25
F16 & cubs	1/26/08	1	VHF & GPS
M55	1/26/08	1	VHF & GPS
M32 & Unk.F	1/31/08	1	VHF (GPS NA)[b]
M32	2/6/08	1	VHF (GPS NA)
F25 & cub F57	2/12/08	2	VHF & GPS
F16 & cubs	2/13/08	1	VHF & GPS
F16	2/14/08	1	VHF & GPS
F16 & 3 cubs	2/15/08	1	VHF & GPS
F8	2/21/08	2	VHF (GPS NA)
F23	2/28/08	1	VHF & GPS
F23	3/12/08	2	VHF & GPS
F8	3/12/08	1	VHF (GPS NA)
F25 & cub F57	4/12/08	1	VHF (GPS inconclusive)
F16 & 3 cubs	4/12/08	1	VHF (GPS inconclusive)
F24 & 2 cubs	4/24/08	1	VHF (GPS NA)

[a] Eleven individual adult radio- and/or GPS-collared pumas were first detected by tracks on snow, then identified by radio- and GPS data, including one visual observation, a total of 34 times.
[b] GPS NA means the GPS instrument was non-functional, but the VHF beacon was working.

Table 9. Minimum puma population estimate based on numbers of known radio-collared pumas and track counts of suspected unmarked pumas on Uncompahgre Plateau study area, Colorado, November 2007 to March 2008.

	Adults		Subadults		Cubs		
Region	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Unknown sex**
East slope	10	4	3	4	4	4	7
West slope	6	4	2	0	1	2	2-3
Totals	16	8	5	4	5	6	9-10
	Total Independent Pumas = 33[a,b]						

[a] Of the total, 23−24 (70−73%) independent pumas were marked and 9-10 (27−30%) were assumed to be unmarked.
[b] The unmarked independent pumas included: 1adult female with 2 large cubs in Happy Canyon, 1 adult female with 1 large cub in Potter Creek and 25-mile Mesa, 1 adult female with 2 large cubs in Monitor Creek, 1 adult female with 2 medium-size cubs in Potter Creek, 1 adult female with 2-3 cubs in San Miguel Canyon, and 1 female or F28 with a non-functional collar Big Bucktail Creek to San Miguel Canyon.

Table 10. Puma reproduction, Uncompahgre Plateau, Colorado, 2005-2008.

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	83	M51	60	03/31/08	07/03/08	21.5	94	3
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	58	M73	49	02/28-29/08	05/29/08	22.5	90-91	2
F16	32				09/22/05			4
F16	52				05/24/07	19.9		4
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	2
F24	75	M29	92	04/12-15/07	06/14/07		90-93	4
F25	74				08/01/05			1
F25	94				04/16/07	20.5		1
F28*	36				06/09/06			2
F28	48	M29	88	12/27-29/06	03/30/07	11.7	92-93	≥2 tracks
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
F72*	29				07/09/08			1
F75	32				06/01/07			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 and radio-telemetry data.
[c] Estimated birth dates were indicated by GPS and radio-telemetry data of mothers at nurseries.
[d] Observed number of cubs do not represent litter sizes as some cubs were observed when they were 5 to 6 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 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.

Table 11. Summary for individual adult puma survival and mortality, December 8, 2004 to July 31, 2008, Uncompahgre Plateau, Colorado.

Puma I.D.	Monitoring span	No. days	Status: Alive/Lost contact/Dead; Cause of death
M1	12-08-04 to 08-16-06	616	Lost contact− failed GPS/VHF collar. M1 ranged principally north of the study area.
M4	01-28-05 to 12-28-05	333	Dead; killed by a male puma. Estimated age at death 37−45 months.
M5	08-01-06 to 07-31-08	730	Alive. Born on study area; offspring of F3. He 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.
M6	02-18-05 to 07-31-08	1259	Alive.
M27	03-10-06 to 01-22-08	683	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.
M29	04-14-06 to 01-11-08	637	Lost contact− failed GPS/VHF collar. Possibly visually observed on study area with F23 on 02-25-08.
M32	04-26-06 to 07-31-08	827	Alive.
M51	01-07-07 to 07-31-08	571	Alive.
M55	01-21-07 to 07-31-08	557	Alive.
M71	01-29-08 to 07-31-08	184	Alive.
M73	02-21-08 to 07-31-08	161	Alive.
F2	01-07-05 to 07-31-08	1301	Alive.
F3	01-21-05 to 07-31-08	1287	Alive.
F7	02-24-05 to 07-31-08	1253	Alive.
F8	03-21-05 to 07-31-08	1228	Alive.
F16	10-11-05 to 07-31-08	1024	Alive.
F23	02-05-06 to 07-31-08	907	Alive.
F24	01-17-06 to 07-31-08	926	Alive.
F25	02-08-06 to 07-31-08	904	Alive.
F28	03-23-06 to 09-25-07	551	Lost contact− failed GPS/VHF collar.
F30	04-15-06 to 07-29-08	836	Died; killed by another puma (sex of puma unknown). Estimated age at death 60 months.
F50	12-14-06 to 03-26-07	102	Died of natural causes; exact agent unknown. Estimated age at death 30 months.
F54	01-12-07 to 08-18-07	218	Died; killed by a male puma while in direct competition for prey (i.e., mule deer fawn). Estimated age at death 49 months.
F70	01-14-08 to 07-31-08	199	Alive.
F72	02-12-08 to 07-31-08	170	Alive.
F75	03-26-08 to 07-31-08	127	Alive.

Table 12. Preliminary estimated survival rates *(S)* of adult-age pumas during the *reference period* (i.e., the study area is closed to puma hunting), 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) and the hunting season period (November 1 through March 31). Survival rates were estimated only for periods when $n \geq 5$ individuals.

Period of interest	Females			Males		
	S	**SE**	***n***	***S***	**SE**	***n***
Annual 8/1/2006 to 7/31/2007	0.909	0.0867	11	1.000	0.0000	5
Annual 8/1/2007 to 7/31/2008	0.825	0.1041	13	1.000	0.0000	9
Hunting season 11/1/2006 to 3/31/2007	0.909	0.0867	11	1.000	0.0000	5
Hunting season 11/1/2007 to 3/31/2008	1.000	0.0000	12	1.000	0.0000	9

Table 13. Summary of subadult puma survival and mortality, December 2004 to June 2008, Uncompahgre Plateau, Colorado.

Puma I.D.	**Monitoring span**	**No. days**	**Status: Alive/Survived to adult stage/ Lost contact/Dead; Cause of death**
M5	09-16-05 to 06-30-06	308	Alive; independent and dispersed from natal area at 13 months old. Established adult territory on northwest slope of Uncompahgre Plateau.
M11	06-21-06 to 12-02-07	529	Dead. Independent at 13 months old. Dispersed from natal area at 14 months old. Moved to Dolores River valley, CO, by Dec. 14, 2006. Killed by a puma hunter Dec. 12, 2007 when 30 months old.
F23	01-04-06 to 02-04-06	31	Alive. Captured on the study area when ~17 months old. Survived to adult stage; gave birth to first litter at ~21 months old.
M31	04-19-06 to 04-26-06	7	Lost contact. Probable disperser. M31's estimated age at capture was 25 months, at the lower margin of puberty for puma. He may have been a dispersing subadult, and could have moved away from the study area.
M49	03-26-07 to 10-01-07	189	Lost contact. M49 was orphaned at about 9 months old, when his mother 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 ~15 months old, he shed his expandable radio-collar on ~10-01-07 at a yearling cow elk kill on the northeast slope of the Uncompahgre Plateau.
F52	01-10-07 to 05-15-07	125	Lost contact. Dispersed from study area as a subadult by Jan. 16, 2007. F52's last location was Crystal Creek, a tributary of the Gunnison River east of the Black Canyon.
M69	01-11-08 to 04-07-08	87	Lost contact. Captured on the study area when ~14-18 months old. Emigrated from the study area as subadult by Mar. 19, 2008. Last location was in Beaton Creek, east side of Uncompahgre River valley.

Table 14. Summary of preliminary puma population model parameter estimates obtained from the Uncompahgre Plateau Puma Project and from the published literature on puma.

Survival

Sex and age stage	Estimate	Reference
Adult Female	0.87	Estimated average annual survival rate (*n* = 2 years) for 11−13 adult females on Uncompahgre Plateau study area.
Adult Male	0.91	Estimated average annual survival rate (*n* = 8 years) for adult males in a non-hunted New Mexico puma population (Logan and Sweanor 2001:127-128). Estimated annual survival rate (*n* = 2 years) for 5−9 adult males on Uncompahgre Plateau study area was 1.00.
Subadult Female	0.80	Estimated subadult female survival in New Mexico (0.88, *n* = 16; Logan and Sweanor 2001:122) adjusted downward for potential lower survival for pumas 12-24 months old on Uncompahgre Plateau (0.642, *n* = 14 females and 10 males combined, life stages not known or described in Anderson et al. 1992:53). Survival of 7 radio-collared pumas (5 males, 2 females) in the subadult stage in the current Uncompahgre Plateau puma study is 1.00.
Subadult Male	0.60	Estimated subadult male survival in New Mexico (i.e., 0.56, *n* = 9; Logan and Sweanor 2001:122) adjusted upward for potential slightly higher survival for pumas 12-24 months old (i.e., 0.642) on Uncompahgre Plateau (Anderson et al. 1992:53). Survival of 7 radio-collared pumas (5 males, 2 females) in the subadult stage in the current Uncompahgre Plateau puma study is 1.00.
Cub	0.50	Estimated cub survival rate (*n* = 38 cubs combined sexes), on Uncompahgre Plateau study area. This survival rate is applied to the model starting with the expected number of cubs from birth in RY5.
	0.90	Estimated cub survival for cubs ≥7 months old, and is applied to RY4 cubs only, because the minimum count of pumas in RY4 was tallied when most cub mortality had already occurred. Survival of cubs ≥7 months old in the literature is about 0.95 (Logan and Sweanor 2001). Here, a more conservative 0.90 is used in this model.

Reproduction

Parameter	Estimate	Reference
Adult age	2+ years	Assume all females 2 years old and older are adults (Logan and Sweanor 2001: 93-94).
Litter size	2.81	Average litter size for 21 litters on the Uncompahgre Plateau study area = 2.810 ± 0.9808*SD*; litters were examined when the cubs were 26 to 42 days old.
Secondary sex ratio observed at nurseries	1:1	Secondary sex ratio was 33:26 for 21 litters examined at 29 to 42 days old on the Uncompahgre Plateau study area (not significantly different from 1:1, ($X^2 = 0.8305 < 3.841$, $\alpha = 0.05$, 1 d.f.). Also see Robinette et al. 1961, Logan and Sweanor 2001:69-70.
Proportion of adult females producing new litters each year	0.65	Proportion of adult females giving birth each year (n = 3 years for *ns* = 12, 13, 12 females), Uncompahgre Plateau study area. Proportion for a non-hunted puma population in New Mexico was 0.50 (Logan and Sweanor 2001:98).

Progeny + Immigrant Recruits /Emigration Ratio

Parameter	Estimated Ratio	Reference
Subadult female	1.02	No data for pumas in Colorado exists. Assume the ratio of female immigrants to emigrants = 1.02. This ratio is consistent with estimates for a New Mexico puma population that functioned as a source (Sweanor et al. 2000).
Subadult male	0.94	No data for pumas in Colorado exists. Assume the ratio of male immigrants to emigrants = 0.94, (i.e., male immigration is half of emigration). This ratio is consistent with estimates for a New Mexico puma population that functioned as a source (Sweanor et al. 2000).

Table 15. Summary of puma mother and cub associations by distance (m) during airplane flights, each winter, Uncompahgre Plateau, Colorado.

Monitoring period	Month	No. flights	No. puma families[a]	Ages of cubs (mo.)	No. observations with mothers & cubs ≤520 m apart	No. observations with mothers & cubs >520 m apart
Nov. 9, 2005 to Mar. 29, 2006	Nov.	3	4	2−6	10	2
	Dec.	4	4	3−7	16	4
	Jan.	5	4	4−8	16	4
	Feb.	4	5	5−9	16	2
	Mar.	2	5	6−10	9	0
	Totals	18	4−5	2−10	67	12[b]
Nov. 7, 2006 to Mar. 22, 2007	Nov.	4	4	2−3	10	1
	Dec.	4	4	2−5	11	1
	Jan.	5	3	4−6	9	3
	Feb.	4	4	5−7	9	2
	Mar.	3	1	8	2	1
	Totals	20	1−4	2−8	41	8[c]
Nov. 13, 2007 to Feb. 14, 2008	Nov.	2	1	6	1	1
	Dec.	0	1	7	NA	NA
	Jan.	3	1	8	2	1
	Feb.	3	1	9	2	1
	Totals	8	1	6−9	5	3[d]

[a] All puma mothers wore GPS-radiocollars. At least 1 cub in the litter wore a VHF radiocollar.
[b] Mean = 1,060 m, *SD* = 325.99, range = 650−1,600.
[c] Mean = 1,120 m, *SD* = 1,214.40, range = 616−4,101.
[d] Mean = 1,317 m, *SD* = 530, range = 750−1,800.

Table 16. Results of MARK (Cooch and White 2004) simulations to investigate precision as a function of individual capture probabilities and population size.

Capture Probability (*p*)	Expected Standard Error: Large Population (n = 50)	Expected Standard Error: Small Population (n = 25)	Confidence Interval width: Large Population (n = 50)	Confidence Interval width: Small Population (n = 25)	Large Pop. Lower Bound	Small Pop. Upper Bound
0.2	21	13	84	52	8	32
0.3	9.6	7.8	38.4	31.2	31	29
0.4	5.5	4.2	22	16.8	39	27
0.5	3.5	2.5	14	10	43	26

Table 17. Numbers of GPS locations and spans of monitoring for pumas captured on the Uncompahgre Plateau, Colorado, December 2004 to July 2008.

Puma I.D.	Sex	Age stage	Dates monitored [a]	No. locations
M1	M	adult	12-08-04 to 07-20-06	1,797
M4	M	adult	01-28-05 to 01-14-06	958
M6	M	adult	02-18-05 to 05-14-08	1,035
M27	M	adult	03-12-06 to 06-21-06	313
M29	M	adult	04-14-06 to 01-01-08	1,599
M51	M	adult	01-07-07 to 05-17-08	1,464
M55	M	adult	01-21-07 to 05-01-08	1,334
F2	F	adult	01-07-05 to 05-07-08	3,239
F3	F	adult	01-21-05 to 04-01-08	3,205
F7	F	adult	02-24-05 to 07-30-07	2,401
F8	F	adult	03-21-05 to 10-10-06	1,541
F16	F	adult	10-12-05 to 04-01-08	2,089
F23	F	subadult,	01-04-06 to 02-04-06	113
		adult	02-05-06 to 05-07-08	746
F24	F	adult	01-17-06 to 07-25-07	1,812
F25	F	adult	02-09-06 to 04-07-08	1,854
F28	F	adult	03-24-06 to 08-15-07	1,499
F30	F	adult	03-30-07 to 02-22-08	1,057
F50	F	adult	12-14-06 to 03-26-07	352
F52	F	subadult	01-10-07 to 05-08-07	383
F54	F	adult	01-12-07 to 08-01-08	686
F70	F	adult	01-14-08 to 07-31-08	685
F72	F	adult	02-12-08 to 07-31-08	737
F75	F	adult	03-26-08 to 07-02-08	287

[a] GPS collars on pumas are remotely downloaded at approximately 1-month intervals. The last date in *Dates monitored* includes last location from the last GPS data download acquired for an individual puma in this report period.

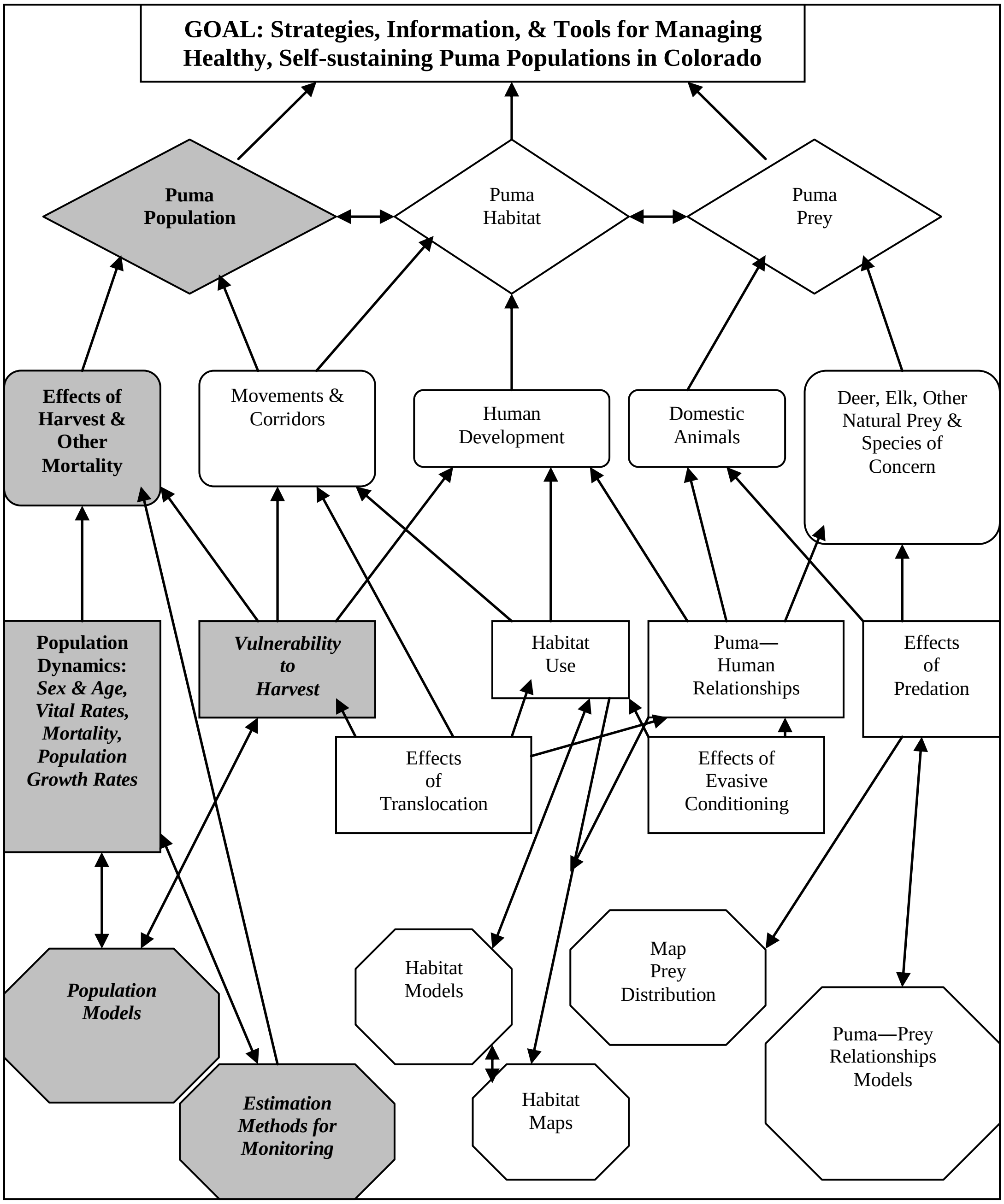

Figure. 1. An ecologically-based conceptual model of the Colorado Puma Research Program that provides the contextual framework for this and proposed puma research in Colorado. Gray-shaded shapes identify areas of research addressed by puma research on the Uncompahgre Plateau for the puma management goal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

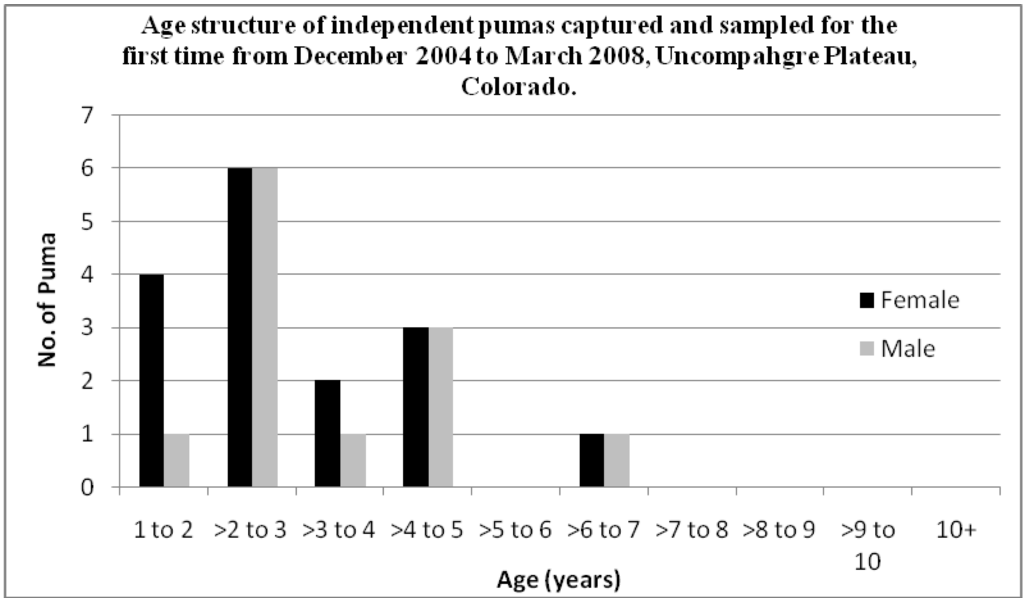

Figure 2. Age structure of independent pumas captured and sampled for the first time on the Uncompahgre Plateau, Colorado, December 2004 to March 2008.

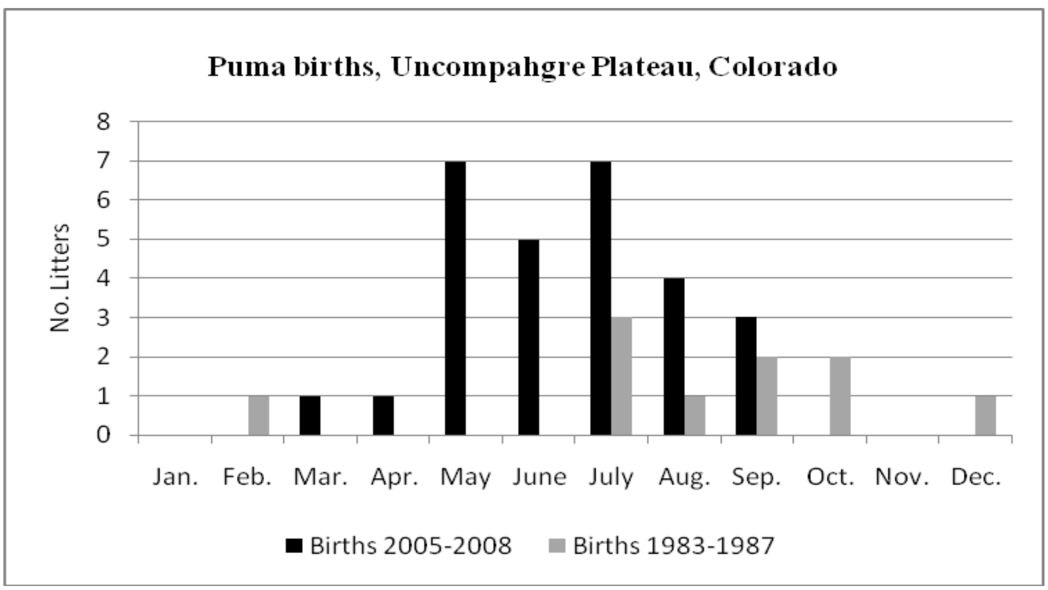

Figure 3. Puma births detected by month during the current research effort, 2005 to 2008 (*n* = 28 litters of 15 females), and during the earlier effort by Anderson et al. (1992; 1983 to 1987, *n* = 10 litters of 8 females), Uncompahgre Plateau, Colorado.

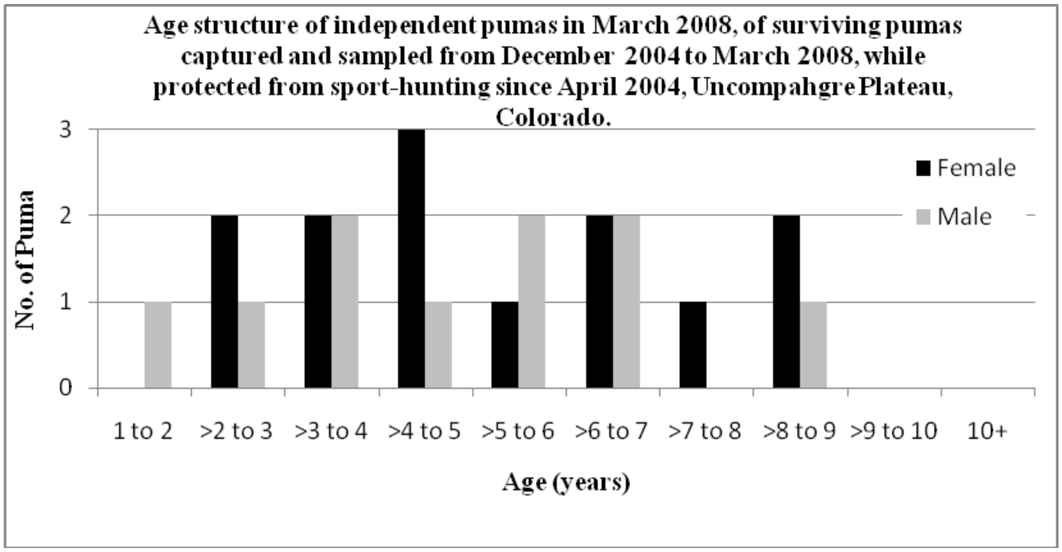

Figure 4. Age structure of surviving independent pumas captured and sampled on the Uncompahgre Plateau, Colorado, in March 2008, and after protection from sport-hunting mortality since April 2004, which includes 4 hunting seasons (Nov. through Mar., 2004-05 to 2007-08). In addition, no other human-caused mortalities were documented in the radio- and GPS-collared sample of independent pumas. This age structure assumes that puma M27 and M29 were alive on March 31, 2008; they each had non-functional GPS collars, and were detected alive on 1-22-08 and 1-11-08, respectively. Pumas M5 and M27 range north of the study area and were protected from legal sport-harvest because they are visually tagged animals. Mean ± *SD* of adult female and adult male ages, respectively: 5.35 ± 2.11 yr. (64.23 ± 25.36 mo.); 4.79 ± 2.17 yr. (57.50 ± 26.06 mo.).

Appendix A. Summary of individual puma cub survival and mortality, December 2004 to 2008, 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 04-07-08	~1,345	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.	F3
F9	31	5-28-05	06-27-05 to 4-19-06	326-333	Lost contact— 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	Lost contact— shed 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 12-2-07	918	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. 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	Lost contact— 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	Dead; killed and eaten by a puma (sex unspecified) about 8-28-05.	F7
F14	26	6-26-05	07-22-05 to 02-07-06— 03-10-06	226-257	Lost contact— 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	Lost contact— shed radiocollar 06-06-06 to 06-14-06.	F8
F17	34	9-22-05	10-26-05 to 08-18-06	330	Dead. Lost contact— shed radiocollar 06-06-06 to 06-14-06. Killed by a car on highway 550 on 08-18-06. Probably dependent on F16.	F16
F18	34	9-22-05	10-26-05 to 07-20 to 27-06	301-308	Dead; probably killed by another puma. Multiple bite wounds to skull. 10 mo. old.	F16
M19	34	9-22-05	10-26-05 to 07-27 to 08-02-06	308-314	Lost contact— shed radiocollar 07-27-06 to 08-02-06.	F16
M20	34	9-22-05	10-26-05 to 05-24-06	244-245	Lost contact— shed radiocollar 05-24-06—05-25-06.	F16
F21	37	9-26-05	11-02-05 to 08-16-06	324	Lost contact; radiocollar quit. Last aerial location 8-16-06, live signal.	F3

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.
M22	37	9-26-05	11-02-05 to 12-21-05—12-22-05	86-87	Dead; killed and eaten by male puma 12-21-05—12-22-05.	F3
M26	183	8-1-05	02-08-06 to 03-21 to 24-06	~232-235	Lost contact— shed radiocollar 03-21-06—03-24-06.	F25
F33	31	5-30-06	06-30-06 to 07-31-06	63-65	Dead. 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	Dead. 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	Dead. 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	Dead. 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	Lost contact— shed radiocollar found 03-06-07. Photo (trail camera in McKenzie Cr.) of M38 & Unm. F sibling with F2 on 7/16-17/07 at 352-353 days old.	F2
M39	29	8-13-06	09-11-06 to 09-20-06 to 04-25-07	9 255	Lost contact— shed radiocollar by 09-20-06, but seen alive on that date. Tracks of 2 cubs following F8 on 04-25-07.	F8
F40	29	8-13-06	09-11-06 to 09-20-06 to 04-25-07	9 255	Lost contact— 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	Assumed dead. Lost Contact— shed radiocollar or died (blood on collar) between 10-05-06 (last live signal) & 10-13-06 (collar found); assumed dead.	F8
M42	29	8-13-06	09-11-06 to 11-27-06	106	Dead; research-related fatality.[b]	F8
M43	33	8-13-06	09-15-06 03-01-07	200	Treed, visually observed 03-01-07.	F7
M44	33	8-13-06	09-15-06 to 02-14-07	479	Treed, visually observed 02-14-07; sibling (?) M56 also captured, sampled, & marked for 1st time. Killed by Wildlife Services for depredation control on 12/5/07, for killing 4 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.
F45	33	8-13-06	09-15-06 to 5-20 to 23-07	280-283	Dead. 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.	F7
M46	31	9-17-06	10-18-06 to 12-15-06	89 360	Lost contact— 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.	F3
M47	31	9-17-06	10-18-06 to 12-15-06 to 09-12-07	89 360	Lost contact— 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.	F3
M48	31	9-17-06	10-18-06 to 12-15-06 to 09-12-07	89 360	Lost contact— 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.	F3
M49	153	7-1-06	12-05-06 to 07-31-07 to 01-01-07	~456	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.	F50
F53	183	7-1-06	01-12-07 to 02-23-07	42 ~428 subad.	Lost contact— shed radiocollar 2-23-07. F53 visually observed by P. & F. Star, on 9-2-07, 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	Lost contact— shed radiocollar 2-27-07. M56 observed 03-01-07.	F7 (?)
F57	35	4-16-07	05-21-07 to 06-06-07	52	Lost contact— 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.	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.
F59	34	5-24-07	06-27-07 to 08-21-07	55 324 434	Alive. Observed alive 11-20-07 with F16, but without siblings M58 & F61. 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.	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	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.	F16
M62	34	7-14-07	08-17-07		Not radio-collared.	F24
M63	34	7-14-07	08-17-07		Not radio-collared.	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
M65	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
F66	37	7-17-07	08-23-07 to 5-31 to 6-1-08	282-283	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.	F30
M67	37	7-17-07	08-23-07		Not radio-collared. M67 or M68 was photographed with sibling F66 & mother F30 on 5/31-6/1/08.	F30
M68	37	7-17-07	08-23-07		Not radio-collared. M67 or M68 was photographed with sibling F66 & mother F30 on 5/31-6/1/08. One male cub might have died or was not observed.	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		Not radio-collared.	F2
M77	30	5-19-08	06-18-08		Not radio-collared.	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		Not radio-collared.	F2
M79	30	5-19-08	06-18-08		Not radio-collared.	F2
F80	40	5-23-08	07-02-08		Not radio-collared.	F23
F81	40	5-23-08	07-02-08		Radio-collared.	F23
M82	37	5-29-08	07-05-08		Radio-collared.	F8
M83	37	5-29-08	07-05-08		Not radio-collared.	F8
M84	36	6-5-08	07-11-08	~69	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; assuming M84 died, he probably died around 8-13-08 when cub F85 was located ~340m south of the eartag in the East fork Dolores Cyn.	F70
F85	36	6-5-08	07-11-08		Radio-collared.	F70
F86	36	6-5-08	07-11-08		Radio-collared 7-22-08.	F70
M87	28	7-3-08	07-31-08		Not radio-collared.	F3
M88	28	7-3-08	07-31-08		Not radio-collared.	F3
F89	28	7-3-08	07-31-08		Radio-collared	F3
M90	36	7-9-08	08-14-08		Radio-collared	F72
7MA	28-35	7-10-08	08-08 to 13-08		Examined, but not tagged.	F7
7MB	28-35	7-10-08	08-08 to 13-08		Examined, but not tagged.	F7
7FC	28-35	7-10-08	08-08 to 13-08		Examined, but not tagged.	F7

[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, possibly restricting movement.

Appendix B. Puma population models and simulation results as preliminary assessments of current CDOW puma management assumptions and population manipulations for the *treatment period*.

Modeling Scenarios

We modeled a set of scenarios that pertain to current CDOW puma management assumptions and to potential puma research direction on the Uncompahgre Plateau for the *treatment period*:

1) Puma population dynamics without hunting-caused mortality.
2) Puma harvest that would induce a stable (i.e., no growth) phase to identify a population tipping point induced by harvest mortality.
3) Puma harvest at the upper limit (i.e., 15% of 8-15% range, CDOW 2007) that CDOW assumes would result in a stable to increasing puma population, with harvest apportioned equally among independent males and females.
4) Puma harvest at the upper limit (i.e., 15% of 8-15% range, CDOW 2007) that CDOW assumes would result in a stable to increasing puma population, but with harvest comprised of 40% females and 60% males, which is consistent with the sex composition of puma harvest in Colorado.
5) Puma harvest at the upper limit (i.e., 28% of 16-28% range, CDOW 2007) that CDOW assumes would result in a declining puma population, with harvest apportioned equally among independent males and females.
6) Puma harvest at the upper limit (i.e., 28% of >15-28% range, CDOW 2007) that CDOW assumes would result in a declining puma population, but with harvest comprised of 40% females and 60% males, which is consistent with the sex composition of puma harvest in Colorado.
7) A harvest scenario applied the historic puma harvest on the study area. Puma mortality data for the study area during the 10 years previous (i.e., 1994-2003) to the beginning of the *reference period* was quantified after carefully geo-referencing mortality locations on the study area (see last table in Appendix B). Model parameters from those data include: mortality rate of 14.3 independent puma mortalities per year (rounded to 14/yr.), and sex proportions of 55% males and 45% females. No other puma population data or parameter estimates were available for the study area at that time. Therefore, the scenario that was modeled pertained to the expected impact of the average annual puma mortality of independent pumas (i.e., adults and subadults) if the hypothetical population was the same as the non-hunted minimum expected puma population in *treatment period* year 1 (i.e., TY1). A harvest of 14 pumas per year is a 26% harvest rate on the expected TY1 non-hunted minimum independent puma population (i.e., 14/53). Another way of stating this scenario is; what would occur if puma harvest was applied to the puma population on the study area during the *treatment period* at the average rate of puma mortality that was recorded during 1994 to 2003?

Results of Puma Population Simulations

The following tables contain the expected minimum population sizes for independent pumas and annual rates of population increase for independent pumas conditional upon the minimum number of independent pumas detected in Reference Year 4 (RY4) and the model input parameters and assumptions (Table 14, this report). Notes below each table explain how results may be interpreted relative to other research results on puma population dynamics and specific CDOW puma management assumptions. The harvest levels for each model are clearly stated in the left column of each table. Simulations involving harvest apply the harvest following *reference year* 5 (RY5) and starting with *treatment year* 1 (TY1).

Harvest Level	Year	Projected Minimum Puma Population Size					Independent Pumas	
		Adult		Subadult		Cub		
		Female	Male	Female	Male	F&M	Total	Lambda
No harvest.	RY4	16	8	5	4	20	33	
	RY5	18	10	9	8	33	45	1.27
	TY1	23	14	8	8	42	53	1.14
	TY2	27	17	11	10	49	64	1.18
	TY3	32	22	12	11	58	77	1.17
	TY4	38	27	15	14	69	92	1.17
	TY5	44	32	17	16	81	110	1.16

Note: Expected lambda for the modeled non-hunted puma population on the Uncompahgre Plateau approach the high range of observed average annual rates of population increase for a non-hunted puma population in good quality habitat in southern New Mexico (i.e., r = 0.21, n = 4; r = 0.28, n = 4; r = 0.17, n = 4; r = 0.11, n = 7; Logan and Sweanor 2001:169-175). Puma population growth could be higher on the Uncompahgre Plateau because of higher quality habitat (i.e., greater prey biomass), and if puma sources are nearby to the study area.

Harvest Level	Year	Projected Minimum Puma Population Size					Independent Pumas	
		Adult		Subadult		Cub		
		Female	Male	Female	Male	F&M	Total	Lambda
16% of independent pumas, sexes are harvested equally; i.e., *stable phase model.*	RY4	16	8	5	4	20	33	
	RY5	18	10	9	8	33	45	1.27
	TY1	19	12	7	6	35	44	0.98
	TY2	19	12	8	7	34	45	1.02
	TY3	19	13	7	7	34	46	1.01
	TY4	19	13	7	7	34	46	1.01
	TY5	19	14	7	7	34	46	1.00

Note: The tipping point of population stability and decline is expected to be about 16% harvest of independent male and female pumas, consistent with current CDOW puma harvest assumptions.

Harvest Level	Year	Projected Minimum Puma Population Size					Independent Pumas	
		Adult		Subadult		Cub		
		Female	Male	Female	Male	F&M	Total	Lambda
15% of independent pumas, sexes are harvested equally.	RY4	16	8	5	4	20	33	
	RY5	18	10	9	8	33	45	1.27
	TY1	19	12	7	7	36	45	0.99
	TY2	19	12	8	7	35	47	1.03
	TY3	19	13	8	7	36	47	1.02
	TY4	20	14	8	7	36	48	1.02
	TY5	20	14	8	7	36	49	1.01

Note: This result is consistent with the current CDOW puma harvest assumption for a stable-to-increasing population, with very slow growth attributed to equal harvest of females and males.

Harvest Level	Year	Projected Minimum Puma Population Size					Independent Pumas	
		Adult		Subadult		Cub		
		Female	Male	Female	Male	F&M	Total	Lambda
15% of independent pumas, comprised of 40% females & 60% males.	RY4	16	8	5	4	20	33	
	RY5	18	10	9	8	33	45	1.27
	TY1	21	11	8	6	38	45	0.99
	TY2	22	10	9	7	39	47	1.05
	TY3	23	10	9	7	42	50	1.05
	TY4	25	11	10	8	45	53	1.05
	TY5	26	11	10	8	48	56	1.06

Note: This result is consistent with the current CDOW puma harvest assumption for a stable-to-increasing population, with increased growth due to reduced female mortality.

Harvest Level	Year	Projected Minimum Puma Population Size					Independent Pumas	
		Adult		Subadult		Cub		
		Female	Male	Female	Male	F&M	Total	Lambda
28% of independent pumas, sexes are harvested equally.	RY4	16	8	5	4	20	33	
	RY5	18	10	9	8	33	45	1.27
	TY1	17	10	6	6	30	38	0.81
	TY2	14	9	6	5	25	33	0.86
	TY3	12	8	5	4	22	29	0.84
	TY4	10	7	4	4	18	25	0.84
	TY5	9	6	3	3	16	21	0.84

Note: This result is consistent with the current CDOW puma harvest assumption for a declining population.

Harvest Level	Year	Projected Minimum Puma Population Size					Independent Pumas	
		Adult		Subadult		Cub		
		Female	Male	Female	Male	F&M	Total	Lambda
28% of independent pumas, comprised of 40% females & 60% males.	RY4	16	8	5	4	20	33	
	RY5	18	10	9	8	33	45	1.27
	TY1	19	8	7	4	34	38	0.81
	TY2	18	6	7	5	32	35	0.92
	TY3	17	5	7	4	31	33	0.93
	TY4	16	4	6	4	30	31	0.95
	TY5	16	4	6	4	29	30	0.95

Note: This result is consistent with the current CDOW puma harvest assumption for a declining population even with harvest weighted toward males.

Harvest Level	Year	Projected Minimum Puma Population Size					Independent Pumas	
		Adult		Subadult		Cub		
		Female	Male	Female	Male	F&M	Total	Lambda
26% of independent pumas, comprised of 45% females & 55% males; i.e. *historical harvest model*	RY4	16	8	5	4	20	33	
	RY5	18	10	9	8	33	45	1.27
	TY1	18	9	7	6	33	41	0.89
	TY2	17	8	7	6	31	39	0.94
	TY3	16	8	7	6	30	36	0.94
	TY4	16	7	7	5	28	35	0.95
	TY5	15	7	6	5	27	33	0.95

Note: Results of this model indicate that the expected outcome is that the puma population would decline.

Appendix B (continued). Puma mortality data for portions of Game Management Units (GMUs) 61, 62, 70 that comprise the Uncompahgre Plateau Study Area, 1994-2003.

GMU	Year	Adult Male	Subadult Male	Adult Female	Subadult Female	Subtotals
61	2003	4	2	3	0	9
62	2003	1	1	1	3	6
70	2003	0	0	0	0	0
61	2002	1	0	2	0	3
62	2002	0	0	3	1	4
70	2002	1	0	0	0	1
61	2001	4	0	5	0	9
62	2001	2	1	2	1	6
70	2001	1	0	1	0	2
61	2000	5	0	1	2	8
62	2000	0	0	0	0	0
70	2000	0	0	1	1	2
61	1999	3	1	3	0	7
62	1999	2	0	1	0	3
70	1999	2	0	1	0	3
61	1998	3	1	3	1	8
62	1998	3	1	0	0	4
70	1998	1	0	3	0	4
61	1997	5	1	1	0	7
62	1997	2	0	2	1	5
70	1997	1	0	0	0	1
61	1996	3	0	2	0	5
62	1996	2	1	3	0	6
70	1996	1	0	0	0	1
61	1995	6	1	4	0	11
62	1995	9	0	4	0	13
70	1995	1	0	0	0	1
61	1994	2	0	3	0	5
62	1994	3	1	4	0	8
70	1994	0	0	1	0	1
	Subtotal	68	11	54	10	143 **Total**
		79 males (55%)		64 females (45%)		14.3/yr.

Note: Nine puma records did not designate adult or subadult age stages. Those data were determined with a coin-toss for this table, resulting in 6 males designated as 3 adults and 3 subadults, and 3 females designated as 1 adult and 2 subadults. Three mortalities were recorded as "road-kills" (1 subadult male, 2 subadult females). Two adult male deaths were recorded as "other". Two adult male deaths were recorded as "landowner". All other deaths were recorded as "hunter harvest". Source of records: Colorado Division of Wildlife, 6060 Broadway, Denver, CO, and K. Crane, CDOW DWM, Ridgway.

Appendix C. Collaborative project on disease surveillance in wild felids.

College of Veterinary Medicine and Biomedical Sciences
Department of Microbiology, Immunology & Pathology
1619 Campus Delivery
Fort Collins, CO 80523-1619
970-491-6144 (voice)
970-491-0603 (fax)
TO: Ken Logan, Mammals Researcher, Colorado Division of Wildlife, Montrose, CO.
FROM: Sue VandeWoude, DVM, Associate Professor, DMIP
RE: Disease Seroprevalence in UP Pumas
DATE: August 26, 2007

Attached please find the consolidated report on infectious disease surveillance for the mountain lion samples you have provided to our laboratory as an adjunct to your CDOW ongoing studies. Our laboratory has performed puma-lentivirus (PLV) antibody screening using a sensitive western blot assay developed in our laboratory and found 13 of 18 samples conclusively positive (72%), with two additional samples inconclusive and one not tested. Dr. Michael Lappin, a veterinary internal medicine specialist with expertise in feline infectious disease has tested a subset of 6 samples for antibodies to Feline Calicivirus (FCV), Feline Herpes Virus (FHV), Feline parvovirus (FPV), *Toxoplasma gondii* (IgM, indicating recent infection, IgG indicating past exposure), and *Bartonella hensalae* (the agent associated with cat scratch disease). At least one of six animals tested has been positive for each of these agents. Further results are pending from the remaining samples you have provided for these 5 assays. In addition, Dr. Martin Scriefer at Fort Collins CDC has also tested 6 animals for evidence of antibodies to the agent responsible for plague (*Yersinia pestis*). Interestingly, 3 of 6 animals demonstrate significant exposure to this agent as well.

These specific agents were selected for analysis in order to provide a variety of types of agents (viruses: PLV, FCV, FHV, FPV; bacteria: *Bartonella henselae* and *Yersinia pestis*; and coccidian: *T. gondii*), a variety of modes of transmission (direct intra-specific contact, PLV; direct contact with domestic cats, FCV, FHV, FPV; arthropod transmission, *B. henselae, Y. pestis*; prey ingestion, *T. gondii, Y. pestis*). Further, at least three of these agents (PLV, FCV, B. henselae) result in chronic infections, allowing the possibility of determining genetic relatedness among organisms isolated from different individuals, and three of these agents (*B. henselae, Y. pestis, T. gondii*) are also potential zoonotic agents.

As you are aware, our laboratory has recently been awarded a 5 year NSF Ecology of Infectious Disease grant entitled, "The effects of urban fragmentation and landscape connectivity on disease prevalence and transmission in North American felids", with co-PI Dr. Kevin Crooks, an associate professor in the Warner College of Natural Resources at CSU. The aims of this grant are to model the effects of urbanization and resultant habitat fragmentation on disease dynamics in large carnivore species as described on the following page. The letter of support provided by you and Mr. Dave Freddy were pivotal in demonstrating a large cohort of capable and active field collaborators willing to provide samples to support our studies. The mountain lion field work being led by your team, and the newly initiated studies by your colleague, Dr. Mat Alldredge, have provided us with renewed enthusiasm for developing our collaborations to support the goals of our study. We foresee the opportunity to interact in a mutually beneficial partnership to further the goals of all of our studies, and to maximize the information that can be gleaned about these important and ecologically significant species.

We anticipate that the data we are generating will be useful for comparative seroprevalence of different geographic populations of bobcats and pumas, and for genetic phenotyping of pathogens to compare relationships among diseases spread by arthropod vectors, domestic cats, feral rodents, and inter-specific contacts. As we discussed during your recent visit to CSU, these samples are most valuable to us if we can receive them directly as quickly as possible after collection. I have provided an SOP providing information about the types of samples that will be most valuable, and a draft of a 'permissions' document that you can use with each sample submission to provide us with guidance for any testing that is permissible on the materials we receive. This latter document will be filed and recorded electronically. We will continue to provide annual updates and communications about any publications that utilize the data resulting from your samples.

Again thank you for providing these extremely valuable samples, and we look forward to our continued collaborations.
Sincerely,
Sue VandeWoude

The effects of urban fragmentation and landscape connectivity on disease prevalence and transmission in North American felids
Project Summary
Sue VandeWoude (co-PI), Kevin Crooks (co-PI), Michael Lappin, Mo Salman, Walter Boyce, Ken Logan, Mat Alldredge, Carolyn Krumm, Don Hunter, Lisa Lyren, Seth Riley, Jennifer Troyer

The objective of this study is to model the effects of urbanization and resultant habitat fragmentation on disease dynamics in carnivore species. Bobcats, puma, and domestic cats will be evaluated simultaneously in three divergent ecosystems: high mountain desert (Colorado), everglades (Florida), and Mediterranean scrub habitat (California). The research will: 1) assess the relationship between habitat fragmentation and prevalence of viral, bacterial, and parasitic pathogens across a gradient of urbanization, 2) use transmission dynamics of selected disease agents as markers of connectivity of fragmented populations, and 3) evaluate the effect of urbanization on the incidence of cross-species disease transmission. The results of this research will give wildlife managers a better understanding of how urbanization affects their local wildlife and assist them in future disease management planning.

The combination of a uniquely qualified, broadly based research team with an extensive dataset on carnivores from across the country presents an unprecedented opportunity to investigate the disease dynamics in these rare and difficult to study species. The research efforts of each regional team will support and provide new insights for all of the regions involved, not simply their own. Training of graduate students in ecology, infectious disease, and epidemiology will be emphasized, as will training for pre- and post-doctoral veterinarians.

Results will be made widely available to other scientists, conservation practitioners, and the general public. This research has a tremendous capacity to broadly impact areas of public and post-graduate education, career development for new investigators and persons from underrepresented groups, and to enhance understanding of complex infectious disease ecological problems using extensive multi-disciplinary collaborations.

Appendix C (continued). Preliminary results of infectious disease surveillance for puma, Uncompahgre Plateau, Colorado, 2005-2008.

Puma ID	Sex	Capture Date	GPS NAD27 U.T.M.: Zone, E, N	PLV[a]	FCV[b]	FHV[c]	FPV[d]	T.g. [e] IgM	T.g.[e] IgG	B.h. [f]	Y.p. [g]
UPCO2	F	1/8/2008	13S, 245722, 4244166	+	-	-	-	+	-	-	+
UPCO3	F	1/21/2005	13S, 241606, 4251510	-	+[h]	+	+	-	+	-	++
UPCO7	F	2/24/2005	13S, 246328, 4244230	+	+	-	-	-	+	-	+++
UPCO7	F	3/30/2006	13S, 245901, 4247627	+	P[h]	P	P	P	P	P	P
UPCO7	F	3/3/2007	13S, 247645, 4246097	I[h]	P	P	P	P	P	P	P
UPCO8	F	3/21/2005	12S, 727808, 4239029	I	-	-	-	-	+	-	++
UPCO4	M	1/28/2005	13S, 257565, 4239606	+	-	-	-	-	+	+	I
UPCO5	M	2/4/2005	13S, 240577, 4251037	-	-	+	+	-	+	-	I
UPCO6	M	2/18/2005	13S, 247399, 4254006	+	-	-	-	-	+	-	I
UPCO6	M	4/12/2008	13S, 257516, 4239696	P	P	P	P	P	P	P	+
UPCO23	F	2/25/2008	12S, 723304, 4242231	P	P	P	P	P	P	P	+
UPCO25	F	2/8/2006	13S, 258374, 4230480	+	P	P	P	P	P	P	P
UPCO28	F	3/23/2006	12S, 722868, 4240115	+	P	P	P	P	P	P	P
UPCO29	M	4/14/2006	12S, 723458, 4242340	+	P	P	P	P	P	P	P
UPCO31	M	4/19/2006	12S, 746919, 4225441	+	P	P	P	P	P	P	P
UPCO23	F	1/4/2006	12S, 730188, 4234861	-	P	P	P	P	P	P	P
UPCO27	M	3/10/2006	12S, 722339, 4245212	-	P	P	P	P	P	P	P
UPCO30	F	4/15/2006	13S, 248551, 4242095	-	P	P	P	P	P	P	P
UPCO50	F	12/14/2006	12S, 753639, 4260149	+	P	P	P	P	P	P	P
UPCO51	M	1/7/2007	13S, 238783, 4252390	+	P	P	P	P	P	P	P
UPCO52	F	1/10/2007	13S, 258058, 4236260	I	P	P	P	P	P	P	P
UPCO54	F	1/12/2007	13S, 252688, 4228050	+	P	P	P	P	P	P	P
UPCO55	M	1/21/2007	13S, 258133, 4228691	+	P	P	P	P	P	P	P
UPCO24	F	1/17/2006	12S, 737151, 4233273	+	P	P	P	P	P	P	P
UPCO69	M	1/11/2008	13S, 248191, 4246810	+	+	+	+	-	+	-	-
UPCO70	F	1/20/2008	13S, 247122, 4245760	+	+	+	+	-	+	-	+
UPCO71	M	1/29/2008	12S, 754611, 4256842	P	P	P	P	P	P	P	-
UPCO72	F	2/12/2008	13S, 258294, 4234597	P	P	P	P	P	P	P	-
UPCO73	F	2/21/2008	12S, 728576, 4241799	P	P	P	P	P	P	P	+
UPCO74	F	3/12/2008	12S, 729678, 4239555	P	P	P	P	P	P	P	-
UPCO75	F	3/26/2008	12S, 732894, 4239423	P	P	P	P	P	P	P	+

[a] PLV is Puma Lentivirus.
[b] FCV is Feline Calicivirus.
[c] FHV is Feline Herpesvirus.
[d] FPV is Feline Panleukopenia Virus
[e] T. g. is *Toxoplasma gondii*.
[f] B. h. is *Bartonella hensalae*.
[g] Y. p. is *Yersinia pestis*.
[h] Results: + (positive result), P (Pending result), I (Inconclusive result).

Colorado Division of Wildlife
July 2007 - June 2008

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of 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.	N/A		

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ABSTRACT

We continued to examine the statewide population structure of both black bears and cougars. Using 75 and 56 samples each from bears and cougars respectively, we examined genetic population structure for the state. Based on these data, the concept of a megapopulation is a more realistic representation of the bear and cougar populations, as opposed to ideas of subpopulations within the state. No evidence for any population sub-structure was seen in the analyses so no further genetic work on this project is recommended.

We also began analyzing cougar fecal samples collected from the 3 sibling cougars in captivity at the Foothills Wildlife Research Facility. Feces were stored at controlled temperatures after deposition and sub-sampled at monthly intervals. Genetic material has been found in samples up to 4 months post-deposition, but genotyping error rates have not yet been assessed. Sampling cougar feces in the field may be a feasible non-invasive sampling method to estimate cougar populations.

The front-range cougar project began intensive capture efforts during the 2007-2008 year, especially starting in November with the use of hounds. Cougar captures exceeded expectations with a total of 18 cougars being captured during the year. Human caused and natural mortality was high during the year with 5 of the 18 collared cougars dying during the year. We had 5 cougars interact with humans, 4 of which were initially captured in relation to a human interaction. All of these cougars were aversively conditioned following the interaction with humans. The first year of the study was successful, however we are switching to a different GPS/telemetry system as failure rates with the current collar system is unacceptable.

WILDLIFE RESEARCH REPORT

COUGAR DEMOGRAPHICS AND HUMAN INTERACTIONS ALONG THE URBAN-EXURBAN FRONT-RANGE OF COLORADO

MATHEW W. ALLDREDGE

P.N. 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*) and estimating population densities of cougars for the state of Colorado.

SEGMENT OBJECTIVES

1. Determine the efficacy of using microsatellites or mtDNA to delineate female cougar and black bear subpopulations across the state of Colorado.
2. Evaluate differences in DNA quantity from either a scat surface collection or a cross-sectional collection.
3. Evaluate differences in DNA quantity from successive feces depositions to determine the variation in quantities of genetic material in scats. Quantify differences in epithelial shedding rates.
4. Evaluate temporal, environmental, and seasonal effects on DNA quantity and quality for both controlled and uncontrolled conditions.
5. Determine the effectiveness of cage traps and hounds for capturing cougars on the Front-Range of Colorado.
6. Determine functionality and suitability of GPS collars on cougars in Front-Range habitats.
7. Implement cougar-human risk protocols and communications within CDOW and among public entities and determine if modifications are necessary.
8. Determine the feasibility of aversive conditioning techniques on cougars within urban/exurban areas, including use of hounds and shotgun-fired bean bags or rubber bullets.
9. Evaluate political/social response to cougar research activities.

INTRODUCTION

Cougar management is a growing concern for the Colorado Division of Wildlife (CDOW). Cougar conservation and the maintenance of viable populations is a statewide issue as CDOW is charged with the management of cougars. However, the nexus created between cougar conservation and human health and safety is becoming a high priority issue within the urban and exurban areas of the state. Cougar conflicts (livestock depredation, pet depredation, and direct human interaction) within urban and exurban areas appear to be increasing as humans continue to encroach into cougar habitats. Because of the diversity of cougar management issues across the state, cougar research is focused on both statewide issues of cougar population structure and methods of estimating population demographics, and on urban/exurban issues of cougar/human interaction.

Genetic techniques for monitoring or research of rare, elusive, and wide ranging species are of particular interest as other techniques are either impractical or financially prohibitive. Genetic techniques for monitoring and research of cougars in Colorado may be invaluable as alternative techniques are expensive and in many situations may not be possible. Capture and handling of cougars is expensive, time consuming, and may not give representative samples of the population. Large dispersal distances of cougars, especially males, will require impractically large study areas in order to understand demographic patterns that are affected by immigration. Capture may not even be possible in suburban and exurban areas of Colorado as logistical constraints associated with private land owners will likely prohibit the use of many capture techniques.

Noninvasive genetic sampling (Hoss et al. 1992, Taberlet and Bouvet 1992) has the potential to provide a realistic method of sampling a population of interest. Noninvasive sampling techniques include the use of hair snares, and scat collections (Harrison et al. 2004, Smith et al. 2005). The use of scats for sampling cougar populations may be particularly useful and provide a representative sample of the population. Scat collections can either be done by searching transects with human observers (Harrison et al. 2004) or with trained dogs (Smith et al. 2005). Scats could also be collected from kill sites. Kill sites would need to be based on mortalities of radio-collared ungulate populations. Data from noninvasive sampling techniques are useful in describing dispersal patterns and estimating population size. Noninvasive genetic data are error prone, which in many cases is because of the quantity and quality of genetic material relative to the collection of noninvasive samples. Therefore, one objective over the last year has been to develop a study to evaluate degradation rates of DNA in fecal samples with respect to time and temperature.

Use of genetic data for other purposes, such as delineating subpopulations, is also very useful for managing cougar and bear populations in the state. In these cases the goal is to examine local characteristics of the genetic data and determine if it is different among areas (subpopulation structure) or is similar across all areas (panmictic population). Nuclear DNA is inherited from both the mother and the father and therefore is less likely to describe sex-linked population structure. Male cougars and bears generally disperse over greater distances than females and therefore a female population substructure may be easier to detect than male population substructure. Examination of cougar and bear population structure has been examined using nuclear DNA but few studies have examined cougar population structure using mitochondrial DNA (mtDNA). Mitochondrial DNA is only inherited from the female in mammals and therefore lends itself to delineating female cougar population substructures. A second objective has been to determine if any genetic population structure can be identified for cougars and bears across the state by examining nuclear and mtDNA from statewide female cougar and bear harvest.

At the local scale efforts have been made to initiate a 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 CDOW is charged with the management of cougar, 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 (CDOW, unpublished data).

There is a growing voice from the public that CDOW do more to mitigate potential conflicts, and the Director of CDOW has requested that research efforts be conducted to help minimize future human/cougar conflicts. In order to meet these goals CDOW believes we need 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 will 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 CMGWG (2005) recommend 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 state that there is no scientific evidence to indicate that cougar habituation to humans affects the risk of attack.

Studying individual and population level responses of cougars will require capturing and radio-collaring cougars, as well as standardizing responses of CDOW personnel to human/cougar interactions. Therefore, in this initial year, we tested various cougar capture techniques in urban/exurban areas of interest for effectiveness and public acceptance and assessed the reliability of GPS collars as monitoring tools to assess cougar responses to management prescriptions. More importantly, clearly defined protocols have been implemented within CDOW (APPENDIX I, sub-appendix II) to direct how researchers and field managers should deal with various levels of risk to human health and safety, and these protocols were tested and evaluated in the field.

A large portion of the Front-Range is a mosaic of private, city, county, State, and Federal public lands. An assessment of capture techniques allows future assessments of research feasibility and limitations that might be imposed by various land ownerships. Testing capture techniques and potential management actions also allows for an assessment of the receptiveness of future research within the various political/social environments.

STUDY AREA

GENETICS

Identifying population structure for cougars and bears is a statewide effort. The initial effort for cougars is based on the entire female segment of harvested cougars for the state. The female harvest for bears is much larger, so the sample involved a group of bears from each of the northwest, northeast, southwest, and southeast state regional portions of bear habitat, in an attempt to capture the greatest genetic diversity for the state through spatial separation of sample areas.

The genetic degradation study is being conducted at the Foothills Wildlife Research Facility, located in Fort Collins, Colorado. This is the facility where 3 sibling cougars have been raised in captivity and are part of other ongoing research efforts.

COUGAR/HUMAN INTERACTION

The pilot field study is being conducted in Boulder and Jefferson counties, in an area from near Interstate 70 north to approximately Lyons, Colorado, which is also a likely area for addressing long-term research objectives (see Figure 1). This 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.

METHODS

GENETICS

Genetic samples for the statewide population structure were obtained from statewide voluntary tooth collections from harvested bears and cougars. DNA was extracted from teeth using the DNeasy Blood and Tissue Kit (see Alldredge 2007, Study Plan APPENDIX I-A, sub-appendix I). Following extraction, samples were sent to Sara Oyler-McCance at the Rocky Mountain Center for Conservation Genetics and Systematics, for PCR and sequencing (again, see Alldredge 2007, sub-appendix I for specific methods).

Fecal samples were also collected from the 3 sibling cougars located at the Foothills Wildlife Research Facility. During the year 20 to 30 feces were collected from each cat and samples were placed at random into one of three treatment groups (-5 C, +5 C, and +15 C). Genetic samples were collected from these at the time of initial collection and at 2 weeks, and 1, 2, 3, 4, and 6 months post deposition. DNA was extracted and then stored at -20 C until PCR and genetic sequencing was done at the Rocky Mountain Center for Conservation Genetics and Systematics laboratory.

COUGAR/HUMAN INTERACTION

Baiting, using deer and elk carcasses, has been conducted regularly beginning in May, 2007. 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, 2007 and continuing through April, 2008, hounds were also used several times per week to capture cougars. Captured cougars were anesthetized, monitored for vital signs, aged, measured, and ear-tagged. All independent cougars (> 18 months old) were fitted with GPS collars. For detailed capture and handling procedures see the study plan APPENDIX I.

A supplemental study plan was written as a justification for increasing sample size requirements and to specifically address aversive conditioning treatments and implementation (Appendix I). Cougars involved in human interactions that invoke a management response are subject to aversive conditioning treatments and were treated at the time of the incident. Additional cougars were also captured and added to the study because of their interaction with humans.

RESULTS AND DISCUSSION

GENETICS

DNA was extracted from all 568 bear teeth collected from harvested bears during 2007. Of those, 75 females were selected for genetic sequencing, representing 4 distinct regional spatial groups across the state. Using 8 microsatellite loci, all 75 female bears were genotyped. Using program STRUCTURE (2007), the data indicate that bears in Colorado function as one mega-population, rather than as distinct subpopulations (Figure 2). Given this data combined with the previous year's data (n = 49 females, Alldredge 2007), the statewide bear population can probably be viewed and managed as a mega-population.

DNA was extracted from all 192 cougar teeth collected from harvested cougars during 2007-2008. Additionally, DNA was extracted from samples taken from the Uncompahgre Plateau cougar study (Logan 2006), and from samples taken from the front-range cougar study (Alldredge 2007). All female samples from the harvest plus additional samples from the research projects were selected for genetic sequencing for a total of 56 samples across the state. Given the limited sample size for females, spatially distinct regional groups were not available. Using 15 microsatellite loci, all 56 samples were genotyped. The data revealed almost no population structure for cougars across the state (Figure 3). Again, given this data in conjunction with the previous year's data (n = 54 females, Alldredge 2007), the statewide cougar population can probably be viewed and managed as a mega-population.

Close to 200 genetic samples from the genetic degradation study have been analyzed. This work is still ongoing so an assessment of genotyping error rates cannot be made. However, sufficient genetic material for genotyping has been found in samples up to 4 months old. Therefore, we will continue to collect samples from feces in treatment categories out to 6 months.

COUGAR/HUMAN INTERACTION

Starting in September, 2007 cougar capture efforts were maintained across the study area on city and county open space properties. From November, 2007 through April, 2008, capture efforts included the use of hounds on the larger open space properties. Throughout this period there was excellent cooperation with the conduct of the research project among branches within the CDOW and among the CDOW and city and county entities involved with the study. This cooperation included numerous volunteers from these entities to assist with checking bait sites and running hounds.

A total of 18 cougars were captured during the 2007-2008 year (Table 1). Hound capture was the most effective with 9 initial captures. Captures from reported cougar kills using cage traps were also effective with 5 total captures. Only 1 initial capture was from a bait site. Cage traps following pet/livestock depredation accounted for 2 captures. The final capture was a cougar that was free-range darted in the city of Boulder. Of the 18 total cougars captured, 10 were males. Of the males, 3 of these were adults. Over half (10 of 18) of the captured cougars were between 1 and 2 years old.

Home ranges for collared cougars have been determined using minimum convex polygons (MCP) to depict the general pattern of use (Figure 4). Home ranges are fairly linear in a north-south direction. The two adult male home ranges are the largest with areas of 537 km^2 and 233 km^2 for AM06 and AM04, respectively. Female home ranges are smaller with areas between 90 and 118 km^2. Subadult male home ranges are the smallest with areas between 40 and 50 km^2. The home range for AF03 appears large but this is representing a dispersal movement and not a true home range.

Mortalities of collared cougars were high with 5 of 18 (28%) dying during the year (Table 1). One of these was a young male (AM02) interacting with an adult male (AM04) and being killed. Two of the mortalities were road kills (AF10 and her kittens, and AM07). AM20 was depredating sheep and was shot by the land-owner as AM20 approached the barn where the sheep were being held. We located AF17 from a mortality beacon, but, aside from some trauma to her front shoulder, cause of death could not be determined.

During 2007-2008 there have been 5 cougars that have been aversively conditioned. AM04 provided the first aversive conditioning opportunity after he killed several goats near Eldorado Springs in October, 2007. AM04 was captured near the depredation site, relocated to his original capture location and shot with beanbags. Prior to the aversive conditioning AM04 used this depredation area frequently, but has not used the area much following the treatment (Figure 5). In April, 2008, AM04 was seen in the city of Boulder and had to be darted as a number of onlookers pushed him deeper into the city. At this time he was moved outside the city and shot with beanbags. AM04 entered the city again in August, 2008 and killed a deer in Boulder. He was trapped, relocated to the southwestern edge of his home range and shot with beanbags. Although AM04 uses urban areas, he is rarely seen by people and does not appear to be a threat or habituated to humans.

Both AF17 and AM13 were captured and aversively conditioned following depredation events on Sugarloaf, northwest of Boulder. AF17 was captured after killing a dog. She was relocated approximately 2 km to remove her from the urban area and shot with beanbags on release. AM13 was captured after killing a llama on the remote edge of private property. He was released on site because of the remote location and shot with beanbags on release. To date, neither AF17 nor AM13 have had any further human interaction.

Both AF12 and AM14 were captured in the city of Boulder and aversively conditioned, but have since been relocated. AF12 killed a deer in Boulder on May 7, 2008 and was captured, relocated about 10 kilometers outside the city and shot with beanbags on release. AM14 was seen in the city on May 15, 2008 and was darted out from under a home-owner's deck, relocated about 5 km outside the city and released. AM14 and AF12 returned to the city within 5 and 21 days, respectively, and were captured and relocated more than 40 km from the city and shot with beanbags on release. AF12 has returned to the

Boulder area but has not been captured again. AM14 has remained near his release sight and may have been seen in urban areas near Nederland.

Initially the Lotek GPS collars appeared to be performing satisfactorily with an approximate acquisition success rate for locations of 60%. However, several collars have failed after several months in the field and several of the collars recently deployed have failed. These collars are not transmitting the VHF beacon or the beacon has a very weak signal, or the collars are not acquiring any GPS locations. In the coming year we will try Northstar GPS-satellite collars as a more reliable/economical method to track cougars during the study.

SUMMARY

A total of 75 and 56 black bear and cougar samples, respectively, were used to assess genetic population structure across the state. Analyses suggest that both black bear and cougar populations are panmictic, representing more of a megapopulation than a metapopulation. This is reasonable given the high dispersal rates and large dispersal distances typical for both species.

Genetic analysis for cougar feces revealed that DNA is still present in samples after feces have been in controlled temperature environments for up to 4 months. Genotyping error rates still need to be assessed. However, the presence of DNA in these samples suggests that field detection of cougar scats may be a viable non-invasive population sampling technique.

A total of 18 independent cougars were captured during 2007-2008 on the front-range cougar pilot study. Both the use of cage traps and hounds proved to be effective methods for capturing cougars, although luring cougars to bait sites has very limited success. Mortalities during the year were high with a total of 5 cougars dying from both natural and human related causes. Aversive conditioning was done on 5 cougars with mixed results. Lotek GPS collars are proving to be unreliable and North Star Satellite collars will be used in the upcoming year.

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Prepared by ____

Mathew W. Alldredge, Wildlife Researcher

Table 1. Summary of cougars captured during 2007-2008. Ages are based on tooth wear. Capture types are hound captures (hound), free-range darted, (free-range), cage trapping from bait sites (bait), or cage trapping from reported cougar kills (kill). Status indicates a cat that is still alive or indicates the type of mortality.

Cougar ID	Date	Sex	Age	Capture type	Location	Status
AM02	1/10/08	M	1.5	Hound	White Ranch	Intraspecific
AM04	7/14/07	M	7	Bait	White Ranch	Alive
AM06	11/21/07	M	5	Hound	Heil Valley	Alive
AF03	11/29/07	F	4	Kill	Flagstaff	Alive
AF01	12/17/07	F	2	Kill	NCAR	Alive
AM05	12/19/07	M	1.5	Hound	White Ranch	Alive
AM07	12/26/07	M	1.5	Hound	Heil Valley	Road kill
AF08	12/26/07	F	1.5	Hound	Heil Valley	Missing
AM09	12/28/07	M	1.5	Hound	Heil Valley	Missing
AF10	1/15/08	F	7+	Kill	Apex	Road kill
AF19	3/4/08	F	8	Hound	Heil Valley	Alive
AF11	3/5/08	F	1.5	Kill	Table Mesa	Alive
AM20	3/6/08	M	4	Hound	White Ranch	Depredation
AF15	3/18/08	F	6	Hound	Coffin Top	Alive
AF17	3/29/08	F	9	Depredation	Sugarloaf	Unknown
AM13	5/8/08	M	2	Depredation	Sugarloaf	Alive
AF12	5/8/08	F	2	Kill	Boulder	Alive
AM14	5/15/08	M	2	Free-range	Boulder	Alive

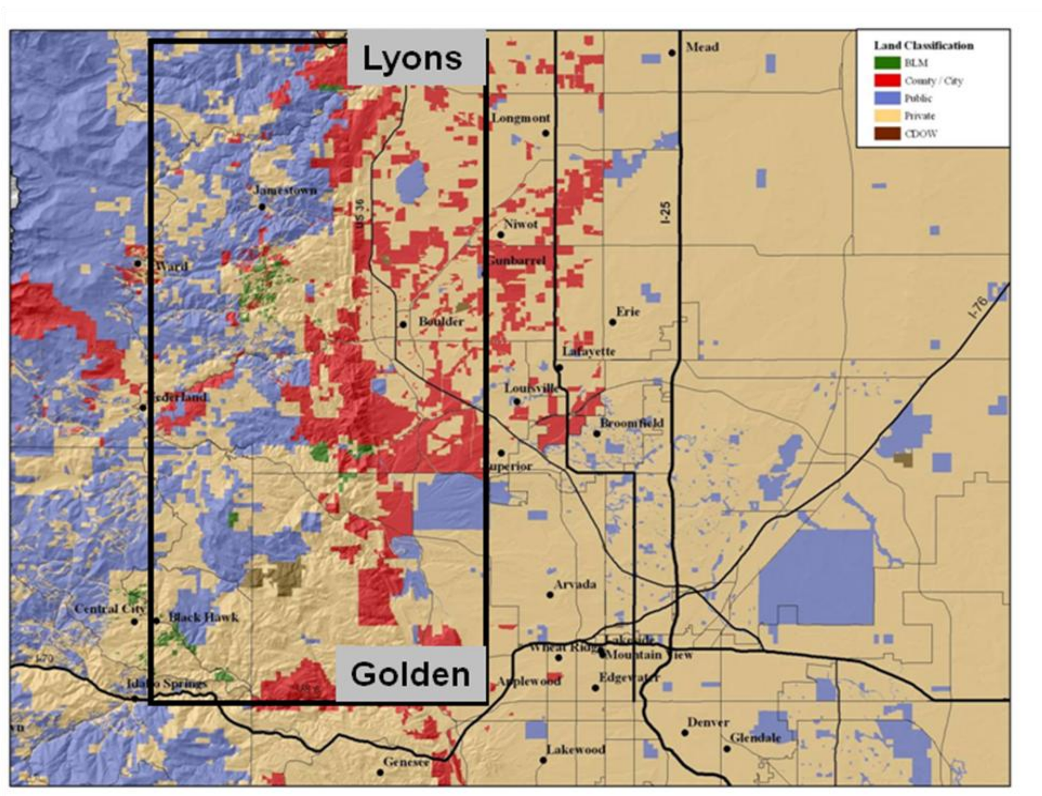

Figure 1. Study area for 2007-2008 Front Range cougar pilot study extending from Lyons to Golden.

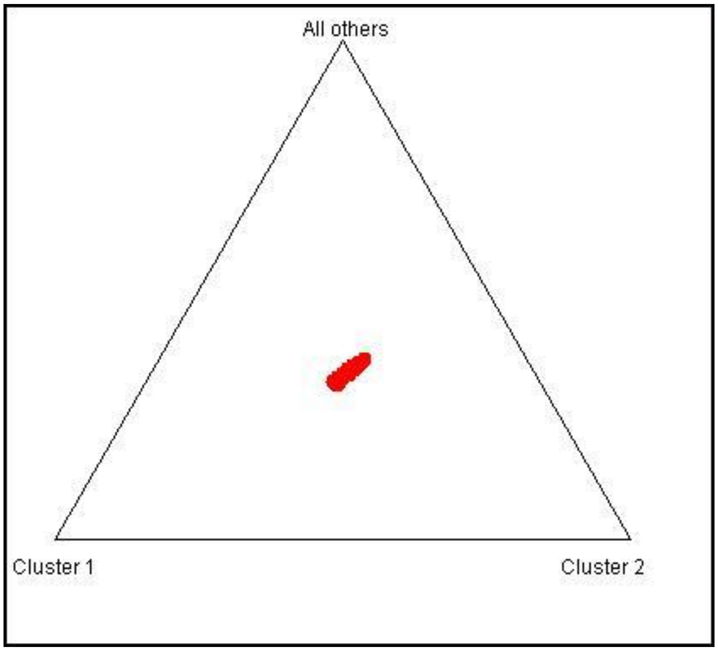

Figure 2. Cluster diagram of microsatellite data identifying little evidence of population substructure for bears across the state of Colorado based on 75 individual females harvested in 2007 from four distinct spatial locations representing the northeastern, northwestern, southwestern, and southeastern portions of Colorado.

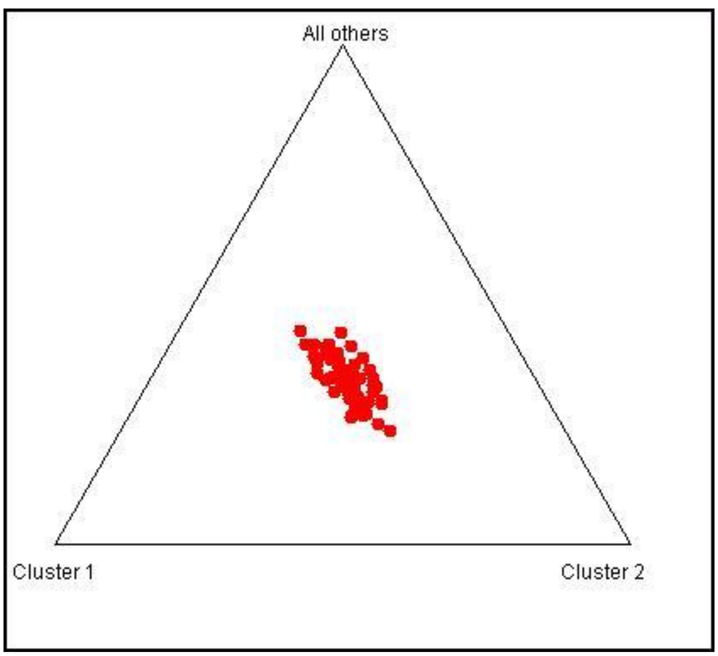

Figure 3. Cluster diagram of microsatellite data identifying little evidence of population substructure for cougars across the state of Colorado based on 56 individual females harvested in 2007 and from cougars sampled as part of ongoing research from across Colorado.

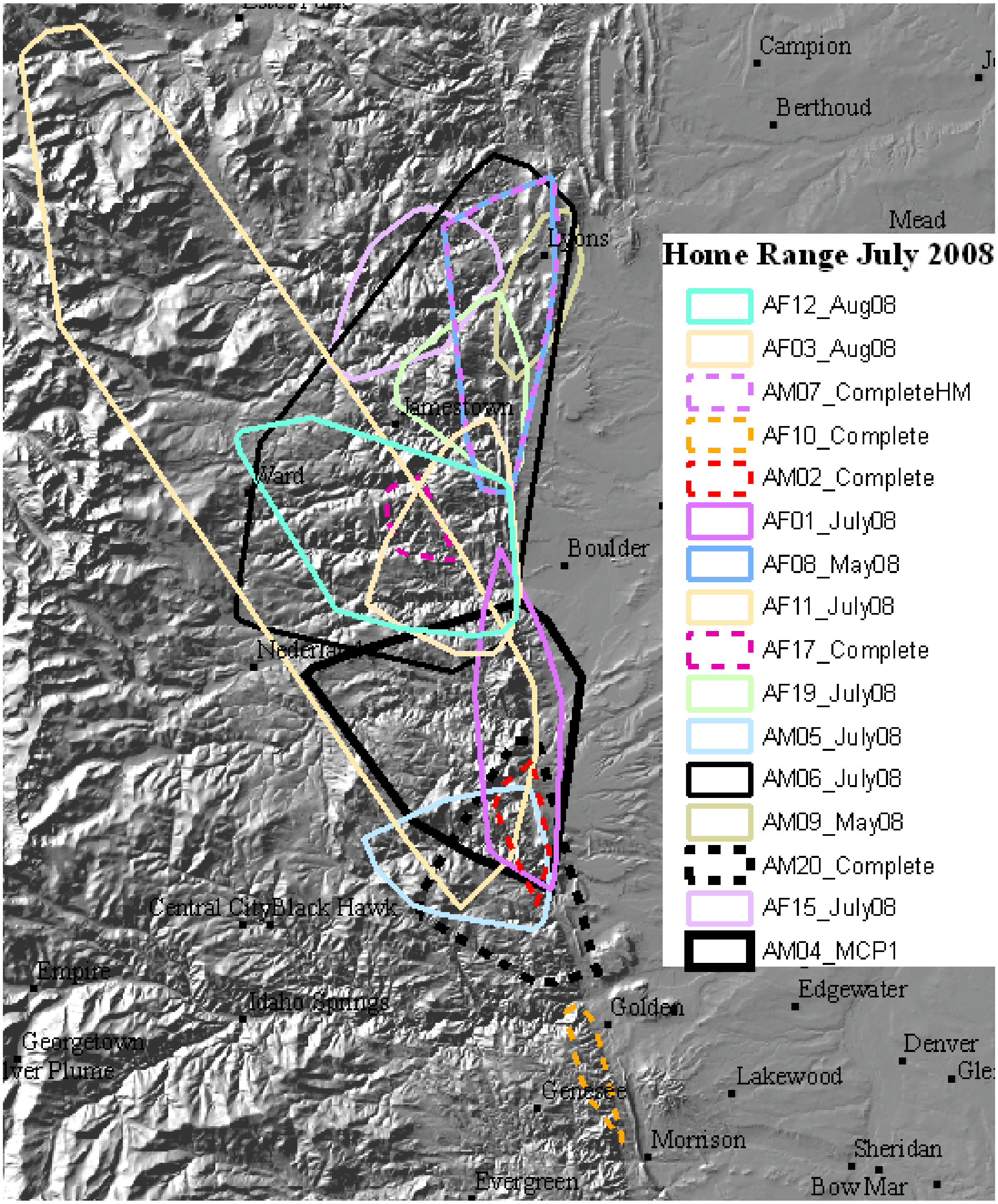

Figure 4. Minimum convex polygon home-ranges for cougars captured during the 2007-2008 front-range cougar pilot study.

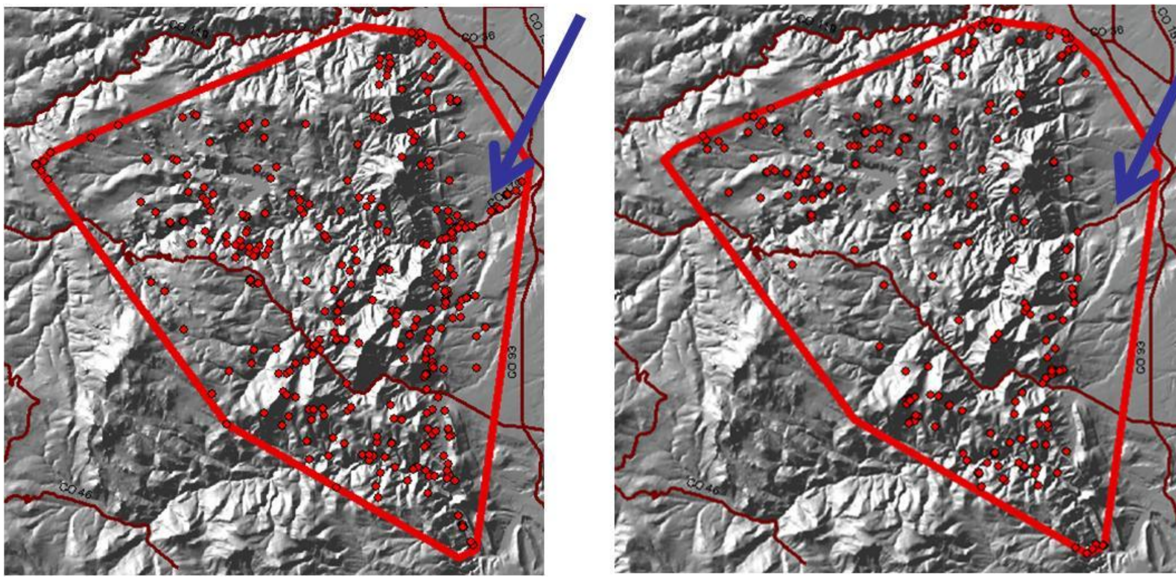

Figure 5. Home-range maps for cougar AM04 depicting home-range and location from July 14, 2007 until October 17, 2007 (left) and October 18, 2007 until January 5, 2008 (right). Arrows point to Eldorado Springs area where AM04 was captured and aversively conditioned following a goat depredation. The lack of locations in this area following aversive conditioning is evident in the home-range on the right.

APPENDIX I

PROGRAM NARRATIVE PILOT STUDY PLAN
FOR MAMMALS RESEARCH
FY 2007-08

State of:	Colorado	:	Division of Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	3003	:	Predatory Mammals Conservation
Task No.:	2	:	Front-range Cougar-Human Interaction Pilot
		:	Study: Feasibility Assessment of Field
		:	Techniques and Protocols, Phase II: Enhancing
		:	Assessment of Aversive Conditioning Techniques
		:	For Cougar Human Interactions
Federal Aid Project No.	N/A		

FRONT-RANGE COUGAR-HUMAN INTERACTION PILOT STUDY: FEASIBILITY ASSESSMENT OF FIELD TECHNIQUES AND PROTOCOLS, PHASE II, ENHANCING ASSESSMENT OF AVERSIVE CONDITIONING TECHNIQUES FOR COUGAR-HUMAN INTERACTIONS

Phase II January 2008

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Study Plan Approval

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Reviewed by:	Chad J. Bishop	Date:	
		Date:	
		Date:	
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Approved by:	Dave Freddy Mammals Research Leader	Date:	

PROGRAM NARRATIVE PILOT STUDY PLAN
FY 2007-08

FRONT-RANGE COUGAR-HUMAN INTERACTION PILOT STUDY: FEASIBILITY ASSESSMENT OF FIELD TECHNIQUES AND PROTOCOLS, PHASE II, ENHANCING ASSESSMENT OF AVERSIVE CONDITIONING TECHNIQUES FOR COUGAR-HUMAN INTERACTIONS

Phase II January 2008

A pilot study plan enhancement submitted by:

Mathew W. Alldredge, Wildlife Researcher, Mammals Research
David J. Freddy, Mammals Research Leader

PREFACE

Alldredge (2007) in his initial pilot study plan approved in March 2007 listed 5 objectives to begin addressing with the initial capture and radio/GPS-collaring of 6 cougars. This pilot study plan enhancement (Phase II) focuses on expanding efforts to assess objective 4: determine the feasibility of aversive conditioning techniques on cougars within urban/exurban areas. From May through December 2007, project efforts resulted in capturing 6 cougars which have provided valuable information on effectiveness and deployment of capture techniques, effectiveness of GPS collars, cougar movements, and initial but limited information on cougar-human interactions; with all results to date supporting all original objectives 1-5 (see page 4 of this document). We are confident to move forward with radio-collaring more cougars to enhance our abilities to address the feasibility of aversive conditioning both in the short- and long-term and provide our rationale in this document for expanding the number of cougars to be captured during our pilot study phase. Especially important, is maintaining our immediate ability to capture cougars during the winter months of January-February when winter snow conditions are most likely to be optimal for detecting and tracking cougars. Our multi-year, Front-range cougar project study plan, incorporating results of our pilot efforts, will address cougar-human interactions over an expanded geographic area and will utilize all cougars captured and collared during the pilot phases of this project. We anticipate the multi-year study plan will be completed and approved by April 2008. In the interim, this enhanced plan will allow us to expand our capture effort from the original 6 cougars, which was the absolute minimum to start the project, to 20 additional cougars. All original pilot study plan objectives will be enhanced by this additional capture effort.

NEED

Although cougar attacks on humans are rare (CMGWG 2005), they have increased in recent decades. From 1890 to 1990 there were a documented 9 fatal attacks and 54 non-fatal attacks on humans in the United States and Canada (Beier 1991, Fitzhugh et al. 2003). Seven fatal and 38 non-fatal attacks on humans occurred following Beier's 1991 publication and Fitzhugh et al.'s 2003 publication. Cougar attack rates on the front-range of Colorado have been estimated at one in every 2.2 million person-days. The increase in attacks also corresponds to a large increase in human-cougar incidents, which are likely due to habitat reduction, human encroachment, increased human recreational activities, and possible increases in cougar populations (CMGWG 2005). Torres et al. (1996) found no differences associated with gender in the likelihood of a cougar attack on humans. However, Ruth (1991) did find that sub-adults were the age group most likely to interact with humans. The CMGWG (2005) found that a combination of inexperience and unfamiliarity with their environment, as well as hunger, may cause young cougars to have more negative interactions with humans.

CDOW wildlife managers are faced with decisions about how to manage cougar populations and individual cougars in order to maintain viable populations and maintain acceptable levels of human safety. Defining acceptable levels of human safety is difficult because people's perceptions are different when interactions do not directly affect them. In the 2005 public opinions survey, only 44% of respondents felt it acceptable to destroy a cougar that attacks and injures or kills a person that is recreating in cougar habitat, while 49% found eliminating the cougar unacceptable (CDOW, unpublished data). Other difficulties associated with managing cougar populations in areas with high levels of human interaction are caused by the limited amount of information that is currently known about cougars in these exurban situations and responses of cougars to management prescriptions (CMGWG 2005).

There is a growing voice from the public that CDOW do more to mitigate potential conflicts (CMGWG 2005), and the Director of CDOW has requested that research efforts be conducted to help minimize future human/cougar conflicts. In order to meet these goals CDOW believes we need to directly test management prescriptions in terms of desired cougar population and individual levels of responses.

Long-term study objectives for the Front-Range Cougar Research project will involve directly testing management responses of cougars at various levels of human interaction. The CMGWG (2005) recommend 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. These categories are defined as (CMGWG 2005):

> Habituated—frequent use of developed area and cougars appear comfortable in the presence of humans.
>
> Overly familiar—a cougar purposefully approaches a human, or allows a human to approach it after the cougar has seen the human.
>
> Nuisance—cougar exhibits overly familiar behaviors more than once.
>
> Dangerous—displayed non-defensive aggression towards humans (postures, vocalizations, and actions communicating an intent to harm).

Note that aggressive behaviors could also be defensive if the cougar perceives the human as a threat to itself, its young, or a food source, or if the cougar is surprised or harassed by humans. The CMGWG (2005) describes cougar behaviors and the level of risk to humans as perceived by the authors (Appendix III, Table 1). We have added an additional column that categorizes the level of risk, which will be used to determine management treatments that will be applied during research efforts. Although cougars may habituate to human developments and activities (Ruth 1991), both habituated and non-habituated cougars may experiment with humans as potential prey (Aune 1991). The CMGWG (2005) clearly state that there is no scientific evidence to indicate that cougar habituation to humans affects the risk of attack.

Clearly, cougars representing a danger to human health and safety should be removed, but the appropriate response to cougars that are overly familiar or habituated to humans is unclear. Lethal control is loosing public support (Reiter et al. 1999) so other options need to be examined. Shivik and Martin (2000) emphasize the need to research and determine effective non-lethal control techniques, or managers risk loosing credibility with the public.

There have been no studies confirming the effectiveness of aversive conditioning on cougars (CMGWG 2005). Beier (1991) describes two unsuccessful attempts at aversive conditioning (one cougar shot with rock salt, one treed and collared), however, one of these was already exhibiting aggressive behavior and the other was in poor body condition. McBride et al. (2005), used hound capture, and subsequent hound chases as a form of aversive conditioning on 4 Florida panthers with some degree of success.

Studying individual and population level responses of cougars will require capturing and radio-collaring cougars, as well as standardizing responses of CDOW personnel to human/cougar interactions. In doing this we will be able to develop a series of comparable case histories that can demonstrate effective methods for dealing with cougars interacting with humans.

A primary objective of this study is to determine the feasibility and effectiveness of aversive conditioning techniques on cougars within urban/exurban areas, including use of hounds, rubber bullets, beanbag bullets and pepper spray fired from a shotgun. In conjunction with aversive conditioning, relocation of cougars will generally be part of the treatment as this will be a required management action when the cougar-human incident occurs within neighborhoods. Additionally we do not want to chase a cougar from one neighborhood to another. Treatments will be applied in a manner that is consistent with management options so that wildlife managers in the future will be able to implement these techniques without the aid of cougars being radio-collared. Making this assessment of aversive conditioning techniques will provide crucial information for developing long-term management prescriptions for dealing with cougars interacting with humans and possibly preventing habituation to humans.

OBJECTIVES

1. Determine the effectiveness of cage traps and hounds for capturing cougars on the Front-Range of Colorado.
2. Determine functionality and suitability of GPS collars in front-range habitats.
3. Implement cougar-human risk protocols and communications within CDOW and among public entities and determine if modifications are necessary (see Appendix III).
4. Determine the feasibility of aversive conditioning techniques on cougars within urban/exurban areas, including use of hounds and rubber bullets.
    a. Assess the effectiveness of various methods of aversive conditioning in terms of decreased use by individual cougars of urban areas and future incident rates.
    b. Statistically test the effectiveness of the aversive methods in affecting cougar behavior.
5. Evaluate political/social response to cougar research activities.

EXPECTED BENEFITS

An assessment of aversive conditioning techniques will provide future guidance for wildlife managers in dealing with cougar-human conflicts. Understanding the likely response of a cougar to a management treatment will help managers chose the right response to a particular situation. This will also give us credibility with the public with regard to the management actions chosen for a particular event, because we will have some understanding of the long-term effects on the cougar's future behavior and not just a short-term solution to an incident that may be repeated.

APPROACH

Cougars have been captured during the initial phases of this pilot project (Alldredge 2007) and cougars will continue to be captured on large publicly owned properties, such as city and county open-space. These cougars are captured in their natural environments and we have no knowledge of any interaction with humans among these cougars, although the potential exists. These cougars will be incorporated into the aversive conditioning treatments as they are reported as interacting with humans, or as they demonstrate selection for urban areas which could be viewed as potential habituation to humans. Radio/GPS-collared cougars that travel through urban areas and/or occasionally kill naturally occurring prey items in urban areas will not be viewed as problem cougars and will not be included in aversive conditioning treatments. See Appendix I for approved capture and handling protocols

Additional cougars for aversive conditioning treatments will be obtained from actual reported cougar/human interactions. In general, these will not include cougars that are reported to have killed naturally occurring prey items on private properties resembling the naturally occurring environment. These cougars will be individuals involved in human-interactions that would typically result in management actions, such as hazing or relocation , that resemble aversive conditioning treatments. All such management level cougars will be radio/GPS-collared and treated with aversive conditioning for this portion of the study.

At this time, we consider aversive conditioning treatments on cougars to potentially be: multiple captures and handling of cougars, single or multiple treatments using rubber buckshot, beanbags, or pepper spray fired from a shotgun, single or multiple chases using hounds, and potential combinations of capture, hound chases, and rubber buckshot or beanbags or pepper spray (specific application of treatments are outlined in Appendix II). Initially, we want to assess situations and methods that are already being implemented by local wildlife managers.

The most likely scenario will involve incidents occurring in neighborhoods, where relocating the cougar is necessary prior to any application of an aversive conditioning treatment. For these situations, all treatments will require the relocation of the offending cougar to an adjacent open-space property or similar area. Following relocation and at the point of release, we will either chase the cougar off using rubber bullets or beanbag rounds, pepper spray, or hounds. For first time offenders we will initially try rubber bullets or beanbag rounds. Second time offenders will be chased with hounds. If rubber bullets or beanbag rounds are not affecting cougar behavior, we will begin using pepper spray on first time offenders.

The other potential scenarios that will occur are incidents in areas where a cougar can be directly conditioned or chased from the incident area. We will mimic the above approach as much as possible, and use rubber bullets or beanbag rounds on first time offenders. If possible we will chase individuals with hounds on their second offense, although this may not always be practical. Pepper spray may not be practical either in many situations. As a second level treatment where direct hound chases are not practical, we will attempt to capture, relocate, and aversive condition the individual.

At this time, these aversive treatment efforts will be primarily observational. Once we have determined a method that routinely elicits the desired response we will focus on that method to achieve a statistically valid sample size. Response variables would be, future incident rates following aversive conditioning and change in use patterns associated with urban areas. However, this may take several months or years to accomplish. To demonstrate required sample sizes we have run a detailed simulation of the potential human interaction and aversive conditioning phase of the study in order to obtain expected values and standard errors for a hypothetical sample of 20 collared cougars some of which may interact with humans at a level requiring management actions. Very little information exists about human-cougar interaction rates and variability and effectiveness of aversive conditioning; therefore many assumptions must be made to conduct any kind of statistical power analysis. The assumptions are as follows:

1. 80% of all cougars in the study area will interact negatively with humans.
2. All cougars behave and respond the same to the urban environment and aversive conditioning (i.e. no sex or age effects).

3. 25% of cougars that have a negative interaction with humans are not habituated to urban environments and will not interact with humans again. The remaining portion of the population (75%) will have additional negative interactions following the first interaction.
4. Aversive conditioning is 50% effective, so that half of the treatment group (on average) will not interact with humans following the aversive treatment.

Based on these assumptions we would expect 16 of the 20 collared cougars to interact negatively with humans. Following the first negative interaction, half of the cougars would be placed in a control group and half in a treatment group, giving an expected 8 cougars in each group. No aversive conditioning would be applied to the control group, while aversive conditioning (chased by hounds and/or shot with bean bags) would be applied to all of the treatment animals. Based on our assumptions we would expect 6 of the control animals to continue to interact negatively with humans and 3 of the treatment animals to continue negative human interactions.

Using these assumptions we simulated the aversive conditioning process 1000 times, assuming a binomial process (success-failure) and only 1 aversive conditioning attempt. The average number of control and treatment cougars from the simulations was 8±2 cougars each with a minimum of 4 and a maximum of 10 in each group. The average number of control cougars that continued to have negative human interactions was 5.8±4.06, with a minimum of 1 and a maximum of 10. The average number of treatment animals that continued to have negative interactions was 2.8±3.81, with a minimum of 0 and a maximum of 7.

Location of Work:

This work will be conducted along Colorado's front-range, in Boulder, Jefferson, Gilpin and Larimer counties. The study area is defined by the existing boundary for the ongoing cougar research project.

Schedule of Work:

Time	Activity
January 2008, ongoing	Capture Cougars/Begin treating cougars involved in human incidents
September 2008, ongoing	Summary report of findings

Estimated Costs:

Salaries of permanent employees, as well as many other logistical costs (vehicles and aerial flights) will be covered by existing project funds in the CDOW carnivore research and terrestrial management programs.

Category	2007-2008
Personnel	
Field Technician(s) (6 months)	$14,050
Operating Expenses	
Field/Capture Equipment	$ 6,000
Lotek GPS collars (14)	$63,000
ATS VHF collars (6)	$ 1,500
Vehicle Mileage/Lease	$ 8,000
Total Expenses	$92,550

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APPENDIX II

CAPTURING AND HANDLING PROCEDURES FOR FREE-RANGING COUGARS

Modified by MWA on 1/18/2007: Puma changed to cougar and schedule for monitoring cage traps modified after consultation with CDOW veterinarian L. Wolfe.

Delivery of anesthetic drugs via projectile syringe or jab pole, cage traps, or foot snare may be used to capture cougars. All of these techniques have proven effective and safe for capturing cougars under field conditions commonly encountered in Colorado. This document is intended to serve as a comprehensive reference for future cougar studies to avoid unnecessary complexity in study protocols submitted for ACUC review.

Capture Techniques

Trained hound pursuit

As described in Shaw (1979), an experienced houndsman with trained dogs is used to track and tree or bay each cougar. Field anesthesia is determined under the supervision of the attending veterinarian. Anesthetic drugs will be administered intramuscularly (preferably the caudal thigh) via projectile syringe using a gas-powered projector. For capture, cougars will be anesthetized with Telazol® (6-9 mg/kg) and xylazine HCl (1.8-2 mg/kg) or ketamine (10-11mg/kg) and xylazine HCl (1.8-2mg/kg) or ketamine (2 mg/kg) and medetomidine (0.075 mg/kg) (Shaw 1979, Logan et al. 1986, Kreeger 1996). See drug dosages below (Table 1, Appendix II).

If the cougar is treed, then people and dogs should be removed from the immediate area to give the animal a chance to descend before becoming completely anesthetized. If the cougar remains in the tree until almost completely anesthetized, then someone wearing climbing gear will climb to the cougar and attach either a chest harness (preferred) or hind leg noose (e.g. bovine hobbles) to 2 legs and quickly lower the animal to the ground. If possible, other personnel will hold a taunt net, 3 by 3 meters square, below to break the cougar's fall should it slip before a harness or rope can be secured. If there aren't enough people to hold the net, anchor the net about 2 m above the ground and on adjacent trees or branches using ropes & carabiners.

Occasionally cougars will jump from the tree immediately after being darted. If there is snow cover, the cougar should be tracked with the dogs on leads. Attention should be given to changes to the cougar's gait and direction of travel. When anesthesia is effective, the cougar's tracks will weave and show signs of stumbling. Usually the cougar can be found laying or sitting on top of the snow. If after 15 minutes, it appears that the cougar is traveling normally, then dogs can be released on the cougar's tracks again to encourage it to tree. When the ground is bare, at least one non-aggressive dog will be released on the cougar's trail to drive the dog to bay. If the cougar is radio-collared, radio-telemetry can be used to track the cougar.

Upon first approach of an apparently anesthetized cougar, a 4-5 foot stick will be used to gently prod the paws and muzzle of the animal; if there is no response (i.e. snarling or biting), then assume anesthesia is sufficient for handling. Once anesthetized apply an antibiotic or mineral oil based eye ointment and a blindfold to reduce visual stimuli and protect the eyes from bright sun light and debris.

Vital signs should be monitored in the anesthetized cougar. Normal signs: pulse ≈ 70—80 bpm, respiration ≈ 20 bpm, capillary refill time ≤2 sec., rectal temperature ≈ 101°F average, range = 95—104°F (Wildlife Restraint Handbook, 1996, California Dep. of Fish and Game, Wildlife Investigation

Laboratory, Sacramento, Kreeger et al. 2002). In temperatures near or at sub-freezing wrap the anesthetized cougar in a thermal blanket. In hot temperatures, the cougar should be treated with water on the head, abdomen, and inguinal area. Cougars that receive lacerations during capture will be given antibiotics. When the cougar is being sampled it should be moved from one side to the other or in sternal recumbency about every 10 minutes to prevent hypostasis in the downside lung.

When sampling procedures are completed, the blind-fold and leg restraints (e.g. hobbles or snare cable) will be quickly removed, and the cougar will be allowed to recover from the sedation either naturally or with the aid of an antagonist. When prescribed, yohimbine HCl (0.125 mg/kg IV) will be used to antagonize xylazine sedation and atipamezole (0.3 mg/kg) will be used to antagonize medetomidine sedation.

Cage trapping

A cage-type trap for live capture of bears was developed by Beck (1993). The trap measures 1.8m long and 1.0m high and wide. The frame is constructed of angle iron, and all side and top panels are wire mesh of 1.9cm mesh size. The floor is 16-gauge steel. A spring-powered, solid aluminum door is mounted on a full-length hinge at one end. A full-length latching mechanism holds the door closed. The door is triggered via a treadle pedal mounted on the floor 1.0m from the door. A standard garage door coil spring provides the closing power. Along one side of the trap is a hinged panel measuring 1.8m by 0.3m. Vertical bars placed on 0.3m centers behind this panel. Swinging the window up allows access through the barred area for administering immobilizing drugs by jabpole. Each trap weighs approximately 236kg.

In the first study in which these traps were used, there was only one injury to a bear in 134 captures. An adult male broke a canine tooth while in the trap. Of the limited number of times these trap have been used for cougars, no known injuries have occurred to date (T. Beck, pers. comm.).

A cage trap designed specifically for the capture of cougar has been used to manage cougar human conflicts in California since the late 1980s (Shuler 1992). A similar cage trap was used to safely capture cougar for research on cougar human interactions in San Diego County, California (Sweanor et al. *in prep*.). The cage trap for that study measured 48 in. tall, 40 in. wide, and 10 ft. long. It was built on a frame of 1 ½ in. angle iron with 2 in. by 4 in. grid horse panel made of 3/16 in. welded steel rod for the walls, floor, door, and roof. It weighed about 250 lb (113kg).

A cage trap was designed by Don Hunter (USGS) and Colorado State University's Mechanical Engineering Department. The trap was designed to be smaller, lighter, collapsible, and safer than what was previously available. A counter-weighted door drops closed slowly and quietly so as not to injure any members of a family group caught in the doorway. In addition, there are air-pressured cylinders that slow the door even further and a rubber bumper along the edge in case a tail is caught in the way of the closing door. The trap is 3.5 ft. tall, 3.5 ft. wide and 6 ft. long, constructed of 2 in. by 4 in. grid pattern steel horse panel with 0.225 in. rod.

A cage trap will be baited with a deer carcass that will be tied to the end mesh panel opposite the door of the trap. The trap will be checked as early as possible the following morning or immediately after a capture occurs if fitted with a transmitter to be triggered upon closing of the door. The researchers should monitor the trap as soon as possible after sunrise every morning to minimize time in the trap and to avoid human interference from recreational activities. Normally, when a cougar has claimed a bait at a cage trap, it is caught fairly soon after night-fall. Researchers can work the cougar with a spot-light, head lamps, and lantern. Cougars will be immobilized with a jab-pole or syringe as described above. Drug dosages and animal handling will be as described above.

Foothold Snares

Foot-hold snares are an effective, relatively safe technique for capturing cougars particularly in areas not conducive to using trained hounds (Logan et al. 1999).

The snares are constructed to minimize injuries to the cougar. The snare, also called the Aldrich foot snare, was originally designed for the capture of bears. It has been modified to use for cougars. The spring activated snare secures a 3/16 inch steel cable around the foot of the cougar, closing tight with the action of a small piece of angle iron fashioned into a sliding lock mechanism. The snares have been modified considerably over the years for cougars by incorporating a large spring to diminish force applied to the foot and a shock absorption device into the cable. The inside of the loop is wrapped with duct tape to minimize the surface abrasion on the skin of the foot. An in-line swivel is placed in the cable to avoid torsion of the foot and potential bone fracture. A short lead is attached to the snare to further minimize stress to the leg. The lead is then secured to a multi-branched flexible bush with a double off-set hook drag made of 5/8 in. rebar steel. It can also be secured to a tree 4 inches or greater in diameter with 3/16 in. or ¼ in. steel cable clamped and stapled to the base of the tree so the cougar can not climb the tree with the snare. Branches of the tree are lopped of with a saw or an axe about 8 ft. up the tree so the cougar can not hang itself from a branch by the snare cable. An area of 5 meters or more is cleared around the snare site to eliminate potential leg fractures resulting from a fulcrum situation in conjunction to an adjacent tree (Duggins Wroe, pers. comm.) or torque on the leg bones caused by revolutionary twisting of the cable when the swivel is isolated by the foot-loop cable becoming wrapped around stout vegetation. Details on how to safely structure the snare and to choose and prepare snare sites are in Logan et al. 1999.

Modifications have been made to avoid capturing non-target animals. The concealed 10 inch loop of cable is positioned over the trigger of the spring. The trigger has a 4 inch plastic trap pan adhered to the top surface. The pan and trigger are positioned over a hole dug in the ground and filled with a 12x12x4 inch piece of high density foam. This foam prevents smaller animals from triggering the snare. Large branches are angled over the snare to force ungulates to step over or go around the snare. The duct tape on the loop keeps it from closing too tightly and usually allows smaller-footed animals such as ungulates, coyotes and bobcats to slip free. The loop size is set smaller than for a black bear, there is, however, a possibility of catching a smaller-footed black bear (Duggins Wroe, pers. comm.). Bears will be drugged and released if caught. Any other non-target animals caught will be examined and treated for injuries and released with snare poles.

Preferred sites will have limber bushes with multiple basal stems to securely anchor the snare drag, and a safety area with a circumference 5 m or more around the anchor point. The snares will not be set near cliff or water, and potentially dangerous vegetation will be cleared from the safety area. Snares will be checked as quickly as possible after sunrise every morning to reduce stress and possibility of hyperthermia. Snares will be checked at least twice a day and will not be reset on extremely hot days (Logan et al. 1999, Logan and Sweanor 2001). Logan et al. (1999) found snaring to be a relatively safe technique for capturing cougars. Life-threatening injuries occurred in 5 of 209 captures. The majority of these injuries were fractures to ulna and/or radius of the snared leg. Adult cougars will be immobilized with anesthetics delivered by jab-pole or CO_2 pistol and projectile syringe as described above. Capture operations will be halted if ambient temperature falls below 0°F or rises above 90°F.

Delivery of anesthetic drugs via projectile syringe:

In situations where pursuit by hounds is not possible and snaring or trapping is difficult due to the high abundance of non-target animals, a lure may be used to bring a cougar in close proximity to dart with a projectile syringe using a gas-powered projector. Lures may include a fresh kill made by the target animal, a deer carcass placed out as bait, or a predator call. A hound on a lead will be

available to track the animal once it has been darted. The caudal thigh is the preferred target for the dart. The anesthetic choice is at the discretion of the attending veterinarian.

Hand capture of cubs

Nursing cougar cubs can be safely captured by hand or with a catch-pole at nurseries when they are 4 to 10 weeks old (Logan and Sweanor 2001). Cubs usually weigh less than 10 kg, and can be examined and tagged without the need for anesthetics. Nurseries can be located when VHF-collared mothers are present, or by using GPS data from GPS-collared mothers. Wait for a time when the mother is away from the nursery, as determined by VHF-radio-telemetry, in order to capture the cubs. Cubs should be handled with clean leather gloves. They can be picked up by the nape of the neck. A catch-pole may be necessary to extract cubs from holes and crevices. Cubs should be contained together, or in pairs, in new burlap bags to allow ample air circulation. The cubs should be moved about 100 m from the nursery to minimize human activity, disturbance, and odors at the nursery. Individual cubs that are being examined can be held in a separate burlap bag. Once the cubs are processed, they should be returned to the exact nursery, and the researchers should leave the area immediately.

Throughout this process a receiver tuned to the frequency of the radio-collared mother should be constantly monitored. If it appears that the mother is returning, the cubs should be put back in the nursery immediately, and researchers should vacate the area.

Injuries and Euthanasia

If an animal is seriously injured (e.g. fractured or broken appendage, vertebrae, pelvis, or jaw, severe dislocation, laceration or any other injury that compromises its ability to survive and/or causes severe pain or distress) during capture or recovery, then it will be quickly and humanely euthanized. Cougars will be deeply anesthetized with ketamine or Telazol® and xylazine (IV or IM) and euthanized via rapid IV KCl administration (400-800 mEq). Alternatively, if an injured cougar cannot be handled then euthanasia will be a gunshot to the head or neck with a $\geq$0.22 caliber magnum rifle or pistol.

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Table 1: Drug dosage by weight for cougars as recommended by CDOW veterinarian L. Wolfe.

		Dosage mg/kg	Conc mg/ml	Cougar Dose (ml) by animal weight (kg)									
				10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**100**	**110**
ANTIBIOTICS													
Oxytetracycline		3	200	0.2	0.3	0.5	0.6	0.8	0.9	1.1	1.2	1.5	1.7
Penicillin G	SID	20000	300000	0.7	1.3	2.0	2.7	3.3	4.0	4.7	5.3	6.7	7.3
PAINKILLERS													
Ketoprofen	SID	2	100	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	2.0	2.2
ANESTHETICS													
ketamine (+ med) 200		2	200	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.1
medatomidine 20		0.1	20	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.6
tolazoline		4	100	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.2	4.0	4.4
atipamazole		0.3	5	0.6	1.2	1.8	2.4	3.0	3.6	4.2	4.8	6.0	6.6
Dopram		1	20	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	5.5
Atropine		0.03	0.5	0.6	1.2	1.8	2.4	3.0	3.6	4.2	4.8	6.0	6.6
MISC													
fluids maint ml/ day		60	1	600.0	1200.0	1800.0	2400.0	3000.0	3600.0	4200.0	4800.0	6000.0	6600.0

APPENDIX III

APPLICATION OF AVERSIVE CONDITIONING TECHNIQUES TO COUGARS

Management options for CDOW managers when dealing with cougar-human interactions include firing rubber bullets or beanbags from a 12 gauge shotgun at the offending cougar, pepper spray, and capturing and relocating offending cougars. Chasing a cougar with hounds as a means of aversive conditioning is also a viable option for treating cougars interacting with humans. Below we describe the application of each of these treatments.

Fired Projectiles:

There are a wide variety of less than lethal projectiles that are designed to be fired from 12 gauge shotguns to control humans in law enforcement situations. These projectiles are also used by wildlife managers to chase nuisance animals away from areas where these animals are not wanted. These projectiles are designed to strike an individual, which may cause pain, but do not penetrate the skin or cause any permanent injury. Rubber bullets, beanbag rounds, and pepper-spray rounds are three such projectiles that are less than lethal munitions that can be used. Each of these has different designs or ballistics for specific distances. Depending on the type, they can be fired at ranges from 2 yards to over 50 yards.

We will use rubber bullets, beanbag rounds, and pepper-spray rounds designed to be fired at distances greater than 5 yards. These rounds will be fired at cougars facing away from the shooter at distances exceeding 10 yards to avoid striking the cougar in the head or facial area. Cougars will be released from capture and while initially fleeing, cougars may be hit with projectiles up to four times within one treatment with only large muscle masses, such as the rump, being targeted.

Pepper Spray:

Pepper spray may be fired at a cougar from a 12 gauge shotgun or a pepper-ball gun. In these cases the cougar will be hit with the pepper spray in the chest or the ground in front of the animal will be hit in order to get the spray to contact the animal in the face. Such pepper spray rounds are approved for use as less than lethal ammunition and has been used by CDOW for management purposes on bears and cougars.

Alternatively, a cougar will be sprayed in the face by hand while the animal is exiting a cage trap. Such action will ensure that the cougar will associate the action with direct human interaction. When this treatment is administered it will be done following the directions provided with pepper spray sold commercially. This will be a one second spray applied directly in the cougars face at a distance of approximately 2 to 4 meters.

Hound Chases:

Hound chases will be designed to mimic hound capture techniques that are currently being used to capture cougars in open space areas. Cougars will either be chased directly from the property where the incident occurs or will be chased upon release from a cage trap. In either case, hounds will not be released until the cougar is fleeing and is at least 20 m from the hounds. Cougars are faster than hounds, so this approach will avoid any direct contact between the cougar and hounds.

Cougars will be chased until treed, by two to five hounds. In general, chases should be short in duration as cougars tend to tree quickly with hounds in immediate pursuit. After being treed, the hounds will be removed on leashes and the cougar will be left in the tree with no further human contact. However, if cougars opt to not become treed, we will terminate the chase after 1-hour and/or when cougar crosses property boundaries where hounds are not allowed.

Relocation:

In many situations (i.e. neighborhoods) direct application of aversive conditioning will not be possible to prevent secondary incidents within neighborhoods and management actions will require the relocation of the offending animal. In these situations, the cougar will be drug-captured or cage-trapped and transported to an appropriate open-space location or other large property that represents natural cougar habitat. If the cougar has not been previously captured, it will have to be anesthetized and radio-collared. Cougars that are already radio-collared and do not need new collars will generally not be anesthetized when possible. These cougars will be lifted into the back of a truck in a cage trap and relocated. Cougars that must be anesthetized will be reversed with an antagonist drug and awakened prior to transport.

Injuries and Euthanasia:

If an animal is seriously injured (e.g. fractured or broken appendage, vertebrae, pelvis, or jaw, severe dislocation, laceration or any other injury that compromises its ability to survive and/or causes severe pain or distress) during capture, recovery, or relocation, then it will be quickly and humanely euthanized. Cougars will be deeply anesthetized with ketamine or Telazol® and xylazine (IV or IM) and euthanized via rapid IV KCl administration (400-800 mEq). Alternatively, if an injured cougar cannot be handled then euthanasia will be a gunshot to the head or neck with a ≥0.22 caliber magnum rifle or pistol.

APPENDIX IV

COLORADO DIVISION OF WILDLIFE PROTOCOLS FOR FRONT-RANGE COUGAR PILOT RESEARCH PROJECT

Public safety will be the fundamental issue guiding decisions on how to respond to and manage human interactions involving cougars radio-collared for the Colorado Division of Wildlife (CDOW) Front-Range cougar research project. CDOW Administrative Directive W-20 will serve as a basic guideline for managing cougar incidents. These protocols amend Administrative Directive W-20 and provide guidance specific to the Front-Range cougar research project. Human safety will not be compromised for research purposes; original guidelines in Directive W-20 will be explicitly followed for cougar-human interactions defined as 'Level D-Attack' in W-20. These amendments allow additional flexibility and options for managing lower level cougar-human interactions as part of the research and management evaluation process.

Under the management guidelines of Directive W-20, section C, it is specified that any cougar that is tranquilized, handled and released by the Division under the authority of W-20 will be ear-tagged with the appropriate color tag for that region, and will be tattooed on the inside of the ear prior to release. All cougars captured for research purposes will also be ear-tagged with the appropriate color for the region using a tag code starting with an R followed by a three digit number. Cougars will only be tattooed on the inside of the ear if they would have been tranquilized, handled and released by the division under the authority of W-20 regardless of the associated research project. If tattooing does occur, the tattoo will match the code used on the ear-tag.

The purpose of the Front-range cougar project is to expand our understanding of how to better manage cougar-human interactions within the expanding suburban-rural human environment so that we can sustain both the existence of cougars and ensure public safety. For this study to succeed we must capture and radio-collar cougars that live in or near the suburban-rural environment to acquire basic information on cougar movements and prey selection and the potential for cougars to interact with humans. An inherent risk is that some radio-collared cougars will, at some point in time, likely interact to some degree with humans.

These management protocols will provide CDOW managers and researchers an initial menu of choices to consistently guide decisions involving interactions between radio-collared cougars and humans. Cougars will be radio-collared by capturing cougars during planned and systematic efforts or opportunistically during low-level human-interaction circumstances. Protocols address 5 major topics: A) radio-collared cougars, B) project communications, C) research data, D) external media, and E) cooperators awareness of ongoing proposed project protocols and study plan. These protocols will be a 'living document' that will evolve as the research project progresses with the input of field managers and researchers. Changes to the protocols will occur through informed discussions among CDOW managers and scheduled as needed as the research project unfolds or objectives are modified.

A. INTERNAL *CDOW* PROTOCOLS FOR MANAGING FRONT-RANGE RESEARCH RADIO-COLLARED COUGARS

a. Cougar-Human Interaction Levels

Interactions involving radio-collared cougars and humans will span a potential range from benign to dangerous as depicted in the diagram below (**Levels I – V**).

I..Cougar not seen, or detected, by public, nor near human dwellings or infrastructure.

II. Cougar sighted by public or passes near human infrastructure but no level of interaction between cougar and humans and not perceived as a safety concern.

III. Cougar seen by public or passes near human infrastructure with some low level of interaction between cougar and humans but no threatening behavior documented.

IV. Cougar seen by public or passes near human infrastructure with a level of interaction between cougar and humans reasonably considered to be threatening to humans.

V. **Cougar seen by public or passes near human infrastructure with a level of interaction between cougar and humans considered to be dangerous to humans.**

Defining the risk to humans that could be associated with observed cougar behaviors is difficult. We relied on the interpretations of cougar behavior as outlined in the Cougar Management Guidelines and adapted these interpreted levels of risk to our cougar-human interaction Levels 1 -5 (Table 1). Interpretations of cougar behavior would be highly dependent on the observer's skills and experience and the skills and experience of CDOW personnel who would interview the person who had the interaction with the cougar. In threatening or dangerous interactions (Levels 4 and 5), investigating personnel would attempt to determine whether the cougar was defending an animal carcass, kill site, den site, or young.

Table 1. Interpretations of cougar behaviors occurring during cougar-human interactions in order of increasing risk to humans. Columns 1-3, except for 'Attack" behavior, were copied from the 'Cougar Management Guidelines Working Group, 2005, Wild Futures Press' while column 4 represents Levels of Interaction as defined for these Front-range Cougar project protocols.

Human Observation of Cougar Behavior	**Interpretation of Cougar Behavior**	**Level of Likely Human Risk**	**Front-Range Cougar Risk Category**
Cougar opportunistically viewed at a distance	Secretive	Low	Non-threatening, Level 2
Cougar flight or hiding	Avoidance	Low	Non-threatening, Level 2 or 3
Cougar lack of attention, various movements not directed towards person.	Indifference or actively avoiding inducing aggression	Low	Non-threatening, Level 2 or 3
Cougar has various body positions, ears up, may be shifting positions, intent attention, following behavior	Curiosity	Low, provided human response is appropriate	Non-threatening to threatening, Level 3 or 4
Intense staring, following and hiding behavior	Assessing success of attack	Moderate	Threatening, Level 4
Hissing, snarling, vocalization	Defensive behaviors, attack may be imminent	Moderate depending on distance between human and cougar	Threatening, Level 4
Crouching, tail twitching, intense staring, ears flattened like wings, body low to ground, head may be up	Pre-attack	High	Dangerous, Level 5
Ears flat, fur out, tail twitching, body and head low to ground, rear legs "pumping"	Imminent attack	Very High and Immediate	Dangerous, Level 5
Cougar attempts to or actually strikes, claws, or physically comes into contact with human.	Attack	Extremely High	Dangerous, Level 5

An indirect interaction between humans and cougars involves cougars and domestic pets or livestock and such interactions do occur along the Front-range. There is the possibility that pet-cougar interactions may be a signal that a cougar may be inclined to eventually become involved in a cougar-human interaction. Similar to cougar-human interactions, we propose a gradient of cougar-pet/livestock interactions that would be assessed relative to the risk of these cougar behaviors to humans (Table 2). Key distinctions among cougar-pet/livestock interactions are whether the incident happened in an open space area and 'off-leash', within a confined area such as a fenced yard, within animal/livestock holding pen, or while the pet/livestock was on leash/halter and accompanied by a human. Definitions of domestic pet and domestic livestock will follow guidelines established for W-20.

Table 2. Interpretations of cougar behaviors occurring during cougar-pet/livestock interactions in order of increasing risk to humans.

Human Observation of Cougar Behavior Associated with Pet or Livestock	Interpretation of Cougar Behavior	Front-Range Cougar Risk Category when Occurs in Open Space or Similar Areas away from Dwellings	Front-Range Cougar Risk Category When Occurs in Confined Area or On Leash Accompanied by Human
Cougar seen in proximity to domestic pet/livestock	Secretive or possibly Curious	Non-threatening, Level 1	Non-threatening, Level 2
Cougar displays flight or hiding	Avoidance	Non-threatening, Level 1	Non-threatening, Level 2
Cougar approaches pet/livestock, displays various body positions, ears up, intent attention, following behavior	Curiosity or possibly assessing success of attack	Non-threatening, Level 2	Non-threatening, Level 3, providing human response is appropriate.
Hissing, snarling, vocalizations	Defensive behavior, or possible attack	Non-threatening, Level 2	Non-threatening, Level 3, or Threatening Level 4 if pet closely accompanied by a human
Crouching, tail twitching, intense staring, body near or low to ground, rear legs may be 'pumping'	Pre-attack or Imminent Attack	Non-threatening, Level 3	Non-threatening Level 3, or Threatening Level 4 if pet closely accompanied by a human
Cougar kills or injures pet	Attack Occurred	Level 3	Threatening Level 4, or Dangerous Level 5 if pet closely accompanied by a human
Cougar kills or injures livestock	Attack Occurred	Level 3	Threatening Level 4, or Dangerous Level 5 if livestock closely accompanied by a human

b. Decision Process for Evaluating Responses to Cougar-Human Interactions

Abbreviations in this section used in reference to CDOW personnel positions are: District Wildlife Manager (DWM), Area Wildlife Manager, (AWM), Regional Manager (RM), Wildlife Researcher (WR), Wildlife Research Leader (RL), Terrestrial Section Manager (TSM).

At any level of cougar-human interaction, the minimum Decision Response Team will consist of the primary WR, the area DWM, and the appropriate area AWM, unless immediate action is needed to benefit public safety whereby the AWM could act independently of the Decision Response Team. Input and options provided by all 3 of these persons will be assessed by the group which will attempt to reach a consensus decision. The Decision Response Team will objectively weigh the options available for each interaction/situation and make the most appropriate decision that considers the objectives of the research project while maintaining public safety. The decision will be a process of informed judgment. The AWM, or AWM designee, will be the official CDOW representative for the final decision. If the Decision Response Team cannot reach a decision of consensus, then the AWM will engage the RM, RL, and TSM in the decision process. At any level of response, any member of the response team may opt to consult with appropriate adjoining AWMs, RM, RL and TSM. The AWM will be responsible for forwarding situational and decision information to appropriate field personnel via internal email, phone, or via the Public Information Specialist. The CDOW Regional Public Information Specialist will be responsible for providing information to the CDOW Denver Public Information Specialist and the media.

As the level of cougar-human interaction increases from **Level 1 to Level 5**, the decision rationale shall shift and become more weighted towards public safety and preventing further cougar-human interactions as opposed to assessing or moderating cougar behavior. Decisions would therefore shift towards reducing imminent risks to humans.

<u>Examples of Cougar-Human Interaction Decision Options</u>

Example situations representing radio-collared cougar interaction **Levels 1-5** and possible response decision options for responding to the interaction situation are presented below. The known history/behavior of a cougar in relation to levels of human interaction ***will weigh heavily*** on research/management decision options. We emphasize that the situations described below are not all encompassing. Furthermore, there may be rare situations where cougar-human interactions occur that prevent responsive management options because of extraneous factors such as access, snow conditions, or proper identification of the interacting cougar.

Level 1. A radio-collared cougar is known to remain in open space lands, utilize natural prey, and utilize areas near public trails based on radio-telemetry information but is not known to have been seen by the public or involved in any level of interaction.

<u>Research/Management Options:</u>

a. No management prescriptions are applied to the cougar.
b. 'Cougar In Area' signs may or may not posted on nearby public trails.
c. Aversive conditioning tactics are applied to the cougar consistent with the research study design.

Level 2. A radio-collared cougar is known to remain primarily in open space lands and utilize natural prey but is seen by the public near a public trail or is seen or is otherwise documented to occasionally be near human residences or businesses. Additionally, a cougar not previously radio-collared is seen by the public near a public trail or is seen or is otherwise documented to occasionally be near human residences or businesses

<u>Research/Management Options:</u>

a. No management prescriptions are applied to the radio-collared cougar.
b. The cougar is captured and radio-collared and subjected to management prescriptions consistent with the research study design.
c. "Cougar In Area" signs may or may not be posted on nearby public trails.
d. "Cougar In Area" signs are posted near human infrastructure. Persons living or working within affected human infrastructure are directly contacted by CDOW.
e. Aversive conditioning tactics are applied to the cougar consistent with the research study design. Aversive conditioning tactics may include; pursuing cougar with trained hounds, pepper spray application to cougar, or impacting cougar with rubber pellets fired from a shotgun.
f. Cougar is captured for the first time, or recaptured and relocated to an appropriate area of natural habitat consistent with the research study design. Relocation distances shall not be constrained by Directive W-20.

Level 3. A radio-collared cougar is known to use open space lands and areas having considerable human infrastructure. The cougar has been, or is likely to have been seen by the public on more than 1 occasion near human residences, businesses, or schools and there is reasonable concern for public safety but the cougar has not been perceived as exhibiting any current or past level of threatening behavior.

Additionally, a cougar not previously radio-collared is known or likely seen by the public on more than 1 occasion near human residences, businesses, or schools and there is reasonable concern for public safety because of proximity, but the cougar has not been observed as exhibiting any current or past level of threatening behavior.

Research/Management Options:

a. No management prescriptions are applied to the radio-collared cougar but monitoring of cougar behavior is intensified by obtaining multiple telemetry locations per day and attempting multiple visual monitoring sessions per day.
b. The non-collared cougar is captured and radio-collared, subsequent behavior is closely monitored by obtaining multiple telemetry locations per day and attempting multiple visual monitoring sessions per day.
c. Warnings are posted or communicated to the appropriate public using signs or other media.
d. Newly collared or previously collared cougars could be subjected to management prescriptions consistent with the research study design.
e. Aversive conditioning tactics are applied to the cougar consistent with the research study design.
f. Cougar is recaptured and relocated to an appropriate area of natural habitat consistent with the research study design.
g. Cougar is recaptured, additional aversive conditioning tactics are applied to the cougar, and the cougar is relocated to an appropriate area of natural habitat consistent with the research study design.

Level 4. A radio-collared cougar is known to use open space lands and areas having considerable human infrastructure. The cougar has been or is likely to have been seen by the public on several occasions near human residences, businesses, or schools, or there is 1 documented interaction where the behavior of the cougar was reasonably considered to be somewhat threatening to humans but there was no evidence of attacking humans (such as cougar defending an animal carcass, kill site, den site, or young as demonstrated by snarling and vocalizing without stalking). Additionally, a cougar not previously radio-collared is known or likely seen by the public on several occasions near human residences, businesses, or schools, or there is 1 documented interaction where the behavior of the cougar was reasonably considered to be somewhat threatening to humans but there was no evidence of attacking humans (such as cougar defending an animal carcass, kill site, den site, or young as demonstrated by snarling and vocalizing without stalking).

Research/Management Options:

a. Warnings are posted or communicated to the appropriate public using signs or other media, and,
b. The non-collared cougar is captured and radio-collared, or if involving a previously radio-collared cougar, the subsequent behavior of either cougar is closely monitored by obtaining multiple telemetry locations per day and attempting multiple visual monitoring sessions per day.
c. Aversive conditioning tactics are applied to the cougar consistent with the research study design.
d. Cougar is initially captured and radio-collared, or recaptured, additional aversive conditioning tactics are applied to the cougar, and the cougar is relocated to an appropriate area of natural habitat consistent with the research study design.
e. If a cougar is involved in 1, Level 4 interaction and subsequently becomes involved in another Level 4 interaction, the cougar is euthanized.
f. Cougar is captured and euthanized.

Level 5. A cougar, whether previously radio-collared or non-collared, is involved in 1 interaction where the behavior of the cougar was highly threatening to humans or an attack of a human occurred.

Research/Management Options:

a. Actions follow protocols outlined in W-20, Level D-Attack. Attempts are made to capture the cougar and likely euthanize the cougar.

Cougars that must be euthanized will be necropsied by the Colorado State University pathology laboratory with reports provided to the Area Wildlife Manager, primary Wildlife Researcher, and the CDOW Wildlife Health Section. Remains of the cougar, such as head, hide, and tissue will be disposed of based on existing CDOW Regional guidelines with decisions the responsibility of the appropriate AWM.

B. INTERNAL *CDOW* PROTOCOLS MANAGING FRONT-RANGE COUGAR RESEARCH COMMUNICATIONS

This research project will demand frequent and routine communication between Research, Terrestrial biologists, Area Field Operations personnel, and CDOW Regional and Denver Public Information Specialists. Timing of routine field activities such as baiting, trapping, capturing, and handling of cougars and monitoring of radio-collared cougars will be communicated frequently via email or phone in order to achieve coordinated success of such activities and to maintain informed local knowledge of radio-collared cougar behavior and whereabouts.

For cougar-human interaction concerns, the minimum communication tree will be the WR, DWM, AWM, RL, and Senior Terrestrial biologist responsible for the geographic area(s) containing the field research activities and/or inhabited by the radio-collared cougar. Communication should be by cell phone, communications radio, or email as needed for appropriate expediency. Frequency of communication will be decided mutually among these 5 persons. Behavior of individual cougars, and especially changes in behavior of cougars, may necessitate changes in frequency of communication.

As the potential for a cougar-human interaction increases from Level 1 to Level 5 as judged by the Decision Response Team based on acute or cumulated changes in cougar behavior or cougar location, communication frequency will increase, and ultimately communications will be a part of and dictated by the Decision Response Team. At any time the AWM or RL can expand the communications tree to include the TSM, RM, or other CDOW representatives but will also be responsible for sending the communications to these additional levels. The AWM will be responsible for disseminating appropriate information to other appropriate agencies or entities. The AWM will communicate with the Regional Public Information Specialist who will be responsible for coordinating activities with and providing information to the Denver Public Information specialist and the media.

C. INTERNAL *CDOW* PROTOCOLS FOR MANAGING FRONT-RANGE COUGAR RESEARCH DATA

Because the cougar project will be high in profile and involves human safety issues, there will be a constant demand for information because of the perceived ‘need to know’ both by internal CDOW staff and the public. Finding the correct balance between the time spent obtaining information and the time spent distributing information, and to whom, will be a learning process and there will be real costs involved in personnel time. Furthermore, what information is distributed and to whom will be a learning process. The Decision Response Team shall clearly state that no 'real-time' data of cougar activity will be released, primarily because 'real-time' data capabilities will not be possible within the scope of the project.

Under current CORA guidelines, subject to legal interpretation, the raw, non-summarized data obtained during an on-going research project is protected from being obtained by the public via CORA. Examples of raw data would be the actual latitude-longitude or UTM coordinates of cougar locations or locations of critical den sites or kill-caches. Our intent is that this raw data would not be released to the public at-large, not only to protect the cougars as individuals, but also to protect our copyright on the data the agency has obtained. The current lynx reintroduction project sets a precedent for this approach with the caveat that lynx are a threatened species.

As part of the *internal-only* communication process and internal agency ‘knowledge gathering’ the WR will, once per month, provide the appropriate DWM, AWM, RL, and Senior Terrestrial biologist with e-maps (jpeg files) showing the distribution of radio-collared cougars in relation to important topographic and cultural features, so that these CDOW individuals are adequately aware of cougar locations and movement patterns. If cougar behavior changes such as to increase the likelihood of cougar-human interactions, monitoring of the cougar using VHF telemetry will be increased and frequency of internal communications will increase appropriately. The AWM and WR will work together to provide a reasonable frequency of *‘internal-only’* information transfer with both individuals cognizant of the trade-offs between study objectives and needs and human safety issues. Cooperating public land-use agencies will be provided the same information on the same established schedule so as to keep these entities similarly informed.

The AWM, WR, RL, and the Regional Public Information Specialist will cooperatively discuss what type of information is released to the public and when such releases occur. However, as the public learns that CDOW has gained information about cougars in suburban-rural areas because CDOW radio-collared cougars and employed GPS collars and can map detailed cougar locations, post-event, CDOW can expect a variety of demands for information that will need to be addressed and a rising challenge as to how often and in what detail information is provided. The WR will provide a written report by 1 October summarizing the progress of the research project on an annual basis to Area and Regional personnel. This report will be available to the public through our standard Wildlife Research Report distribution process.

D. EXTERNAL COMMUNICATIONS

The Front-range cougar research project will attract the interest, curiosity, and involvement of the media such as newspapers, magazines, radio, and television. Appropriately interacting with the media will be important to maintaining credibility with the public and with providing educational opportunities to the public. Requests by the media for involvement with the research project should be assessed as consistently and appropriately as possible by the Decision Response Team. The Decision Response Team shall clearly state that no 'real-time' data of cougar activity will be released, primarily because 'real-time' data capabilities will not be possible within the scope of the project. We propose that requests be assessed as a dichotomy of cougar-human 'non-incident' and 'incident' requests (Table 3).

Table 3. Guidelines for responding to requests from the media.

Media Involvement Request	**Request Associated with Non-Interaction Cougar-Human Activity**	**Request Associated with Cougar-Human Interaction**
Field Trip on Project Activities	Media schedules time with CDOW Field Personnel; Activity will not jeopardize key field activities such as capturing & handling cougars or create unnecessary safety issues. Researcher identifies most appropriate time for activity to the Decision Response Team. Decision Response Team will notify Regional Public Information Specialist.	Likely Not Appropriate, Follow W-20 Guidelines-
Filming or Photographing Project Activities	Filming/photography to be done by CDOW information specialists who will provide footage/photos to media for media use. Filming coordinated by Decision Response Team. CDOW retains right to review all footage/photos prior to release whether provided by CDOW or private media. Decision Response Team will notify Regional Public Information Specialist.	Follow W-20 Guidelines
Interview of Project Personnel	Requests for interviews of project personnel will be relayed to the Decision Response Team whenever possible. Interviews will occur to minimize interrupting routine project activities. As a minimum, the RL and the AWM will be notified of the request to conduct the interview. Decision Response Team will notify Regional Public Information Specialist.	Follow W-20 Guidelines with the exception that questions pertaining to research project objectives, research results, and research protocols will be deferred to the Decision Response Team for accurate answers.

E. DOCUMENT COOPERATORS AWARENESS OF FRONT-RANGE COUGAR RESEARCH PROJECT

We recommend that representatives of cooperating entities, such as, Boulder County Parks and Open Space, Jefferson County Open Space, and City of Boulder Open Space and Mountain Parks be made aware of these protocols and the CDOW approved research study plan that will guide this project.

_______________________________________ _____________

Bruce L. McCloskey, Director Date
Colorado Division of Wildlife
Approval to Implement These Protocols for
Front-range Cougar Research Project

Colorado Division of Wildlife
July 2007 – June 2008

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of 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, 2007 – June 30, 2008

Author: D. J. Freddy

Personnel: D. J. Freddy

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

After providing 17 years of professional library services for the entire Colorado Division of Wildlife, research librarian Jackie Boss retired in April 2007. The permanent position was retained and a formal hiring process was initiated in Fall 2007. In the interim, the library remained closed to all services. In June 2008, Kay Horton Knudsen was hired as the new research librarian and was scheduled to begin employment with the Colorado Division of Wildlife in August 2008. Under the direction of the new librarian, the electronic/digital capabilities of library services will be expanded to the entire Colorado Division of Wildlife.

WILDLIFE RESEARCH REPORT

COLORADO DIVISION OF WILDLIFE RESEARCH LIBRARY SERVICES

D. J. FREDDY

P.N. OBJECTIVE

Provide an effective support program of library services at minimal cost through centralization and enhancement of accountability for Colorado Division of Wildlife (CDOW) employees, cooperators, wildlife educators, and the public.

SEGMENT OBJECTIVES

1. Continue to improve and modernize library services.
2. Continue to develop, improve, and implement the CDOW Research Center Library web-site.

SUMMARY OF LIBRARY SERVICES

The library was closed during most of FY2007-08 because a new permanent librarian was yet to be hired. As such, the following usual services were temporarily halted:

Maintain and Build Electronic Catalogs of all Research Library Holdings
Acquire Publications for the Research Center Library
Receive Publications Donated to the Research Center Library
Acquire AV Materials for the Research Center Library
Acquire Theses, Dissertations, Documents and Books through Interlibrary Loan
Conduct Literature Searches and Deliver Information to Employees
Archive CDOW Published Manuscripts

Prepared by ____________________________
D. J. Freddy