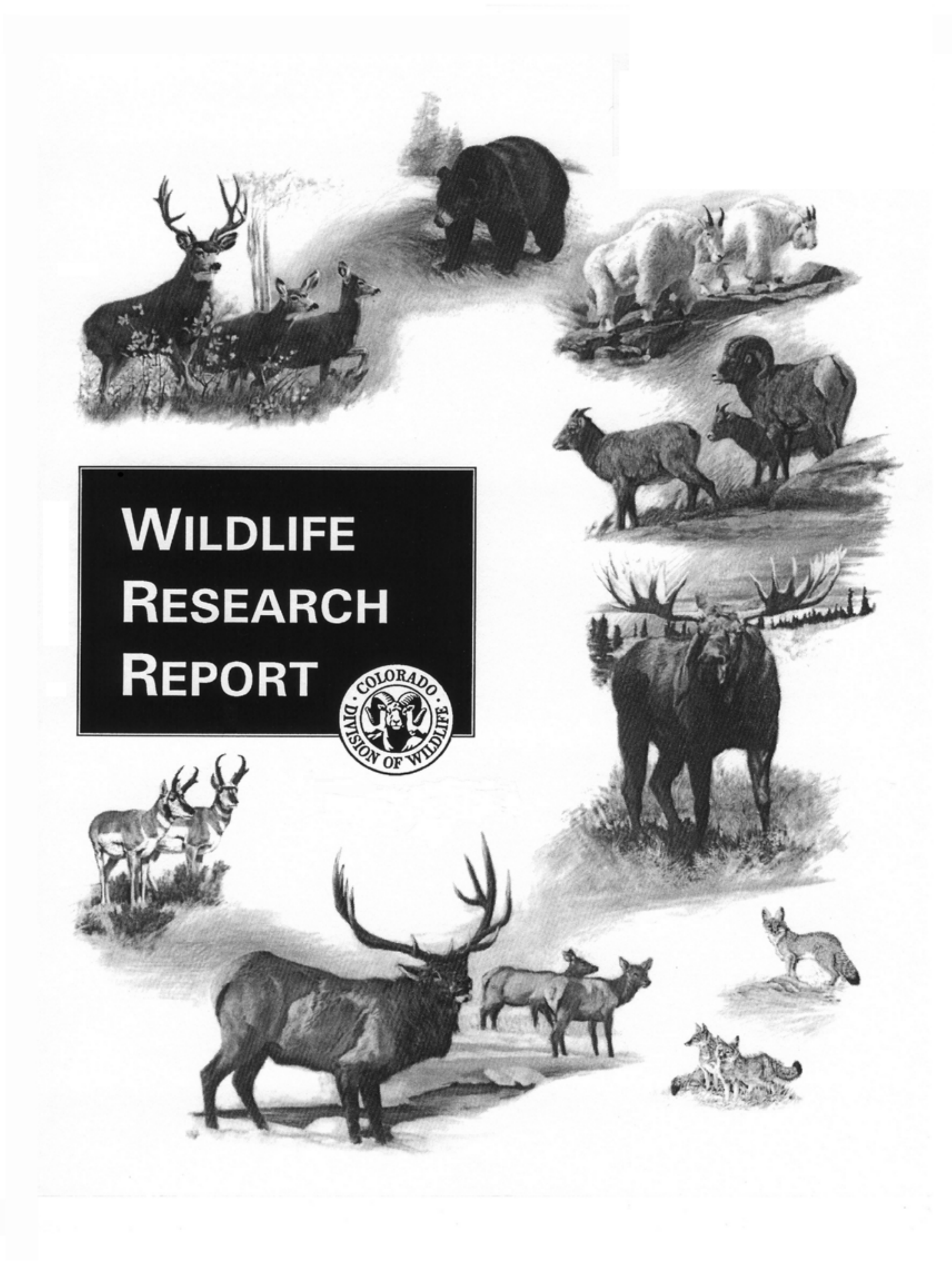
MAMMALS - JULY 2009



WILDLIFE RESEARCH REPORTS

JULY 2008 – JUNE 2009

MAMMALS PROGRAM

COLORADO DIVISION OF WILDLIFE
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Colorado Division of Wildlife
July 2008 – June 2009

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Colorado Division of Wildlife
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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
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Period Covered: July 1, 2008 – August 31, 2009

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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 1999-2006, 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 = 11,580) and satellite (n = 29,258) tracking. Most lynx remained near the core release area in southwestern Colorado. From 1999-August 2009, there were 118 mortalities of released adult lynx. Approximately 29.7% were either human-induced or likely human-induced through either collisions with vehicles or shot. Starvation and disease/illness accounted for 18.6% of the deaths while 37.3% of the deaths were from unknown causes. Of these mortalities, 26.3% 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, 2006 and 2009. No dens were documented in 2007 or 2008. From snow-tracking, the primary winter prey species (n = 604 kills) were snowshoe hare (*Lepus americanus*, annual $\bar{x}$ = 69.4%, SE = 5.6, n = 11) and red squirrel (*Tamiasciurus hudsonicus*, annual $\bar{x}$ = 22.6%, SE = 5.7, n = 11); 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. Three years of a study to evaluate snowshoe hare densities, demography and seasonal movement patterns among small and medium tree-sized lodgepole pine (*Pinus contorta*) stands and mature spruce/fir stands have been completed in 2006-2009 (see Appendix I of this report). A pilot study to evaluate the efficacy of using minimally-invasive monitoring techniques was developed to estimate the extent, stability and potential distribution of lynx throughout Colorado. 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 2008-09 field data collection on lynx habitat use at the landscape scale, hunting behavior, diet, mortalities, and movement patterns.
2. Complete winter 2008-09 lynx trapping field season to collar Colorado born lynx and re-collar adult lynx.
3. Complete spring 2009 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 third and final 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).
6. Complete a pilot study to evaluate the efficacy of using minimally-invasive monitoring techniques to estimate the extent, stability and potential distribution of lynx throughout Colorado (see Appendix II).

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.

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.

Lynx populations in Canada and Alaska have long been known to cycle in response to the 10-year snowshoe hare (*Lepus americana*) cycle (Elton and Nicholson 1942). Northern populations of lynx respond to snowshoe hare lows first through a decline in reproduction followed by an increase in adult mortality; when snowshoe hare populations increase, lynx respond with increased survival and reproduction (O'Donoghue et al. 2001). Therefore, annual survival and reproduction are highly variable but must be sufficient, overall, to result in long-term persistence of the population. It is not known if snowshoe hare populations in Colorado cycle and if so, where in the approximate 10-year cycle we are currently. Given this uncertainty, documenting persistence of lynx in Colorado for a period of at least 10-15 years would provide support that a viable population of lynx can be sustained in Colorado even in the event snowshoe hares do cycle in the state.

Therefore, to document the continued viability of lynx in Colorado beyond the initial reintroduction period, some form of long-term monitoring must be used to determine whether recruitment exceeds mortality for a period of time long enough to encompass possible snowshoe hare cycles. In addition, a challenge facing CDOW is how efforts should be allocated between focusing on monitoring the persistence of those lynx that have established within the core release area (Shenk 2007, Shenk 2008) and those lynx that may be pioneering and expanding into other portions of the state. Reproduction and known recruitment have been observed to be sporadic in the core area. To continue to document lynx reproduction through den site visits and to document survival of those kittens through tracking the adult females in winter looking for accompanying kittens requires a continued trapping effort to capture and radio-collar adult females. Lynx trapping is typically a time consuming and expensive operation as the lynx are territorial with large home ranges that may be entirely located within or largely comprised of inaccessible areas (e.g., wilderness areas). Alternatively, occupancy modeling using minimally-invasive techniques could be a feasible alternative for ascertaining trends in population status.

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.

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. These data collections remain ongoing and all information will be used for future habitat use and survival analyses.

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. 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 April 2009 while the truncated satellite location dataset began October 2000 and extended through April 2009. 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

Preliminary estimates of 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. Final estimates of annual home range size will completed with the addition of data collected through 2009 and in conjunction with current habitat use analyses and publications to be completed in 2009-2010.

Survival

Multi-state mark-recapture models were used to estimate monthly mortality rates and described in detail in Devineau et al. 2009a (*in review*) for the first year post-release and for 10 years post-release in Devineau et al. 2009b (*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, 2008 or 2009. 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 2010.

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 11,580 aerial and 29,258 satellite locations were obtained from the 218 reintroduced lynx, radio-collared Colorado kittens (n = 16) and unmarked lynx captured in Colorado (n = 3) as of August 31, 2009. 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. All 218 lynx released in Colorado, all radio-collared kittens and 3 captured unmarked adults were located at least once in Colorado. The majority of these lynx remained in Colorado. Single use density surfaces were calculated for both truncated aerial and truncated satellite datasets in Colorado up to March 2007 and presented in Shenk (2008). Relative use-density surfaces were also generated for New Mexico, Wyoming and Utah and presented in detail in Shenk (2007). 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.

A single use-density surface was calculated for the satellite non-truncated dataset from April 2000-April 2009 (n = 18,240). The use-density surface was displayed for the satellite non-truncated dataset in Colorado (Figure 3) and for all documented use (Figure 4). 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.

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 analysis of lynx mortality was completed and described in Devineau et al. 2009a (*in review*) to evaluate how the different release protocols used to reintroduce lynx in Colorado (Shenk 2001) affected mortality within the first year post-release. Average monthly mortality in the study area during the first year decreased with time in captivity from 0.205 [95% CI 0.069, 0.475] for lynx having spent up to 7 days in captivity to 0.028 [95% CI 0.012, 0.064] for lynx spending > 45 days in captivity before release (Devineau et al. 2009). The results also suggest that keeping lynx in captivity beyond 5 or 6 weeks accrued little benefit in terms of monthly survival. On a monthly average basis, lynx were as likely to move out (probability = 0.196, SE=0.032) as well as back on (probability = 0.143, SE=0.034) the reintroduction area (i.e., study area) during the first year after release. Mortality was 1.6x greater outside of the reintroduction area.

Detailed analysis of lynx mortality over the first 10 years post-reintroduction was completed and described in Devineau et al. 2009b (*in review*). In summary, 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 31, 2009, CDOW was actively monitoring/tracking 37 of the 100 lynx still possibly alive (Table 2). There are 61 lynx that we have not heard signals on since at least August 31, 2008 and these animals are classified as 'missing' (Table 2). One of these missing lynx is a mortality of unknown identity, thus only 60 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 118 known mortalities as of August 31, 2009 (Table 2). Starvation was a significant cause of mortality in the first year of releases only. The primary known causes of death included 29.7% human-induced deaths which were confirmed or probably caused by collisions with vehicles or gunshot (Table 3). Malnutrition and disease/illness accounted for 18.6% of the deaths. An additional 37.3% of known mortalities were from unknown causes.

Mortalities occurred throughout the areas through which lynx moved, with 26.3% (*n*=31) occurring outside of Colorado. The out of state mortalities included 14 in New Mexico, 5 in Utah, 4 in Wyoming 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, 2006, and 2009. 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 proportion 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). 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). In 2009, 22.7% of females being monitored (*n* = 22) had dens. Two kittens were found at each of these 5 dens, a decrease in the mean of 2.78 (SE= 0.05) kittens per litter found in other years. Sex ratio was also more biased towards female kittens in 2009 (0.4 males/females) than found in previous years.

Den Sites.-- A total of 42 dens were found from 2003-2009. 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. Habitat measurements conducted through 2006 (*n*=37) document that 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 (*n* = 42) were located within the winter use areas used by the females.

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; 10 in 2008 and 11 in 2009. All lynx captured in Colorado from 2005-2009were caught in box-traps.

In addition, as part of the collaring trapping effort, 16 Colorado-born kittens were captured and collared at approximately 10-months of age. Seven 2004-born kittens were collared in spring 2005; 7 2005-born kittens were collared in spring 2006; and 1 2004- and 1 2005 born kitten were first captured and collared in 2009. We also captured 3 adults (approximate age 2 years old) in winters 2006-09 that had no PIT-tags or radio collars. We assume these 3 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 31, 2009 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). There were no apparent commonalities among these animals.

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 31, 2009. 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 a 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 604 kills were located from February 1999-April 2009. We collected over 990 scat samples from February 1999-April 2009 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 30.4% in 2009 to a high of 90.77% in winter 2002-2003. An annual mean of 69.39% (SE = 5.6) 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

Three 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 2006, 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 2009, there were 118 mortalities of released adult lynx. Human-caused mortality factors are currently the highest causes of death with approximately 29.7% attributed to collisions with vehicles or gunshot. Starvation and disease/illness accounted for 18.6% of the deaths while 37.3% of the deaths were from unknown causes. Lynx mortalities were documented throughout all areas lynx used, including 31 (26.3%) occurring in other states (Figure 2, Table 3). Nearly half (14 of 30) of the out-of-state mortalities were documented in New Mexico.

Detailed analysis of lynx mortality was completed and described in Devineau et al. 2009a to evaluate how the different release protocols used to reintroduce lynx in Colorado (Shenk 2002) affected mortality within the first year post-release. Average monthly mortality in the study area during the first year decreased with time in captivity from 0.205 [95% CI 0.069, 0.475] for lynx having spent up to 7 days in captivity to 0.028 [95% CI 0.012, 0.064] for lynx spending > 45 days in captivity before release (Devineau et al. 2009a). The results also suggest that keeping lynx in captivity beyond 5 or 6 weeks accrued little benefit in terms of monthly survival. On a monthly average basis, lynx were as likely to move out (probability = 0.196, SE=0.032) as well as back on (probability = 0.143, SE=0.034) the reintroduction area during the first year after release. Mortality was 1.6x greater outside of the study area suggesting that permanent emigration and differential mortality rates on and off reintroduction areas should be factored into sample size calculations for an effective reintroduction effort. A post-release monitoring plan is critical to providing information to assess aspects of release protocols in order to improve the survival of individuals. Future lynx, as well as other carnivore, reintroductions may use our results to help design reintroduction programs including both their release and post-release monitoring protocols.

Over the 10 years of the reintroduction effort, 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 (Devineau et al. 2009b). 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 (Devineau et al. 2009, in review).

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. Reproduction was again observed in 2009 with 5 dens and 10 kittens found in Colorado. Litter size was smaller than previously documented with only2 kittens found in each litter in comparison to a mean of 2.78 found in previous years. In addition, a sex bias towards female kittens was evident in 2009 which was not evident in prior years. Two litters found in 2009 had both parents born in Colorado, resulting in the first documented third generation Colorado lynx from the reintroduction.

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. Primary winter prey species (*n* = 604) were snowshoe hare and red squirrel (Table 7), which comprised 69.4% (SE = 5.6, *n* = 11) and 22.6.2% (SE = 5.7, *n* = 11) of the annual diet, respectively. 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, 2006 and 2008 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, 2006-07 and 2008-09 (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 that most 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.

FUTURE STUDIES

Monitoring of individuals through telemetry continues in an effort to document the viability of the reintroduced lynx population. However, as time since release increases, battery failure of telemetry collars also increases resulting in fewer released animals having working collars. In addition, few Colorado-born lynx have been captured and fitted with telemetry collars. Although trapping efforts have been conducted in earnest since 2003 to capture and fit animals with working telemetry collars, we have not been able to collar a sufficient number of animals throughout the state to document the status and trends of lynx distribution and demography throughout Colorado from these collared animals. The extent of lynx dispersal and current distribution beyond the Core Research Area and the difficulty of trapping lynx in all areas they inhabit, particularly large tracts of wilderness, requires redesigning our sampling and monitoring efforts to provide valid estimates of lynx distribution. Exploring occupancy modeling using non-invasive techniques may be a feasible alternative for ascertaining trends in population status and forming a basis for a large scale area monitoring program

Therefore, we propose that monitoring lynx distribution would consist of 3 potential primary objectives to document the extent, stability and potential distribution of lynx (at the species and individual level) in Colorado. To estimate patterns in lynx distribution in Colorado a monitoring program could be developed that will: 1) annually estimate the spatial distribution of lynx in the core area and assess changes in lynx distribution over time; 2) detect colonization or expansion of lynx into other portions of the state, and 3) determine whether distribution or persistence are associated with habitat features, measured at the landscape-scale (stand age or composition).

In order to design the most efficient statewide monitoring program, however, we will first evaluate the detection probabilities and efficacy of 3 methods of detection. These include snow-tracking, hair snares and camera surveillance. All of these methods can be conducted with minimal (camera surveillance or collection of hair) or non-invasive approaches (collection of scat samples) to individual animals. A pilot study will be conducted first to establish the most valid, efficient method to estimate the distribution and persistence of lynx. (see Appendix II for the detailed study plan).

Information from the pilot study will then be used to design the most efficient strategy to meet the objectives of larger-scale monitoring programs to detect changes in lynx persistence and distribution as a foundation for assessing whether lynx have become established and will persist in Colorado. First, a minimally invasive monitoring program will be designed and implemented within the Core Research Area to describe lynx distribution and distribution trends in this area. A statewide plan could then be implemented to describe lynx distribution and distribution trends throughout Colorado. This monitoring protocol could result in the development of a standardized methodology that might be used by multiple entities to monitor the status of lynx throughout their range in North America.

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 31, 2009.

Lynx	Females	Males	Unknown	TOTALS
Released	115	103		218
Known Dead	65	52	1	118
Possible Alive	50	51		100
Missing	27	35		61[a]
Monitoring/tracking	20	17		37

[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 31, 2009.

Cause of Death	Mortalities		
	Total (%)	In Colorado (%)	Outside Colorado (%)
Unknown	44 (37.3)	29 (24.6)	15 (12.7)
Gunshot	16 (13.6)	10 (8.5)	6 (5.1)
Hit by Vehicle	14 (11.9)	9 (7.6)	5 (4.2)
Starvation	12 (10.2)	11 (9.3)	1 (0.8)
Other Trauma	8 (6.8)	7 (5.9)	1 (0.8)
Plague	7 (5.9)	7 (5.9)	0 (0)
Predation	6 (5.1)	6 (5.1)	0 (0)
Probable Gunshot	5 (4.2)	4 (3.4)	1 (0.8)
Probable Predation	3 (2.5)	2 (1.7)	1 (0.8)
Illness	3 (2.5)	2 (1.7)	1 (0.8)
Total Mortalities	118	87 (73.7)	31 (26.3)

Table 4. Known lynx mortalities (*n* = 31) and causes of death documented by state outside of Colorado from February 1999 – August 31, 2009.

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
BC06M13	Utah	12/11/08	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 1999-2009. 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	35.3	0	2.67 (0.33)	16	1.0
2004	26	11	46.2	2	2.83 (0.24)	39	1.5
2005	40	17	42.5	1	2.88 (0.18)	50	0.8
2006	42	4	9.5	0	2.75 (0.47)	11	1.2
2007	34	0	0.0	0		0	
2008	28	0	0.0	0		0	
2009	22	5	22.7	-	2.00 (0.00)	10	0.4
TOTAL /MEAN					2.63(0.16)	126	0.98 (0.18)

Table 6. Lynx captured because they were in poor body condition or were in atypical habitat and their fates 6 months post re-release as of August 31, 2009.

Lynx ID	Date of Capture	State Where Captured	Reason For Capture	Date of Re-release	Status 6 Months Post Re-release
BC99F6	3/25/1999	Colorado	Poor body condition	5/28/1999	Dead
AK99M9	3/24/2000	Colorado	Poor body condition	5/3/2000	Missing
AK99F2	4/18/2000	Colorado	Poor body condition	5/22/2000	Alive in Colorado
BC00F7	2/11/2001	Colorado	Poor body condition	N/A	Dead
BC00M13	3/21/2001	Wyoming	Poor body condition	4/24/2001	Alive in Colorado
BC03M08	9/5/2003	Colorado	Poor body condition	1/1/2004	Alive in Colorado
QU04M07	2/2/2006	Colorado	Poor body condition	N/A	Dead
BC04M01	11/5/2004	Utah	Atypical habitat	12/5/2004	Alive in Colorado
QU04F02	4/10/2005	Nebraska	Atypical habitat	5/7/2005	Alive in Wyoming
QU05M08	11/25/2005	Wyoming	Atypical habitat	4/18/2006	Dead
QU04M04	12/5/2006	Utah	Atypical habitat	1/20/2007	Dead in Colorado
YK00F07	12/12/2006	Utah	Atypical habitat	1/20/2007	Alive in Utah
YK05M02	1/1/2007	Kansas	Atypical habitat	2/2/2007	Alive in Iowa
BC04M08	1/22/2007	Wyoming	Atypical habitat	2/15/2007	Alive in Colorado

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
2008-2009	56	30.4	66.1	0	3.5
Total/Mean	604	69.39 (SE=5.6)	22.55 (SE=5.7)	1.17 (SE=0.82)	5.96 (SE=1.92)

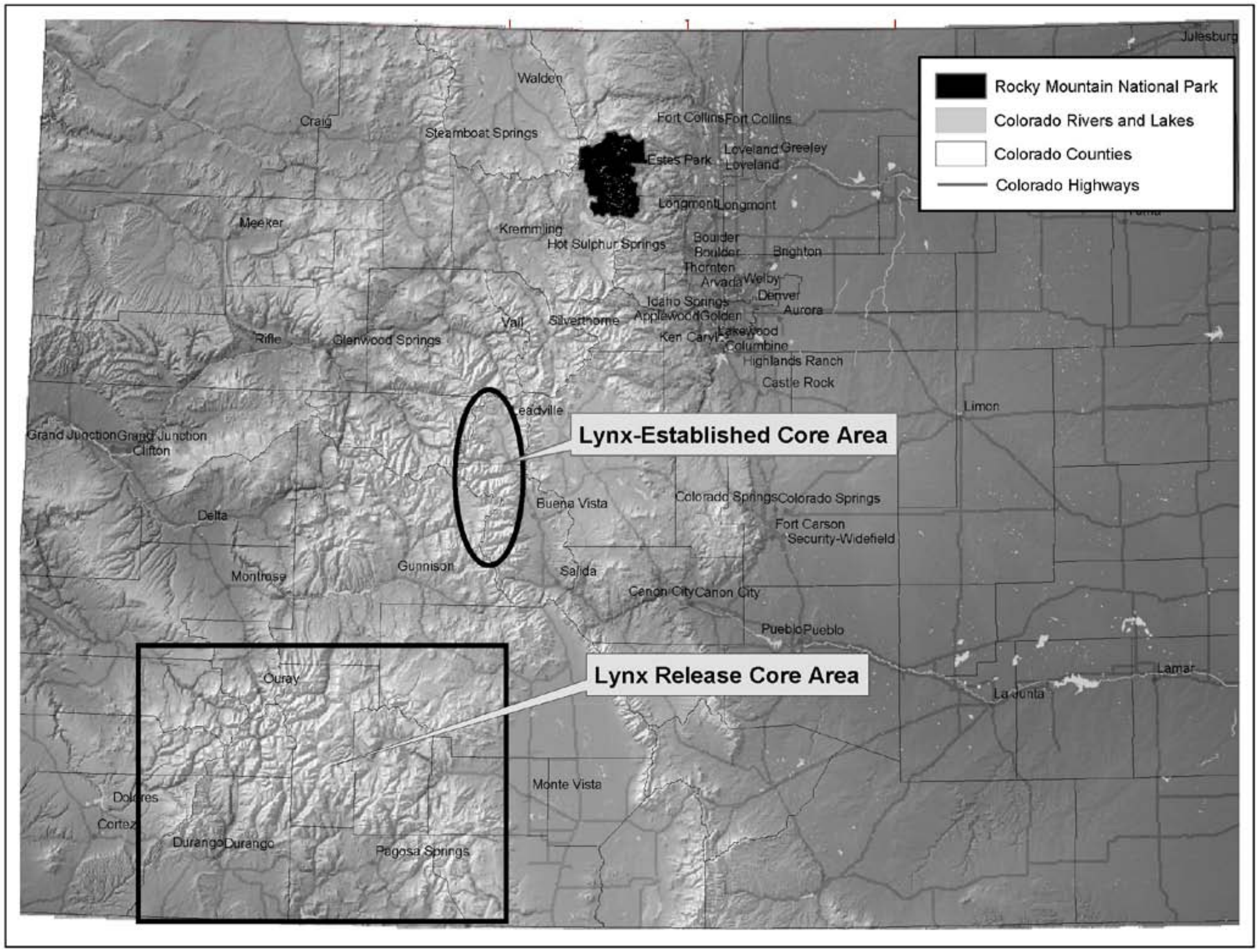

Figure 1. Lynx are monitored throughout Colorado and by satellite throughout the western United States. The lynx core release area, where all lynx were released, is located in southwestern Colorado (outlines in white). A lynx-established core use area has developed in the Taylor Park and Collegiate Peak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

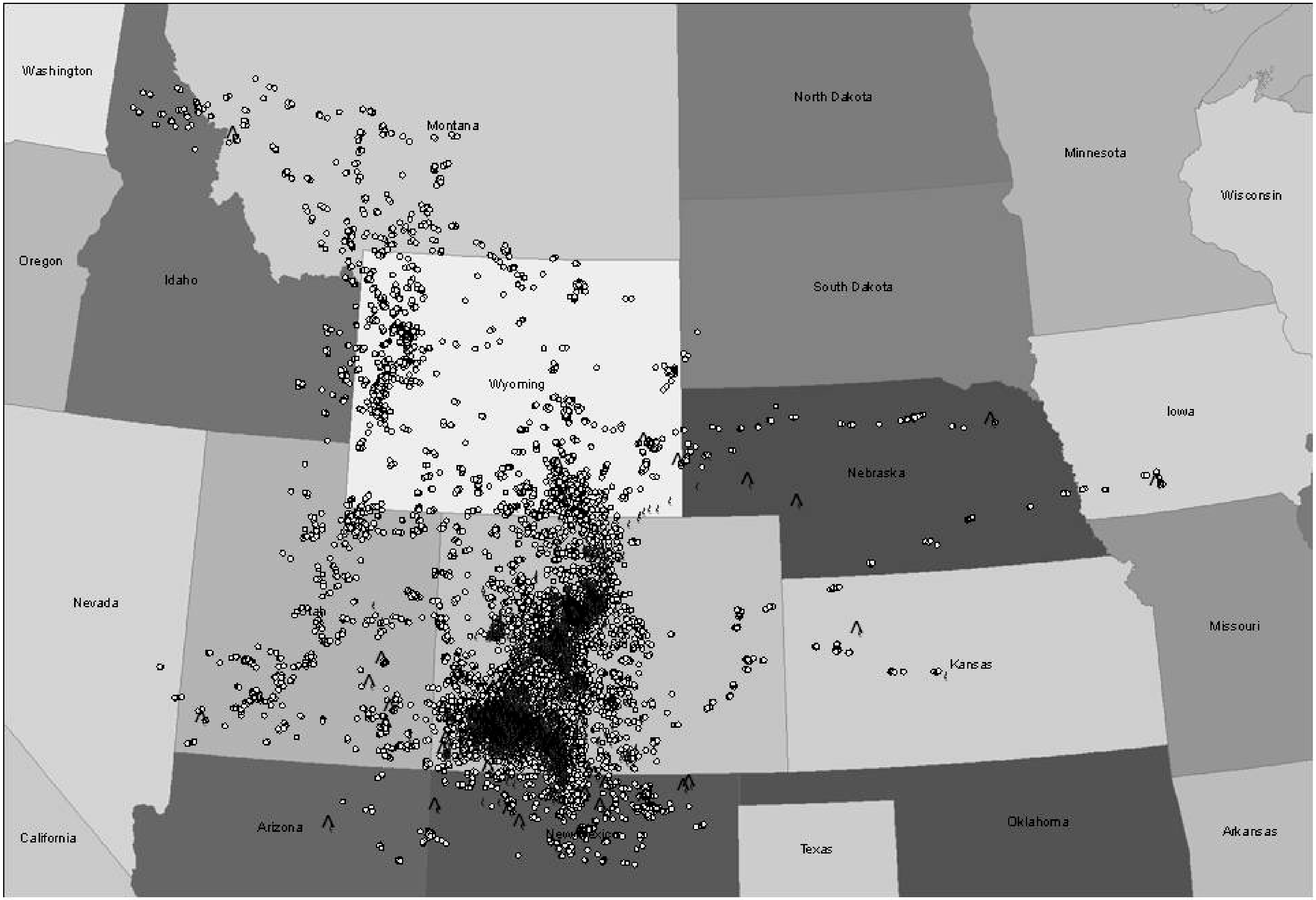

Figure 2. All documented lynx locations (non-truncated datasets) obtained from either aerial (red circles) or satellite (yellow circles) tracking from February 1999 through August 31, 2009 All known lynx mortality locations (n = 112) are displayed as black stars.

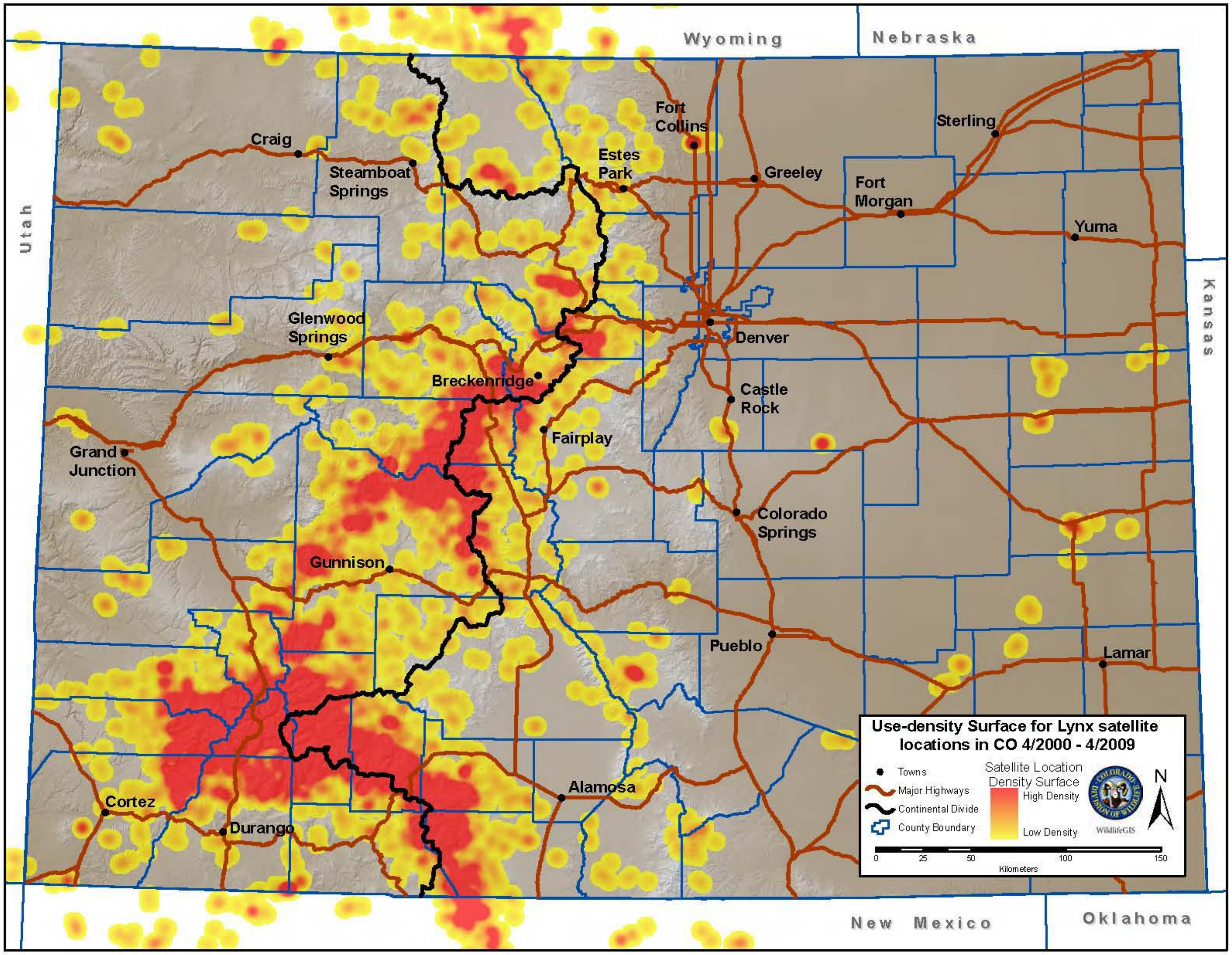

Figure 3. Use-density surface for lynx satellite locations (non-truncated dataset) in Colorado from April 2000-April 2009.

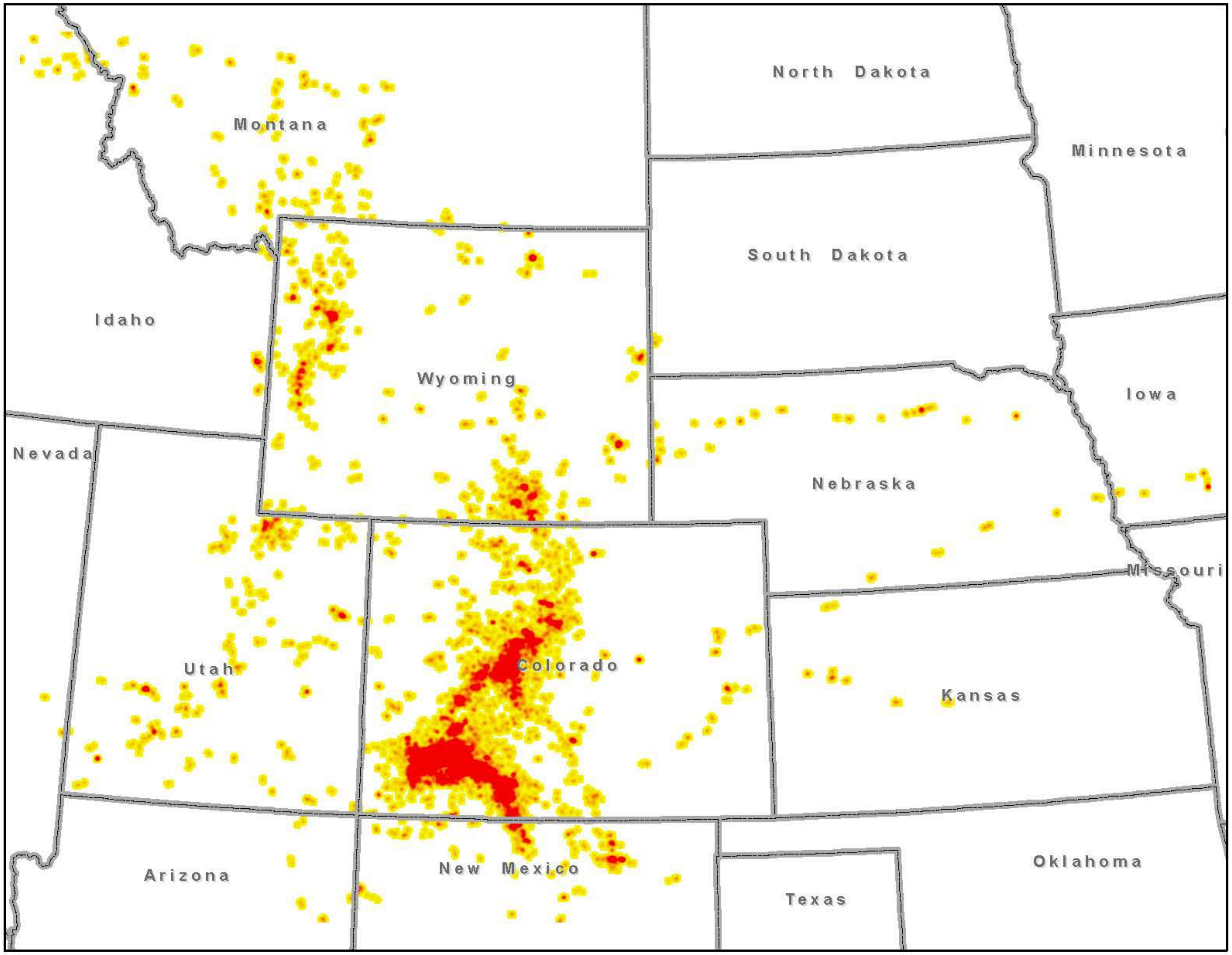

Figure 4. Use-density surface for lynx satellite locations (non- truncated dataset) in Colorado from April 2000-April 2009

APPENDIX I

Colorado Division of Wildlife
August 2009

WILDLIFE RESEARCH REPORT

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

Period Covered: July 1, 2008- June 30, 2009

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 in most winters. 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 Engelmann spruce (*Picea engelmannii*)-subalpine fir (*Abies lasiocarpa*) forests, sapling lodgepole pine (*Pinus contorta*) 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.

Snowshoe hare densities on the study area are low compared to densities reported elsewhere. Within the study area, hare densities during summer were generally highest in small lodgepole stands, followed by mature spruce/fir and medium lodgepole, respectively. Absolute hare densities declined considerably in summer 2007 and rebounded only slightly during summer 2008. Hare density in small and medium lodgepole stands equalized during winters. However, as with summer, overall density was much lower during the second winter compared to the first and rebounded somewhat during the last winter.

Hare survival from summer to winter was relatively high whereas winter to summer survival is quite low. Survival does not appear to differ between stand types or years, although a much more thorough analysis that will include known-fate telemetry data is forthcoming. This combined analysis will provide a final winter-summer estimate, will bring much more information to bear on the estimation process, and should increase precision of all estimates by a fair amount.

WILDIFE RESEARCH REPORT

DENSITY AND SURVIVAL OF SNOWSHOE HARES IN TAYLOR PARK AND PITKIN

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.

INTRODUCTION

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). Analysis of scat collected from winter snow tracking indicates that snowshoe hares (*Lepus americanus*) comprise 65–90% of the winter diet of reintroduced lynx during most winters (T. Shenk, Colorado Division of Wildlife, unpublished data). Thus, as in the far north where the 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 cover (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 shrubs (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.

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. I determined that 2 classes of regenerating lodgepole could provide adequate hare habitat. Thus, I sampled both "small" (2.54-12.69 cm dbh) and "medium" (12.70-22.85 cm dbh) stands regenerating from clearcutting 20 and 40 years ago, respectively (Figure 1). Medium lodgepole stands were pre-commercially thinned 20 years ago; small lodgepole stands have not yet been thinned. Density and demography will be estimated primarily from mark-recapture techniques as data from such approaches can simultaneously provide information on both aspects of hare ecology. However, I will augment both density and demographic analyses with telemetry data to improve the accuracy and precision of estimates. The estimates reported here do not yet reflect addition of telemetry information.

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.

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 conventional "boundary strip" techniques (Wilson and Anderson 1985) in this report. Stand-specific demographic parameters were estimated primarily from capture-mark-recapture methods. As such, apparent survival was defined as the probability that a marked animal alive and in the population at time i survived and was in the population at time $i + 1$. Apparent survival encompassed 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 re-set 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 minimized 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 and development of genitalia. 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 between July 16 – September 22 and between January 20–March 26. 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 was conducted in June and July 2008. 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 × 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 center point (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 Robust Design data type in Program MARK (White and Burnham 1999) and used the Huggins closed capture model (Huggins 1989, 1991) for secondary periods. I obtained estimates of apparent survival ($\hat{\phi}_i$)between each primary period. I followed 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). For this report, I used a relatively simple model where capture probability varied by stand type and season (i.e., winter and summer), while survival was allowed to vary by stand type, season, and time.

RESULTS AND DISCUSSION

During summer, density estimates 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 generally intermediate in density with the exception of the final summer. Telemetry data collected during this last sampling period suggests that many hares were present on spruce/fir sites, but were never caught. Therefore, I believe spruce/fir densities were much higher than actually measured during the final summer. While the relationship in density between stand types remained fairly constant throughout the study, the absolute density of hares dropped considerably from summer 2006 to summer 2007 and rebounded only slightly during summer 2008. It is unclear why this sharp decline occurred, 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 is quite high from summer to winter but very low from winter to summer (Figure 6). However, survival did not appear to differ between stand types or among years of this study. A deeper analysis of these data will occur over the next several months in which known-fate telemetry data will be combined with the current mark-recapture dataset. This combined analysis will bring significantly more information to bear on the process which should improve precision of estimates and may elucidate differences between stands or years that are not yet apparent. A much larger suite of models will be considered in that analysis. Model selection and model averaging (Burnham and Anderson 2002) will be used to more thoroughly assess survival of hares. Additionally, combining telemetry data with the current dataset will allow for another estimate of survival from winter 2009 to summer 2009.

Hare recruitment and finite population growth rate will be estimated as derived parameters following the combined survival analysis.

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 from winter to summer 2007 but has recovered somewhat since then.
- Summer to winter hare survival was consistently high but winter to summer survival is quite low. A more thorough analysis including known-fate survival data is forthcoming. This new analysis should improve precision of estimates and will add a sixth survival estimate to the current time series.

ACKNOWLEDGMENTS

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), and Brent Bibles (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, Caylen Cummins, DeVaughn Fraser, Mark Ratchford, Mike Petriello, Cynthia Soria, Roblyn Stitt, Sarah Ryan, Eric Newkirk, Kyle Heinrick, Matt Strauser, Doug Miles, and Cate Brown. 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.

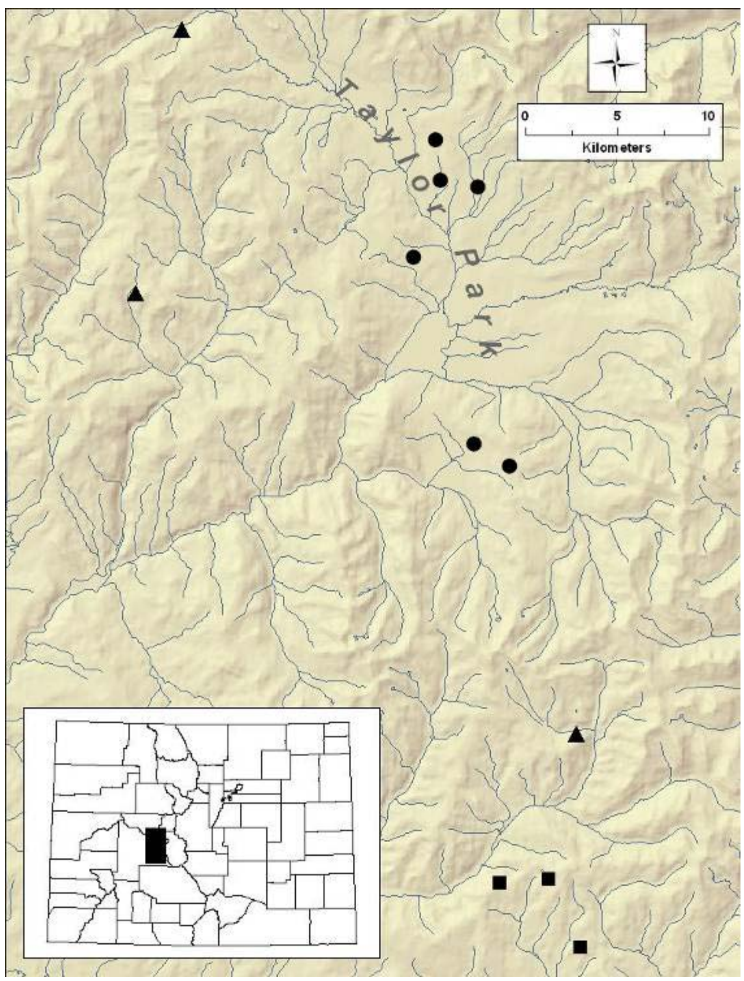

Figure 2. Study area near Taylor Park and Pitkin, Colorado including medium lodgepole (squares), small lodgepole (circles), and spruce/fir (triangles) stands selected for mark-recapture sampling.

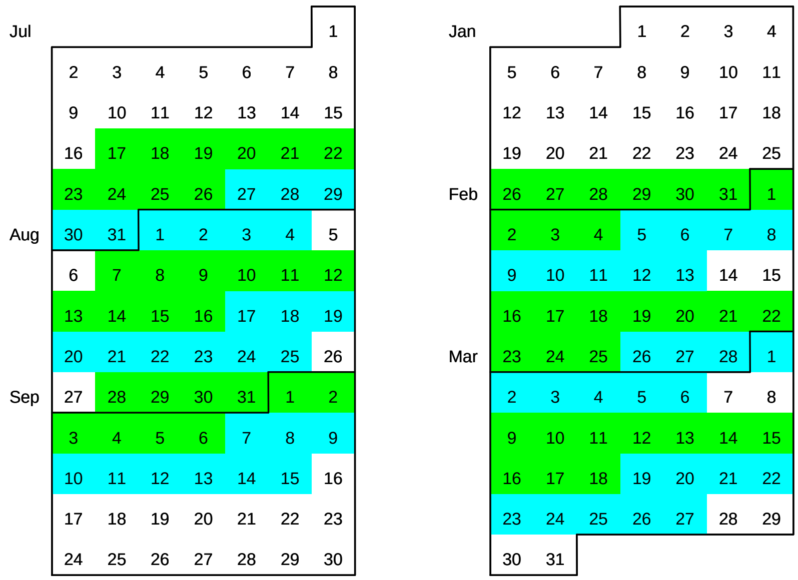

Figure 3. Approximate annual data collection schedule for trapping (■) and telemetry (■). Dates and weeks changed depending on calendar year and pay schedule. During telemetry work, the 6-person crew was divided into 2 teams, only one of which worked at any given time. Monthly locations on radio-collared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

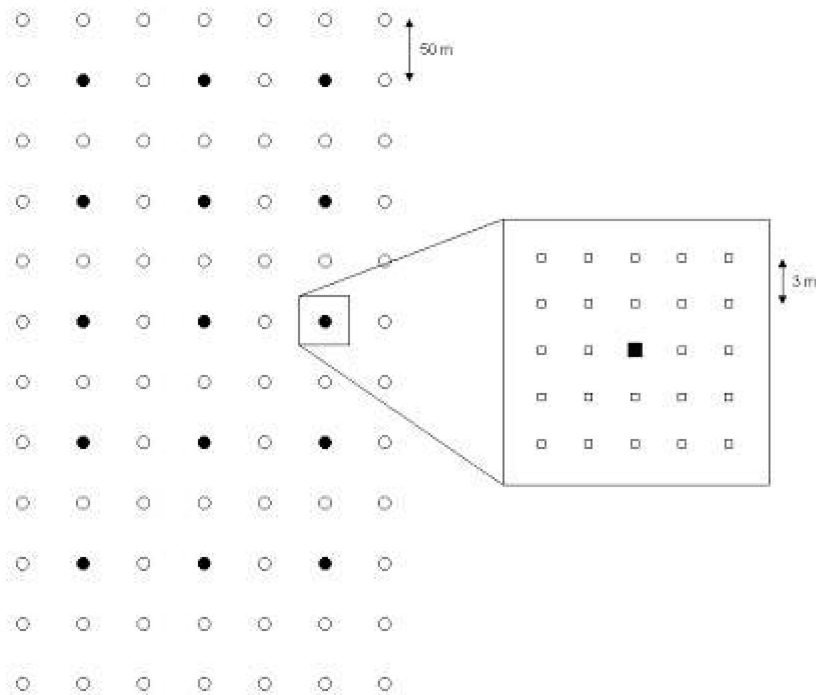

Figure 4. 15 trap locations (•) on 7 × 12 trapping grid where vegetation was sampled by measuring stem density, horizontal cover, downed woody material, and basal area. Additionally, the 25-point grid superimposed on each of the 15 trap locations (inset) was used to quantify canopy cover).

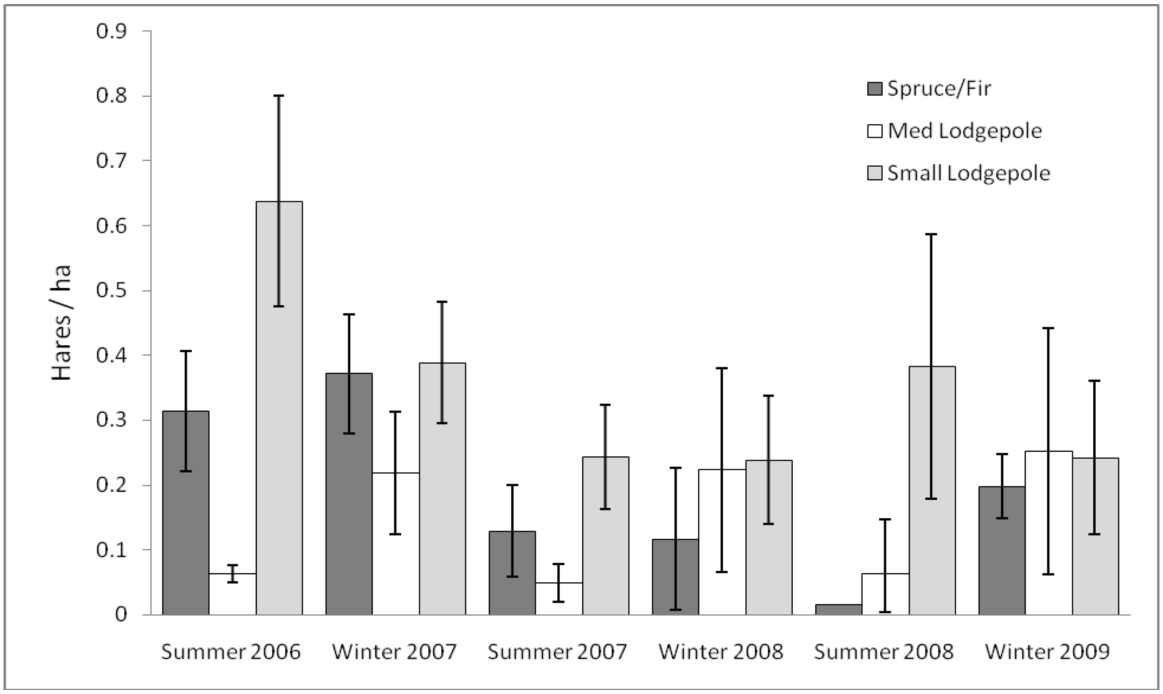

Figure 5. Snowshoe hare density and 95% confidence intervals in 3 types of stands in central Colorado as determined by ½ mean maximum distance moved, summer 2006 through winter 2009.

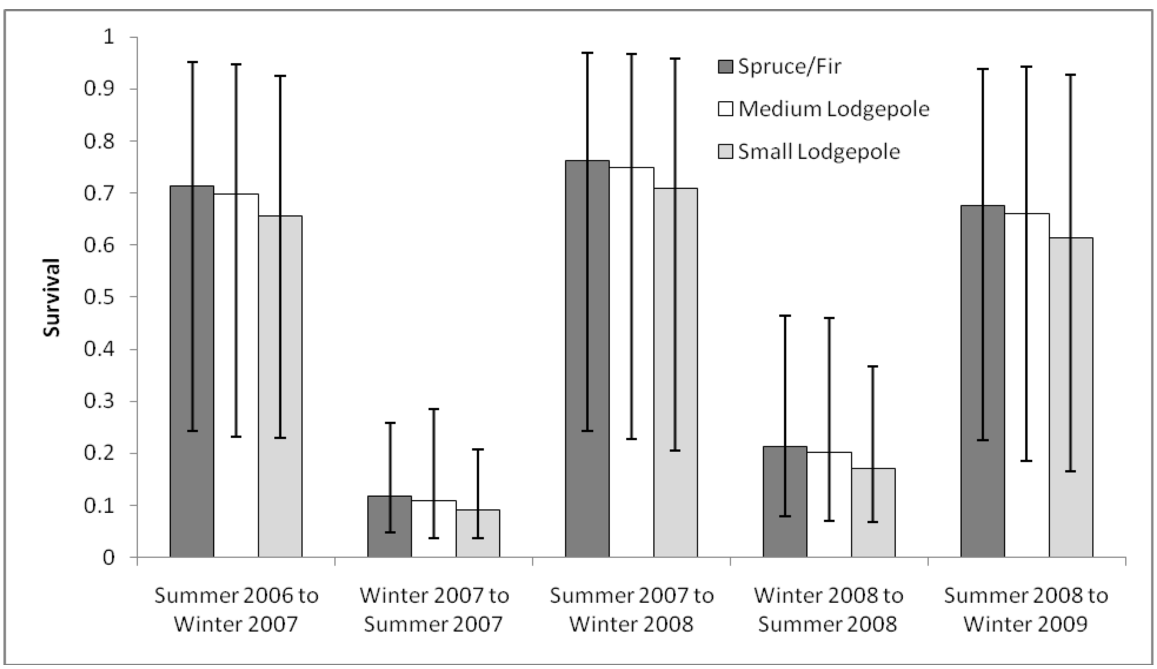

Figure 6. Snowshoe hare survival and 95% confidence intervals between summer and winter sampling seasons in 3 types of stands in central Colorado as determined by mark-recapture, 2006-2009.

APPENDIX II

PROGRAM NARRATIVE STUDY PLAN
FOR MAMMALS RESEARCH
FY 2009 – 10

State of:	Colorado	:	Division of Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	0670	:	Lynx Conservation
Task No.:	3	:	Estimating Potential Changes in Distribution of
		:	Canada Lynx in Colorado: A Pilot Study Plan to
			Estimate Lynx Detection Probabilities
Federal Aid Project No.	N/A		

ESTIMATING POTENTIAL CHANGES IN DISTRIBUTION OF CANADA LYNX IN COLORADO; A PILOT STUDY PLAN TO ESTIMATE LYNX DETECTION PROBABILITIES

Principal Investigator

Tanya M. Shenk, Wildlife Researcher, Mammals Research

Cooperators

Rick H. Kahn, Terrestrial Management Coordinator, CDOW
Paul M. Lukacs, Biometrician, CDOW
Grant J. Merrill, Research Associate, CSU Cooperative Research Unit
Robert D. Dickman, CDOW
Mike Miller, Acting Mammals Research Leader, CDOW

STUDY PLAN APPROVAL

Prepared by:	______________	Date:	________
Submitted by;	______________	Date:	________
Reviewed by:	______________	Date:	________
	______________	Date:	________
	______________	Date:	________
Biometrician Review	______________	Date:	________
Approved by:	______________ Mammals Research Leader	Date:	________

PROGRAM NARRATIVE STUDY PLAN
FOR MAMMALS RESEARCH
FY 2009-10

ESTIMATING THE EXTENT, STABILITY AND POTENTIAL DISTRIBUTION OF CANADA LYNX (*LYNX CANADENSIS*) IN COLORADO: A PILOT STUDY TO ESTIMATE LYNX DETECTION PROBABILITIES

A Research Proposal Submitted By

Tanya M. Shenk, Wildlife Researcher, Mammals Research

A. Background:

The Canada lynx (*Lynx canadensis*) occurs throughout the boreal forests of northern North America. While Canada and Alaska support healthy populations of the species, the lynx is currently listed as threatened under the Endangered Species Act (ESA) of 1973, as amended (16 U. S. C. 1531 et. seq.; U. S. Fish and Wildlife Service 2000) in the coterminous United States. Colorado represents the southern-most historical distribution of naturally occurring lynx, where the species occupied the higher elevation, montane forests in the state (U. S. Fish and Wildlife Service 2000). Thus, Colorado is included in the federal listing as lynx habitat. Lynx were extirpated or reduced to a few animals in Colorado, however, by the late 1970’s (U. S. Fish and Wildlife Service 2000), most likely due to multiple human-associated factors, including predator control efforts such as poisoning and trapping (Meaney 2002). Given the isolation of and distance from Colorado to the nearest northern populations of lynx, the Colorado Division of Wildlife (CDOW) considered reintroduction as the only option to attempt to reestablish the species in the state.

Therefore, a reintroduction effort was begun in 1997, with the first lynx released in Colorado in 1999. To date, 218 wild lynx were captured in Alaska or Canada and 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 the success of the reintroduction effort. Seven critical criteria were identified that must be met before concluding a viable population had been established: 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) site fidelity by lynx to areas supporting good habitat and in densities sufficient to breed, 4) reintroduced lynx must breed, 5) breeding must lead to production of surviving kittens, 6) lynx born in Colorado must reach breeding age and reproduce successfully, and 7) recruitment must equal to or be greater than mortality over an extended (~10 year) period of time (Shenk 2006). The fundamental approach taken to evaluate the status of each of these criteria was to PIT-tag and place telemetry collars on every lynx released and as many Colorado-born kittens surviving to adulthood as possible, followed by intensive monitoring of these animals through satellite, aerial and ground-tracking. All establishment criteria, except (7) have been achieved.

Lynx populations in Canada and Alaska have long been known to cycle in response to the 10-year snowshoe hare (*Lepus americana*) cycle (Elton and Nicholson 1942). Northern populations of lynx respond to snowshoe hare lows first through a decline in reproduction followed by an increase in adult mortality; when snowshoe hare populations increase, lynx respond with increased survival and reproduction (O’Donoghue et al. 2001). Therefore, annual survival and reproduction are highly variable but must be sufficient, overall, to result in long-term persistence of the population. It is not known if snowshoe hare populations in Colorado cycle and if so, where in the approximate 10-year cycle we are currently. Given this uncertainty, documenting persistence of lynx in Colorado for a period of at least 10-

15 years would provide support that a viable population of lynx can be sustained in Colorado even in the event snowshoe hares do cycle in the state.

Therefore, to document viability of the lynx population in Colorado, some form of long-term monitoring must be used to determine whether recruitment exceeds mortality for a period of time long enough to encompass a possible snowshoe hare cycle, and thus, determine the reintroduction a success. A challenge facing CDOW is how efforts should be allocated between focusing on monitoring the persistence of those lynx that have established within the core release area (Shenk 2007, Shenk 2008) and those lynx that may be pioneering and expanding into other portions of the state. Reproduction and known recruitment have been observed to be sporadic in the core area. To continue to document lynx reproduction through den site visits and to document survival of those kittens through tracking the adult females in winter looking for accompanying kittens requires a continued trapping effort to capture and radio-collar adult females. Lynx trapping is typically a time consuming and expensive operation as the lynx are territorial with large home ranges that may be entirely located within or largely comprised of inaccessible areas (e.g., wilderness areas). Alternatively, exploring occupancy modeling using non-invasive techniques may be a feasible alternative for ascertaining trends in population status and forming a basis for a large scale area monitoring program.

Monitoring of individuals through telemetry continues in an effort to document the viability of the reintroduced lynx population. However, as time since release increases, battery failure of telemetry collars also increases resulting in fewer released animals having working collars. In addition, few Colorado-born lynx have been captured and fitted with telemetry collars. Although trapping efforts have been conducted in earnest since 2003 to capture and fit animals with working telemetry collars, we have not been able to collar a sufficient number of animals throughout the state to document the status and trends of lynx distribution and demography throughout Colorado from these collared animals. The extent of lynx dispersal and current distribution beyond the Core Research Area and the difficulty of trapping lynx in all areas they inhabit, particularly large tracts of wilderness, requires redesigning our sampling and monitoring efforts to provide valid estimates of lynx distribution.

We propose that monitoring lynx distribution would consist of 3 potential primary objectives to document the extent, stability and potential distribution of lynx (at the species and individual level) in Colorado. To estimate patterns in lynx distribution in Colorado a monitoring program could be developed that will: 1) annually estimate the spatial distribution of lynx in the core area and assess changes in lynx distribution over time; 2) detect colonization or expansion of lynx into other portions of the state, and 3) determine whether distribution or persistence are associated with habitat features, measured at the landscape-scale (stand age or composition). A pilot study will be conducted first to establish the most valid, efficient method to estimate the distribution and persistence of lynx.

B. Need

The primary goal of the Colorado lynx reintroduction program is to establish a self-sustaining, viable population of Canada lynx in Colorado. The approach taken to reach this goal was to initially establish a lynx population within a core reintroduction area in southwestern Colorado. From this core reintroduction area, lynx could disperse on their own throughout the suitable habitat in the state, or additional reintroductions north of the core area could be conducted. The current lynx population in Colorado is comprised of surviving reintroduced adults, lynx born in Colorado from the reintroduced animals and possibly some naturally occurring lynx.

Research and monitoring efforts over the last 9 years, since the first lynx were released, have focused primarily on monitoring reintroduced animals through VHF and satellite telemetry and estimating demographic parameters of these animals (e.g., Devineau et al. 2009). However, as more of these animals become unavailable for monitoring due to failed telemetry collars, death or movement out of the Core

Research Area, it becomes more difficult to accurately evaluate the status of the entire lynx population in Colorado, including the Core Research Area.

A dual monitoring approach will provide a comprehensive, feasible and valid estimation of the demography of the lynx population throughout the state. The first approach would continue to estimate reproduction within the Core Research Area through the use of telemetry. The second approach would obtain information on the status and trend of the distribution of lynx throughout the high elevation, montane areas of Colorado. Below we first outline the objectives and approach for the statewide distribution study and then propose a pilot study to establish the most valid, efficient methods to estimate the statewide distribution and persistence of lynx.

A minimally-invasive monitoring program can be developed to estimate the extent, stability and potential distribution of lynx throughout Colorado. The primary objectives of the monitoring program will be to document the current distribution of lynx throughout Colorado, the stability, growth or shrinkage of this distribution over time, and to identify potential areas lynx may occupy in the future. The proposed goal would be to annually monitor lynx into the long-term future, with regular analyses of change (e.g., every 5 years). The fundamental structure of such a monitoring program will consist of:

1. Creating a sampling frame of all potential lynx home range sized primary sampling units within Colorado.
2. Annually estimating winter site occupancy and persistence within this sampling frame.
3. Measuring key habitat features that have been documented to be important for both snowshoe hare and lynx at the landscape-scale within annually sampled sites.
4. Predicting potential distribution of lynx throughout Colorado based on these habitat relationships.

In the past, biologists referred to presence/absence as present/not detected, because absence cannot be absolutely determined. This term, however, confuses the status of being present or not present with the activity of either detecting or not detecting an animal. This monitoring program adopts the term presence/absence with the argument that although absence cannot be determined, it can be estimated statistically using a known or estimated detection probability. The indicator used to determine the distribution of occurrence of lynx is *P*, the proportion of primary sampling units (PSU's) (Levy and Lemeshow 1999) with lynx presence. A PSU is a square sampling unit of $75km^2$, the approximate mean size of a lynx winter home range as estimated by a 90% kernel utilization distribution (Shenk 2007). For the statewide monitoring program, the sampling frame would consist of a grid of PSU's laid over all areas of Colorado above 2591 meters (8500 feet). We would then estimate *P* from a random sample of PSU's, using a sample size that is sufficient for attaining an estimate that is within 10% of the actual frequency 90% of the time (see Table 6.1, pg. 168 in MacKenzie et al. 2006).

In order to design the most efficient statewide monitoring program, however, we will first evaluate the detection probabilities and efficacy of 3 methods of detection. These include snow-tracking, hair snares and camera surveillance. All of these methods can be conducted with minimal (camera surveillance or collection of hair) or non-invasive approaches (collection of scat samples) to individual animals. Identification of species will allow us to determine the presence of lynx in a PSU; identifying individual lynx within PSU's will allow for monitoring individual movement patterns across PSU's, reproduction, social structure and possibly apparent survival rates. Such non-invasive techniques are widely desirable because they are considered to have a minimal impact on animals and are inexpensive relative to other methods. Methodologies for identifying the species and individual lynx from blood and scat samples has been completed by the USFS Conservation Genetics Laboratory in Missoula, Montana. Thus, development costs have already been expended (by other agencies) and we need only cover the costs of genetic sample processing and interpretation of results. In order to begin genetic tracking of individual lynx a genetic library should be created from all lynx released in Colorado as part of the Colorado lynx reintroduction program, all documented kittens and lynx of unknown origin captured in Colorado. These samples have already been collected and are currently archived at the CDOW. This genetic library would be used to help determine paternity of Colorado-born kittens for future, detailed reproduction studies, document the dispersal of individuals throughout Colorado and also be available for research conducted on continent-wide studies of Canada lynx (e.g., Schwartz et al. 2002, Schwartz et al. 2003). Collecting scat samples during the pilot study will allow a test of these methodologies for the larger study as well as providing an opportunity to establish the protocols with the conservation genetics lab for collection, transport and analysis of the samples.

This pilot study will provide necessary information to (1) identify the most efficient method of detecting lynx in a PSU and (2) provide an estimate of detection probability within a PSU. This detection probability will then be used to design the most efficient strategy to meet the objectives of larger-scale monitoring programs to detect changes in lynx persistence and distribution as a foundation for assessing whether lynx have become established and will persist in Colorado. First, a minimally invasive monitoring program will be designed and implemented within the Core Research Area to describe lynx distribution and distribution trends in this area. A statewide plan could then be implemented to describe lynx distribution and distribution trends throughout Colorado. This monitoring protocol could result in the development of a standardized methodology that might be used by multiple entities to monitor the status of lynx throughout their range in North America.

This monitoring design will not provide a means of estimating total population size in the state because detection of a lynx may represent a single territorial animal, a breeding pair or a family unit. To obtain a statewide lynx abundance estimate, further efforts beyond this sampling design would be needed to establish the actual or estimated number of lynx in a PSU. Furthermore, this monitoring program is not designed to provide information on reproductive success or estimate survival.

C. <u>Objectives</u>:

The primary objectives of this pilot study are to:

1. Provide information needed to estimate the detection probability (*p*) of 3 different, minimally-invasive methods to detect lynx in a PSU in winter, where lynx are known to occur but in extremely low densities (approximately 1 per 75 km^2).
2. Evaluate and compare the efficacy of the 3 methods of lynx detection in winter within a PSU.
3. Develop a standardized, valid methodology for describing various landscape-scale habitat features, including those important to snowshoe hare, within a PSU.

D. <u>Expected Results or Benefits</u>:

The methodologies developed during this pilot study will be used to develop a valid, non-invasive or minimally invasive inventory and monitoring program to estimate the distribution of Canada lynx in Colorado. The monitoring program will provide information on the annual winter distribution, extent and habitat relationships of these parameters as well as their long-term trend which will be evaluated every 5 years. The protocols developed will be made available to any other agencies or entities that want to monitor lynx. The proposed methodology to estimate and monitor trends in lynx distribution throughout Colorado is designed to make use of technologies (e.g., genetic identification) reliant only on non-invasive or minimally invasive techniques. Such non-invasive techniques are widely desirable because they require minimal impact to the animals and because of their cost efficiencies.

E. <u>Approach</u>

The primary objective of the pilot study is to evaluate the efficacy of the proposed sampling techniques for detecting lynx presence. However, the pilot study will also include qualitative evaluation of all design methods that will be employed in a future, larger research area and statewide monitoring efforts, (i.e., the complete sampling frame).

<u>Sampling Frame and Primary Sampling Unit Selection</u>

The sampling frame will consist of all forested areas in Colorado >2591 m (8500 ft) in elevation. The sampling frame will be randomly overlayed with a contiguous grid of 75 km^2 squares. The size of the square reflects a mean annual home range size of a reproducing lynx in Colorado (Shenk 2007) and similar to home range estimates obtained for lynx in Montana (Squires and Laurion 1999). If a grid square is >50% forested it will be identified as a PSU.

We will assume the lowest detection probabilities for lynx would occur in a PSU occupied by only 1 lynx. Given that we want to estimate lynx detection probabilities under the worst case scenario, we will eliminate all PSU's where we know, through VHF or satellite-tracking, there is more than one lynx occupying the area. We will then select 6 PSU's where we know at least 1 but not likely more than 1 lynx occupies the area.

The assumptions that must be met in estimating occupancy are 1) surveyed sites can be occupied by the species of interest throughout the duration of the study, with no sites becoming occupied or unoccupied during the survey period (i.e., the system is closed), 2) species are not falsely detected, but can remain undetected if present, and 3) species detection at a site is assumed to be independent of species detection at other sites (MacKenzie et al. 2006). For this pilot study, there will be 3 different methods of detection (snow-tracking, hair snares and camera surveillance). Snow-tracking and camera surveillance will be evaluated at 2 different levels of effort; hair snares will be evaluated at 3 levels of effort resulting in 7 total detection approaches. In order to meet the assumptions for estimating occupancy and assuming the different detection approaches don't influence each other, each of the 6 PSU's will be assigned all detection approaches (except for the higher level of hair-snaring) for 3 weeks, allowing for completing surveys of 2 PSU's per month. The increased hair snare effort will be conducted on a PSU the month following the initial survey effort (see below). Thus, by the end of four months each PSU will have had each detection approach applied to it. This will result in 6 spatial replications of each of 3 detection approaches applied to a PSU for 3 weeks. Maximum levels of effort will be applied to each PSU and then the data sub-sampled to evaluate lower levels of effort.

<u>Field Methods</u>

Temporal aspects of the sampling design

In order to verify the detection methods being evaluated in this pilot study are effective at detecting lynx when they are present, we need to conduct the study while we have active radio collars on lynx. Currently, we are continuing to monitor and re-collar lynx within the Core Research Area for data on the demography and movement patterns of the reintroduced lynx. Thus, completing this pilot study at the same time that active monitoring is being conducted in the research area eliminates the need for future radio-collaring efforts to conduct this pilot study.

All data collection will be conducted from January 1-March 31 (Table 1). This is within the time period (October–April) when lynx typically maintain fidelity to a winter home range and when breeding occurs, the period of interest for document long-term persistence of lynx.

Table 1. Data collection and crew work schedule for the six PSU's to be sampled.

PSU	Month	Week	Crew	Activity
1	January	1	I	Set-up detection routes and 5 detection stations with hair snares and cameras; Snow-track (2 10-hour days)
		2	I	Snow-track (4 10-hour days)
		3	I	Snow-track (4 10-hour days)-
		4	I	Snow-track (2 10-hour days); Retrieve cameras and hair snares at the 5 detection stations, place 20 hair snares along the detection route; Travel to next PSU
2	January	1	II	Set-up detection routes and stations with hair snares and cameras; Snow-track (2 10-hour days)
		2	II	Snow-track (4 10-hour days)
		3	II	Snow-track (4 10-hour days)-
		4	II	Snow-track (2 10-hour days); Retrieve cameras and hair snares at the 5 detection stations, place 20 hair snares along the detection route; Travel to next PSU
3	February	1	I	Set-up detection routes and stations with hair snares and cameras; Snow-track (2 10-hour days)
		2	I	Snow-track (4 10-hour days)
		3	I	Snow-track (4 10-hour days)-
		4	I	Snow-track (2 10-hour days); Retrieve cameras and hair snares at the 5 detection stations, place 20 hair snares along the detection route; Travel to next PSU
4	February	1	II	Set-up detection routes and stations with hair snares and cameras; Snow-track (2 10-hour days)
		2	II	Snow-track (4 10-hour days)
		3	II	Snow-track (4 10-hour days)-
		4	II	Snow-track (2 10-hour days); Retrieve cameras and hair snares at the 5 detection stations, place 20 hair snares along the detection route; Travel to next PSU
5	March	1	I	Set-up detection routes and stations with hair snares and cameras; Snow-track (2 10-hour days)
		2	I	Snow-track (4 10-hour days)
		3	I	Snow-track (4 10-hour days)-
		4	I	Snow-track (2 10-hour days); Retrieve cameras and hair snares at the 5 detection stations, place 20 hair snares along the detection route; Travel to next PSU
6	March	1	II	Set-up detection routes and stations with hair snares and cameras; Snow-track (2 10-hour days)
		2	II	Snow-track (4 10-hour days)
		3	II	Snow-track (4 10-hour days)-
		4	II	Snow-track (2 10-hour days); Retrieve cameras and hair snares at the 5 detection stations, place 20 hair snares along the detection route; Travel to next PSU

Lynx Detection Data Collection

Three methods will be evaluated to determine which is most efficient in detecting the presence of lynx. These methods include 1) documenting the presence of lynx tracks in the snow coupled with a DNA sample collection (hair or scat found through snow-tracking), 2) a photograph of a lynx captured by a surveillance camera, or 3) documenting the presence of lynx from a hair DNA sample collected on a hair snag at a scent and visual lure station. All methods will be applied to the same stations within a PSU at the same time. Each method will be implemented in the areas within the selected PSU that a lynx would most likely use. Based on lynx habitat use in Colorado (Shenk 2005), this will include areas of mature Engelmann spruce-subalpine fir forest stands with 42-65% canopy cover and 15-20% conifer understory cover, mean slopes of 16° and elevations above 2591 m. In addition, selection of specific detection stations will be based on natural travel routes or the presence of lynx sign (i.e., tracks or scat). Chances of detecting lynx at these locations will be further enhanced by placing scent and visual lures at these sites. Other feline species may be attracted to these same lures, however, the probability will be low as the study will be conducted in winter and the deep snows at these elevations should preclude species such as mountain lion (*Puma concolor*) and bobcat (*Lynx rufus*) from using these areas. Different levels of sampling intensity will be evaluated for each method to determine the most efficient sampling design.

Establishing Detection Stations & Routes. – To eliminate bias in site selection of detection stations and routes, any known lynx locations in the selected PSU's will not be made available to the field technicians who will be establishing the detection routes, detection stations and collecting the detection data. Field personnel will be provided information to select routes that are both the most feasible and likely areas to detect lynx within a PSU (see above). Detection stations will be set up in areas along those selected routes in areas of good lynx habitat. Commercial scent lures and visual lures (e.g., CD's, waterfowl wings) will be used at each detection station to enhance the probability of drawing a lynx into the station. To increase the probability of lynx using the hair snares, the hair snares will be placed on landscape features at the detection station known to be used as scent posts by lynx such as tree stumps, small trees and broken logs protruding from the snow at approximate head height of a lynx (Schmidt and Kowalczyk 2006).

Snow-Tracking. –Searches for tracks will be attempted by hiking, driving or snowmobiling detection station routes in the PSU once enough snow has accumulated. Due to the inaccessibility of wilderness and roadless areas after significant snowfall, surveys will be conducted in these areas first, while snow accumulations are great enough to detect tracks but not so great as to preclude human access to the area. Once tracks are observed, personnel will follow the tracks until either lynx hair or scat are found and collected or the distance tracks are followed exceeds 1 km. All hair found in day beds or a single scat will constitute a sample. Because lynx are a federally listed species, which can result in regulatory protection, we will eliminate doubt about the presence of lynx by submitting hair or scat sampled to a conservation genetics lab to confirm species identification (see McKelvey et al. 2006). All hair and fecal samples will be submitted to a conservation genetics lab for identification to species and individual, if possible. The distance a track is followed will be limited to 1 km to increase efficiency in lynx detection within the PSU (i.e., it will be assumed it is quicker to find a new lynx track to follow to locate hair or scat than to pursue a single track for more than 1 km; see McKelvey et al. 2006).

Two levels of search effort for lynx tracks will be implemented within a PSU. The first tracking intensity will be 4 consecutive tracking days (although there may be days of no tracking within this period – e.g., days off, cancellation of tracking effort due to weather etc.), the second will be 8 consecutive days of tracking. All PSU's will be snow-tracked for 12 days (3 week field effort, see Table 1). This will provide 3 replicates of a 4-day tracking session and 2 replicates of an 8-day tracking session (replicating one of the 4-day tracking sessions).

Camera Traps. – Digital infrared surveillance cameras (RECONYX RapidFire™ Professional PC85) will be placed at 5 randomly selected detection stations among those that appear the most likely places where lynx would encounter them within the PSU, as defined above. Cameras will be encased in heavy duty 16 gauge steel security enclosure, attached to a tree with a Master Lock ™ Python™ cable lock and powered by 3-volt C-cell lithium batteries.

We will evaluate detection probabilities for 2 levels of camera surveillance, placing either 2 cameras within the grid or 5 cameras. Five cameras will be placed in all PSU's, a random subset of 2 cameras from these 5 will be selected to evaluate the efficacy of the lesser effort. Cameras will run continuously for the 3.5 week period. We can evaluate the most efficient number of days required to detect a lynx and the interaction between number of cameras and length of time cameras are active.

Hair-Snares. - Barbed wire and carpet hair traps, scented with commercial lynx lures as described by McDaniel et al. (2000) will be placed at each of the detection stations within the PSU in areas where lynx would most likely encounter them (see above). A sample will be defined as all hairs from a single hair snare. Each hair sample will be placed in a uniquely numbered paper envelop, and a flame passed under the barbs to remove any genetic material so that the hair snare can be used again without contaminating future samples. All hair samples will be submitted to a conservation genetics lab for identification to species. Hair snares have been shown to be highly reliable for lynx identification to species (Schwartz et al. 2002) but not for individual lynx identification (Lukacs 2005).

We will evaluate detection probabilities of lynx for 3 sample intensity levels of hair snares. First, hair snares will be set up within the PSU at each of the 5 detection stations. A the end of the 3.5 week monitoring session of a PSU, 20 hair snares, at least 100 meters apart (McDaniel et al. 2000) will be placed along the detection route (assuming detection routes will be approximately 25 km long) and collected approximately 1 month later (by the crew leader). Both the detection probability for the 20 hair snares and a random subset of 10 hair snares from these 20 will be selected to evaluate the efficacy of the lesser effort. This larger effort of 20 hair snares will be completed in a PSU after the monitoring conducted by snow-tracking and camera traps as the presence of additional scent stations may affect the use of the 5 camera detection stations.

Data Analysis

We will estimate the probability of detecting a lynx (p) on each of the PSU's for each of the detection methods and level of effort for each of those methods. Aerial or satellite telemetry will be used to confirm the presence of at least one lynx in each of the six sampled PSU's. An evaluation of each of the detection methods will be completed to determine the most reliable, efficient (e.g., cost of equipment, labor) and feasible method of detecting a lynx on a PSU when at least one lynx is present.

Project Schedule

Completed by Dec. 2009

1. Complete sampling frame and selection of primary sampling units.
2. Purchase and test equipment.

Jan.–Mar. 2010

1. Set up detection stations.
2. Conduct lynx snow-tracking surveys.
3. Conduct lynx hair snare sampling.
4. Conduct camera surveillance surveys.
5. Process and submit all genetic samples collected during surveys to a genetic conservation lab (e.g., USDAFS Conservation Genetics Lab in Missoula, Montana, USGS Conservation Genetics Lab in Denver, Colorado).

Apr.–May 2010

1. Data entry, analyses and complete report.

Personnel:
Project Leader: Tanya Shenk, Wildlife Researcher, CDOW
Responsibilities: Design study, work with research associate to implement and complete field work and data entry, complete analysis, write report.

Crew Leader:
Responsibilities: Assist is study design and selection of PSU's, supervise field technician, complete all data entry, and perform other duties as needed associated with the post-release monitoring program and the reproduction study.

Field Technicians
Responsibilities. To establish detection routes, detection stations, place hair snags, cameras and conduct all snow-tracking.

Data Analysis:
Tanya Shenk, Wildlife Researcher, CDOW
Paul Lukacs, Biometrician CDOW
Gary White, Professor Emeritus, CSU
Paul Doherty, Associate Professor, CSU

Estimated Annual Budget:

January 2009 – April 2010	
Salary (Tech III, Jan 2009 –Apr 2010)	$ 15,000
Salary (4 Field Technicians, Tech II Jan 2010 – Mar 2010)	$ 36,100
Travel, housing	$ 5,000
Misc. Supplies/Operating	$ 4,000
Equipment Repair, maintenance (snowmobiles)	$ 5000
Detection cameras (11 @$1,000 each)	$ 11,000
Processing of genetic samples collected during monitoring	$ 4,000
Vehicles (3)	$ 6,000
TOTAL	**$86,100**

G. **Location**:

Southwestern and central Colorado is characterized by wide plateaus, river valleys, and rugged mountains that reach elevations over 4200 m. Engelmann spruce-subalpine fir is the most widely distributed coniferous forest type at elevations most typically used by lynx (2591-3353 m). The Core Reintroduction Research Area is defined as areas >2591 m in elevation within the area bounded by the New Mexico state line to the south, Taylor Mesa to the west and Monarch Pass on the north and east (Figure 1). Project headquarters will at the Fort Collins CDOW Research Center.

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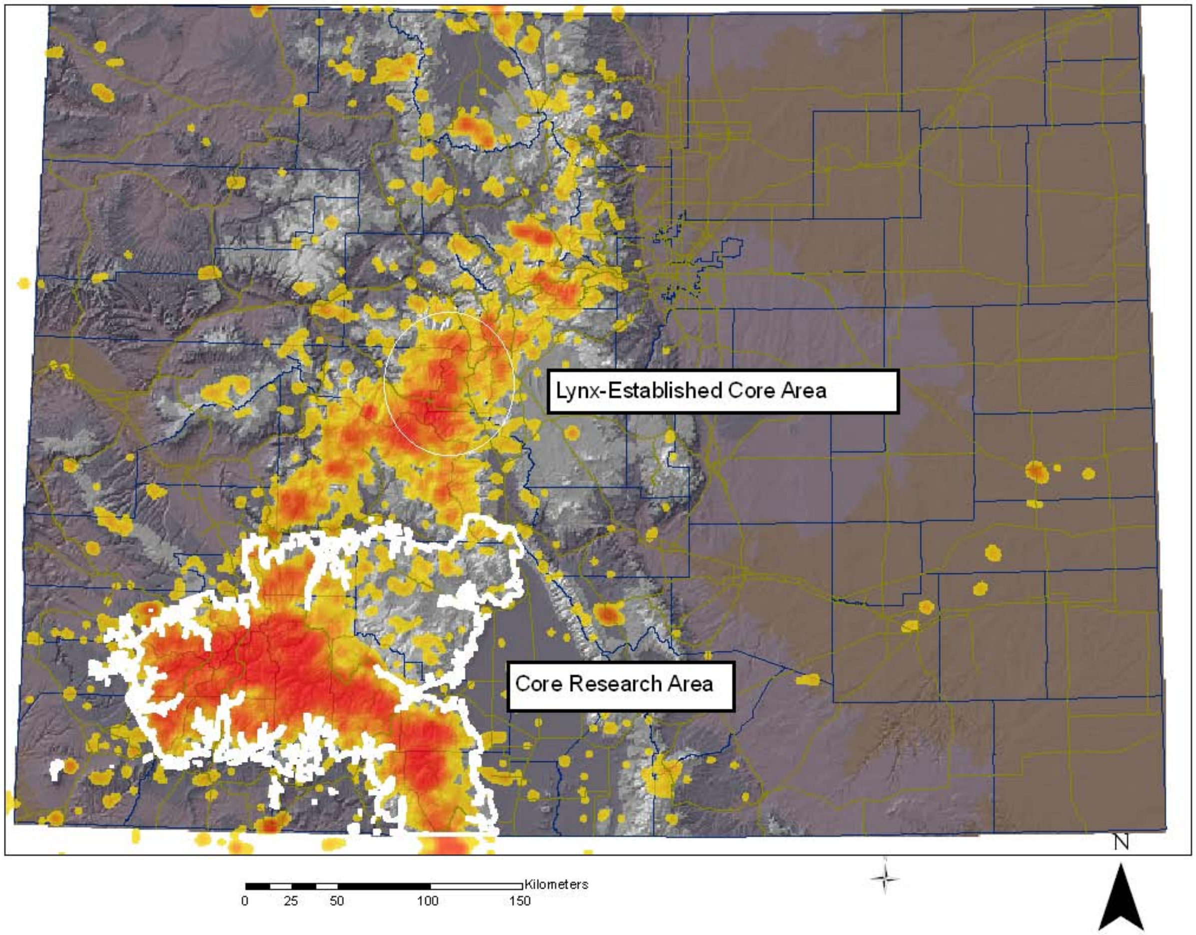

Figure 3. Study area depicting the Core Research Area, Lynx-established Core Area and relative lynx use (red is high intensity use, yellow is low intensity use).

Colorado Division of Wildlife
July 2008 – June 2009

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	3001	:	Deer Conservation
Task No.:	4	:	Development of an Automated Device
		:	for Collaring and Weighing Mule Deer Fawns
Federal Aid Project No.	W-185-R		

Period Covered: July 1, 2008 – June 30, 2009

Authors: C. J. Bishop, D. P. Walsh, M. W. Alldredge, E. J. Bergman, and C. R. Anderson.

ABSTRACT

We initiated an effort to design, produce, and evaluate a trap-like device for mule deer that would automatically attach a radio collar to a ≥6-month-old fawn and record the fawn's weight and sex, without requiring physical restraint or handling of the animal. A passive collaring device would allow biologists and researchers to radio-collar, weigh, and identify sex of ≥6-month-old mule deer fawns with minimal expense and labor when compared to traditional mule deer capture techniques. Such a technique would significantly reduce stress that is typically associated with capture and handling and would eliminate capture-related mortality. We wrote a study plan (Appendix I) and collaborated with students and faculty in the Mechanical Engineering Department at Colorado State University in an attempt to produce a prototype device. We evaluated device components in phases throughout the year using captive deer at the Foothills Wildlife Research Facility (FWRF) in Fort Collins, Colorado. The students did a good job with the mechanical aspects of the design when developing a prototype, but the electrical controls to run the device were too advanced for them. Although the prototype lacked several key components, we were able to evaluate various aspects of the device to guide further development. We tested the device at FWRF and then conducted a field evaluation with free-ranging deer during April and May, 2009. The latter provided extensive information on how deer interacted with the device. Most importantly, we could have collared free-ranging deer without handling them had the device been fully automated. To produce a fully functional device, we are pursuing a contract with a professional engineering firm capable of meeting our detailed device specifications.

WILDLIFE RESEARCH REPORT

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

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

P. N. OBJECTIVE

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

SEGMENT OBJECTIVES

1. Write a study plan to guide development and evaluation of the automated collaring device.
2. Produce a prototype device and conduct a preliminary field evaluation with mule deer.

INTRODUCTION

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

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

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

STUDY AREA

We conducted all evaluations with captive deer at the FWRF in Fort Collins, Colorado. We conducted limited evaluations with free-ranging deer near Fort Collins in north-central Colorado. We plan to conduct extensive field evaluations in the Piceance Basin in northwest Colorado once a fully-functioning device is produced.

METHODS

We wrote a study plan and identified detailed device specifications to guide development of the automated collaring device (Appendix I). We approached Colorado State University's Mechanical Engineering Department to discuss their interest in helping design such a device. In result, the collaring device became a senior design project for 6 CSU engineering students during the 2008-09 school year. We met with the students weekly and provided them a materials budget of $10,000 to produce a prototype device. We conducted staged evaluations of device components during the year by working with captive deer at FWRF. We also conducted limited evaluations with free-ranging deer near the end of the year. Field evaluations focused primarily on how deer utilized and interacted with the device to guide subsequent design and development decisions. We documented utilization and interactions using direct observation and motion-sensor digital cameras. We relied exclusively on digital cameras when we were not on-site during an evaluation. Automation of the collaring device was disabled any time we were not present to prevent any potential harm to deer.

RESULTS AND DISCUSSION

We completed the study plan and detailed device specifications (Appendix I). The student engineers did a good job with the mechanical aspects of the design, but the electrical controls to run the device were too advanced for them. The students therefore approached a private electrical engineering design firm located in Fort Collins – Dynamic Group Circuit Design (DGCD). DGCD donated many hours to the project to help the students produce a prototype. By spring 2009, we were interacting directly with DGCD in an attempt to make the prototype device function. Although the device lacked several key components, a number of aspects were ready for evaluation. We therefore tested the device at FWRF and then conducted a field evaluation with free-ranging deer during April and May, 2009. The latter provided extensive information on how deer interacted with the device. Most importantly, we could have collared free-ranging deer without handling them had the device been fully automated. In order to produce a fully functional device, we are presently pursuing a contract with DGCD because of their capability to incorporate our complete set of design specifications into the device.

SUMMARY

We made significant progress toward developing an automated collaring device for mule deer. We now depend on services of professional engineers to complete prototype development and evaluation. If we are successful, the automated collaring device would allow biologists and researchers to radio-collar portions of their deer samples with minimal time and expense because no animal handling would be required and deer could be collared at any time. Primary time commitments would include baiting sites, moving device(s) among sites, and adding collars to the devices. Once design work is completed, the current estimate for producing one fully functional collaring device is $7,000. At the current net-gunning rate of roughly $550/deer, an individual collaring device would be paid off after 13 deer were collared. Over time, as an individual biologist or researcher accumulated several of these devices, it is reasonable to assume they could collar 25-35 deer with a few weeks of limited effort, amounting to a savings of roughly $14,000-$20,000 per study per year once the devices were paid off. The collaring device would also have distinct benefits for studies in urban environments by providing a non-invasive technique for collaring deer. The collaring device would significantly reduce stress that is typically associated with capture and handling and there should be no capture-related mortality. We also have designed the collaring device so that it should be relatively easy to adjust to target adult deer and other ungulate species. Last, the collaring device would have wide applicability for ungulate researchers and managers beyond Colorado.

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van Reenen, G. 1982. Field experience in the capture of red deer by helicopter in New Zealand with reference to post-capture sequela and management. Pages 408–421 *in* L. Nielsen, J. C. Haigh, and M. E. Fowler, editors. Chemical immobilization of North American wildlife. Wisconsin Humane Society, Milwaukee, USA.

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Prepared by _____________________________

Chad J. Bishop, Wildlife Researcher

APPENDIX I

PROGRAM NARRATIVE STUDY PLAN
FOR MAMMALS RESEARCH
FY 2008-09 – FY 2009-10

State of:	Colorado	:	Division of Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	3001	:	Deer Conservation
Task No.	8	:	Development of an Automated Device
		:	for Collaring and Weighing Mule Deer Fawns
Federal Aid Project No.	W-185-R		

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

Principal Investigators

Chad J. Bishop, Mammals Researcher, Colorado Division of Wildlife
Daniel P. Walsh, Wildlife Health Researcher, Colorado Division of Wildlife
Eric J. Bergman, Mammals Researcher, Colorado Division of Wildlife
Mathew W. Alldredge, Mammals Researcher, Colorado Division of Wildlife
Chuck R. Anderson, Mammals Researcher, Colorado Division of Wildlife

Cooperators

Mechanical Engineering Department, Colorado State University
Michael Sirochman, Veterinarian Technician, Colorado Division of Wildlife
John Broderick, Senior Terrestrial Biologist, Colorado Division of Wildlife
Lisa L. Wolfe, Veterinarian, Colorado Division of Wildlife
Michael W. Miller, Wildlife Health Leader, Colorado Division of Wildlife
Stewart Breck, Research Wildlife Biologist, National Wildlife Research Center

STUDY PLAN APPROVAL

Prepared by:	Chad J. Bishop	Date:	Nov 2008
Submitted by:	Chad J. Bishop	Date:	Nov 2008
Reviewed by:		Date:	
		Date:	
Biometrician:		Date:	
Approved by:	Michael W. Miller Mammals Research Leader, Acting	Date:	

PROGRAM NARRATIVE STUDY PLAN FOR MAMMALS RESEARCH

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

A Study Plan Proposal Submitted by:
Chad J. Bishop, Mammals Researcher, Colorado Division of Wildlife
Daniel P. Walsh, Wildlife Health Researcher, Colorado Division of Wildlife
Eric J. Bergman, Mammals Researcher, Colorado Division of Wildlife
Mathew W. Alldredge, Mammals Researcher, Colorado Division of Wildlife
Chuck R. Anderson, Mammals Researcher, Colorado Division of Wildlife

A. Need

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

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

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

B. Objectives

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

C. Expected Results or Benefits

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

D. Approach

1. *Device Specifications*

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

<u>Collaring Device</u>

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

<u>Radio collar</u>

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

<u>Controls</u>

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

i. Gonads (most reliable)
ii. Antler stubs (less reliable)
5. Obtain photo of captured animal.

2. *Device Design*

Working with engineering students and faculty at Colorado State University, we designed the device in stages using a series of prototypes. For example, we initially constructed the device frame out of cheap material and evaluated it using captive deer at the Foothills Wildlife Research Facility in Fort Collins, CO. We observed deer interactions with the prototype to evaluate device dimensions and placement of the radio collar within the device (Figs. 1, 2). We then modified the prototype accordingly and reevaluated until we were comfortable the dimensions were adequate. Once staged prototype testing was completed, we constructed the various device components using materials we believed were suitable for employing the device in winter field conditions. The device frame was constructed from steel and coated to prevent rust and to lessen wear and tear (Fig. 3). The sides of the device comprise one-gay gates, which prevent entry from outside the device yet allow deer to exit the device at any point they choose. The one-way gates were constructed from aluminum and are being mounted with hinges and springs to allow one-way movement. Deer will enter the device through a 14" x 32" opening in the front of the device; entry dimensions were derived from experience feeding deer fawns in Idaho (G. Scholten, Idaho Department of Fish and Game - retired, personal communication).

The radio collar and collaring mechanism will be positioned at the rear of the device and in front of the bait compartment (Fig. 4). To access the bait, a deer will be required to extend its head and neck through an expandable collar in the fully expanded position (Fig. 5). The radio collar was made expandable using springs, which was patterned after an expandable adult buck collar designed by Michael Sirochman (Colorado Division of Wildlife, personal communication). The springs prevent the collar from being too loose on a small fawn while not being too tight on a large fawn. Expandable fawn collars are not a new concept and have been commonly used elsewhere on 6-month-old fawns and are sold by telemetry companies. The floor of the device will comprise a scale to estimate the animal's weight. The animal's weight will be correctly recorded no matter where the animal stands within the device. A door will close and prevent access to the collaring mechanism/bait compartment if an animal is heavier than 103 lbs, which will allow us to target fawns and prevent older deer from sticking their head through the expanded collar. To be collared, a deer must extend its head through the collar and nudge a joystick positioned in the center of the bait container. The collar will not release unless an animal is heavier than 43 lbs (and less than 103 lbs), which will prevent small animals that may access the bait from triggering the collar. When the joystick is moved and the animal is in the correct weight range, a solenoid will be activated that causes the collar to release around the deer's neck (Fig. 5).

To prevent double-collaring, radio frequency identification (RFID) tags will be attached to all fawn collars. An antenna will be positioned around the opening of the device and connected to an RFID reader. When a previously collared fawn enters the device, the RFID reader will detect the tag and cause the door to the collaring mechanism/bait compartment to close. Digital cameras will be positioned in several locations in the device to photograph the animal when the collar is released. We are currently in the process of assembling the various device components. Once fully assembled and operational, we will evaluate the device with captive deer at FWRF. As necessary, we will make modifications or adjustments to the device until it meets all of our specifications listed above.

3. *Field Testing*

We will evaluate the device with free-ranging deer after we have confirmed the device is working correctly with captive deer. Initially, we will evaluate the device under close supervision in the Fort Collins area to record deer interactions with the trap and to document any problems we may have failed to anticipate. We will be on-site during this initial field testing and we will secure the device entry to prevent access when we're not present. This will allow us to directly observe how animals interact with the device and to free any animals if there is a problem. If there is a problem, we will use a pole or rod to simultaneously pull back the bars forming the one-way gates on the sides of the trap to encourage the animal to exit and/or to assist the animal with exiting. In the unlikely event we were to seriously injure an animal or kill an animal, we would cease the field study and go back to the design phase to address the problem that caused the animal harm. Animals will be released from the device with functioning radio collars and will be monitored one week post-collaring and every few weeks thereafter. Collars will have surgical tubing between the transmitter and the springs, thereby allowing the collar to drop-off when the surgical tubing degrades. We are using surgical tubing because it is the standard technique used to collar 6-month-old fawns in Colorado, and thus we want to test deployment of collars that will actually be used with this device. However, we will use a knife to make small cuts in the surgical tubing to cause the collars to shed from the animals within a few months of being deployed.

Once we have radio-collared several fawns successively without incident and confirmed the device is working correctly, we will begin more widespread testing. During November-December 2009, we will employ ≥1 devices on mule deer winter range to capture fawns as part of ongoing research (Anderson and Freddy 2008). We will document whether the collars cause any ill effects to fawns during the field evaluations by following up on fawns and evaluating whether any mortalities might be related to collaring. We will record numbers of fawns successfully radio-collared and measured relative to person-hours expended setting and moving the device. We will then contrast costs and efficiency with other fawn capture techniques. Finally, we will project the cost-savings over a 10-year period associated with using the device for 3 weeks on each deer research and management study in Colorado.

It is highly unlikely that an animal would require euthanasia in this study because we will not restrain animals and animals will be able to readily exit the collaring device in any of 3 directions. However, if a deer were to suffer a broken leg, back, neck, pelvis, or other similar wound, it will be euthanized by deep anesthesia with the drug combination of ketamine or Telazol© and xylazine (IV or IM) with dosage based on estimated weight, followed by intravenous administration of KCl (~350 mg KCl/ml sterile water, dosed at >50 mg KCl/kg estimated body mass). In situations where administration of KCl is not feasible, then euthanasia will be performed via a gunshot to the head.

E. Location

We will conduct all evaluations with captive deer at the FWRF in Fort Collins, CO. We will conduct limited evaluations with free-ranging deer near Fort Collins in north-central Colorado and extensive field evaluations in the Piceance Basin in northwest Colorado. Anderson and Freddy (2008) provided a detailed description of winter range study sites where 6-month-old fawn mule deer will be captured in the Piceance Basin.

F. Schedule Of Work

Activity	Date
Complete Initial Device Specifications	Sept 2008
Design and Evaluate Prototypes of Device Components	Sept 2008–Feb 2009
Assemble and Evaluate Prototype Device with Captive Deer	Mar 2009
Initial Evaluation of Device with Free-Ranging Deer	Mar–Apr 2009
Set up Contract with Professional Engineering Firm	July–Aug 2009
Complete Design Requirements and Fabricate Working Device	Sept–Dec 2009
Extensive Evaluation of Device with Free-Ranging Deer	Dec 2009–Feb 2010
Prepare Final Report	Mar–Apr 2010
Submit Manuscript to JWM for Publication	May–July 2010

G. Estimated Costs

Category	Item or Position	FY 08-09	FY 09-10
Personnel	Chad Bishop	0.06 PFTE	0.06 PFTE
	Dan Walsh	0.06 PFTE	0.04 PFTE
	Mat Alldredge	0.03 PFTE	0.01 PFTE
	Eric Bergman	0.03 PFTE	0.01 PFTE
	Chuck Anderson	0.00 PFTE	0.03 PFTE
Operating	Device Design and Fabrication	$9,000	$22,000
	Field Evaluations	$1,000	$3,000

H. Related Federal Projects

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

I. Literature Cited

Anderson, C. R., and D. J. Freddy. 2008. Population performance of Piceance Basin mule deer in response to natural gas resource extraction and mitigation efforts to address human activity and habitat degradation. Study Plan, Colorado Division of Wildlife, Fort Collins, USA.

Barrett, M. W., J. W. Nolan, and L. D. Roy. 1982. Evaluation of a hand-held net-gun to capture large mammals. Wildlife Society Bulletin 10:108–114.

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Wolfe, L. L., M. W. Miller, and E. S. Williams. 2004. Feasibility of "test-and-cull" for managing chronic wasting disease in urban mule deer. Wildlife Society Bulletin 32:500–505.

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

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

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

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

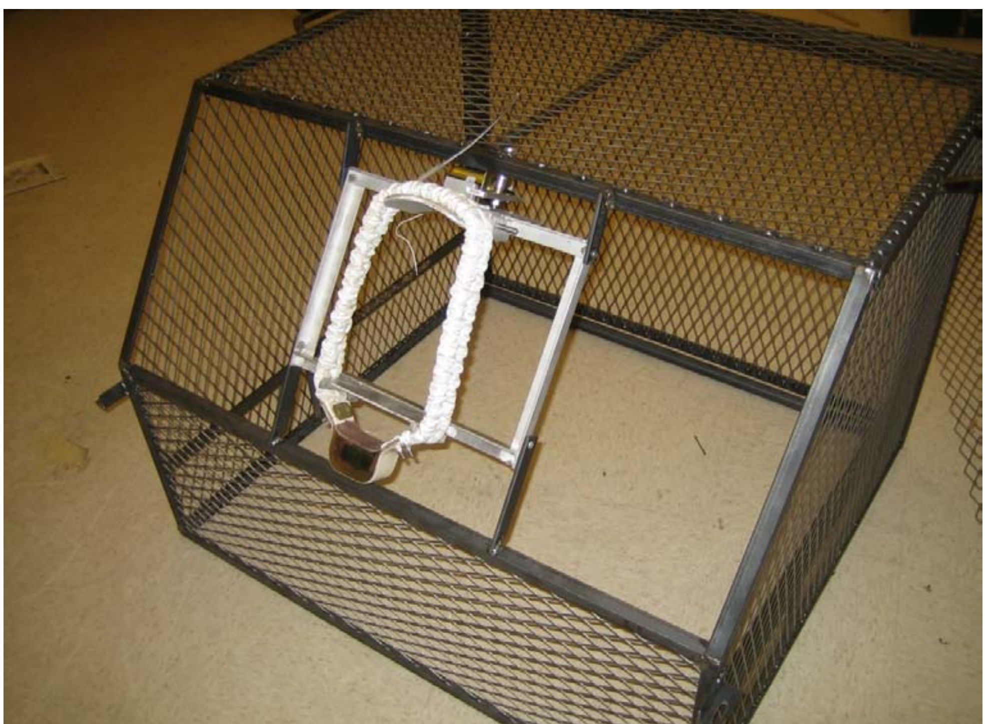

Figure 5. Radio collar in fully expanded position situated at the entry to the bait compartment. Clear plexi-glass will be placed on either side of the collar to prevent deer from accessing the bait from the side yet will allow visibility. When activated, a solenoid positioned at the top of the collaring device pushes a lever that releases the collar.

Colorado Division of Wildlife
July 2008 – June 2009

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	3001	:	Deer Conservation
Task No.:	4	:	Effectiveness of a Redesigned Vaginal Implant
		:	Transmitter in Mule Deer
Federal Aid Project No.	W-185-R		

Period Covered: July 1, 2008 – June 30, 2009

Authors: C. J. Bishop, C. R. Anderson, D. P. Walsh, P. Kuechle, J. Roth, and E. J. Bergman.

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

Our understanding of factors that limit mule deer populations may be improved by evaluating neonatal survival as a function of dam characteristics under free-ranging conditions, which generally requires that both neonates and dams are radiocollared. The only viable technique facilitating capture of neonates from radiocollared adult females is use of vaginal implant transmitters (VITs). To date, VITs have allowed research opportunities that were not possible previously; however, VITs are often expelled from adult females prepartum, which limits their utility. We redesigned an existing vaginal implant transmitter (VIT) manufactured by Advanced Telemetry Systems (ATS) by lengthening and widening wings used to retain the VIT in an adult female. Our objective was to increase VIT retention rates to increase likelihood of locating birth sites and newborn fawns. We placed VITs with modified wings in 59 adult female mule deer and evaluated probability of retention to parturition and probability of locating newborn fawns. Probability of a VIT being expelled during parturition (i.e., success) was 0.766 (SE = 0.0605) and probability of a VIT being expelled ≤3 days prepartum (i.e., partial success) was 0.128 (SE = 0.0477). Thus, probability of a VIT being at least partially successful was 0.894 (SE = 0.0441). Probability of locating at least 1 neonate from successful or partially successful VITs was 0.952 (SE = 0.0333) and probability of locating both fawns from twin litters was 0.588 (SE = 0.0857). We expended approximately 12 person-hours per detected neonate. Our modifications to VIT wings effectively increased VIT retention in mule deer, allowing more neonate fawns to be located per unit cost and effort. Researchers employing VITs with modified wings should require minimal oversampling to offset failures caused by early expulsion. To aid researchers in planning future studies, we developed an equation for determining VIT sample size necessary to achieve a specified sample size of neonates. Our study expands opportunities for conducting research that links adult female attributes to productivity and offspring survival.

WILDLIFE RESEARCH REPORT

EFFECTIVENESS OF A REDESIGNED VAGINAL IMPLANT TRANSMITTER FOR CAPTURING MULE DEER NEONATES FROM TARGETED ADULT FEMALES

CHAD J. BISHOP, CHUCK R. ANDERSON, DANIEL P. WALSH, PETER KUECHLE, JOHN ROTH, AND ERIC J. BERGMAN

P. N. OBJECTIVE

To redesign vaginal implant transmitters (VITs) and evaluate their retention in free-ranging mule deer.

SEGMENT OBJECTIVES

1. Redesign and manufacture the silicone-covered plastic wings used to retain VITs in deer.
2. Evaluate rates of VIT retention to parturition and fawn capture success using the newly-designed wings in free-ranging mule deer.

INTRODUCTION

Mule deer (*Odocoileus hemionus*) fawn production and neonatal survival is influenced by dam characteristics (e.g., body condition, disease status, habitat use). To understand fawn-dam relationships, manipulative field studies are needed that allow fawn production and survival to be estimated as a function of treatments applied to adult females. For example, a study evaluating the effectiveness of winter range habitat treatments on subsequent neonatal survival would require the capture of fawns from marked adult females that verifiably used, or did not use, the habitat treatments the previous winter(s). Such studies depend on a technique that enables newborn fawns to be captured from marked adult females.

The most promising technique employed to capture neonates from marked adult females is use of vaginal implant transmitters (VITs), which are placed in the vagina of adult females during early to mid gestation. In theory, adult females retain VITs until parturition, at which point VITs are expelled at birth sites along with newborn fawns. Assuming VITs are routinely monitored, researchers can promptly radio-locate shed VITs and capture the newborn fawns. Recent applications of VITs in white-tailed deer (*O. hemionus*), black-tailed deer (*O. hemionus columbianus*), and mule deer have been moderately successful (Bowman and Jacobson 1998, Carstensen et al. 2003, Pamplin 2003, Bishop et al. 2007). Vaginal implant transmitters also permit measurement of fetal survival in free-ranging populations, which has important implications in populations where stillborn mortality occurs (Bishop et al. 2007, 2008, 2009). An additional advantage of using VITs to capture neonates may be a reduction in sample bias when compared to capture techniques that rely on opportunistic fawn capture (White et al. 1972, Ballard et al. 1998, Pojar and Bowden 2004). Opportunistic techniques are susceptible to bias because of unequal capture success among vegetation types, road densities, fawn ages, and stages of fawning. When using VITs, neonate captures should be more random as long as VIT signals are monitored with equal intensity during fawning, and assuming the sample of radio-collared does was captured with minimal bias. Thus, VITs could have broad applicability regardless of whether study objectives require that fawns be captured from previously marked adult females.

The most significant problem associated with VITs has been premature expulsion and subsequent failure to locate birth sites or newborn fawns (Bowman and Jacobson 1998, Carstensen et al. 2003, Pamplin 2003, Johnstone-Yellin et al. 2006, Bishop et al. 2007). The VIT has flexible, plastic wings coated with a soft silicone that induce pressure against the vaginal wall to retain the transmitter. The VIT design facilitates a quick, non-surgical insertion process and is safe for the animal (Johnson et al. 2006), but the current wing design is inadequate with respect to retention. Bishop et al. (2007) found that 43% (SE = 4.7) of VITs in mule deer shed prepartum, although capture success was high when VITs shed only 1–3 days prepartum. More importantly, Bishop et al. (2007) found that 25% (SE = 4.1) of VITs shed >3 days prepartum and that retention probability declined as deer body size increased, indicating the retention wings were too small to be effective in larger deer. Based on these results, considerable oversampling would be required in the design of future projects to achieve a target sample size of fawns. Oversampling is not desirable from an animal care and use perspective or from a cost perspective. Thus, the plastic-silicone retention wings of VITs need to be redesigned to allow maximum retention in deer.

To date, the wings used to retain VITs have been purchased from a company in New Zealand (Carter Holt Harvey Plastic Products, Hamilton, New Zealand) that originally produced them for an application in the livestock industry (Bowman and Jacobson 1998). The company manufactured 1 large wing and 1 small wing; the former has been used to produce VITs for bison (*Bison bison*) and elk (*Cervus elaphus*) whereas the latter has been used to produce VITs for deer (Advanced Telemetry Systems, Isanti, MN). Advanced Telemetry Systems (ATS), in cooperation with wildlife researchers, made an initial effort in 2004 to lengthen the retention wings by adding resin to the wing tips. Using these VITs and with antennas cut to the appropriate length, S. P. Haskell (Texas Tech University, unpublished data) reported that 81% of VITs (n = 21) in deer were retained until parturition. Although retention improved, this aftermarket modification was not ideal. The modified wing tips were hard because of the resin addition and thus not ideal for placement in the vaginal canal. Also, there remained a need to further increase retention rate. We therefore developed a study plan (Appendix A), redesigned retention wings of VITs used in deer and similar-sized ungulates, fabricated a new production mold, and evaluated retention rates of VITs in free-ranging mule deer.

STUDY AREA

We conducted our research in Piceance Basin and on Roan Plateau in northwest Colorado (Fig. 1). Our winter range study area comprised 4 study units distributed across much of the Piceance Basin. The 4 units ranged in size from 70 to 130 km^2 and are referenced as Magnolia, Story-Sprague, Ryan Gulch, and Yellow Creek (Fig. 2). These study units are part of a larger research study evaluating effects of natural gas development and mitigation on mule deer (Anderson and Freddy 2008). Winter range habitat comprised predominantly pinyon pine (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*) and secondarily big sagebrush (*Artemisia tridentata*), serviceberry (*Amelanchier utahensis*), mountain mahogany (*Cercocarpus montanus*), bitterbrush (*Purshia tridentata*), and rabbitbrush (*Chrysothamnus* spp.). Drainage bottoms were characterized by stands of big sagebrush, saltbush (*Atriplex* spp.), and black greasewood (*Sarcobatus vermiculatus*), with the majority of the primary drainage bottoms having been converted to irrigated, grass hay fields. Elevations ranged from 1860 m at Piceance Creek in Ryan Gulch to 2280 m in Yellow Creek and Story-Sprague. Our summer range study area comprised roughly 1700 km^2 across the Roan Plateau and Piceance Basin (Fig. 1). Principal summer range habitat types included aspen (*Populus tremuloides*), mountain shrub, oakbrush (*Quercus gambellii*), big sagebrush, and pinyon-juniper. Serviceberry, snowberry (*Symphoricarpos* spp.), and chokecherry (*Prunus virginiana*) were common species in mountain shrub communities. Elevation ranged from 2000 m in Piceance Creek at the mouth of Story Gulch to 2600 m on Roan Plateau.

METHODS

VIT Modification

We worked with ATS personnel to redesign the M3930 VIT presently manufactured by ATS. The existing M3930 has been described in detail elsewhere (Bowman and Jacobson 1998, Carstensen et al. 2003, Johnstone-Yellin et al. 2006, Bishop et al. 2007). Our redesign included changes to the retention wings and the way in which wings are attached to the transmitter body. Specifically, we extended the length and width of the retention wings and added ridges to the wing surface, both of which were intended to increase probability of retention to parturition (Fig. 3). The wings were made of flexible plastic encased in silicone. We initially produced a small number of the newly-designed wings using a relatively inexpensive prototype mold, which met our target specifications and therefore was deemed acceptable. We then manufactured a production mold, necessary to produce a large number of the wings. We incorporated ejector pins into the VIT design that allow wings to be attached to the VIT transmitter body in the field. In the original design, wings were permanently affixed to the transmitter body during the VIT assembly process. Although we only used one wing size in this study, field-attachment will allow researchers to use more than one wing size or style, without purchasing extra transmitters, if additional production molds are manufactured over time. For each wing design (i.e., production mold), extra wings could be inexpensively purchased and available in the field to affix to the fixed number of transmitter bodies. Researchers could then individually fit VITs to animals in the field much in the same way radiocollars are individually fitted.

Deer Capture and VIT Insertion

During late February and early March, 2009, we captured 59 adult female deer utilizing helicopter net guns (Barrett et al. 1982, van Reenen 1982) in conjunction with ongoing research addressing other objectives (Anderson and Freddy 2008). We captured 20 deer in Ryan Gulch, 19 deer in Yellow Creek, and 10 deer each in South Magnolia and Story-Sprague study units. Captured deer were hobbled, blind-folded, and ferried ≤5 km by helicopter to a central handling location. For each captured deer, we used transabdominal ultrasonography (SonoVet 2000, Universal Medical Systems, Bedford Hills, NY) to determine pregnancy status and number of fetuses (Stephenson et al. 1995, Bishop et al. 2007, Bishop et al. 2009). We shaved the left caudal abdomen from the last rib and applied lubricant to facilitate transabdominal scanning using a 3-MHz linear transducer. We fitted each pregnant deer with a VIT and a radiocollar equipped with a mortality sensor and store-on-board global position system (GPS). The mortality sensor was programmed to switch signal transmission from a slow pulse to a fast pulse after remaining motionless for 4 hours. We also measured mass, chest girth, and hind foot length of each deer and estimated age by evaluating tooth replacement and wear (Severinghaus 1949, Robinette et al. 1957, Hamlin et al. 2000). We performed the ultrasound and VIT insertion procedures in a wall-frame tent to minimize disturbance from helicopter rotor wash and adverse weather conditions and to create a dim environment to facilitate ultrasonography.

We sterilized VITs in a chlorhexidine solution prior to insertion in the field. We inserted VITs using a clear, plastic swine vaginoscope (Jorgensen Laboratories, Inc., Loveland, Colo.) and alligator forceps. The vaginoscope was 15.2 cm long with a 1.59 cm internal diameter and had a smoothed end to minimize vaginal trauma. We placed vaginoscopes and alligator forceps in cold sterilization containers with chlorhexidine solution between each use and used a new pair of surgical gloves to handle the vaginoscope and VIT for each deer, and we applied a lidocaine cream to the deer's vagina prior to insertion. To insert a VIT, we folded the wings together and placed the VIT into the end of the vaginoscope. We liberally applied sterile KY Jelly® to the scope and inserted it into the vaginal canal until the tip of the VIT antenna was approximately flush with the vulva. We used previous field experience to guide insertion distance and antenna length (Bishop et al. 2007). We extended alligator forceps through the vaginoscope to firmly hold the VIT in place while the scope was pulled out from the vagina. Each VIT had a temperature-sensitive switch and a pre-cut antenna (6 cm in length) with antenna tip encapsulated in a resin bead to eliminate sharp edges. The temperature-sensitive switch caused the VIT to increase pulse rates from 40 pulses to 80 pulses per minute when the temperature dropped below 32° C. A temperature drop below 32° C was indicative of the VIT being expelled from the deer.

VIT Monitoring and Success Evaluation

We monitored live-dead status and general location of all radiocollared adult females daily from the ground and biweekly from the air during winter and spring. During each morning of June we checked VIT signal status by aerially locating each radio-collared doe having a VIT, weather permitting. We began flights at approximately 0630 hours and completed them by 0900–1100 hours. Early flights were necessary to detect fast signals because temperature sensors of VITs expelled in open habitats and subject to sunlight often exceeded 32° C by mid-day, which caused VITs to switch back to a slow (i.e., prepartum) pulse. When we detected a fast (i.e., postpartum) pulse rate, we used very high frequency (VHF) receivers and directional antennae from the ground to simultaneously locate the VIT and radiocollared doe. We attempted to observe behavior of the collared adult female, establish whether the VIT was shed at a birth site, and search for fawns in the vicinity of the adult female and expelled VIT. In cases where the dam moved away from the VIT (i.e., >200 m), we located the VIT to determine whether shedding occurred at a birth site and whether any stillborn fawn(s) were present and subsequently located the collared dam to search for fawns at her location. We attempted to account for each dam's fetus(es) as live or stillborn. We typically worked in pairs, which allowed us to effectively partition effort across the study area while maintaining reasonable efficiency when searching for neonates (i.e., two people were more effective locating a hidden neonate than one person). We described effort associated with locating fawns by calculating the number of person-hours per fawn. We also quantified cost per fawn by considering all operating and personnel expenses, including capture and VIT costs for adult females.

We assigned the fate of each VIT to one of 4 categories: 1) success (i.e., VIT expelled during parturition), 2) partial success (i.e., VIT expelled ≤3 days prepartum), 3) failure (i.e., VIT expelled >3 days prepartum), or 4) censor. We considered a VIT successful if it was expelled at or near a birth site in conjunction with parturition. For most success events, we located VITs at birth sites and located neonates near the VITs or in close proximity to their dams. In other success cases, we did not locate VITs at birth sites yet we found neonate(s) in close proximity to the dam, sometimes at a birth site a short distance from the expelled VIT. In these cases, we considered a VIT successful if we documented <1-day-old fawn(s) <24 hours after the VIT was expelled. Last, on two occasions, we considered a VIT successful because it was located at an evident birth site even though we could not locate fawns. Birth sites appeared as atypically large deer beds with soil appearing damp and with forbs and grasses flattened and radiating outward, consistent with a deer licking the site clean. On some occasions, fawns and/or placental remains were still present at birth sites when we arrived, providing positive confirmation of birth site characteristics. We considered VITs expelled within 3 days of parturition as partial successes because they provided useful information for locating fawns, consistent with Bishop et al. (2007). We documented such cases by locating a dam's neonates one or more days after the VIT was expelled and comparing neonate age to VIT expulsion date. We censored VITs when adult females died prior to parturition and when adult females were located on private land that we did not have permission to access. In either case, we were unable to evaluate VIT effectiveness. All females dying prior to parturition were still carrying the VITs upon death.

Analysis

We modeled VIT success probability using a generalized logits model (i.e., multinomial logistic regression) in PROC LOGISTIC in SAS (SAS Institute, Cary, NC). We considered 3 levels of success consistent with our description above (success, partial success, failure) and we removed all censors from the dataset prior to analysis. We modeled VIT success as a function of adult female age (yr), mass (kg), hind foot length (cm), chest girth (cm), body fat (%), vegetative cover at VIT expulsion site, and study site. The latter two variables were included to evaluate whether locating fawns, and hence VIT success, was influenced by habitat characteristics. We expressed vegetative cover categorically as low, medium, or high. Low cover class was characterized by limited understory and overstory vegetation with minimal visual obstruction at ground level (e.g., sparsely-vegetated grass, sagebrush, or mountain shrub slopes). Medium cover class was characterized by moderate to heavy vegetative cover within 1 m of the ground but limited cover above 1 m (e.g., typical sagebrush, mountain shrub sites). High cover class comprised moderate to heavy vegetative cover from ground level up to > 1 m with nearly complete visual obstruction (e.g., oakbrush, aspen-mountain shrub, dense serviceberry). We selected among models using Akaike's information criterion adjusted for sample size (AIC_c; Burnham and Anderson 2002). We then estimated the probability of locating ≥ 1 fawn, probability of locating both fawns from twin litters, and probability of locating complete litters from adult females with successful or partially successful VITs. Finally, we developed an equation for determining number of VITs necessary to achieve a specified sample of neonates for planning of future neonatal studies.

RESULTS AND DISCUSSION

We observed 9 adult female mortalities during winter and spring, which was much higher than expected. There was no evidence to suggest VITs were related to the mortality events. Several of the mortalities occurred within 1 week of capture and were likely capture-related. We were unable to ground-monitor 2 other adult females during the fawning period because they were located on private land that we did not have permission to access. One other adult female was inadvertently deleted from the aerial monitoring list due to miscommunication. We censored these 12 deer because they did not permit evaluation of VIT effectiveness, resulting in a sample size of 47 deer. The model of VIT success probability with the lowest AIC_c included only the intercept (no. parameters = 2, AIC_c wt = 0.271; Table 1). Probability of a VIT being expelled during parturition (i.e., success) was 0.766 (SE = 0.0605) and probability of a VIT being expelled ≤3 days prepartum (i.e., partial success) was 0.128 (SE = 0.0477). Thus, probability of a VIT being at least partially successful was 0.894 (SE = 0.0441). For comparison, using the original VIT wing design, Bishop et al. (2007) found that probability of VIT expulsion during parturition was 0.447 (SE = 0.0468), and probability of VIT expulsion during parturition or ≤3 days prepartum was 0.623 (SE = 0.0456). We employed the same methodology as Bishop et al. (2007), except for the wing modification. Assuming the 2 studies are comparable, our wing modification increased VIT retention to parturition by 0.319 (SE = 0.0765) and VIT retention to within 3 days of parturition by 0.271 (SE = 0.0634).

High VIT success probability may largely explain why VIT retention did not vary as a function of any covariates we evaluated. Bishop et al. (2007) found that larger deer were more likely to expel VITs prematurely, which was the basis for modifying VIT wings. Our results suggest the wing modifications effectively reduced premature expulsion in larger deer.

We located 58 neonates and 2 stillborns from 42 adult females with successful or partially successful VITs. For these 42 females, probability of locating at least 1 neonate was 0.952 (SE = 0.0333), probability of locating complete litters was 0.667 (SE = 0.0745), and probability of locating both fawns from twin litters was 0.588 (SE = 0.0857). Fawn location success did not differ between successful and partially successful VITs. Our probability estimate of locating twins is conservative because we did not place radio collars on fawns, and therefore, we could not relocate radiocollared fawns to search for their siblings. The technique of relocating a radiocollared fawn to locate its sibling was found to be successful in a previous study in Colorado (Bishop et al. 2009). During this earlier study, when a dam was known to have twin fetuses yet only one fawn was located and radiocollared during the initial capture attempt, the sibling fawn was found 45% of the time (10/22) by relocating the initial radiocollared fawn 1–2 days post-capture (C. J. Bishop, CDOW, unpublished data). Based on this rate, we would expect our probability of locating both fawns from twin litters to be roughly 0.77 had we radiocollared fawns during our study.

On average, we located 1.3 neonates per VIT excluding censors and 1.0 neonate per VIT including censors. Censors need to be considered when planning VIT sample sizes for neonatal studies. Censored VITs represent the reduction in VIT sample size caused by prepartum mortality of adult females or any factor preventing access to adult females during the fawning period. We developed the following equation for determining the expected number of neonates to be encountered from a sample of VITs:

$$n_{Neo} = n_{VITs} S_{AdF} R_{VIT} p_{Fawn} [1 + T_{AdF} p_{Twins}],$$

where

n_{Neo} = targeted neonate sample size.
n_{VITs} = sample size of adult females with VITs.
S_{AdF} = probability adult female survives to parturition and is accessible.
R_{VIT} = probability of VIT retention to within 3 days of parturition.
p_{Fawn} = probability of detecting ≥1 fawn.
T_{AdF} = probability adult female has twin fetuses.
p_{Twins} = probability of detecting twin neonates given an adult female has twin fetuses.

The purpose of the above equation is to allow determination of VIT sample size once a target neonate sample size has been identified. Thus, it makes more sense to rearrange the equation as:

$$n_{VITs} = \frac{n_{Neo}}{S_{AdF} R_{VIT} p_{Fawn} [1 + T_{AdF} p_{Twins}]} .$$

Incorporating our estimates of retention and detection probabilities, we recommend use of the following equation to plan neonatal studies incorporating VITs with our modified wing design:

$$n_{VITs} = \frac{n_{Neo}}{(0.85) S_{AdF} [1 + (0.59) T_{AdF}]} .$$

We expended roughly 700 person-hours during the fawning period to locate 58 neonates and 2 stillborns, or approximately 12 person-hours per fawn located. This estimate includes hours spent searching for fawns from adult females with failed VITs, although we were never successful in these attempts. Bishop et al. (2007) expended 7 person-hours per captured fawn from adult females with successful VITs, 16 person-hours per fawn from females with partially successful VITs, and 42 person-hours per fawn from females with failed VITs and females not receiving VITs. Given their observed VIT success rates, Bishop et al. (2007) would have required approximately 1,315 person-hours to locate 60 neonates, or 22 person-hours per fawn. Assuming these studies are comparable, increased VIT success associated with our modified wing design resulted in a 45% reduction in labor required to locate a fawn from a radiocollared adult female.

We expended $31,000 to net-gun our sample of adult females, $15,000 on VITs, $10,000 on fixed wing monitoring, and $20,000 on personnel. Thus, we expended approximately $1,267 per neonate located. We did not include adult female radio collars in our cost estimate because we used GPS collars to meet other research objectives, yet VHF collars would have sufficed for locating neonates. Assuming VHF collars were used on adult females at a rate of $250 per collar, our cost estimate becomes $1,520 per fawn. The VIT technique is therefore effective but expensive to employ. Actual cost of the technique depends on what costs are already incurred to meet other research objectives. For example, in Colorado and elsewhere, researchers have begun estimating late-winter deer body condition as a response variable to accompany survival estimates. In these cases, adult female capture and radio collar costs are already accounted for in the base study, and thus, incorporation of VITs to facilitate neonate capture becomes much more cost-effective. In our study, where adult female capture and collar costs were covered by ongoing research efforts, the added cost of incorporating VITs and neonate capture was $750 per fawn.

SUMMARY

Use of VITs in well-designed field studies will increase our understanding of deer limiting factors and population limitation by allowing investigators to link fawn production and survival to dam characteristics under free-ranging conditions. A primary drawback of VITs in deer has been the failure of many adult females to retain VITs to parturition. We increased VIT retention in mule deer by lengthening and widening wings used to retain a VIT in the vaginal canal. Researchers employing VITs with our modified wing design should require minimal oversampling to offset failures caused by early expulsion, thereby rendering the technique more cost-effective and reliable. Our findings provide explicit guidance for planning a fetal-neonatal deer study involving VITs.

Improved VIT effectiveness facilitates increased detection of twins, and therefore, increased likelihood of radio-collaring complete litters. Determining fates of complete litters improves our ecological understanding of fawn production and recruitment and allows assessment of individual reproductive fitness if the same females are captured across years. However, it is not reasonable to assume neonatal twins are independent sample units when analyzing survival. A technique is available to quantify the amount of sibling dependence in a sample of radio-collared fawns comprising siblings to correctly estimate variance of survival rates and to improve understanding of sibling relationships (Bishop et al. 2008).

Although we significantly increased VIT retention, we cannot explain why 10% of adult females expelled VITs several days or weeks prepartum. These individuals were not older or larger than other deer in our sample, making it difficult to recommend future VIT modifications to further improve retention. We speculate that individual behavior may largely explain early VIT expulsion in this study. That is, some deer may be more inclined to attempt to remove VITs than others, making it difficult to eliminate prepartum shedding altogether without dramatically changing how VITs are retained.

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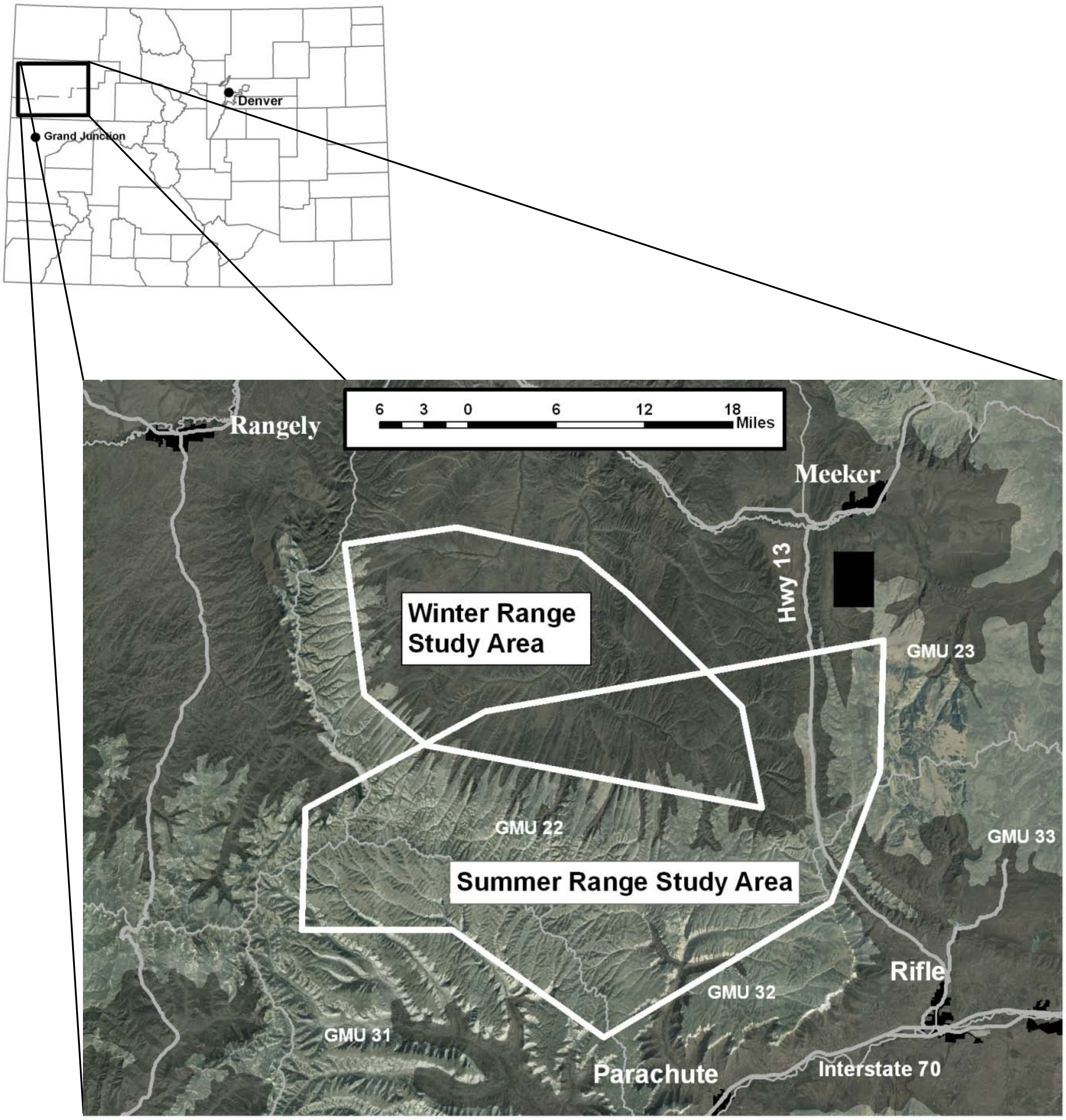

Figure 1. Location of winter and summer range study areas in Piceance Basin and on Roan Plateau, northwest Colorado.

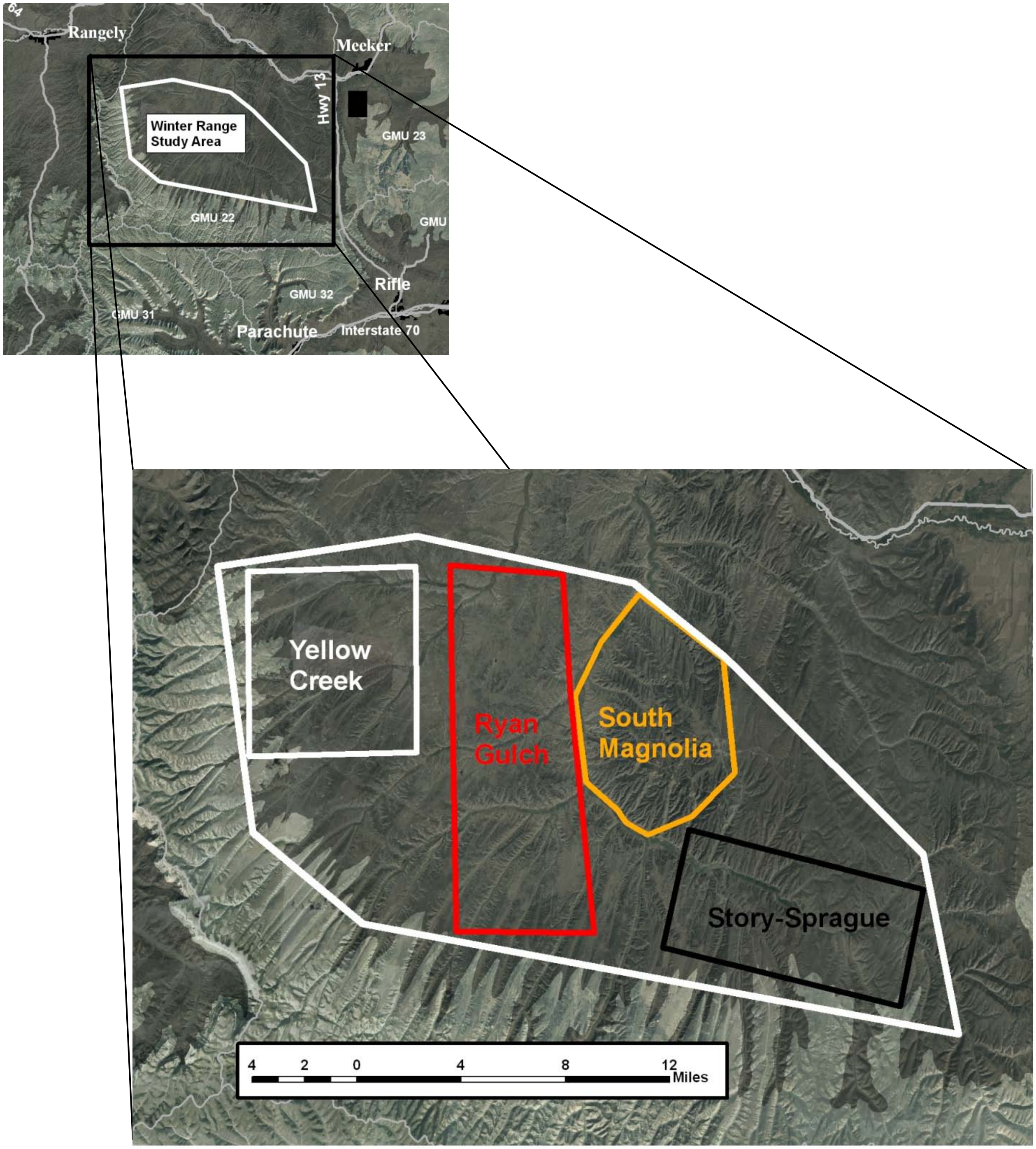

Figure 2. Location of winter range study units where we captured and radio-marked mule deer in Piceance Basin, northwest Colorado. These study units are part of a larger research study evaluating effects of natural gas development and mitigation on mule deer (Anderson and Freddy 2008).

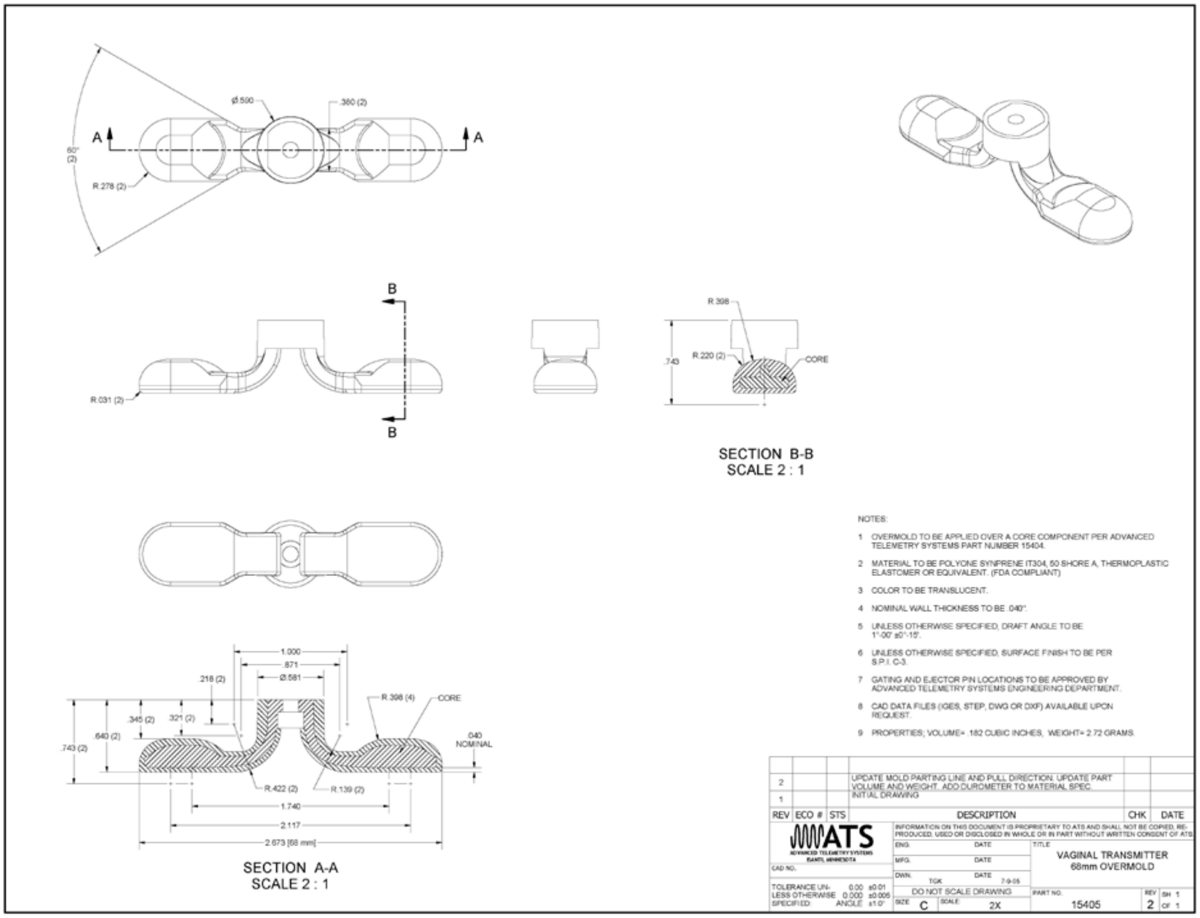

Figure 3. Design and dimensions of a modified retention wing used to retain vaginal implant transmitters in adult female mule deer. The displayed dimensions include a nylon core with an elastomeric overmold that protects deer from any sharp or rigid edges.

APPENDIX A

PROGRAM NARRATIVE STUDY PLAN
FOR MAMMALS RESEARCH
FY 2007-08 – FY 2009-10

State of:	Colorado	:	Division of Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	3001	:	Deer Conservation
Task No.	7	:	Effectiveness of a Redesigned Vaginal Implant
		:	Transmitter in Mule Deer
Federal Aid Project No.	W-185-R		

EFFECTIVENESS OF A REDESIGNED VAGINAL IMPLANT TRANSMITTER FOR CAPTURING MULE DEER NEONATES FROM TARGETED ADULT FEMALES

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STUDY PLAN APPROVAL

Prepared by:	Chad J. Bishop	Date:	July 2008
Submitted by:	Chad J. Bishop	Date:	July 2008
Reviewed by:	Danny Martin	Date:	11/24/2008
	Jon Runge	Date:	11/13/2008
		Date:	
Biometrician Review:	Paul Lukacs	Date:	11/4/2008
Approved by:	David J. Freddy Mammals Research Leader	Date:	Dec. 2008

PROGRAM NARRATIVE STUDY PLAN
FOR MAMMALS RESEARCH

EFFECTIVENESS OF A REDESIGNED VAGINAL IMPLANT TRANSMITTER FOR CAPTURING MULE DEER NEONATES FROM TARGETED ADULT FEMALES.

A Study Plan Proposal Submitted by:
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A. Need

Mule deer (*Odocoileus hemionus*) fawn production and neonatal survival is influenced by dam characteristics (e.g., body condition, disease status, habitat use). To understand fawn-dam relationships, manipulative field studies are needed that allow fawn production and survival to be estimated as a function of treatments applied to adult females. For example, a study evaluating the effectiveness of winter range habitat treatments on subsequent neonatal survival would require the capture of fawns from marked adult females that verifiably used, or did not use, the habitat treatments the previous winter(s). Such studies depend on a technique that enables newborn fawns to be captured from marked adult females.

The most promising technique employed to capture neonates from marked adult females is use of vaginal implant transmitters (VITs), which are placed in the vagina of adult females during early to mid gestation. In theory, adult females retain VITs until parturition, at which point VITs are expelled at birth sites along with newborn fawns. Assuming VITs are routinely monitored, researchers can promptly radio-locate shed VITs and capture the newborn fawns. Recent applications of VITs in white-tailed deer (*O. hemionus*), black-tailed deer (*O. hemionus columbianus*), and mule deer have been moderately successful (Bowman and Jacobson 1998, Carstensen et al. 2003, Pamplin 2003, Bishop et al. 2007). Vaginal implant transmitters also permit measurement of fetal survival in free-ranging populations, which has important implications in populations where stillborn mortality is known to occur (Bishop 2007, Bishop et al. 2007, Bishop et al. 2008). An additional advantage of using VITs to capture neonates may be a reduction in sample bias when compared to capture techniques that rely on opportunistic fawn capture (White et al. 1972, Ballard et al. 1998, Pojar and Bowden 2004). Opportunistic techniques are susceptible to bias because of unequal capture success among vegetation types, road densities, fawn ages, and stages of fawning. When using VITs, neonate captures should be more random as long as VIT signals are monitored with equal intensity during fawning, and assuming the sample of radio-collared does was captured with minimal bias. Thus, VITs could have broad applicability regardless of whether study objectives require that fawns be captured from previously marked does.

The most significant problem associated with VITs has been premature expulsion and subsequent failure to locate birth sites or newborn fawns (Bowman and Jacobson 1998, Carstensen et al. 2003, Pamplin 2003, Johnstone-Yellin et al. 2006, Bishop et al. 2007). The VIT has flexible, plastic wings coated with silicone that induce pressure against the vaginal wall to retain the transmitter. The VIT design facilitates a quick, non-surgical insertion process and is safe for the animal (Johnson et al. 2006), but the current wing design is inadequate with respect to retention. Bishop et al. (2007) found that 43% (SE = 4.7) of VITs in mule deer shed prepartum, although capture success was high when VITs shed only 1–3 days prepartum. More importantly, Bishop et al. (2007) found that 25% (SE = 4.1) of VITs shed >3 days prepartum and that retention probability declined as deer body size increased, indicating the retention wings were too small to be effective in larger deer. Based on these results, considerable oversampling would be required in the design of future projects to achieve a target sample size of fawns. Oversampling is not desirable from an animal care and use perspective or from a cost perspective. Application of VITs in mule deer costs roughly $1,325 per captured fawn given current rates of premature expulsion (Bishop et al. 2007). Thus, the plastic-silicone retention wings of VITs need to be redesigned to allow maximum retention in deer.

To date, the wings used to retain VITs have been purchased from a company in New Zealand (Carter Holt Harvey Plastic Products, Hamilton, New Zealand) that originally produced them for an application in the livestock industry (Bowman and Jacobson 1998). The company manufactures 1 large wing and 1 small wing; the former has been used to produce VITs for bison (*Bison bison*) and elk (*Cervus elaphus*) whereas the latter has been used to produce VITs for deer (Advanced Telemetry Systems, Isanti, MN). Advanced Telemetry Systems (ATS), in cooperation with wildlife researchers, made an initial effort in 2004 to lengthen the retention wings by adding resin to the wing tips. Using these VITs and with antennas cut to the appropriate length, S. P. Haskell (Texas Tech University, unpublished data) reported that 81% of VITs (n = 21) in deer were retained until parturition. Although retention improved, this aftermarket modification is not ideal. The modified wing tips are hard because of the resin addition and thus not ideal for placement in the vaginal canal. Also, we desire a VIT design that will provide >0.9 retention rates to parturition. Ideally, any modification to the VIT wings should be incorporated into the manufacturing process. The silicone-covered plastic wings must be manufactured using a production mold that costs roughly $15,000 to fabricate. To date, this cost has deterred design modifications to VIT wings. There is no economic incentive for a company to fabricate wing production molds exclusively for use in wildlife research given the high manufacturing costs and low anticipated return. However, the opportunity exists to redesign VIT retention wings with suitable funding. We propose to redesign the silicone-covered plastic wings, fabricate a new production mold, and conduct a field evaluation.

B. Objectives

Our study objectives are to (1) redesign and manufacture the silicone-covered plastic wings used to retain VITs in deer, and (2) evaluate rates of VIT retention to parturition and fawn capture rates using the newly designed wings in free-ranging mule deer.

C. Expected Results or Benefits

A redesigned VIT allowing high rates of retention to parturition (i.e., >0.9) would enable researchers to cost-effectively address complex problems associated with deer reproductive ecology, population productivity, and disease transmission in field studies. This field technique would then be efficacious and directly applicable to research evaluating effects of energy development and associated mitigation strategies, which is presently the highest priority facing Colorado Division of Wildlife and several other state wildlife agencies in the West.

D. Approach

1. *Hypotheses*

   1) Redesigned VITs will be retained until parturition in >90% of adult female mule deer.
      - Redesigning VITs by lengthening and widening the retention wings is expected to increase retention rates based on past research (Bishop et al. 2007; S. P. Haskell, Texas Tech University, unpublished data).
   2) Stillborn or neonatal fawns will be located from >85% of adult female mule deer that receive redesigned VITs.
      - Bishop et al. (2007) captured fawns from 92% (SE = 3.7) of adult female mule deer that retained VITs to parturition.

2. *Experimental Design*

Our study design requires 2 key elements: 1) a minimum sample size of 60 adult female mule deer to guarantee suitable precision of VIT retention estimates, and 2) capture of adult female deer during mid-late winter to facilitate in utero fetus detection and to ensure VIT batteries will be operational throughout the fawning period (i.e., through early July). We will augment existing research efforts by placing VITs in adult female mule deer that will be captured in the Piceance Basin to meet other study objectives (Anderson and Freddy 2008).

During 2009–2010, we will place VITs in 60 adult female mule deer each year during late February through early March in the Piceance Basin in northwest Colorado. The adult females will be captured across the Piceance Basin (Anderson and Freddy 2008) and are expected to cover an extensive area during summer (i.e., roughly 3000–4000 mi^2) based on past research in this area (White et al. 1987, Bartmann et al. 1992). Assuming a VIT retention rate of 0.9 (i.e., 90% of VITs shed at birth sites), 60 adult females would allow us to estimate a yearly retention rate with a 95% confidence interval (CI) of 0.79–0.96, or a coefficient of variation (CV) of 4.3%. Following the 2-year study, we will be able to estimate retention rate with a 95% CI of 0.83–0.95 (i.e., CV = 3.1%), if there is no significant year effect. If we observe a year effect, we may be able to identify factor(s) that were potentially responsible and improve our understanding of VIT retention. Also, if we experience a problem in the first year, we may be able to correct it prior to the second year. If we experience high success during the first year (e.g., >0.9 retention to parturition), the second year may become part of a biological study to evaluate effects of energy development on fawn production and neonatal survival.

3. *Procedures*

We worked with ATS personnel to redesign the M3930 VIT presently manufactured by ATS. The existing M3930 has been described in detail elsewhere (Bowman and Jacobson 1998, Carstensen et al. 2003, Johnstone-Yellin et al. 2006, Bishop et al. 2007). Our redesign included changes to the retention wings and the way in which wings are attached to the transmitter body. Specifically, we extended the length and width of the retention wings and added ridges to the wing surface, both of which should increase probability of retention to parturition (Figs. 1, 2). The wings are made of flexible plastic encased in silicone. We initially produced a small number of the newly-designed wings using a relatively inexpensive prototype mold (i.e., $1,200). The prototype was acceptable. We will therefore manufacture a production mold (i.e., ~$15,000), which will allow a large number of the wings to be produced. The wings will be inexpensive to manufacture once the production mold is available. We will incorporate ejector pins into the VIT design that will allow wings to be attached to the VIT transmitter body in the field. Previously, wings were permanently affixed to the transmitter body during the VIT assembly process. Field-attachment would allow researchers to use more than one wing size or style, without purchasing extra transmitters, if additional production molds are manufactured over time. For each wing design (i.e., production mold), extra wings could be inexpensively purchased and available in the field to affix to the fixed number of transmitter bodies. Researchers could then individually fit VITs to animals in the field much in the same way radiocollars are individually fitted.

In late February or early March each year of study, we will capture a total of 60 adult female deer utilizing helicopter net guns (Barrett et al. 1982, van Reenen 1982) in conjunction with ongoing research (Anderson and Freddy 2008). Captured deer will be hobbled, blind-folded, and ferried ≤3.5 km by helicopter to a central handling location. For each captured deer, we will use transabdominal ultrasonography (SonoVet 2000, Universal Medical Systems, Bedford Hills, NY) to determine pregnancy status and number of fetuses (Stephenson et al. 1995, Bishop 2007, Bishop et al. 2007). We will shave the left caudal abdomen from the last rib and apply lubricant to facilitate transabdominal scanning using a 3-MHz linear transducer. We will fit each pregnant deer with a VIT and a radiocollar equipped with a mortality sensor, which will activate after remaining motionless for 4 hours.

We will also measure mass, chest girth, and hind foot length of each deer and estimate age by evaluating tooth replacement and wear (Severinghaus 1949, Robinette et al. 1957, Hamlin et al. 2000). We will perform the ultrasound and VIT insertion procedures in a wall-frame tent or other structure to minimize disturbance from helicopter rotor wash and adverse weather conditions and to create a dim environment to facilitate ultrasonography.

We will sterilize VITs in a chlorhexidine solution prior to insertion in the field. We will insert VITs using a clear, plastic swine vaginoscope (Jorgensen Laboratories, Inc., Loveland, Colo.) and alligator forceps. The vaginoscope is 15.2 cm long with a 1.59 cm internal diameter and has a smoothed end to minimize vaginal trauma. We will place vaginoscopes and alligator forceps in cold sterilization containers with chlorhexidine solution between each use and use a new pair of nitrile surgical gloves to handle the vaginoscope and VIT for each deer, and we will apply a lidocaine cream to the deer's vagina prior to insertion. To insert a VIT, we will fold the silicone wings together and place the VIT into the end of the vaginoscope. We will liberally apply sterile KY Jelly® to the scope and insert it into the vaginal canal until the tip of the VIT antenna is approximately flush with the vulva. We will use previous field experience to guide insertion distance and antenna length (Bishop et al. 2007). We will extend alligator forceps through the vaginoscope to firmly hold the VIT in place while the scope is pulled out from the vagina. Each VIT will have a temperature-sensitive switch, pre-cut antenna (~6 cm in length) with antenna tip encapsulated in a resin bead to eliminate sharp edges, and a 12-hour on-off duty cycle to extend battery life (Bishop et al. 2007). The temperature-sensitive switch will cause the VIT to increase pulse rates from 40 pulses to 80 pulses per minute when the temperature drops below 32° C. A temperature drop below 32° C will be indicative of the VIT being expelled from the deer.

We will regularly monitor live-dead status and general location of all radiocollared adult females during winter and spring. During each morning of June we will check VIT signal status by aerially locating each radio-collared doe having a VIT, weather permitting. We will begin flights at approximately 0530 hours and complete them by approximately 1000–1100 hours. Early flights will be necessary to detect fast signals because temperature sensors of VITs expelled in open habitats and subject to sunlight often exceed 32° C by mid-day, which will cause VITs to switch back to a slow (i.e., prepartum) pulse (Bishop et al. 2007). When we detect a fast (i.e., postpartum) pulse rate, we will use very high frequency (VHF) receivers and directional antennae from the ground to simultaneously locate the VIT and radiocollared doe. We will attempt to observe behavior of the collared adult female, establish whether the VIT is shed at a birth site, and search for fawns in the vicinity of the adult female and expelled VIT. In cases where the dam moves away from the VIT (i.e., >200 m), we will locate the VIT to determine whether shedding occurred at a birth site and whether any stillborn fawn(s) are present and subsequently locate the collared dam to search for fawns at her location. We will attempt to account for each dam's fetus(es) as live or stillborn, which is fundamental to estimating fetal survival (Bishop et al. 2007, 2008). We will wear surgical gloves when handling fawns to help minimize transfer of human scent. We will work in pairs and partition the study area into segments, whereby each 2-person team is responsible for one segment. We anticipate needing 4–5 teams given the expanse of the study area (Fig. 3).

We will assign the fate of each VIT to one of 6 categories: 1) parturition shed, 2) late prepartum shed (i.e., ≤3 days prepartum), 3) early prepartum shed (i.e., >3 days prepartum), 4) battery or transmitter failure, 5) migration loss, or 6) censor (Bishop et al. 2007). We will identify parturition sheds based on identification of a birth site where the VIT is shed or location of <1-day-old fawn(s) <24 hours after a VIT is shed. The latter criterion is useful because not all birth sites can be positively identified once the dam has cleaned up afterbirth and moved the fawns. Although our primary objective is to quantify the proportion of VITs shed at parturition, the remaining VIT fate categories will be useful for understanding why VITs failed and should aid additional technique refinements. We will distinguish between early prepartum sheds and late prepartum sheds because the latter provides useful information for capturing fawns. Neonate capture success rate was 0.792 (SE = 0.0847, n = 24) for dams with VITs shed late prepartum on the Uncompahgre Plateau during 2002–2004 (Bishop et al. 2007). We will document battery failures based on the disappearance of a doe's VIT signal after having consistently heard the signal on a daily basis. Migration losses refer to any VIT signals that disappear during spring migration. These failures are presumably caused by battery failures or early prepartum sheds between winter and summer range, yet the specific cause cannot be determined (Bishop et al. 2007). We will censor VITs associated with prepartum doe mortalities and missing does (i.e., unable to detect radiocollar signal) because these deer will not provide an adequate test of VIT effectiveness (i.e., the failure is independent of VIT technology).

We will quantify the proportion of successful fawn captures associated with VITs shed at parturition as well as those shed ≤3 days prepartum. We will also determine whether we account for the entire litter by comparing the number of fawns located in June to the in utero fetal counts obtained in February–March. We will describe effort associated with fawn capture by calculating the number of person-hours per captured fawn. We will also quantify cost per captured fawn by considering all operating and personnel expenses, including capture and transmitter costs for adult does.

4. *Data Analysis Procedures*

We will use a straight-forward binomial model to estimate the probability of VIT retention until parturition in adult female mule deer. We will contrast this estimate with a previous retention probability estimate (0.447, SE = 0.0468, Bishop et al. 2007) to evaluate the likely effect of our VIT modification. The estimates are not directly comparable because they will not have been measured simultaneously. However, the initial retention estimate measured by Bishop et al. (2007) provides a baseline for evaluating whether our VIT modifications had a positive effect. Ultimately, we will evaluate our retention probability estimate relative to our hypothesized retention rate of 0.9. We will model VIT retention as a function of adult female individual covariates (i.e., age, mass, chest girth, hind foot length) using logistic regression in SAS (SAS Institute, Cary, North Carolina) to improve our understanding of factors related to retention, which will be particularly useful if retention is < 0.9. We will select among models using Akaike's information criterion adjusted for sample size (AIC_c; Burnham and Anderson 2002). We will also estimate fawn detection probability associated with adult females receiving VITs. Specifically, we will estimate separate detection probabilities for adult females that shed VITs prepartum and adult females that shed VITs at parturition. We will then use the detection probabilities to estimate the probability of capturing the complete litter for different sized litters.

E. Location

The proposed research will take place in the vicinity of Piceance Basin and the White River National Forest in northwest Colorado (Fig. 3). Anderson and Freddy (2008) provided a detailed description of winter range study sites where adult female mule deer will be captured. The winter range study area is located primarily within CDOW Game Management Unit (GMU) 22. Summer range will be defined by the movements of the radiocollared adult females captured on winter range. We anticipate the summer range study area will include portions of GMUs 11, 211, 12, 22, 23, 24, 31, 32, and 33 (Fig. 3).

F. Schedule Of Work

Activity	Date
Complete Initial Draft of Study Plan	April–May 2008
Manufacture VIT Retention Wing Production Mold	May–June 2008
Finalize Study Plan and Submit to ACUC	August–October 2008
Order VITs and Purchase Associated Field Equipment	November 2008–2009
Capture Deer and Insert VITs	February–March 2009–2010
Periodically Monitor Radiocollared Deer	March–May 2009–2010
Monitor VITs Daily, Locate Shed VITs, and Conduct Fawn Searches	June 2009–2010
Analyze Data and Prepare Progress Report	July–August 2009
Analyze Data and Prepare Final Report	July–August 2010
Submit VIT Techniques Manuscript for Publication	December 2010

G. Estimated Costs[a]

Category	Item or Position	FY 07-08	FY 08-09	FY 09-10
Personnel	Chad Bishop	0.20 PFTE	0.40 PFTE	0.40 PFTE
	Chuck Anderson	0	0.05 PFTE	0.05 PFTE
	Eric Bergman	0	0.05 PFTE	0.05 PFTE
	Dan Walsh	0.05 PFTE	0.05 PFTE	0.05 PFTE
	TFTE	0	6.5 Mo. - $17,186	7.0 Mo. - $18,760
Operating	VIT Prototype	$2,500	0	0
	VIT Production Mold	$18,500	0	0
	Fixed-wing Monitoring (June)	0	$14,875	$15,750
	Field Supplies	0	$5,000	$4,000
	60 VITs	0	$13,800	$13,800
	Telemetry Equipment	0	$3,000	$1,500
Total Cost		$21,000	$53,861	$53,810

[a]Study costs were minimized by leveraging existing mule deer capture efforts within the ongoing Piceance Basin deer study (Anderson and Freddy 2008).

H. Related Federal Projects

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

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J. Figures And Tables

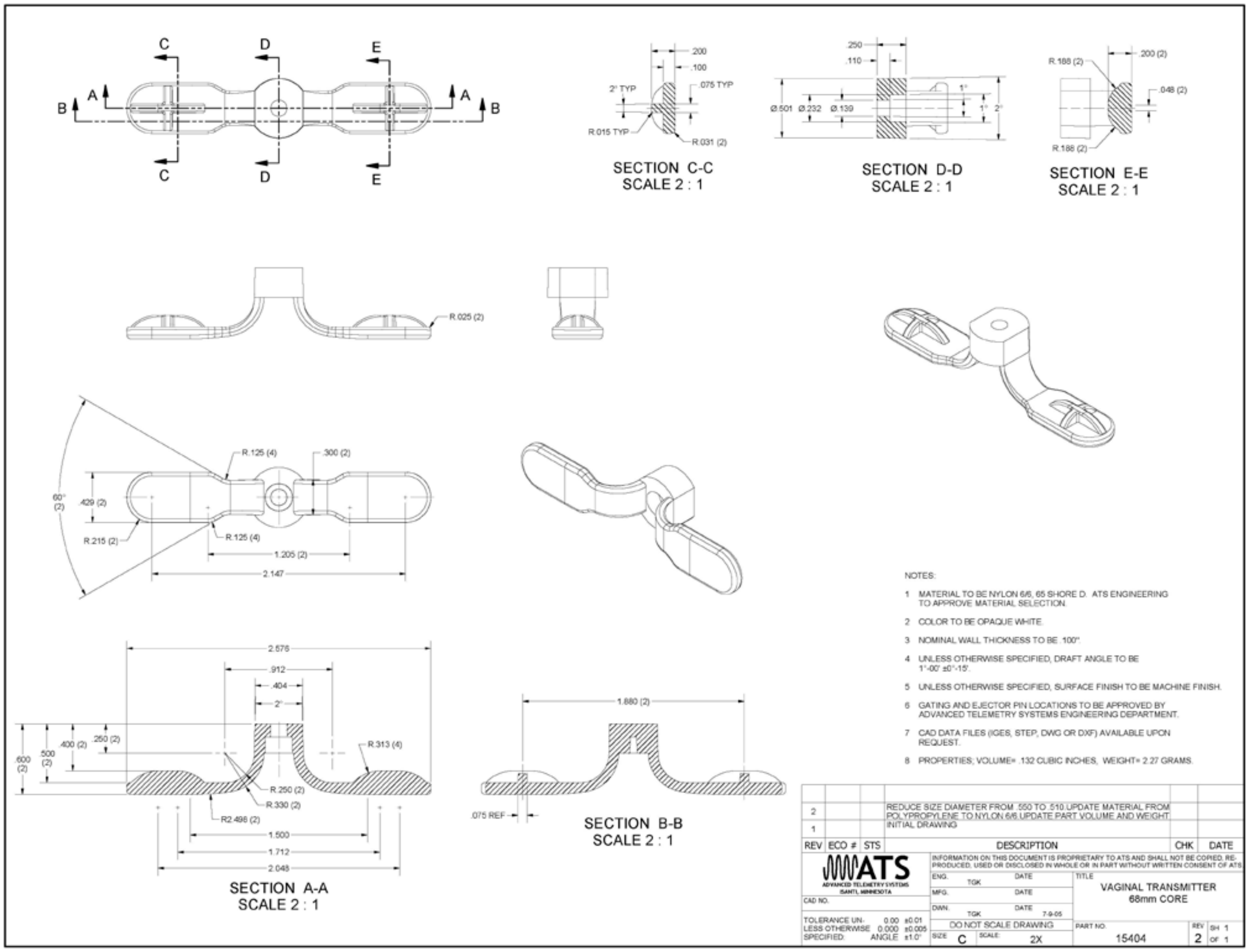

Figure 1. Modified design of the nylon core of retention wings used to retain vaginal implant transmitters in adult female mule deer. We modified the original design by lengthening and widening the wings and modifying the shape. We also incorporated an ejector pin to facilitate attachment of different-sized wings in the field.

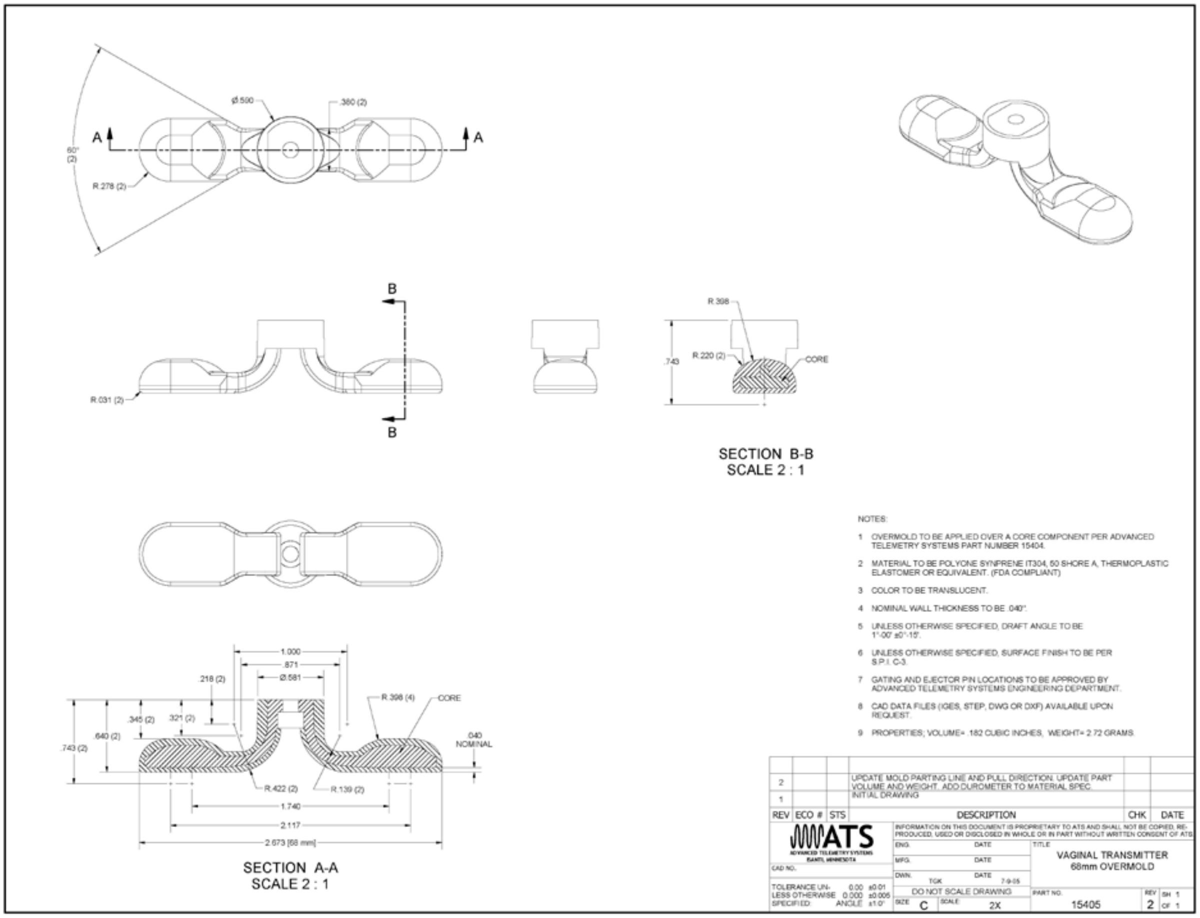

Figure 2. Design and dimensions of a modified retention wing used to retain vaginal implant transmitters in adult female mule deer. The displayed dimensions include the nylon core (Figure 1) with an elastomeric overmold that protects deer from any sharp or rigid edges.

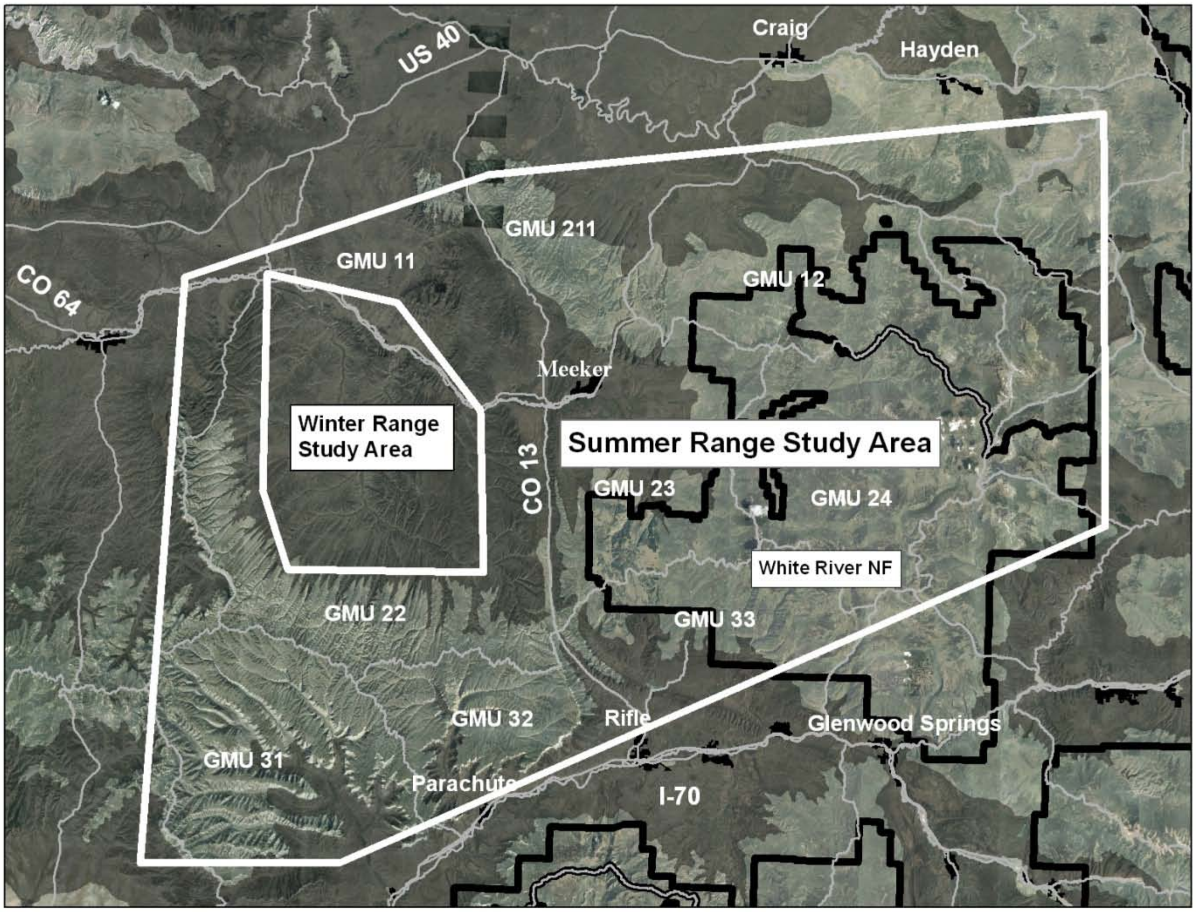

Figure 3. Location of winter range and summer range study areas in the vicinity of Piceance Basin and White River National Forest in northwest Colorado, where we will evaluate the effectiveness of modified vaginal implant transmitters (VITs). Winter and summer range study areas are outlined in white. Mule deer winter range is denoted with dark shading and USFS lands are outlined in black.

K. Appendices

APPENDIX I

HELICOPTER NET-GUN CAPTURE AND HANDLING PROTOCOL FOR MULE DEER

Helicopter net-gunning is a well-established procedure for capturing ungulates (Barrett et al. 1982, van Reenen 1982). Large samples of mule deer and white-tailed deer have been captured using helicopter net-guns with ≤ 1% capture-related mortality (Potvin and Breton 1998, White and Bartmann 1994, Webb et al. 2008). The protocol described below is nearly identical to net-gun protocols approved previously by CDOW's ACUC (CDOW ACUC Project Protocols 11–2000, 10–2005, 15–2007). Capture-related mortality rates in these projects have ranged from 0 to 3.5%, which includes all animals dying ≤1 week post-capture regardless of cause. A capture mortality rate of 3.5% is higher than the preferred rate of 2% (Spraker 1993) but much lower than what has commonly been experienced in the field using other methods to capture deer (Conner et al. 1987, DelGiudice et al. 2005). The 3.5% capture-related mortality rate occurred on the Uncompahgre Plateau when large samples of mule deer were captured within small study sites, creating challenging conditions for helicopter net-gunning (Bishop 2007). The overall capture mortality rate in this study was 2% because a majority of deer were captured with drop nets, where capture mortality was 1%. In other recent studies, capture-related mortality rates associated with helicopter net-gunning have been ≤ 2% (Anderson and Freddy 2008; Bergman et al. 2006, 2007, 2008).

Net-gunning will be performed by Quicksilver Air, Inc., or other qualified vendor selected by the Colorado Division of Wildlife (CDOW) through a request-for-proposal (RFP) process, which is the required procedure for selecting vendors to conduct helicopter work for CDOW. Quicksilver Air, Inc., has captured large samples of deer in Colorado during the past few years with capture-related mortality rates generally ≤ 2% (Anderson and Freddy 2008; Bergman et al. 2006, 2007, 2008; B. E. Watkins, CDOW, personal communication).

<u>Capture and Transport Methods:</u>

Wild mule deer will be pursued and netted by the helicopter net-gunning crew. The crew will consist of one pilot, one net-gunner, and ≤2 handlers. Netted animals will immediately be blind-folded and hobbled and transported by the helicopter to a nearby handling site. Deer will be placed inside the helicopter or slung underneath the helicopter during transport. At the handling site, CDOW personnel (i.e., handling crew) will record measurements, affix transmitters, and release each captured deer. Mule deer will be captured within 1–2 miles of the handling site to minimize the distance deer are transported. The handling crew will be ferried to appropriate handling sites by the helicopter pilot if vehicle access is limited in an area.

Mule deer will be captured with net-guns in late February or early March in Game Management Unit (GMU) 22 in the Piceance Basin. In Meeker, Colorado, mid-late winter snow depths average roughly 12 cm, and rarely exceed 35 cm, where deer will be captured, and mean daily temperatures during late February have averaged –1 °C (30 °F) during recent decades. Under these conditions, mule deer can be captured safely without undue risk of hyperthermia. Maximum allowable pursuit time, or time necessary to chase and net a target animal, will vary given existing weather conditions and animal behavior. For example, in warmer conditions (e.g. >4°C), pursuit times will be minimized, particularly if unfavorable snow conditions are present. Total pursuit time will not exceed 8–10 minutes regardless of conditions, and will generally be less than 5 minutes. Individual deer will not be repeatedly chased. Large deer groups typically fracture upon the initial pursuit, thereby preventing the need to repeatedly chase the same individuals while still allowing the capture of >1 deer from the initial group.

The helicopter pilot, fuel truck driver, and handling crew will be in radio contact with one another. In the event of an accident, the Meeker CDOW office will be contacted by radio, and necessary emergency services will be sent to the site. The ground crew will have direct radio access to the Rio Blanco County Sheriffs Office, Colorado State Patrol, and other emergency law enforcement channels.

Training and Personnel:

The helicopter net-gunning crew will be instructed as to procedures for minimizing stress and injury to the animals. Specifically, they will be instructed on pursuit times, transport distances, and safe handling procedures. The handling crew, comprised of CDOW personnel, will be instructed on proper care and handling procedures to minimize stress and risk of injury to the captured deer. Chad Bishop and Chuck Anderson will be ultimately responsible for all animal care and handling during the capture operation.

Procedures and Manipulations of Animals:

As stated above, netted animals will immediately be blind-folded, hobbled, and transported to the handling site. At the handling site, deer will be removed from the net and/or transport bag if present, and the blind-fold and hobbles will be checked. Deer will be radiocollared and aged by qualitatively evaluating height and wear of incisors and premolars. Radio collars will be of fixed-size and individually fitted to each animal. The following samples will be obtained from each deer: blood, hind foot length, chest girth, and weight. Blood samples will be collected using routine venipuncture for evaluating serum thyroid hormone concentrations and disease serology. Pregnancy status, number of fetuses, and body condition will also be determined using ultrasonography. Please refer to Appendix II for detailed handling procedures (Appendix II. Use of Ultrasonography and Vaginal Implant Transmitters in Adult Female Mule Deer to Capture Neonatal Fawns).

If a captured deer suffers a broken leg, back, neck, pelvis, or other similar wound, it will be euthanized by deep anesthesia with the drug combination of ketamine or Telazol© and xylazine (IV or IM) with dosage based on estimated weight, followed by intravenous administration of KCl (~350 mg KCl/ml sterile water, dosed at >50 mg KCl/kg estimated body mass). In situations where administration of KCl is not feasible, then euthanasia will be performed via a gunshot to the head.

Radiocollared mule deer will not be handled following capture, although they will be radiomonitored from both the ground and air on a routine basis. Except during the fawning period, deer will not be routinely relocated from the ground using VHF telemetry and therefore will not be regularly disturbed. During fawning in June, deer will be radiomonitored daily to determine when vaginal implant trasmitters are shed (see Appendix II. Use of Ultrasonography and Vaginal Implant Transmitters in Adult Female Mule Deer to Locate Neonatal Fawns).

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APPENDIX II

ULTRASONOGRAPHY AND VAGINAL IMPLANT TRANSMITTER PROTOCOLS FOR ADULT FEMALE MULE DEER AND NEONATAL FAWNS

Background:

For some time, radio-transmitter implants in the vaginas of deer have been considered as a technique for locating and capturing newborn fawns from radio-collared does immediately following parturition. Early attempts to employ this technique were largely unsuccessful in terms of both effectiveness and animal welfare (Garrott and Bartmann 1984, Giessman and Dalton 1984, Nelson 1984). This early technique used sutures to partially close the vulva in order to retain the transmitter in the vagina. Later, Bowman and Jacobsen (1998) developed and employed a modified vaginal implant transmitter (VIT) for white-tailed deer, with better success. This transmitter had plastic wings encased in silicone to retain the transmitter in the vagina until parturition; thus, no sutures were used. They found no indications that animals were negatively impacted by the newly designed VIT. Recent studies employing VITs have not identified any negative impacts to animals receiving VITs (Carstensen et al. 2003, Pamplin 2003, Johnstone-Yellin et al. 2006, Bishop et al. 2007), including a VIT study on elk focused exclusively on animal welfare (Johnson et al. 2006). Also, these studies do not indicate that VITs cause major problems with *in utero* fetus survival or birthing, particularly given the success of researchers at finding birth sites and fawns, occasionally from the same adult females over consecutive years. Furthermore, farmed deer in New Zealand with vaginal hormone implants with a similar design have not had any major reproduction problems (Asher and Smith 1987, Asher et al. 1988, Mylrea et al. 1992).

Although the current VIT design apparently causes no harm to the animal, animals often expel VITs prior to parturition, which greatly reduces their utility. Thus, to achieve target sample sizes of newborn fawns, investigators must oversample adult females, causing excess animals to be captured, handled, and implanted with VITs. To reduce premature VIT expulsion, Advanced Telemetry Systems (ATS), in cooperation with wildlife researchers, lengthened the retention wings in 2004 from 58 mm to 68 mm by adding hard resin to the wing tips, which significantly improved VIT retention (S. P. Haskell, Texas Tech University, unpublished data). Since 2004, researchers employing VITs with the longer wings have not documented any ill effects in deer (ATS, unpublished data). Although retention improved and no ill effects have been observed, this aftermarket modification is not ideal. The modified wing tips are hard because of the resin addition and thus not ideal for placement in the vaginal canal. Ideally, any modification to the VIT wings should be incorporated into the manufacturing process. The retention wings must be manufactured using a production mold that costs a minimum of $15,000 to fabricate. We therefore obtained suitable funding and redesigned the VIT production mold. We lengthened the wing mold from 58 mm to 68 mm, consistent with the aftermarket modifications made to VIT wings beginning in 2004. We also widened the wings from 9 mm to 14 mm to increase the contact surface with the vaginal wall.

During spring-summer 2008, we placed 6 prototypes of our newly-manufactured VITs in bighorn sheep ewes at the Foothills Wildlife Research Facility in Fort Collins, CO, where the penned sheep could be closely monitored. We documented no ill effects and all pregnant sheep retained their VITs until parturition. We do not anticipate that our VIT design modifications will pose a risk to animal welfare considering our pilot evaluation in sheep and recent deer studies that employed VITs with aftermarket alterations. In fact, the motivation for developing a new production mold was to improve animal welfare by eliminating the need for aftermarket alterations that create particularly hard wing surfaces. We will monitor fetal survival and neonatal production of all adult female deer receiving VITs to help document whether the newly designed VITs cause any negative effects. We will also monitor survival of the adult females and conduct a thorough necropsy of any deer that die.

Aside from the VIT modifications, the protocols described herein are nearly identical to a protocol approved in the past (CDOW ACUC Project Protocol 1–2002). In this earlier study, we did not document any negative effects to deer associated with ultrasonography or VIT procedures. Also, neonatal fawn survival was higher among fawns captured from adult does that received VITs than fawns captured opportunistically from adult does that did not have VITs (Bishop et al. 2007). Vaginal implants allowed us to remotely monitor adult doe birthing status. If a VIT functioned correctly, we were generally able to capture the adult doe's fawn(s) with only one disturbance event. In the absence of a VIT, when attempting to capture fawns from a targeted adult doe, we typically had to repeatedly locate and disturb the adult doe during the fawning period to capture her fawn(s).

<u>Capture and Transport Technique:</u>

Adult female mule deer will be captured in late February and/or early March via helicopter net-gunning (Barrett et al. 1982, van Reenen 1982). Please refer to Appendix I. for a detailed helicopter net-gunning capture protocol (Appendix I. Helicopter Net-gunning Capture and Handling Protocol for Mule Deer). Net-gunned deer will be blind-folded, hobbled, and ferried a short distance to a handling site.

<u>Procedures and Manipulations of Animals:</u>

We will use ultrasonography to determine pregnancy status (yes/no), fetal count (# fetuses), and body condition (see below). Additionally, we will measure weight, chest girth, hind foot length, and age (based on tooth replacement and wear). We will collect a blood sample using routine venipuncture. If an adult female is pregnant, we will place a nylon radio-collar around the neck and insert a VIT in the vagina posterior to the cervix. Vaginal implant insertion procedures are explained in detail below. Total handling time for an individual deer will typically be ~15 minutes and will not exceed 25 minutes. We will cease manipulations/data collection at any point the welfare of the deer is in question and immediately begin administering fluids, oxygen, or any other warranted procedure under the guidance of CDOW's attending veterinarian.

Ultrasonography:

We will use ultrasonography to determine body condition, diagnose pregnancy, and quantify fetal numbers of each mule deer. Body condition will be measured to meet other research objectives (Anderson and Freddy 2008). Body condition methods are briefly repeated here for completeness.

We will measure maximum subcutaneous fat thickness on the rump and thickness of the longissimus dorsi muscle of each doe using a SonoVet 2000 portable ultrasound unit (Universal Medical Systems, Bedford Hills, NY) with a 5 MHz linear transducer (Stephenson et al. 1998, 2002; Cook et al. 2001; Bishop 2007). A small area of hair will be plucked at each measurement point and lubricant will be used to enhance contact between the transducer and skin. The 2 plucked areas will be ≤15 cm long by ≤5 cm wide. We will determine a body condition score (BCS) for each deer by palpating the rump (Cook et al. 2001, 2007). We will combine ultrasound measurements with the BCS score to estimate body fat of each deer (Cook et al. 2007).

We will quantify reproductive status using a SonoVet 2000 portable ultrasound unit (Universal Medical Systems, Bedford Hills, NY) with a 3 MHz linear transducer. We will shave the left side of the abdomen and apply lubricant to facilitate transabdominal scanning (Stephenson et al. 1995, Bishop 2007, Bishop et al. 2007). Specifically, we will shave an area covering the haired portion of the left ventral abdomen that is 20 cm wide; the area is bounded by the caudal rib cranially, the inguinal fold caudally, and the ventral midline. Both uterine horns will be systematically scanned to identify fetal numbers ranging from 0 to 3.

Vaginal Implant Transmitter (VIT) and Insertion Technique:

Refer to the attached study plan for detailed specifications of VITs to be used in this study. Prior to insertion, we will sterilize VITs in a chlorhexidine solution, rinse them with sterile saline solution, allow them to air-dry, and seal them in air- and water-tight pouches. This will guarantee cleanliness of VITs up until the moment they are placed in deer. We will insert VITs using a clear, plastic swine vaginoscope (Jorgensen Laboratories, Inc., Loveland, Colo.) and alligator forceps. The vaginoscope is 15.2 cm long with a 1.59 cm internal diameter and has a smoothed end to minimize vaginal trauma. We will gauge approximate insertion distance from extensive experience gained on the Uncompahgre Plateau (Bishop et al. 2007). We will place vaginoscopes and alligator forceps in cold sterilization containers with chlorhexidine solution between each use and use a new pair of nitrile surgical gloves to handle the vaginoscope and VIT for each deer, and we will apply a lidocaine cream to the deer's vagina prior to insertion. To insert a VIT, we will fold the silicone wings together and place the VIT into the end of the vaginoscope. We will liberally apply sterile KY Jelly® to the scope and insert it into the vaginal canal until the tip of the VIT antenna is approximately flush with the vulva. We will use the alligator forceps, which extend through the vaginoscope, to firmly hold the VIT in place while the scope is pulled out from the vagina. The tip of the antenna, which may protrude up to 1.5 cm past the vulva, is encapsulated is a resin bead to protect the deer from its sharp edge.

Post-Implantation Monitoring:

From March through May, we will regularly monitor the radio collar and VIT signals of the adult does in our sample. Monitoring will allow us to document any VITs that shed early and the opportunity to perform a necropsy on mortalities. The latter will allow us to evaluate whether VITs caused any tissue irritation or other impact to the adult doe.

Fetus Survival and Neonate Capture:

During each morning of June we will check VIT signal status by aerially locating each radiocollared doe having a VIT, weather permitting. We will also radiomonitor VIT signals from the ground as logistically feasible. When we detect a fast (i.e., postpartum) pulse rate, we will use VHF receivers and directional antennae from the ground to simultaneously locate the VIT and radio-collared doe, which should be in proximity to one another. We will attempt to observe behavior of the collared doe, establish whether the VIT is shed at a birth site, and search for fawns in the vicinity of the doe and expelled VIT. If the doe has moved away from the VIT (i.e., >200 m), we will locate the VIT to determine whether shedding occurred at a birth site and whether any stillborn fawn(s) were present and subsequently locate the collared doe to search for fawns at her location. We will attempt to account for each doe's fetus(es) measured in February as live or stillborn fawns. We will not radiocollar or handle newborn fawns. Thus, once a neonate is located, we will back away and leave the neonate undisturbed. If a VIT is shed prior to parturition, we will radiolocate the adult doe no more than once per day on each successive day and search for fawns in an attempt to determine approximately when the doe actually gives birth. This will allow us to determine how many days a VIT shed prematurely. Neonate searches will typically last up to 30–45 minutes and will not exceed 1 hour. Past deer neonatal studies have reported minimal or no abandonment as a result of neonate capture, handling, and marking (Carstensen et al. 2003, Pojar and Bowden 2004, Bishop 2007). Powell et al. (2005) found no evidence of marking-induced abandonment, and they found that handling time and age-at-capture had no impact on neonatal survival. We therefore do not anticipate that our neonate searches will cause any direct or indirect harm to the neonates or their dams, particularly since we will not be handling fawns.

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Colorado Division of Wildlife
July 2008 – June 2009

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, 2008 - June 30, 2009

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

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ABSTRACT

We completed the fourth and final 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 took place on the Uncompahgre Plateau and in adjacent valleys in southwestern Colorado. Data collection and analysis for the fourth year were consistent with those of the pilot study and first three years of this 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, and tended to be near published long term averages (mean survival rate of 0.59 (0.04 SE)). Survival rates for the fourth year of the study were lower than all previous years, which was surprising given casual observation of winter severity. However, preliminary evidence continues to suggest that areas that have received habitat treatments have higher fawn survival. Based on estimates of total body fat for adult female deer, there was a slight distinction between treatment and reference study areas. Point estimates of deer density on the 5 study areas during the winter of 2008-2009 varied from estimates collected during other winters, but in general density estimates have shown a consistent trend between all winters of the study. Major fluctuations within density estimates are likely attributable to animal movements.

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 et al. 2009). 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, nutrition enhancement treatments increased fawn survival rate by 0.22 (Bishop et al. 2009). 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.

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 5^{th} study area was added to increase the level of inference that could be drawn from this study. For each of the 4 winters covering the study period, this 5^{th} study area shifted between 4 randomly selected areas. The treatment history on each of these additional study areas varied, but was representative of what can be expected of typical winter-range treatments. During the first winter of this study, this 5^{th} study area fell on Shavano Valley. Treatments on Shavano Valley were primarily composed of roller-chopping and reseeding of browse species in the higher pinyon/juniper range. During the second winter of the study, the 5^{th} 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 was primarily composed of brush mowing and chemical control of weeds and dry land fertilization of preferred species. During the third winter of the study, the 5^{th} study area was located at McKenzie Buttes. The treatments at McKenzie Buttes were slightly older (10-15 years) and were also composed of roller-chopping. During the final year of the study, the 5^{th} study area was located at Transfer Road. The treatments available to deer at Transfer were younger (1-2 years) and were composed of hydro-ax and some roller-chopping.

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). All of the other study areas, mentioned above, were 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. 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.

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.

To estimate body condition, an additional 30 adult female deer were captured via helicopter net-gunning and fitted with temporary neckbands, 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 all 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. Estimating survival for study areas was done in 5 different forms. The simplest form was constant survival where all study areas were pooled and survival was estimated using a single parameter (hereafter “constant”). The second simplest form was to estimate survival for each unique study area (i.e., 8 survival estimates were generated, hereafter “area”). The remaining 3 forms allowed study areas to be partitioned according to treatment history. The simplest of these forms was a comparison between treatment areas and reference study areas in which each study areas was partitioned into one of these two categories (i.e., two survival parameters, hereafter “treatment/reference”). The next simplest of these forms segregated study areas by treatment type. In this form, study areas were either reference areas (no treatment), management treatments (areas that received a typical management treatment at some point during the past 10 years), or repeated treatments (areas that received a typical management treatment but also received additional and repeated efforts in an attempt to force treatment effect). Thus, in this form (hereafter “treatment type”), the number of parameters dedicated to estimating survival rates across all study areas was 3. The final form followed the “treatment type” form, but further partitioned study areas according to a density/treatment gradient. A total of 5 parameters were used to estimate survival (high-density repeated treatment, high-density reference, management treatment, low-density super treatment and low-density reference, hereafter “treatment type by density”).

All survival models were evaluated in program MARK using the known-fate model type with logit link function (White and Burnham 1999). All models were compared using Akaike's Information Criterion corrected for small sample size (Burnham and Anderson 2003).

RESULTS AND DISCUSSION

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). With the exception of a single fawn, all deer were captured via helicopter net-gunning during the fourth year of the study. Capture related mortalities occurred on 1 of 184 occasions (0.54%, 1 adult female, spinal injury). Two fawns died of predation within 1week of capture and were censored from the survival analysis due to the potential that effects of capture were still in place. An additional three fawns slipped their radio collars within a week of capture and were also censored. Mean mass of all fawns was 35.1 kg and the observed sex ratio for the sample was 61 males to 64 females (Table 1).

Estimates of fawn survival collected during previous years of this study tended to be above average compared to results from other research throughout the West, as well as on the Uncompahgre Plateau. However, survival rates during the fourth year of the study were noticeably lower. Across our 5 study areas, estimated survival rates ranged between 0.38 (0.10 SE) and 0.65 (0.10 SE), with a mean survival rate of 0.59 (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 tended to be less harsh than those observed during the previous year and survival rates were expected to have been higher during the 2008-2009 winter. Also of note, survival rates in one of our reference (i.e., non-treated) study areas (Buckhorn) was dramatically lower than in its paired treatment study area (Billy Creek). While this trend has been consistent, during previous years of the study the difference between these two study areas was not so dramatic. Survival rates in our low-density study areas were quite comparable to our high-density study areas. During previous winters, the low-density study areas tended to have higher survival.

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, and the most supported model took treatment type by density into account. Closely competing with this model was one which estimated a constant survival rate, but thereby benefited by estimating 4 fewer parameters. The strongest model support for the model that estimated survival rates according to the treatment type by density structure lends credence to the study design and will likely become refined with a more complete analysis.

Late winter body condition estimates for adult females during the winter of 2008-2009 were consistent with those collected during previous years of this study, but also tended to be higher than those estimates during previous research on the Uncompahgre Plateau (Bishop et al. 2009 and C.J. Bishop, personal communication). The lowest single total percent body fat estimate for this study was recorded during this winter, despite the fact that observations of winter severity indicated that body fat estimates likely should have been higher. For the two study areas where body condition estimates were measured, they did have a tendency to reflect the same trends that were observed in survival estimates. However, as has been the case in the past, there was no apparent statistical distinction in total percent body fat 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). Pregnancy rates, based on ultrasonography and/or PSPB, tended to be slightly higher than those observed during the previous year, but not as high as those observed during the first two years of the study. Past rates ranged between 90% and 95%, whereas rates for this past winter were 90% (Buckhorn) and 87% (Billy Creek). During the winter of 2007-2008, pregnancy rates were estimated to be 80% (Buckhorn) and 87% (Billy Creek).

Density estimates were collected during March for all five study areas (Figure 1). No major modifications were made to the methodology, although the number of marked animals in Billy Creek and Buckhorn has decreased since 2007 due to mortality of adult female deer. As such, the precision of estimates for these two was expected to decline. Additionally, during the two week period preceding the density estimation flights, deer in the Buckhorn study area started moving up in elevation into transition range. Similar shifts were not observed in the other study areas, but in Buckhorn it was quantified through relocation of radio-marked animals. Relying on this approach, we estimated that 47% of the deer on Billy Creek had moved off of the study area prior to the density estimation flights, explaining the marked drop in total number of deer on that study area. No major shifts in deer density were observed in Billy Creek, Peach Orchard or Sowbelly.

SUMMARY

Survival rates for mule deer fawns across our study areas averaged 59% with a measured high of 65% and measured low of 38%. Overall body condition parameter estimates for late-winter adult female deer were moderately low, which did not coincide with the milder winter conditions that were observed throughout deer winter range in Colorado. Pregnancy rates were slightly lower, but still within the long term range of observed data. Estimates of total deer density across our study areas continued to reflect historical estimates, but a dramatic early spring shift in movement was observed on one study area. Overall, a consistent trend of higher survival of fawns was observed in treated study areas, indicating winter range treatments likely have a positive effect on survival. The magnitude and overall population effect of these impacts will be quantified during the next 12-18 months.

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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, 2007-2008, and 2008-2009. 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)
Billy Creek	2008	37.2 (13)	34.4 (12)	35.9 (25)
Buckhorn	2008	36.4 (12)	31.7 (13)	34.0 (25)
Transfer	2008	36.8 (13)	32.0 (12)	34.5 (25)
Peach Orchard	2008	37.9 (10)	35.0 (15)	36.2 (25)
Sowbelly	2008	36.7 (13)	33.2 (12)	35.0 (25)

Table 2. Over-winter mule deer fawn survival rates for study areas across the Uncompahgre Plateau during the 4-year 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	2008-2009
Area	$\hat{S}$ (S.E.)	$\hat{S}$ (S.E.)	$\hat{S}$ (S.E.)	$\hat{S}$ (S.E.)
Billy Creek	0.83 (0.76)	0.72 (0.09)	0.71 (0.09)	0.60 (0.10)
Buckhorn	0.76 (0.88)	0.63 (0.10)	0.59 (0.10)	0.38 (0.10)
Colona	N.A.	0.68 (0.09)	N.A.	N.A.
Shavano	0.76 (0.85)	N.A.	N.A.	N.A.
McKenzie Buttes	N.A.	N.A.	0.61 (0.11)	N.A.
Transfer	N.A.	N.A.	N.A.	0.63 (0.10)
Peach Orchard	0.88 (0.65)	0.92 (0.05)	0.79 (0.08)	0.60 (0.11)
Sowbelly	1.00 (0.00)	0.88 (0.07)	0.70 (0.19)	0.65 (0.10)
Other	0.83 (1.08)	N.A.	0.36 (0.13)	N.A.

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	*k*
ŝ (Treatment Type by Density) + mass	1293.577	0.000	0.255	6
ŝ (Constant) + mass	1294.706	1.129	0.145	2
ŝ (Treatment Type by Density) + sex + mass	1294.712	1.135	0.145	7
ŝ (Treatment/Reference) + mass	1295.336	1.759	0.106	3
ŝ (Treatment Type) + mass	1295.557	1.980	0.095	4
ŝ (Constant) + sex + mass	1295.724	2.147	0.087	3
ŝ (Treatment/Reference) + sex + mass	1296.047	2.470	0.074	4
ŝ (Treatment Type) + sex + mass	1296.457	2.880	0.060	5
ŝ (Area) + mass	1298.547	4.970	0.021	9
ŝ (Area) + sex + mass	1299.686	6.109	0.012	10
ŝ (Treatment Type by Density)	1319.598	26.021	0.000	5
ŝ (Treatment Type by Density) + sex	1320.269	26.693	0.000	6
ŝ (Area)	1323.900	30.324	0.000	8
ŝ (Area) + sex	1324.675	31.098	0.000	9
ŝ (Constant)	1324.726	31.149	0.000	1
ŝ (Treatment Type)	1324.915	31.338	0.000	3
ŝ (Constant) + sex	1325.300	31.723	0.000	2
ŝ (Treatment/Reference)	1325.317	31.741	0.000	2
ŝ (Treatment Type) + sex	1325.545	31.968	0.000	4
ŝ (Treatment/Reference) + sex	1326.176	32.599	0.000	3

Table 4. Late-winter body condition estimates for female adult mule deer on the Uncompahgre Plateau in 2 study areas each year of study, 2005-2009. 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
2005-2006	% Body Fat	8.80% (2.02)	N.A.	9.81% (2.88)
	T3*	1.12 (0.28)	N.A.	1.41 (0.51)
	T4	70.69 (20.94)	N.A.	79.97 (15.80)
2006-2007	% Body Fat	7.61% (1.94)	7.03% (1.80)	N.A.
	T3	1.55 (0.53)	1.42 (0.31)	N.A.
	T4	88.23 (19.53)	78.07 (22.34)	N.A.
2007-2008	% Body Fat	8.09% (1.10)	7.20% (1.69)	N.A.
	T3	1.17 (0.28)	1.17 (0.56)	N.A.
	T4*	94.30 (20.7)	56.20 (23.30)	N.A.
2008-2009	% Body Fat	7.20% (1.85)	6.25% (1.63)	N.A.
	T3	1.22 (0.32)	1.26 (0.35)	N.A.
	T4*	74.63 (14.61)	54.77 (19.34)	N.A.

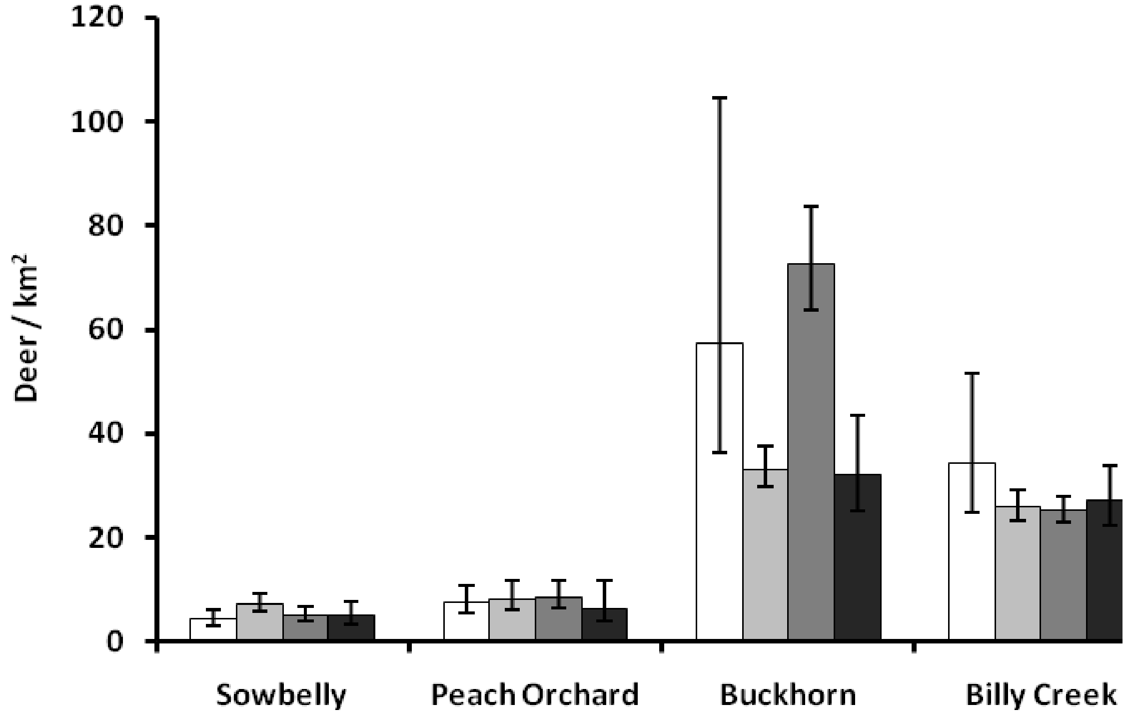

Figure 1. Mule deer density estimates for the 4 permanent study areas. Clear boxes reflect data from the 2005-2006 winter, light grey boxes reflect data from the 2006-2007 winter, grey boxes reflect data from the 2007-2008 winter, and dark gray boxes reflect 2008-2009. Error bars represent the 95% confidence intervals for density estimates.

Colorado Division of Wildlife
July 2008 – June 2009

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
Federal Aid Project:	W-185-R	:

Period Covered: July 1, 2008 – June 30, 2009

Author: C. R. Anderson

Personnel: D. Alkire, E. Bergman, C. Bishop, J. Broderick, B. deVergie, D. Finley, C. Flickinger, D. Freddy, L. Gepfert, K. Kaal, L. Kelly, T. Knowles, P. Lendrum, P. Lukacs, B. Marsh, M. Reitz, T. Segal, K. Taylor, R. Velarde, CDOW; E. Hollowed, BLM; S. Monsen, Western Ecological Consulting, Inc.; G. White, Colorado State University; R. Swisher, Quicksilver Air, Inc. Project support received from Federal Aid in Wildlife Restoration, Colorado Mule Deer Association, Colorado Mule Deer Foundation, Colorado Oil and Gas Conservation Commission, Colorado State Severance Tax Fund, EnCana Corp., Shell Petroleum, and Williams Production LMT Co.

ABSTRACT

I propose to experimentally evaluate habitat treatments that may improve the landscape to benefit mule deer (*Odocoileus hemionus*) and 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. The data presented here represent the first pretreatment year of a long-term study addressing habitat modifications and improved energy development practices intended to improve mule deer fitness in areas exposed to extensive energy development. I selected 5 winter range study areas representing varying levels of development to serve as treatment (Ryan Gulch and Magnolia) and control (Yellow Creek, Story/Sprague, and North Ridge) sites and recorded habitat use and movement patterns using GPS collars (5 locations/day), estimated overwinter fawn and adult female survival, estimated late winter body condition of adult females using ultrasonography, and estimated abundance using helicopter mark-resight surveys. I attached 250 VHF collars (50/study area) to fawns in early December 2008 and 150 VHF (10/study area) and GPS (20/study area) collars to adult female mule deer in late February—early March 2009. In comparing the data among study areas this first year, Story/Sprague deer appear to be in better physical condition than deer from the other winter ranges examined. Migration patterns were similar among 4 of the 5 areas, but Story/Sprague deer traveled shorter distances and spent less time on winter range. Yellow Creek fawns were lighter than

other study areas and exhibited the lowest survival of the areas investigated. North Ridge deer exhibited the highest winter range density and Magnolia and Ryan Gulch deer exhibited the lowest densities. Reasons for these differences are currently unknown, but could be related to several factors including relative habitat conditions, duration on and distance to seasonal ranges, and extent of human activity throughout occupied habitats. Meaningful comparisons will be evident once treatments are implemented and comparisons are possible between areas that are manipulated (treatment areas; Ryan Gulch and Magnolia) and those that are not (control areas: Yellow Creek, Story/Sprague, and North Ridge). 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

CHARLES R. ANDERSON, JR.

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

1. Collect and reattach GPS collars (5 fixes/day) to maintain sample sizes for addressing mule deer habitat use and behavior patterns in 5 study areas experiencing varying levels of energy development of the Piceance Basin, Colorado.
2. Estimate late winter body condition of adult female mule deer in each of the 5 winter herd segments
3. Monitor over-winter survival of fawn and adult female mule deer by daily ground tracking and bi-weekly aerial tracking.
4. Conduct Mark-Resight helicopter surveys to estimate mule deer abundance in each study area.
5. Summarize data and present information in an annual Job Progress Report.

INTRODUCTION

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 through conversion of native habitat vegetation with drill pads, roads, or noxious weeds, by fragmenting habitat because of drill pads and roads, by increasing noise levels via compressor stations and vehicle traffic, and by increasing the year-round presence of human activities. Extraction will indirectly affect deer by increasing the human work-force population of the region resulting in the need for additional landscape for human housing, supporting businesses, and upgraded road/transportation infrastructure. Additionally, increased traffic on rural roads will raise the potential for vehicle-animal collisions and additive direct mortality to 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 contains one of the largest migratory mule deer populations in North America and also exhibits some of the largest natural gas reserves in North America. Projected energy development throughout northwest Colorado within the next 20 years is about 15,000 wells, many of which will occur in the Piceance Basin, which currently supports over 250 active gas well pads (http://cogcc.state.co.us). Anderson and Freddy (2008*a*) in their long-term research proposal identified 6 primary study objectives to assess measures to offset impacts of energy extraction on mule deer population performance. This progress report describes the first year of addressing mule deer population performance during the pretreatment phase, which includes monitoring habitat selection and behavior patterns of adult female mule deer, overwinter fawn and adult female survival, estimates of adult female body condition during late winter, and abundance estimates on 5 winter range herd segments in relation to varying levels of natural gas development in control and treatment experimental areas prior to proposed experimental modifications in energy developmental practices and potential habitat improvement treatments.

STUDY AREAS

The Piceance Basin between the cities of Rangely, Meeker, and Rifle in northwest Colorado was selected as the project area due to its ecological importance as one of the largest migratory mule deer populations in North America and because it exhibits one of the highest natural gas reserves in North America (Fig. 1). Historically, mule deer numbers on winter range were estimated between 15,000-22,000 (Bartmann 1975), and the current number of well pads (Fig.1) and projected number of gas wells in the Piceance Basin over the next 20 years is about 250 and 15,000, respectively. Mule deer winter range in the Piceance Basin is predominantly characterized as a topographically diverse pinion pine (*Pinus edulis*)-Utah juniper (*Juniperus osteosperma*; pinion-juniper) shrubland complex ranging from 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 (*Chrysothamnus* spp.; Bartmann et al. 1992). The Piceance Basin is segmented by numerous drainages characterized by stands of big sagebrush, saltbush (*Atriplex* spp.), and black greasewood (*Sarcobatus vermiculatus*), with the majority of the primary drainages having been converted to mixed-grass hay fields. Grasses and forbs common to the area consist of wheatgrass (*Agropyron* spp.), blue grama (*Bouteloua gracilis*), needle and thread (*Stipa comata*), Indian rice grass (*Oryzopsis hymenoides*), arrowleaf balsamroot (*Balsamorhiza sagittata*), broom snakeweed (*Gutierrezia sarothreae*), pinnate tansymustard (*Descurainia pinnata*), milkvetch (*Astragalus* spp.), Lewis flax (*Linum lewisii*), evening primrose (*Oenothera* spp.), skyrocket gilia (*Gilia aggregata*), buckwheat (*Erigonum* spp.), Indian paintbrush (*Castilleja* spp.), and penstemon (*Penstemon* spp.; Gibbs 1978). The climate of the Piceance Basin is characterized by warm dry summers and cold winters with most of the annual moisture coming from spring snow melt.

Wintering mule deer population segments in the Piceance Basin include: North Ridge (57 km^2) between Dry Fork of Piceance Creek and the White River in the northeastern portion of the Basin, Yellow Creek (70 km^2) along Corral Gulch in the western portion of the Basin, Ryan Gulch (130 km^2) between Ryan Gulch and Dry Gulch in the southwestern portion of the Basin, Magnolia (130 km^2) north and east of Piceance Creek in the central portion of the Basin, and Story/Sprague Gulch (90 km^2) between Story Gulch and Sprague Gulch in the southern portion of the Basin (Fig. 1). Each of these wintering population segments has received varying levels of development, from no development in North Ridge, light development in Story/Sprague Gulch and Yellow Creek, and relatively high development in Ryan Gulch and Magnolia segments (Fig. 1). Among the 5 study areas, Yellow Creek and Story/Sprague will serve as spatial controls to Ryan Gulch and Magnolia, respectively, and North Ridge will serve as a temporal control area. Because the progression and extent of energy development in the future is dynamic and currently unknown, 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 mule deer capture and collaring efforts, monitoring overwinter fawn and adult female survival, estimating adult female body condition during late winter using ultrasonography, and estimating mule deer abundance applying helicopter mark-resight surveys. I employed helicopter net-gunning techniques (Barrett et al. 1982, van Reenen 1982) to capture 50 fawns during early December and 30 adult females during late February-early March in each of the 5 study areas (250 fawns and 150 does total). Once netted, all deer were hobbled and blind folded. Fawns were weighed, radio-collared and released on site, and adult females were transported to a handling site for collection of body measurements and were fitted with GPS (20/area; 5 fixes/day; G2110B, Advanced Telemetry Systems, Isanti, MN, USA) or VHF collars (10/area) and released. Fawn collars were spliced and fitted with 2 lengths of rubber surgical tubing to facilitate collar drop during mid-summer—early autumn, adult VHF collars were attached static, and GPS collars were supplied with timed drop-off mechanisms scheduled to release early April, 2010. All radio-collars were equipped with mortality sensing options (i.e., increased pulse rate following 8 hrs of inactivity).

Mule Deer Habitat Use and Movements

I downloaded and organized data from GPS collars deployed during the pilot study (January 2008; see Anderson and Freddy 2008*b*) following collar drop and retrieval late February 2009. GPS collars redeployed late February-early March 2009 maintained the same fix schedule of attempting fixes every 5 hours. All well pads and roads present throughout the 5 study areas in spring 2009 were mapped using hand-held GPS units and data were incorporated into ArcGIS 9.2 for resource selection analyses. I plotted deer locations and recorded timing and distance of spring and fall 2008 migrations for each study area. Mule deer resource selection analyses for the first winter of research (January—May 2008) are pending acquisition of information on timing of road and well pad development and completion. Analyses of data from winter 2008-2009 will be conducted following retrieval of GPS collars in April 2010.

Over-Winter Survival

Mule deer mortality monitoring consisted of daily ground telemetry tracking and aerial monitoring deer approximately every 2 weeks from fixed-wing aircraft. Once a mortality signal was detected, deer were located and necropsied to assess cause of death. I estimated over-winter survival on a weekly basis using the staggered entry Kaplan-Meier procedure (Kaplan and Meier 1958, Pollock et al. 1989). Capture-related mortalities (any mortalities occurring within 10 days of capture) and collar failures were censored from survival rate estimates. I estimated over-winter survival rates beginning 14 December, 2008—20 June, 2009 for adult females and 14 December, 2008—21 March, 2009 for fawns. Premature failure of surgical tubing integrity beginning late March inhibited my ability to reasonably estimate fawn survival beyond late March.

Adult Female Body Measurements

I applied ultrasonography techniques described by Stephenson et al. (1998, 2002) and Cook et al. (2001) to measure maximum subcutaneous rump fat (mm) and loin depth (longissimus dorsi muscle, mm). I estimated a body condition score (BCS) for each deer by palpating the rump (Cook et al. 2001). I combined ultrasound rump fat measurements with BCS to develop an index (rLIVINDEX; Cook et al. 2001, 2007) of the relative nutritional status of deer from each study area. I examined differences ($P < 0.05$) in nutritional status among study areas using a two-sample *t*-test. Other body measurements recorded included pregnancy status (pregnant, barren) via ultrasound, weight (kg), chest girth (cm), and hind-foot length (cm). Fetal counts were also recorded in 4 of the 5 study areas to assist a Vaginal Implant Transmitter (VIT) evaluation study (see Bishop 2009).

Abundance Estimates

I conducted 4 (Ryan Gulch) or 5 (the remaining study areas) helicopter mark-resight surveys (2 observers and the pilot) during late March—early April, 2009 to estimate deer abundance in each of the 5 study areas. I delineated each study area from GPS locations during the same period the previous year and aerial telemetry locations of radio-collared deer within 2 weeks of the first survey. The survey boundary of each study area was then extended to the nearest section boundary and study areas were divided into 2.6 km^2 sampling blocks. Aerial telemetry surveys were conducted during helicopter surveys to determine which marked deer were within each survey area. Initially, I randomly selected 10 sampling blocks from each study area (total sampling blocks = 22-50/study area) for each survey and surveyed sampling blocks sequentially to minimize flight time. After the first 2—3 surveys, depending on the area, it became apparent that increasing the number of sampling blocks to improve precision could be accomplished without undue expense, and subsequent surveys included all sampling blocks for the smaller areas (North Ridge, Yellow Creek, Story/Sprague) or 40% of the sampling blocks for the larger areas (Ryan Gulch, Magnolia). I delineated flight paths in ArcGIS 9.2 prior to surveys following topographic contours (e.g., drainages, ridges) and approximating 500 m spacing throughout selected survey blocks; flight paths during surveys were followed using GPS navigation in the helicopter. All deer observed within and between sampling blocks within the study area were included in abundance estimates. Two approximately 12 x 12 cm pieces of Ritchey livestock banding material (Ritchey Manufacturing Co., Brighton, CO USA) were uniquely marked using number, symbol combinations and attached to each radio-collar to enhance mark-resight estimates. Each deer observed during surveys was recorded as mark ID#, unmarked, or unidentified mark.

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

RESULTS AND DISSCUSSION

Deer Captures and Survival

The capture crew captured 253 fawns in early December 2008 and 150 does in late February—early March 2009. Three fawn and 0 doe mortalities occurred during capture and 0 fawn and 5 doe mortalities occurred during the myopathy period 10 days post-capture.

Fawn survival during mid-December 2008—late March 2009 varied from 0.688 (Yellow Creek) to 0.925 (Ryan Gulch; Fig 2., Table 1). Fawn survival rates differed ($P < 0.05$) between the Ryan Gulch and Yellow Creek Study areas (Table 1). Adult female survival mid-December 2008—late June 2009 varied from 0.762 (North Ridge) to 0.931 (Magnolia; Fig 1), but were not different ($P > 0.05$) among study areas (Table 1). Smaller sample sizes for adult females reduced my ability to detect differences relative to fawns, but the apparent lower survival of North Ridge females was partly due to 2 mortalities that occurred during early winter before the March capture effort when only 12-13 marked females were available in each study area. Overall, fawn survival was high during the period examined likely due to the mild winter conditions present through late March, and doe survival was consistent with other mule deer populations experiencing normal winter conditions in the western US (Unsworth et al. 1999).

Seasonal Movement Patterns

Mule deer migration patterns during 2008 varied among study areas and within the Magnolia study area. North Ridge and north Magnolia deer migrated east—west typically across US Highway 13; Yellow Creek, Ryan Gulch, and south Magnolia deer migrated south—north summering along the Roan Plateau; and Story/Sprague deer typically migrated relatively short distances south—north (Fig 3.). Although summer and winter ranges differed among study areas, distance and timing of migration was similar among 4 of the 5 study areas. Excluding the Story/Sprague study area, median date of spring migration occurred May 17, 2008 (all 4 study areas) and fall migration occurred from October 17-23, 2008; median straight-line migration distances ranged between 30.6 and 39.4 km among the 4 study areas. I noted unique migration patterns among Story/Sprague deer where median spring and fall migration occurred April 29 and December 17, 2008, respectively, and median migration distance was 9.6 km. Story/Sprague deer generally spent less time on winter range and required shorter migration distances to achieve their seasonal metabolic requirements.

Mule Deer Body Measurements

Body measurements of adult female mule deer recorded 27 February—6 March 2009 were typically highest from the Story/Sprague and North Ridge study areas and lowest from the Yellow Creek and Magnolia study areas (Table 2). Parameters most related to mule deer nutritional status (rLIVINDEX derived from rump fat and BCS; Cook et al. 2001, 2007) suggested mule deer from the Story/Sprague study area were in the best condition and Yellow Creek deer were in the poorest condition. I observed significantly higher rLIVINDEX values ($P < 0.05$) among Story/Sprague females than females from the other 4 areas, but differences were not significant ($P > 0.05$) among the other 4 female groups.

Early December fawn weights of males and females averaged 36.4 kg ($n = 22$, SD = 4.5) and 33.5 kg ($n = 27$, SD = 3.3) from Ryan Gulch, 33.9 kg ($n = 22$, SD = 3.6) and 30.5 ($n = 28$, SD = 4.9) from Yellow Creek, 37.0 kg ($n = 24$, SD = 3.5) and 33.5 kg ($n = 26$, SD = 4.0) from Magnolia, 35.8 kg ($n = 26$, SD = 4.8) and 33.2 kg ($n = 24$, SD = 3.0) from Story/Sprague, and 35.2 kg ($n = 20$, SD = 4.3) and 33.9 kg ($n = 30$, SD = 4.2) from North Ridge. Female fawns from Yellow Creek were significantly lighter (P < 0.05) than female fawns from the other 4 areas and Yellow Creek male fawns were significantly lighter than male fawns from Magnolia ($P = 0.010$).

Mule Deer Population Estimates

Mark-resight models that best predicted abundance estimates (lowest AICc; Burnham and Anderson 2002) exhibited constant population size across surveys (i.e., $\alpha = 0$ suggesting population closure) and homogenous individual sightability ($\sigma^2 = 0$) for all study areas, and variable sightability (P) across surveys in Ryan Gulch and Magnolia or with survey effort in North Ridge, Story/Sprague, and Yellow Creek. North Ridge exhibited the highest deer density (18.1/km2) and Ryan Gulch and Magnolia exhibited relatively low deer densities (5.6 and 6.6/km^2; Table 3).

Abundance estimates were similarly precise from 4 of the 5 study areas (mean CV = 0.16—0.18), with Story/Sprague exhibiting the widest CIs (Table 3; mean CV = 0.29). A relatively small number of marked deer were sighted during surveys (Table 3) suggesting improved precision can be accomplished with increased sample sizes or increasing the number of surveys/study area. Increasing the number of marks/study area by 30 can easily be accomplished by extending GPS drop-off dates beyond the March capture period, which wasn’t the case last winter. I also noted that complete coverage of each study area can reasonably be accomplished by increasing flight time by about 20 to 60 minutes/survey depending on the study area and should be more cost effective than increasing number of surveys/area. By increasing the number of marks and complete survey coverage/study area, CVs should improve likely providing detection of <30% change in population size.

SUMMARY AND FUTURE PLANS

The goal of this study is to investigate habitat treatments and energy development practices that enhance mule deer populations exposed to extensive energy development activity. The information presented here provide data describing mule deer population parameters from the first pre-treatment year of a long-term study intended to address how mule deer react to landscape scale habitat and human activity modifications. The pretreatment period is intended to continue 1 to 2 more winters to provide baseline data to compare against intended improvements in habitat conditions and concentration/reduction in human development activities, which will be maintained for at least 5 years to provide sufficient time to measure how deer respond to these changes. Based on the data collected thus far, Story/Sprague deer appear to be in better physical condition than deer from the other winter ranges examined. Migration patterns were similar among 4 of the 5 areas, but Story/Sprague deer traveled shorter distances and spent less time on winter range. Yellow Creek fawns were lighter than other study areas and exhibited lowest survival of the areas investigated. North Ridge deer exhibited the highest winter range density and Magnolia and Ryan Gulch deer exhibited the lowest densities. Reasons for these differences are currently unknown, but could be related to several factors including relative habitat conditions, duration on and distance to seasonal ranges, and extent of human activity throughout occupied habitats. Meaningful comparisons will be evident once treatments are implemented and comparisons are possible between areas that are manipulated (treatment areas) and those that are not (control areas).

We are currently working towards a habitat improvement plan and identifying beneficial development practices that are both logistically and financially feasible to implement. Investigations of habitat treatment potential are promising in the Magnolia and Ryan Gulch study areas and we expect positive native plant responses with potential acceleration of response through native seeding. Members of CDOW, BLM, and private consultants will be developing a habitat treatment plan for review and approval by the end of the year. Discussions with Williams Production LMT Co. have produced a clustered development plan to be implemented in the Ryan Gulch study area and new technologies will be implemented to reduce human activity through remote monitoring of well pads and fluid collection systems. I recently contracted with Dr. Terry Bowyer and Patrick Lendrum (MS candidate) of Idaho State University to begin a graduate project addressing mule deer migration and potential influences of human activity along migration routes. I collaborated with Chad Bishop this past winter/spring to test a new VIT design that improves VIT retention (see Bishop 2009) and will improve our ability to address neonate survival (in addition to overwinter survival) and identify fawning habitat on summer range; these factors are not currently being addressed, but could strengthen our inference about mule deer and energy development if funding and cooperative agreements were developed for this purpose. We are beginning to work collaboratively with ExxonMobile Production Co. and Colorado State University to enhance funding and potentially provide graduate student assistance addressing additional components of mule deer/energy development interactions. Additional funding and cooperative agreements will be necessary to manipulate habitat conditions to benefit mule deer and our current funding sources will need to be maintained to continue monitoring mule deer population parameters at the current level. 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.

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Table 1. Survival rate estimates ($\hat{S}$) of fawn (14 Dec. 2008—21 Mar. 2009) and adult female (14 Dec.—20 June, 2009) mule deer in 5 winter range study areas of the Piceance in northwest, Colorado.

Cohort Study area	Initial sample size (*n*)	March doe sample[a] (*n*)	$\hat{S}$ (95% CI)
Fawns			
Ryan Gulch	54		0.925 (0.853—1.000)
Yellow Creek	43		0.688 (0.546—0.839)
Magnolia	50		0.800 (0.688—0.911)
Story/Sprague	47		0.823 (0.722—0.937)
North Ridge	48		0.833 (0.728—0.939)
Adult females			
Ryan Gulch	12	28	0.893 (0.778—1.000)
Yellow Creek	13	28	0.890 (0.737—1.000)
Magnolia	12	29	0.931 (0.839—1.000)
Story/Sprague	13	29	0.862 (0.737—0.988)
North Ridge	13	30	0.762 (0.536—0.960)

[a]Adult female sample size following capture and radio-collaring efforts late February—early March, 2009.

Table 2. Mean body measurements, Body Condition Score (BCS), and an index of relative nutritional status (rLIVINDEX) of adult female mule deer from 5 study areas in the Piceance Basin of northwest Colorado, late February—early March, 2009. Sample sizes = 30/study area and values in parentheses = SD.

Study Area	Weight (kg)	Hind foot length (cm)	Chest girth (cm)	Loin depth (mm)	Rump fat (mm)	BCS[a]	rLIVINDEX[b]
Ryan Gulch	52.2 (5.7)	46.9 (1.8)	96.9 (4.1)	40.50 (3.03)	1.73 (1.78)	2.66 (0.55)	2.71 (0.68)
Yellow Creek	52.9 (4.8)	47.2 (1.1)	97.4 (4.2)	40.17 (2.95)	1.47 (0.68)	2.50 (0.60)	2.51 (0.63)
Story/Sprague	55.6 (5.7)	47.2 (1.2)	96.0 (4.1)	40.70 (3.72)	1.97 (1.00)	3.09 (0.72)	3.12 (0.77)
Magnolia	55.3 (5.9)	47.7 (1.5)	87.5 (5.0)	40.53 (3.70)	1.30 (0.79)	2.56 (0.68)	2.57 (0.70)
North Ridge	53.3 (5.6)	47.3 (3.3)	97.2 (4.9)	41.13 (2.70)	1.57 (1.22)	2.60 (0.56)	2.62 (0.60)

[a]Body condition score taken from palpations of the rump (Cook et al. 2001)
[b]rLIVEINDEX = (cm rump fat - 0.2) + BCS if rump fat > 2 mm. Otherwise = BCS (Cook et al. 2001, 2007).

Table 3. Mark-resight abundance (*N*) and density estimates of mule deer from 5 winter range herd segments in the Piceance Basin, northwest Colorado, 25 March—2 April, 2009. Data represent 4 surveys from Ryan Gulch and 5 surveys from the other 4 study areas.

Study area	Mean No. sighted	Mean No. marked	*N* (95% CI)	Density (deer/km^2)
Ryan Gulch	156	12	727 (626—854)	5.6
Yellow Creek	138	7	720 (605—870)	10.3
Magnolia	109	6	854 (716—1,027)	6.6
Story/Sprague	138	5	1,125 (853—1,509)	12.4
North Ridge	238	14	1,028 (874—1,230)	18.1

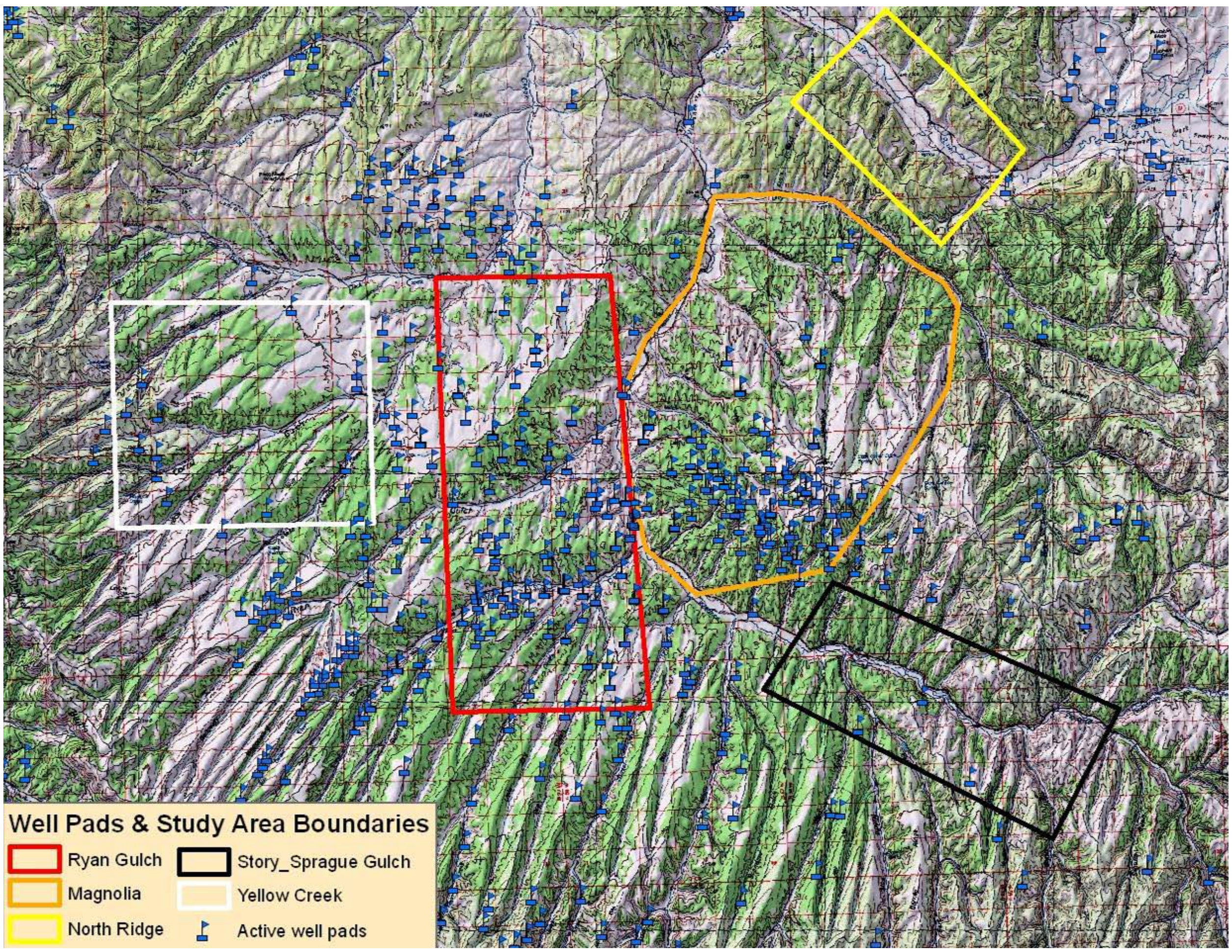
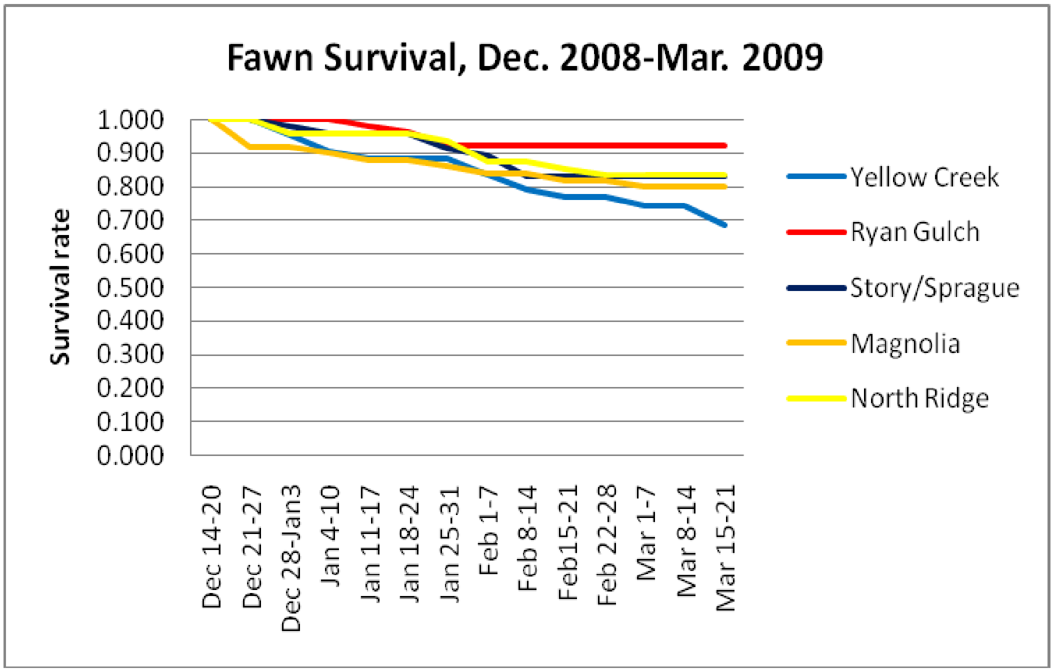


Figure 1. Approximate study area boundaries relative to active natural gas well pads and energy development facilities in the Piceance Basin of northwest Colorado, spring 2009.



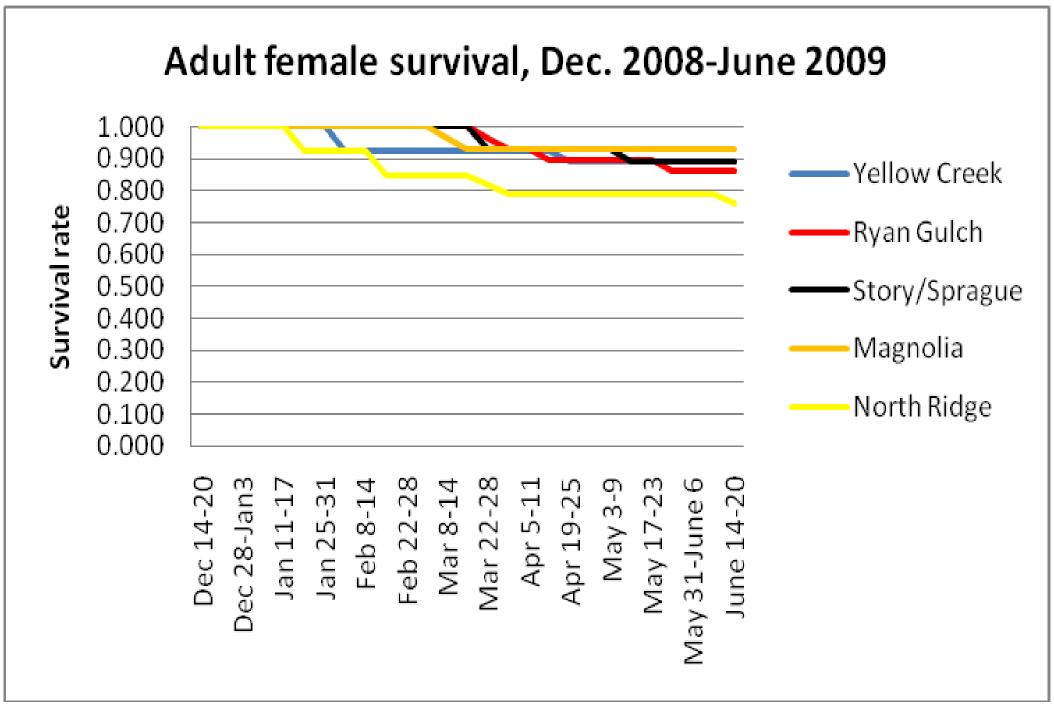


Figure 2. Winter survival rates of fawn (14 December, 2008—21 March, 2009; top) and adult female (14 December—21 June, 2009; bottom) mule deer from 5 study areas in the Piceance Basin of northwest Colorado. Survival rates of Yellow Creek fawns were significantly lower ($P < 0.05$; Table 1) than survival of Ryan Gulch fawns. Survival rates among other fawn and doe groups were not significantly different ($P > 0.05$; Table 1).

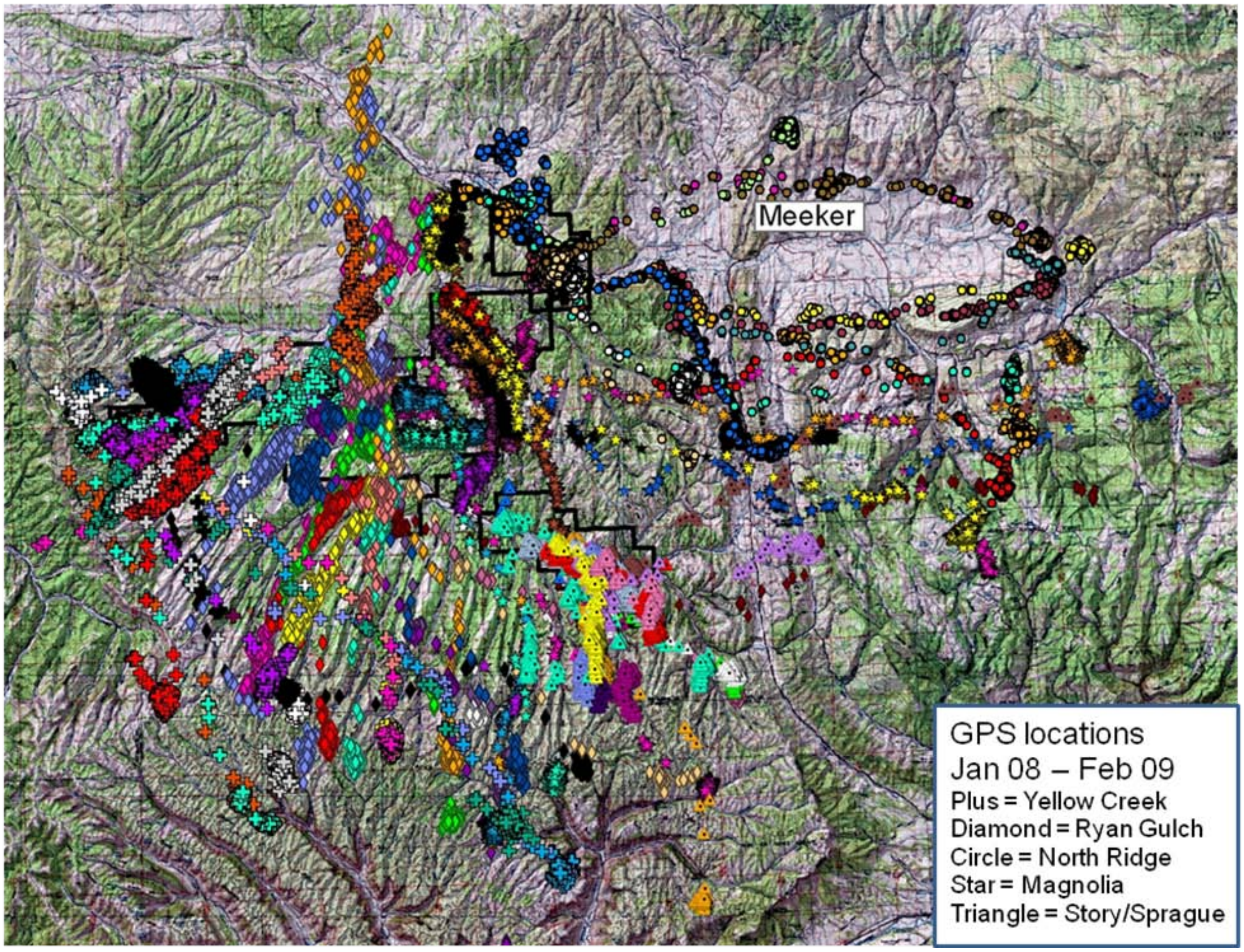


Figure 3. Mule deer GPS locations from 5 winter range study areas (solid lines; 15 does/study area) in the Piceance Basin of northwest Colorado, January 2008—February, 2009.

Colorado Division of Wildlife
July 2008 –July 2009

WILDLIFE RESEARCH REPORT

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

Period covered: July 31, 2008−July 31, 2009

Author: K. A. Logan.

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

ABSTRACT

This report provides information in the fifth year of the *reference period* August 2008 through July 2009 on puma population characteristics and dynamics on the Uncompahgre Plateau. Field operations were impacted by a state government issued hiring freeze that did not allow full staffing of 2 puma capture teams during winter 2008-09. All capture efforts involving use of trained dogs, cage traps, and inspections at nurseries in 2008-09 resulted in a total of 37 puma captures (7 adult females [1 adult female captured 3 times, another captured twice], 4 adult males [1 adult male captured 3 times], 1 subadult female, and 18 cubs [2 of them captured twice each]). Five adults (4 females, 1 male) and 14 cubs were captured and marked for the first time. As of July 2009, there were 17 adults (11 females, 6 males), 1 subadult female, and 5 cubs (2 females, 3 males) with active radio-collars. Efforts to capture, sample, and mark pumas with the use of trained dogs extended from December 9, 2008 to April 30, 2009. Those efforts resulted in 71 search days, 198-202 puma tracks detected, 75-78 pursuits, and 24 puma captures. In 2008-09, capture efforts with ungulate carcasses and cage traps resulted in captures of 2 adult females and 1 subadult female. Capture and search efforts from November 2008 through March 2009 enabled us to estimate a minimum of 37 independent pumas detected on the Uncompahgre Plateau study area during that time, including 26 females and 11 males. *Preliminary* puma population parameters estimated during the past 4.7 years of research, included: population sex and age structure, reproduction rates, and survival rates. Data on puma reproduction rates included: average litter size = 2.77 ± 0.9081 *SD*, n = 26; average birth interval (mo.) = 18.462 ± 4.6035 *SD*, n = 16; average proportion of adult females producing cubs each year = 0.598 ± 0.1094 *SD*, n = 11-13 females per yr. for 4 years; secondary sex ratio = 41:31, consistent with 1:1; and average gestation length (day) = 90.5-92.3(*SD* = 2.5495,

2.1628, respectively). Puma births occurred March through September, with 24 of 27 occurring May through September. Majority of breeding activity was February through June. *Preliminary* estimates of survival rates for both adult and subadult pumas in this *reference period* were high, and may reflect the absence of puma sport-hunting as a mortality factor. An increasing age structure of independent pumas in the *reference period* reflects the high survival rates. Cub survival was about 0.53 (SE = 0.1623-0.1629; Kaplan-Meier procedure) and 0.58 (± 0.1610 95% CI; binomial model). The main cause of mortality in the adults and cubs was aggression by other pumas. Dispersal from the Uncompahgre Plateau study area was documented for 8 pumas (7 male, 1 female) that dispersed during the subadult stage and moved distances ranging from about 61 to 330 linear km. We monitored 7 puma families with a radio-collared mother and at least one radio-collared cub to assess association distances during aerial locations from November 6, 2008 to March 20, 2009. The aggregate data gathered during the past 4 winters generally indicate that mothers were usually within 660 m of their cubs during the day. Preliminary comparisons between our current puma research on the Uncompahgre Plateau (4.7 years duration) and results of the Anderson et al. (1992) puma research on the plateau (7 years duration 1981-1988) were made where appropriate. Data on puma population characteristics and dynamics gathered during the *reference period* was used for a *preliminary* assessment of population-based assumptions used by CDOW to guide puma hunting management and indicated that assumptions pertaining to puma population sex and age structure, density, and expected results from modeled harvest rates are biologically supported. The CDOW structured the puma hunting season for the *treatment period.* The first hunting season will begin mid-November 2009 and extend to January 31, 2010 unless the quota is filled earlier. The management objective will be to achieve a stable to increasing puma population. Population model simulations indicated a harvest quota of 8 independent pumas to achieve the objective. No limit of hunters on the study area is imposed, but each hunter is required to obtain a hunting permit for the study area. In addition, an effort will be made to survey each hunter obtaining a valid permit. All pumas harvested in and around the study area will be inspected by CDOW personnel. A study plan for the *treatment period* was submitted for internal review in the CDOW. The plan was substantially modified and received another internal review. That version will be modified and submitted to the Mammals Research leader in fall 2009. Continuing this research includes manipulating the puma population with sport-hunting in the *treatment period* while also estimating puma population characteristics and vital rates. We are continuing to collaborate with colleagues in Mammals Research and at Colorado State University to assess puma population dynamics and social structure, puma-human interactions, health, habitat use, and we will incorporate a pilot project to examine individual puma detection rates using a camera grid design.

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; model puma population dynamics; and plan for the remaining 5 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 on agent-specific mortality.
5. 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.
6. Use data on population dynamics for a preliminary evaluation of assumptions used by CDOW biologists and managers in the Data Analysis Unit puma management planning process.
7. Work with CDOW biologists and managers to structure the puma hunting manipulation for the first year of the 5 year *treatment phase*.
8. Develop a study plan for remaining 5 years of puma population research on the Uncompahgre Plateau Study Area.
9. Collaborate with other researchers and evaluate other data sources that could be 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 pumas 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 manipulations. Our goal is to provide managers with reliable information on puma population biology and to develop useful tools for their efforts to *adaptively manage* puma in Colorado to maintain healthy, self-sustaining populations.

The highest-priority management needs are being addressed with this intensive population study that focuses on puma population dynamics using sampled, tagged, and GPS/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 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 puma population abundance.

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 manipulate the puma population.

TESTING ASSUMPTIONS AND HYPOTHESES

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

1. Considering limitations (i.e., methods, number of years, assumption violations) to the previous Colorado-specific studies on puma populations (Currier et al. 1977, Anderson et al. 1992, Koloski 2002), managers assume that puma population densities in Colorado are within the range of those quantified in more intensively studied populations in Wyoming (Logan et al. 1986), Idaho (Seidensticker et al. 1973), Alberta (Ross and Jalkotzy 1992, and New Mexico (Logan and Sweanor 2001). The CDOW assumes density ranges of 2.0−4.6 puma/100 km^2 (i.e., includes pumas of all age stages- adults, subadults, and cubs, J. Apker, CDOW Carnivore Biologist, person. commun. Nov. 19, 2003) 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 intensive efforts to capture, mark, and estimate non-marked animals developed and refined during the study to estimate the *minimum* puma population, the following will be tested:

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

2. Recreational puma hunting management in Colorado 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 λ include population density, sex and age structure, female age-at-first-breeding, reproduction rates, sex- and age-specific survival, immigration and emigration.

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

3. The key assumption is that the CDOW can manage puma population growth through recreational hunting on the basis that for a stable puma population hunting removes the annual increment of population growth (i.e., from current judgments on population density, structure, and λ). Puma harvest rate formulations for DAUs 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_3: Total mortality of an estimated 15% of the adults and subadults with no more than 45% of the total mortality comprised of females will not result in a decline of the harvest-age segment of the population by the beginning of the next hunting season.

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

H_4: 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).

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 managers to biologically support and adapt puma management based on Colorado-specific estimated puma population characteristics, parameters, and dynamics.
3. Methods for assessing puma population dynamics will allow managers to evaluate modeled populations and estimate effects of management prescriptions designed to achieve specified puma population objectives in targeted areas of Colorado. Ascertaining puma numbers and densities during the project will allow assessment of monitoring techniques. Potential methods include use of harvest sex and age structure and photographic and DNA genotype capture-recapture. Study plans to develop and test feasible field and analytical methods will be developed 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; Fig. 2). The study area includes about 2,253 km^2 (870 $mi.^2$) of the southern halves of Game Management Units (GMUs) 61 and 62, and about 155 km^2 (60 $mi.^2$) of the northern edge of GMU 70 (between state highway 145 and San Miguel River). The area is bounded by state highway 348 at Delta, 25 Mesa road and Forest Service road FS503 to Nucla, state highway 97 to state highway 141 to state highway 145 to Placerville, state highway 62 to Ridgeway, U.S. highway 550 to Montrose, and U.S. highway 50 to Delta.

The study area seems typical of puma habitat in Colorado that has vegetation cover that varies from the pinion-juniper covered foothills starting from about 1,700 m elevation to the spruce-fir and aspen forests growing to the highest elevations of about 3,000 m. Mule deer (*Odocoileus hemionus*) and elk (*Cervus elaphus*) are the most abundant wild ungulates available for puma prey. 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 Treatment Periods

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

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

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

During the *treatment period*, years 6—10, 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 or suppression (CDOW, Draft L-DAU Plans, 2004). Theoretically, survival of independent pumas will be influenced mainly by recreational hunting, which will be quantified by agent-specific mortality rates of radio-collared pumas. 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 to their mandated responsibility. Dynamics of the puma population will be manipulated to evaluate hypotheses that are related to effects of hunting (i.e.,: effects of harvest rates, relative vulnerability of puma sex and age classes to hunting, variations in puma population structure due to hunting). The killing of tagged and collared pumas during the *treatment period* will not hamper operational needs (as it would during the start-up years), because by the beginning of this period, a majority of independent pumas in the population should be marked, and sampling methods formalized.

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

Field Methods

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

Assuming that the puma population density on the study area was relatively low at the beginning of this study— about 1 adult/100 km^2 and the sex ratio was equal (Anderson et al. 1992, Logan and Sweanor 2001:167), then there might have been 22 adults, 11 males and 11 females. Also assuming that the total population contained 10% subadults and 34% cubs (Logan and Sweanor 2001), then there might have been 4 subadults and 13 cubs with equal sex ratios in a total population of 39 pumas. If we achieved our logistical aim, then we should be able to quantify population characteristics and vital rates of the puma population based on a sample that includes a majority of individuals in the population. Recognizing that the population may grow, we will build upon the tagged number in each subsequent year to maintain a high proportion of marked individuals in the population.

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

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

Pumas usually climbed trees to take refuge from the dogs. Adult and subadult pumas captured for the first time or requiring a change in telemetry collar were immobilized with Telazol (tiletamine hydrochloride/zolazepam hydrochloride) dosed at 5 mg/kg estimated body mass (Lisa Wolfe, DVM, CDOW, attending veterinarian, pers. comm.). Immobilizing agent was delivered into the caudal thigh muscles via a Pneu-Dart® shot from a CO_2-powered pistol. Immediately, a 3m-by-3m square nylon net was deployed beneath the puma to catch it in case it fell from the tree. A researcher climbed the tree, fixed a Y-rope to two legs of the puma and lowered the cat to the ground with an attached climbing rope. Once the puma was on the ground, its head was covered, its legs tethered, and vital signs monitored (Logan et al. 1986). Normal signs include: pulse ~70 to 80 bpm, respiration ~20 bpm, capillary refill time ≤2 sec., rectal temperature ~101^{o}F average, range = 95 to 104^{o}F (Kreeger 1996).

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

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

Marking, Global Positioning System- and Radio-telemetry: Pumas do not possess easily identifiable natural marking, such as tigers (see Karanth and Nichols 1998, 2002), therefore, the capture, marking, and GPS- or VHF- collaring of individual pumas was essential to a number of project objectives, including estimating vital rates and gathering movement data relevant to population dynamics (i.e., emigration and Data Analysis Unit boundaries). Adult, subadult, and cub pumas were marked 3 ways: GPS/VHF- or VHF-collar, ear-tag, and tattoo. The identification number tattooed in the pinna was permanent and could not be lost unless the pinna is severed. A colored (bright yellow or orange), numbered rectangular (5 cm x 1.5 cm) ear-tag (Allflex USA, Inc., DFW Airport, TX) was inserted into each pinna to facilitate individual identification during direct recaptures. Cubs ≤10 weeks old were ear-tagged in only one pinna.

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

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

VHF radio transmitters on GPS collars enabled researchers to find those pumas on the ground in real time to acquire remote GPS data reports, facilitate recaptures for re-collaring, and to check on their reproductive and survival status. VHF transmitters on GPS- and VHF-collars had a mortality mode set to alert researchers when puma was immobile for 3 to 24 hours so that dead pumas could be found to quantify survival rates and agent-specific mortality rates by gender and age. Locations of GPS- and VHF-collared pumas were 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). Aerial locations also provided simultaneous location data on mothers and cubs. GPS- and VHF-collared pumas were located from the ground opportunistically using hand-held yagi antenna. At least 3 bearings on peak aural signals were mapped to fix locations and estimate location error around locations (Logan and Sweanor 2001). Aerial and ground locations were plotted on 7.5 minute USGS maps (NAD 27) and UTMs along with location attributes recorded on standard forms. GPS and aerial locations were mapped using GIS software.

We attempted to collar all cubs in observed litters with small VHF transmitter mounted on an expandable collar that can expand to adult neck size (Wildlife Materials, Murphysboro, Illinois, HLPM-2160, ~50g, or Telonics, Inc., Mesa, Arizona MOD 210, ~100g,) when cubs weighed 2.3―11 kg (5―25 lb). Cubs with mass ≥11 kg could wear these small expandable collars until they are over 12 months old. Cubs were recaptured to replace collars as opportunities allowed. Monitoring radio-collared cubs allowed quantification of survival rates and agent-specific mortality rates (Logan and Sweanor 2001).

Analytical Methods

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

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

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

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

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

Functional Relationships: Once data collection is complete, a variety of analyses will be conducted to estimate parameters and examine functional relationships. Graphical methods will be used to initially examine functional relationships among puma population parameters. Linear regression procedures and coefficients of determination will be used to assess functional relationships if data for the response variable are normally distributed and the variance is the same at each level. If the relationship is not linear, data is non-normal, and variances are unequal, we will consider appropriate transformations of the data for regression procedures (Ott 1993). Non-parametric correlation methods, such as Spearman's rank correlation coefficient, will also be used where appropriate to test for monotonic relationships between puma abundance and other parameters of interest (Conover 1999). Relationships of explanatory variables to survival parameters will be modeled in MARK. Statistical analyses can be performed using SYSTAT, R, and MARK 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 2008 to July 2009. Our plan was to use 2 fully-staffed puma capture teams with dogs November through April, with each team operating on half the study area, with the intent of substantially boosting puma capture and sampling efforts. But, field operations were impacted by a state government mandated hiring freeze. We were limited to the principal investigator and 2 houndmen teams from October 2008 through April 2009. The principal investigator operated with the 2 houndmen teams for a single expanded moving search footprint and performed all immobilization and sampling procedures during winter and spring capture efforts. Our searches to detect puma presence covered the entire study area. By May 2009 technicians could be hired again and assisted in puma captures in cage traps and at nurseries. In addition, the Colorado State University bobcat research team facilitated the recapture of an adult female puma. We made 37 puma captures during the period (7 adult females [1 adult female captured 3 times, another captured twice], 4 adult males [1 adult male captured 3 times], 1 subadult female, and 18 cubs [2 of them captured twice each]). Five adults (4 females, 1 male) and 14 cubs were captured and marked for the first time in 2008-2009. One adult female and 2 cubs were visually observed at capture efforts, but could not be handled. A total of 39 pumas were monitored with radiotelemetry from August 2008 to July 2009 (some of these had been collared during previous years).

Trained dogs were used as our main method to capture, sample, and mark adult and subadult pumas from December 9, 2008 to April 30, 2009. Those efforts resulted in 71 search days, 198-202 puma tracks detected, 75-78 pursuits, and 24 puma captures (Table 1). Puma capture efforts (i.e., search days) with dogs in this period was slightly less than our efforts in the 4 previous winters (Table 2). But, the frequency of tracks encountered was about the same as the previous winter. The pursuits increased over the 4 previous periods, as did our capture rate. The later 2 statistics were probably the result of using 2 houndmen teams. Four adult and 7 cubs were captured for the first time by using dogs (Tables 1 and 3).

This included 2 non-marked cubs that could not be handled for safety reasons. Three adult male pumas and 1 large male cub were captured with dogs but could not be handled for safety reasons, and 1 adult female and her cub were visually observed but could not be caught for marking and sampling (Table 4). Two adult females (1 recaptured twice) and an adult male were recaptured and observed, but there was no need to handle them (Table 5).

Puma capture efforts using ungulate carcasses and cage traps extended from August 20, 2008 to July 20, 2009. We used 36 road-killed mule deer at 17 different sites to capture one adult female and one subadult female (Tables 6). In addition, the Colorado State University bobcat research team recaptured an adult female in a trap set for bobcats, thus, providing an opportunity to change a failing GPS collar. Pumas scavenged 7 of 36 (19.4%) of the ungulate carcasses used for bait. Percentages of puma scavenging ungulate carcasses in the previous 3 years were 20%, 22.5%, and 18.3%. Other carnivores that used the ungulate baits included: black bear, bobcat, gray fox, and domestic dogs.

We captured 14 cubs (8 male:6 female) for the first time (Table 7), and fit 11 of them with radio-collars (Appendix A). Three cubs were not radio-collared. In 1 case the mother returned to the nursery while we were sampling the cubs so we quickly returned the cubs to the nursery, leaving 1 collared and 1 not collared. In the other case, 2 cubs in a litter of 3 were too small to wear the collar design. Three of the cubs were bayed by our dogs and were large enough to require anesthetics for safe handling. The other 11 cubs were handled without anesthetics at their nurseries when they were 34 to 38 days old. Litters bearing these cubs were produced in August (2), September (1), April (1), and May (3).

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

Our search efforts throughout the study area also revealed the presence of at least 14 other independent pumas, we classified as 12 females and 2 males. We could separate the activity of these pumas from the GPS- and VHF- collared pumas in time, space, and track size differences between females and males. Moreover, females in association with cubs of different numbers, sizes, and locations enabled us to separate 5 adult females followed by 1 to 3 medium-to-large-size cubs. One of the adult females was visually observed with 2 of her 3 cubs, 2 of which we captured and marked. The tracks we found of the other pumas were too old to pursue (i.e., probability of capture with the dogs was negligible). It is also possible that 2 of the adult females were previously marked animals wearing non-functional GPS collars (Table 8).

Our search and capture efforts during November 2008 through April 2009 enabled us to estimate a minimum count of 37 independent pumas detected on the Uncompahgre Plateau study area, up from a minimum count of 33 independent pumas during the November 2007 to March 2008 (Table 8). This estimate was based on the number of known radio-collared pumas, the observation of one non-collared female puma, and detection of tracks of suspected non-collared pumas or pumas with non-functional GPS collars on the study area (explained previously). In addition to the independent pumas, we also counted a minimum of 21 cubs. Of the 37 independent pumas, 23 to 25 (62-68%) were marked and 12 to 14 (32-

38%) were assumed to be unmarked animals. Of the expected unmarked pumas, 12 were females and 2 were males, which might reflect lower detection rates of females, making it more difficult for us to capture and mark females. Although, we would have expected to capture, sample, and mark a larger portion of those animals had we fielded the 2 complete capture teams in winter 2008 to 2009 as previously planned. There may be variation in puma numbers on the west and east slopes of the study area. The west slope count includes 16 independent pumas (11 females, 5 males). The east slope count includes 21 independent pumas (15 females, 6 males). We used the minimum puma counts in the past 2 periods, (i.e., 33 independent pumas for November 2007 to March 2008 and 37 independent pumas for November 2008 to April 2009) to calculate preliminary *minimum* densities for the winter puma habitat area estimated at 1,671 km^2 on the Uncompahgre Plateau study area. The minimum densities ranged from 2.0 to 2.2 independent pumas/100 km^2.

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 4.7 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 in pursuit of furbearers, 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. Anderson et al. (1992:49) estimated a minimum density of "resident" pumas (equivalent to our independent pumas) at 1.1 pumas/100 km^2. This was practically half the density of our current preliminary minimum density estimates for independent pumas (see previously).

So far, in our 5 winters, the average effort per winter to capture pumas with dogs is 77.2 days (range = 71 to 82). Of 247 pursuits, 94 (38%) were successful. We captured 41 individual pumas their first time with dogs (i.e., does not include dog-aided recaptures), yielding an average capture rate of 9.4 days per capture (i.e., 386 days/41 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 109 pumas. Of those animals, 91 were radio-collared, allowing us to monitor fates of pumas in all sexes and age stages, including: 19 adult females, 12 adult males, 4 subadult females, 5 subadult males, 30 female cubs, 30 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 and weighed for the first time averaged 61.3 kg for 10 males (*SD* = 3.72, range 55 to 68 kg) and 38.3 kg for 18 females (*SD* =

4.01, range = 31 to 45). Sexual dimorphism is evident in pumas, and has been described for the species throughout its range (Young and Goldman 1946). Sexual dimorphism in the puma has been explained as a potential result of sexual selection (Logan and Sweanor 2001:109).

Segment Objective 2

During the past 4.7 years of this work we compiled data on puma reproduction that was not previously available on pumas in Colorado. We examined 72 cubs from 26 litters aged 26 to 42 days old where we were reasonably sure that we counted all the cubs at the nurseries (Table 9, Appendix A). Using those litters and 1 other litter confirmed by nursling cub tracks with a GPS-collared female (i.e., *n* = 27 litters with approximately known birth dates), the distribution of puma births by month indicate puma births extending from March into September, with 24 of 27 births occurring May through September (Fig. 4). Our data suggests that the majority of puma breeding activity occurs February through June. The secondary male:female sex ratio was 41:31 for 26 litters where all the cubs were sexed. This ratio was not significantly different from 1:1, ($X^2 = 1.389 < 3.841$, $\alpha = 0.05$, 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 extreme sizes of the 26 litters examined at nurseries were 2.77 (±0.9081), 1 to 4 (Table 9). In addition, 16 birth intervals for 9 different female pumas averaged 18.462 months (*SD* = 4.6035), and ranged from 11.7 to 23.9 months (Table 9). During the past 4 biological years (i.e., 2005-06 to 2008-09) when we radio-monitored 12, 13, 12, and 11 adult female pumas per year, respectively, the proportion of adult females that produced cubs each year were 0.67, 0.69, 0.58, 0.45 with a mean ± *SD* of 0.598 ± 0.1094. Based on observations (from GPS and radio-telemetry data) of associations between 9 mothers and putative sires (Table 9), 10 estimated gestation periods, considering a range of days for 7 observations, averaged 90.5 to 92.3 days (*SD* = 2.5495, 2.1628, respectively), 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 27 litters adds to Anderson's data (Fig. 4), and indicates puma births in Colorado occurring in every month except January and November (so far). 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 (Table 9).

Segment Objectives 3 & 4

From December 8, 2004 (capture and collaring of the first adult puma M1) to July 31, 2009, we radio-monitored 12 adult male and 19 adult female pumas to quantify survival and agent-specific mortality rates (Table 10). One adult male is known to have died of natural causes. 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. One adult male, M5, lived in the buffer zone north of the study area where all marked pumas were protected from sport-hunting. However, M5 was killed at 54 months old by a puma hunter when M5 left the buffer zone and ranged into eastern Utah. We lost contact with 3 adult males apparently due to GPS/VHF collar failure: M1, M27, and M29. Direct observations in the field indicated that M27 was alive on 05-07-09 (camera photo), and M29 was alive on 02-25-09 (recapture). Four adult females are known to have died of natural causes. F50 was about 29 to 31 months old when she died apparently of natural causes (exact agent could not be identified). Three adult females, F54, F30, and F2 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 killed by a puma of unknown sex and for unknown circumstances when she was about 60 months old. F2 was killed when she was about 92 months old by a puma of unknown sex (but thought to be a male based on presence of 8 scrapes), as was at least one of her four 87-day-old cubs M79 (Appendix A). All 3 adult females appeared to have fatal bites to the head, with canine punctures that penetrated the skull. One adult female, F7, was killed for depredation control purposes when she was about 107 months old.

Preliminary estimates of adult puma survival rates indicate relatively high survival in this *reference period* (i.e., with no sport-hunting) (Table 11). Survival rates were estimated using the Kaplan-Meier procedure to staggered entry of animals (Pollock et al. 1989) for the past 4 annual and hunting season periods when samples were ≥ 5 animals in each sex category. The survival rates reflect 1 male death and 4 adult female deaths from natural causes. Data on M5 (killed by a hunter) and F7 (killed for depredation control) were right censored after the date they died. In general, adult male puma survival is higher than adult female survival in this non-hunted population state. The adult age structure, as indicated in Figure 4, is indicative of high survival rates during the past 5 winters without sport-hunting mortality. Research in New Mexico on a non-hunted puma population also indicated high adult survival rates with survival rates of adult males higher than adult females and the major cause of death being aggression by male pumas (n = 8 years; Logan and Sweanor 2001:127-138).

We have radio-monitored 9 pumas, 5 males and 4 females, in the subadult age-stage (independent pumas <24 months old) (Table 12). One of those, F66, died of natural causes. F66 died at 23 months old of trauma to internal organs that caused massive bleeding attributed to trampling by an elk or mule deer. We need to increase our efforts to acquire larger samples of male and female radio-monitored subadult pumas to acquire reliable estimates of their survival.

Data from puma hunters provided additional information on fates of 8 pumas, 7 males and 1 female, initially captured and marked as cubs (5 males) or subadults (2 males, 1 female) on the Uncompahgre Plateau puma study area (Table 13). All 7 of the males were killed away from the study area by hunters at linear distances (i.e., from initial capture sites to kill sites) ranging from about 66 to 370 km. Two males with extreme moves were killed in the Snowy Range of southeastern Wyoming (369.6 km) and the Cimarron Range of north-central New Mexico (329.8 km). The female (F52) was treed and released by hunters. These pumas represent dispersal moves from the Uncompahgre Plateau. All of the pumas, except for 1 (M68, 17 months old) had reached adult ages ranging from 24 to 54 months old.

Our current research effort is still too short in duration and samples too small to make meaningful comparisons with evidence in the literature regarding puma 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. 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 understand the significance of those parameters in our study population.

A preliminary estimate of puma cub survival was made with 36 radio-collared cubs (16 males, 20 females) that we marked 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. For the Kaplan-Meier procedure to staggered entry of animals (Pollock et al. 1989), the maximum survival period was assumed to be 365 days after capture (i.e., ~13-14 months old) to coincide with the age that puma cubs would normally be expected to become independent from their mothers (Logan and Sweanor 2001). In this preliminary estimate, observations of siblings are assumed to be independent (i.e., distribution of mortalities among litters is random), but that assumption might not be reliable (Bishop et al. 2008; an overdispersion parameter will need to be estimated). We omitted 3 radio-collared cubs that died as a result of the expandable radiocollars (Appendix A). Otherwise, cubs were right censored when they reached independence, or from the date after we lost contact. Dates that bracketed the deaths of cubs were used to estimate minimum and maximum survival rates. The estimated minimum survival rate using the Kaplan-Meier procedure was 0.5285 (SE = 0.1623). The maximum estimated cub survival was practically the same, 0.5328 (SE = 0.1629). Cub survival estimated with a binomial model (Williams et al. 2001) for the same sample was 0.5833 ± 0.1610 (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 other, especially male, pumas. We attributed 8 cub mortalities to infanticide, and it is probable that 5 other cubs died directly from infanticide or because their mother was killed when her 4 cubs were at an age (87 days) when they could not survive without her (Appendix A). Male-caused infanticide, 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, social structure, and life history strategies in pumas (Logan and Sweanor 2001).

The 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* operated as designed to remove sport-hunting as a cause of death in the study population. Of the adult and subadult pumas wearing a functional GPS/VHF-collar, only 1 adult puma died due to human causes on the study or buffer areas (F7 killed for depredation control, mentioned previously). This reference condition enabled us to quantify puma population structure, survival rates, and agent-specific mortality rates of pumas in the absence of direct human-caused mortality by sport-hunting, and will allow comparisons with the *treatment period* when puma hunting manipulates the puma population on the study area.

Furthermore, we recorded deaths of 7 non-marked pumas that died since 2004, mainly from human causes (Table 14). Six non-marked pumas (2 males, 4 females) were struck by vehicles on highways or a county road along boundaries of the study area. In addition, 2 marked female cubs (mentioned previously) were killed in vehicle collisions on a highway. Both of those cubs were offspring of F16 which has a home range straddling highway 550 south of Montrose. Of the 8 pumas killed by vehicles, 5 were dependent cubs, 2 were probably subadults, and 1 was an adult female. A bizarre natural mortality case we documented was of a non-marked adult female found in Roubideau Canyon that was lodged in a narrow fork of an aspen tree and probably died of asphyxia due to compression of the thorax.

Anderson et al. (1992:50) reported on the fates of 21 radio-collared pumas (11 pumas <24 months old, and 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 of the 21 deaths (i.e., 90%) were due to human causes, attributed to: legal kill outside the study area (7), research 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) effort 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 category were not given. There were no quantitative data allowing estimation of survival and agent-specific mortality for cubs less than 12 months old.

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).

Segment Objective 5

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 are ≤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 7 puma families with a radio-collared mother and at least 1 radio-collared cub from November 6, 2008 to March 20, 2009 during 11 airplane flights (Table 15). To assess whether mothers were apart or in close association with cubs, we considered error in aerial locations. We recovered 28 puma radiocollars (i.e., of dead pumas or shed collars from cubs) that we located from the airplane and then fixed the actual locations of collars on the ground with hand-held GPS receivers. Range of location error was 5 to 660 m (mean = 260, *SD* = 179.73). We used distances greater than the extreme high range of location error (660 m) as the metric to decide if puma mothers might be detected away from their cubs by hunters. In aggregate, the data for the past 4 winters include 171 observations for 1−7 families per winter (Table 15), and generally indicate that puma mothers are more likely (87% of observations) to be within 660 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. If the total sample size allows, we want to examine variation in mother-cub association distances on an individual female basis. Moreover, we will gather direct information on the frequency that cubs are orphaned and their survival during the *treatment period* when the pumas are hunted.

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 6

We used the data gathered so far in the *reference period* for a *preliminary* evaluation of 5 assumptions used by CDOW biologists and managers to manage puma populations with sport-hunting.

Assumption 1: The CDOW assumes density ranges of 2.0 to 4.6 puma/100 km^2 (i.e., includes pumas of all age stages- adults, subadults, and cubs, J. Apker, CDOW Carnivore Biologist, person. commun. Nov. 19, 2003) to extrapolate to DAUs to guide the model-based quota-setting process. Assuming that on average 66% of the population is comprised of adults and subadults (previously), then the range of density for independent pumas would be 1.3 to 3.0/100 km^2. The population sex and age structure is also assumed to be similar to puma populations described in the intensive studies in the literature on puma populations (CDOW 2007).

H_1: Puma densities during the *reference period* and the *treatment period* will vary within the range of 2.0 to 4.6 puma/100 km^2 and will exhibit a similar sex and age structure to puma populations studied intensively in Wyoming, Idaho, Alberta, and New Mexico (CDOW 2007).

We have partially addressed H_1 with a *preliminary* minimum estimated density of 2.0 to 2.2 independent pumas/100 km^2 of estimated winter habitat on the Uncompahgre Plateau study area in RY4 (i.e., 33 *minimum* independent pumas/1,671 km^2) and RY5 (i.e., 37 *minimum* independent pumas/1,671 km^2). These minimum density estimates represent the mid-to-high range of density for independent resident pumas in some North American populations (i.e., range 0.3-2.2/100 km^2, Logan and Sweanor 2001:167), but lower than higher estimates for independent pumas in more recent studies in Wyoming (3.4/100 km^2, Anderson and Lindzey 2005) and Utah (3.2/100 km^2, Choate et al. 2006). Moreover, the sex and age structure of the minimum population observed in winter of reference year 4 (i.e., RY4) is similar to descriptions of other puma populations in western states (Logan and Sweanor 2001:167).

<u>Assumption 2</u>: The adult plus subadult (i.e., harvest-age pumas) segment of the population exhibit a moderate annual rate of growth of 15% (i.e., $\lambda = 1.15$, CDOW 2007).

H_2: Population parameters estimated during a 5-year *reference period* (in absence of recreational puma hunting) will yield an estimated annual adult plus subadult population growth rate that will match or exceed $\lambda = 1.15$.

Puma population modeling using population characteristics and vital rates from this current research effort supports this assumption (Appendix B). Expected lambda (i.e., finite rate of population change of independent pumas) ranges from 1.17 to 1.22 and an average of 1.20 ± 0.0182 *SD* ($n = 5$; TY1-TY5) for the *no harvest model* (Appendix B, Table B.7). Expected lambda for the modeled non-hunted puma population on the Uncompahgre Plateau are consistent with 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., $r = 0.21$, $n = 4$ yr.; $r = 0.28$, $n = 4$ yr.; $r = 0.17$, $n = 4$ yr.; $r = 0.11$, $n = 7$ yr.; Logan and Sweanor 2001:169-175). Puma population growth might be higher on the Uncompahgre Plateau because of higher quality habitat (i.e., greater vulnerable prey biomass), and if puma sources are nearby to the study area which provide immigrants.

<u>Assumption 3</u>: Puma harvest rate formulations for DAUs assume that total mortality (i.e., harvest plus other natural deaths) in the range of 8 to 15% of the harvest-age population (i.e., independent pumas comprised of adults plus subadults) with the total mortality comprised of 35 to 45% females (i.e., adults and subadults) is acceptable to manage for a stable-to-increasing puma population (CDOW 2007). Harvest is assumed to be additive to natural mortality.

H_{3a}: The puma population is not expected to decline, therefore, we should be observing puma population parameters characteristic of a stable or increasing hunted puma population.

Preliminary modeling results with 15% and 16% mortality in the harvest-age population indicates expected stable or increase population phases, with additive harvest mortality (Appendix B, Tables B.3, B.4, B.5, B.8, B.9, Fig. B.2).

H_{3b}: Harvest mortality of 15% of the adults and subadults will be strongly additive to other natural causes of mortality.

Preliminary survival rates for annual and shorter-term hunting season periods for adult-age pumas in the *reference period* indicate high survival (Table 11). Similarly, a course survival rate for 9 subadult radio-collared pumas in the *reference period* is also high (finite rate of survival during the subadult stage: 8/9 = 0.89). These rates partially support the assumption that additive mortality caused by hunting can be expected. A direct test of this assumption will develop in the *treatment period*.

<u>Assumption 4</u>: 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_4:** 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).

Preliminary modeling results with 16% mortality or greater in the harvest-age population and with greater than 45% of the harvest comprised of females indicates expected puma population declines (Appendix B, Tables B.6, B.10, B.12−B.16, Figs. B.2−B.4).

Assumption 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.

Preliminary results as indicated by the age structure of independent pumas captured for the first time in 2004-05 (Logan 2005), at first capture (Fig. 3), and the age structure of the independent puma population in March 2009 (Fig. 5), and apparently high adult and subadult survival rates during the *reference period* support the hypothesis for a young age structure early in the *reference period* with an aging structure later at the end of the period.

Segment Objective 7

Principal investigator K. Logan with CDOW biologists and managers developed by consensus a *preliminary* structure (i.e., official approval pending Wildlife Commission decision in September 2009) to manipulate the puma population with sport-hunting on the study area during the *treatment period*. The hunting season will begin in mid-November and extend to January 31, unless the last puma on the design quota is killed before January 31, which will effectively close the season on the study area. The harvest quota will be 8 pumas (i.e., 15% harvest of the estimated minimum number of independent pumas), with the objective to manage for a stable to increasing population. The quota of 8 is based on the projected minimum number of independent pumas expected on the study area in winter 2009-10, modeled from a minimum count during winter 2007-08 (see Appendix B, Table B.7). No assumptions about additional pumas on the study area are made or contrived. The quota of 8 is expected to allow the population to achieve a stable or increase phase even if the quota is exceeded due to potential ideal snow-tracking conditions that could result in multiple pumas being killed within a mandatory 48-hour reporting period. Such an overharvest might be expected to reach 20 to 30% over the design harvest (in this case ~2 pumas killed over the harvest; J. Apker, Carnivore Biologist, CDOW, person. comm. June 8, 2009).

The number of hunters on the study area at any particular time each hunting season will not be limited. However, each hunter on the study area will be *required* to obtain a hunting permit from the CDOW Montrose Service Center. Permits will be free and unlimited. Each permit will allow the individual hunter with a legal puma hunting license in Colorado to hunt in the puma study area for up to 14 days from the issue date. Unsuccessful hunters that wish to continue hunting past the permit expiration date can request a new permit for another 14 days or until the hunting season on the study area closes due to the quota being reached or the end of the hunting season. (The number of pumas killed on the study area each winter will be regulated by the design quota, discussed previously.) This permit system is expected to allow the CDOW to monitor the number of hunters on the study area and to contact each hunter for survey information.

All pumas harvested on the study area will be subject to the examination check and seal mandated by the State of Colorado. Hunters must report their puma kill to CDOW within 48 hours of harvest and present the puma carcass for inspection within 5 days of harvest. At the time of carcass check-in a biologist with the puma research team will inspect the puma to assist in recording information on the CDOW puma harvest data form and to collect an upper premolar tooth for aging (i.e., mandatory) and a tissue sample using a 6 mm biopsy punch (i.e., voluntary) for DNA genotyping. Each successful hunter will also be asked at that time to complete a one-page hunter survey form. All other hunters that do not report a puma kill on the study area will be contacted and asked to complete the survey.

Hunter harvest will provide direct evidence of removal rates of marked puma for survival and agent-specific mortality data, and to help evaluate the relative vulnerability of pumas to harvest and potential for hunter selectivity. Hunter harvest will also reveal availability and sex and age classes of unmarked pumas on the study area.

After the design quota is filled or January 31 (whichever comes first), puma research teams will immediately activate for capture operations with trained dogs. Two fully-staffed capture teams, one detailed on the east slope and one detailed on the west slope, will systematically and thoroughly search the study area to capture, sample, and GPS/VHF radiocollar pumas the remainder of winter and early spring when snow-tracking conditions can facilitate those efforts. These efforts are necessary to maintain samples to quantify population sex and age structure and estimate *minimum* population size and other population parameters.

Segment Objective 8

Principal investigator K. Logan developed another draft study plan pertaining to the next 5 years of puma research on the Uncompahgre Plateau. The draft plan was subjected to an internal review by researchers and was circulated for review to Carnivore Biologist J. Apker, Area 18 Biologist B. Banulis, Southwest Regional Biologist S. Wait, and Area 18 Wildlife Manager R. Del Piccolo. Comments were incorporated into a substantially modified study plan which was reviewed by Mammals Researcher Dr. Chad Bishop (now the Mammals Research Leader). That study plan will be modified to address new considerations and will be submitted to Mammals Research Leader Chad Bishop in fall 2009.

Segment Objective 9

Data from 26 (8 male, 18 female) GPS-collared pumas, totaling over 39 thousand GPS locations (Table 16) will be used to examine the social structure of the puma population on the Uncompahgre Plateau and to examine movements of pumas relative to Game and Data Analysis Unit boundaries. Those data will also be used in a set of collaborative projects, including: examination of puma behavior in relation to human development with Mammals Researcher Dr. Mat Alldredge, who is studying puma-human interactions on the Colorado Front Range; modeling and mapping puma habitat in Colorado and other western states with Dr. Kevin Crooks and Dr. Chris Burdett (Department of Fish, Wildlife and Conservation Biology, Colorado State University- DFWCB, CSU); evaluation of puma detection rates using camera grids with Dr. Kevin Crooks and Ph.D. candidate Jesse Lewis (DFWCB, CSU). Furthermore, puma population and genetic data from the Uncompahgre Plateau can be used in collaboration with Dr. Alldredge's puma research efforts on the Front Range to examine similarities or differences in puma population dynamics and social structure between the 2 environments.

We are currently collaborating with Dr. Sue VandeWoude and Dr. Kevin Crooks, and post-doctoral and graduate students at the College of Veterinary Medicine and Biomedical Sciences, Department of Microbiology, Pathology, and Immunology, Colorado State University in 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 DMIP for analyses. That project has been 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 35 individual pumas (22 independent females, 12 independent males, and 1 male cub) sampled on the Uncompahgre Plateau are presented in Appendix C. Those data contributed to a publication in *Emerging Infectious Diseases* (accepted), titled *Plague and wild felids: zoonotic disease in the western US* , a paper on seroprevalence in populations of pumas and bobcats in the western United States by collaborators: Sarah N. Bevins[1], Jeff A. Tracey[1], Sam P. Franklin[1], Virginia L. Schmit[1], Martha L. MacMillan[1], Kenneth L. Gage[2], Martin E. Schriefer[2], Kenneth A. Logan[3], Linda L. Sweanor[1], Mat W. Alldredge[3], Karoline Krumm[1], Walter M. Boyce[4], Winston Vickers[4], Seth P.D. Riley[5], Lisa M. Lyren[6], Erin E. Boydston[6], Melody E. Roelke[7], Robert Fischer[6], Kevin R. Crooks[1], and Sue VandeWoude[1] ([1]Colorado State University, USA; [2]DVBID Centers for Disease Control, USA; [3]Colorado Division of Wildlife, USA; [4]University of California, Davis, USA; [5]National Park Service, USA; [6]United States Geological Survey, USA; [7] National Cancer Institute, USA).

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 4.7 years of effort in a *reference period*, 109 pumas have been captured, sampled, marked, and released. Of those animals, 91 were radio-collared, allowing us to monitor fates of pumas in all sexes and age stages, including: 19 adult females, 12 adult males, 4 subadult females, 5 subadult males, 30 female cubs, 30 male cubs (some individuals occur in more than one age-stage). Data from the marked animals are used to quantify puma population characteristics and vital rates in a *reference* situation without sport-hunting off-take as a mortality factor. Our efforts to quantify puma population characteristics and vital rates in a reference condition positioned us to develop a puma population model, and to use the population data and modeling scenarios to conduct a preliminary assessment of CDOW puma management assumptions and to guide directions for the remainder of the puma research on the Uncompahgre Plateau. Moreover, our data and model provide tools currently useful to CDOW wildlife biologists and managers for assessing puma harvest strategies. To improve data on puma population vital rates, attention will be given to increasing radio-collared sample sizes on life stages and sexes. The *treatment period*, scheduled to begin winter 2009-10 and to extend the following 5 years, will be a population-wide evaluation of sport-hunting impacts on a puma population. Furthermore, we will continue collaboration efforts with colleagues on investigations of puma population parameter estimation, puma-human relations, puma habitat modeling and mapping, wild felid disease surveillance, and individual puma detection rates in camera grid designs. 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 December 9, 2008 to April 30, 2009, 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, observed, or identified
December	11	16 tracks: 6 male, 6 female, 4 cub	10 pursuits: 5 males, 5 females, 4 cubs	6 pumas captured 8 times: M71 recaptured (not handled), M55 recaptured twice (not handled to change faulty GPS collar due to dangerous tree & cliffs), F93 captured twice- the first time, then with her 2 large cubs F95 and a male cub that could not be handled in a hole, F94 captured for the first time. In addition, male puma tracks found and attributed to M32 by VHF telemetry (no pursuit with hounds).
January	17	38 tracks: 17 male, 10 female, 11 cub	17 pursuits: 6 males, 4 females, 7 cubs	5 pumas captured 6 times: M55 (faulty GPS collar changed), F93 recaptured while cub F95 and unmarked male cub escaped, F16 recaptured (faulty GPS collar changed) while M6 (consort) escaped, F96 captured for first time while 2 cubs escaped, F96 recaptured while 2 cubs escaped, cub M84 recaptured (handled to fit with new expandable cub collar). In addition, M6 and F16 were detected by tracks and identified with VHF telemetry on 2 other occasions. M51 was detected by tracks and identified with VHF telemetry and pursued, but was not caught to change his GPS collar on low battery. F93 and F95 were detected by tracks with non-marked cub and identified with VHF telemetry.
February	15	64-65 tracks: 12-17 male, 26-31 female, 24-27 cub	26 pursuits: 3-4 males, 7-8 females, 15 cubs	5 pumas captured: cub F97 captured for the first time while mother F23 & sibling F81 escaped. Cub M82 recaptured and fit with new VHF collar, while mother F8 escaped and confirmed with VHF telemetry. Cub F98 captured for the first time; one of three cubs of an unmarked adult female puma visually observed with F98 on 2-17-09. M29 recaptured, but could not be handled in dangerous cliffs to replace faulty GPS collar. M99 captured for first time; sibling of F98.
March	15	56 tracks: 24-26 male, 21-23 female, 9 cub	15 pursuits: 4-5 males, 3-4 females, 7 cubs	4 pumas captured 5 times: F98 recaptured while mother and 2 sibling cubs escaped, M99 captured for first time while mother and siblings F98 and non-marked cub escaped, M99 and non-tagged cub visually observed, M100 captured for the first time.
April	13	24-27 tracks: 17 male, 6 female, 1-4 cub	7-10 pursuits: 4 males, 2 females, 1-4 cubs	0 pumas captured. One male pursued identified as M55 with GPS data. Another male pursued identified as M100 with GPS data. Two females and their cubs pursued identified as F70 and F96 with 1-4 cubs with VHF telemetry.
TOTALS	71	198-202 tracks: 76-83 male, 69-76 female, 49-55 cub	75-78 pursuits: 22-24 males, 21-23 females, 34-37 cubs	24 captures of 17 individuals: 4 independent pumas (F93, F94, F96, M100) and 4 marked (F95, F97, F98, M99) and 2 non-marked cubs were captured for the 1st time. 10 independent pumas were detected by tracks and identified with GPS/VHF telemetry 12 times: M6 (twice), F8, F16 (twice), M32, M51, M55, F70, F93, F96, M100.

[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 too 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 2009, Uncompahgre Plateau, Colorado.

Period	Track detection effort	Pursuit effort	Puma capture effort	Effort to capture an independent puma for the first time
Dec. 2, 2004 to May 12, 2005	109/78 = 1.40 tracks/day	35/78 = 0.45 pursuit/day 78/35 = 2.23 day/pursuit	14/78 = 0.18 capture/day 78/14 = 5.57 day/capture	11 pumas captured for first time 11/78 = 0.14 capture/day 78/11 = 7.09 day/capture
Nov. 21, 2005 to May 26, 2006	149/82 = 1.82 tracks/day	43/82 = 0.52 pursuit/day 82/43 = 1.91 day/pursuit	14/82 = 0.17 capture/day 82/14 = 5.86 day/capture	7 pumas captured for first time 7/82 = 0.08 capture/day 82/7 = 11.71 day/capture
Nov. 13, 2006 to May 11, 2007	177/78 to 182/78 = 2.27-2.33 tracks/day	45/78 to 47/78 = 0.58-0.60 pursuit/day 78/47 to 78/45 = 1.66-1.73 day/pursuit	22/78 = 0.28 capture/day 78/22 = 3.54 day/capture	7 pumas captured for first time 7/78 = 0.09 capture/day 78/7 = 11.14 day/capture
Nov. 19, 2007 to April 24, 2008	217/77 to 218/77 = 2.82-2.83 tracks/day	49/77 = 0.64 pursuit/day 77/49 = 1.57 day/pursuit	20/77 = 0.26 capture/day 77/20 = 3.85 day/capture	7 pumas captured for first time 7/77 = 0.09 capture/day 77/7 = 11.00 day/capture
Dec. 9, 2008 to April 30, 2009	198/71 to 202/71 = 2.79-2.84 tracks/day	75/71 to 78/71 = 1.06-1.10 pursuit/day 71/75 to 71/78 = 0.91-0.95 day/pursuit	24/71 = 0.34 capture/day 71/24 = 2.96 day/capture	9 pumas captured for first time 9/71 = 0.13 capture/day 71/9 = 7.89 day/capture

Table 3. Adult and subadult pumas captured for the first time, sampled, tagged, and released from December 2008 to May 2009, Uncompahgre Plateau, Colorado.

Puma I.D.	Sex	Estimated Age (mo.)	Mass (kg)	Capture date	Capture method	Location
F93	F	72	32	12-15-08	Dogs	Coal Bank Canyon
F94	F	41	36	12-19-08	Dogs	Shavano Valley
F96	F	36	40	01-28-09	Dogs	Dolores Canyon
M100	M	72	64-68 estimated*	03-27-09	Dogs	San Miguel Canyon
F104	F	96	40	05-21-09	Cage Trap	Roubideau Canyon

*M100 could not be weighed by scale due to steepness of terrain.

Table 4. Pumas that were captured and observed with aid of dogs, or observed in association with another radio-collared puma, but were not handled at that time for safety or other reasons, December 2008 to March 2009, Uncompahgre Plateau, Colorado.

Puma sex	Age stage or months	Capture date	Location	Comments
M55	42	12-12-08	Dolores Canyon	M55 bayed in a hole then climbed a tree too dangerous for handling to replace non-functioning GPS collar.
M55	42	12-21-08	Spring Creek	M55 bayed on cliffs too dangerous for handling.
Male	16	12-29-08	Dry Creek Basin	Non-marked male cub of F93 and sibling of F95 took refuge in narrow hole; unable to handle him.
Female	Unk. adult	02-19-09	San Miguel Canyon	Non-marked adult female puma was visually observed with radio-collared cub F98 and a non-marked cub (either M99 later marked or non-marked sibling below), but could not be caught with dogs.
Unknown	5	02-19-09	San Miguel Canyon	Non-marked cub was visually observed with radio-collared cub F98 and non-marked adult puma, but could not be caught with dogs.
M29	129	02-25-09	Big Bucktail Canyon	M29 bayed in cliffs too dangerous for handling.
Unknown	6	03-11-09	San Miguel Canyon	Non-marked cub- sibling of F98 & M99- visually observed with radio-collared cub M99, but could not be caught with dogs.

Table 5. Pumas recaptured with dogs, cage traps, or visually observed, December 2008 to January 2009, Uncompahgre Plateau, Colorado.

Puma I.D.	Recapture Date	Mass (kg)	Estimated Age (mo.)	Capture Method/ Location	Process
M71	12-08-08	Observed	35	Dogs/Shavano Mesa	M71 wore a functioning vhf collar; no need to handle him.
F93	12-29-08	Observed	72	Dogs/Dry Creek Basin	F93 wore a functioning GPS collar; no need to handle her.
F93	01-08-09	Observed	72	Dogs/Shavano Valley	F93 wore a functioning GPS collar; no need to handle her.
F96	01-29-09	Observed	36	Dogs/Dolores Canyon	F96 wore a functioning GPS collar; no need to handle her.

Table 6. Summary of puma capture efforts with ungulate road-kill baits and cage traps from August 20, 2008 to July 20, 2009, Uncompahgre Plateau, Colorado.[a]

Month	No. of Sites	Carnivore activity & capture effort results[b]
August	2	No puma activity detected. One deer carcass scavenged by coyotes.
September	5	Deer carcasses scavenged by male puma 9-14-08; likely M55 (trail camera photos). Set cage trap 9-15-08. Puma did not return. Bobcat fed on deer carcass in cage trap. A bobcat, a black bear and domestic dogs scavenged 3 different deer carcasses.
October	3	Deer carcass scavenged by bobcat.
November	6	Female puma scavenged a deer carcass 11-21 to 22-08. Cage trap set 11-23-08; but, female puma did not return. Male puma scavenged a deer carcass 11-24-08, and cage trap set 11-24-08. The male puma returned, walked around the trap, but did not enter. Female puma and bobcat scavenged a carcass 11-24-08. Cage trap set 11-24-08. Bobcat captured and released 11-24-08. Subadult female puma F66 recaptured and radio-collared 11-25-08.
December	2	No puma activity detected.
February	2	A female or small male puma walked ~20 m past a deer carcass but did not feed. Another deer carcass was scavenged by a bobcat.
March	4	A male puma walked ~5 m past 2 different deer carcasses but did not feed. Three deer carcasses were scavenged by 2 gray foxes and 2 bobcats.
April	1	Male puma M55 scavenged a deer carcass 5-6-09. No need to recapture him.
May	4	Female puma fed on a deer carcass 5-8 to 10-09. Set cage trap 5-11-09. Female puma returned but did not enter cage trap. Set 2 cage traps 5-12-09; but female puma did not return. Female puma (possibly same as previous) scavenged deer carcass 5-21-09. Cage trap set 5-21-09. F104 captured. A black bear scavenged one deer carcass.
July	2	Puma F72[b] was recaptured 7-20-09 in cage trap set for bobcat study. Her malfunctioning GPS collar was replaced. A non-marked puma was photographed at one deer bait 7-17-09; but it did not feed. Same deer bait was scavenged by ~5 different black bears.

[a] We used 36 road-killed mule deer at 17 different sites. Of the road-killed ungulate baits, 7 of 36 (19.4%) were scavenged by pumas.
[b] Adult female puma F72 was recaptured in a bobcat cage trap baited with a predator call box and visual attractant.

Table 7. Puma cubs sampled September 2008 to June 2009 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)
M91	M	August 19, 2008	35	2.5	F25	110
M92	M	August 19, 2008	35	2.8	F25	110
F95	F	August 2007	488	33	F93	56
F97	F	May 23, 2008	257	20	F23	45
F98	F	Sep.-Oct. 2008	122-152	9.5	F[b]	Unk.
M99	M	Sep.-Oct. 2008	152	13.6	F[b]	Unk.
M101	M	April 15, 2009	35	2.8	F16	75
M102	M	April 15, 2009	35	2.5	F16	75
F103	F	April 15, 2009	35	2.1	F16	75
M105	M	May 7, 2009	38	2.6	F75	55
F106	F	May 7, 2009	38	2.6	F75	55
M107	M	May 25, 2009	34	2.0	F94	46
F108	F	May 25, 2009	34	1.75	F94	46
M109	M	May 25, 2009	34	1.75	F94	46

[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] F98 and M99 were captured in association with an non-marked adult female puma and another non-marked cub.

Table 8. Minimum puma population estimate based on numbers of known radio-collared pumas, visual observations of non-marked pumas, and track counts of suspected non-marked pumas on the study area during the past 2 winters, November 2007 to March 2008 and November 2008 to April 2009, Uncompahgre Plateau study area, Colorado.

Winter & Region	Adults		Subadults		Cubs		
	Female	**Male**	**Female**	**Male**	**Female**	**Male**	**Unknown sex**
Nov.07-Mar.08							
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]						
Nov.08-Apr.09							
East slope	11-13	5-6	2-4	0-1	2	5	5
West slope	9-10	4	1-2	1	3	2	4
Totals	20-23	9-10	3-6	1-2	5	7	9
	Total Independent Pumas = 37[c,d]						

[a] Of the total, 23−24 (70−73%) independent pumas were marked and 9-10 (27−30%) were assumed to be non-marked, but some might have ear-tags, tattoos, or non-functional GPS/VHF collars.

[b] The non-marked 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.

[c] Of the total, 23−25 (62−68%) independent pumas were marked and 12-14 (32−38%) were assumed to be non-collared, but some might have ear-tags, tattoos, or non-functional GPS/VHF collars.

[d] The non-marked independent pumas included: 1 adult female with 2 cubs on N. McKenzie Mesa, 1 subadult or adult female in Linscott Creek, 1 adult female in Monitor Creek, 1 subadult or adult female in Roubideau Canyon, 1 subadult or adult male in Monitor Creek, 1 adult female with 3 cubs in San Miguel Canyon, 1 adult female with ≥1 cub or F28 with a non-functional GPS collar in Big Bucktail Canyon to N. Fork Cottonwood Creek, 1 adult female or F24 with non-functional GPS collar in Horsefly Creek to Dead Horse Mesa, 1 adult female or F28 with non-functional GPS collar in San Miguel Canyon W of Pinion, 1 adult female with ≥1 cub on Mailbox Park, 1 adult female with 1 cub from McKenzie Creek to Iron Springs Mesa. 1 subadult or adult female on Iron Springs Mesa, 1 subadult female in Big Bucktail Canyon to ridge E of Nucla, 1 subadult male from Pinion across Big Bucktail Canyon and ridge E of Nucla.

Table 9. Individual puma reproduction histories, Uncompahgre Plateau, Colorado, 2005-2009.

Consort pairs and estimated ages[a]				Dates pairs consorted[b]	Estimated birth date[c]	Estimated birth interval (mo.)	Estimated gestation (days)	Observed number of cubs[d]
Female	Age (mo.)	Male	Age (mo.)					
F2	53				05/28/05			3
F2	67				07/29/06	14.0		2
F2	89				05/19/08	22.0		4
F3	36				08/01/04			1
F3	50	M6	37	06/22-24/05	09/26/05	13.8	93-95	2
F3	62				09/17/06	11.7		3
F3	84	M51	60	03/31/08	07/03/08	21.5	94	3
F7	67				05/19/05			2
F7	82				08/13/06	14.9		4
F7	106				07/10/08	23.9		3
F8*[e]	24				06/26/05			2
F8	37				08/13/06	13.4		4
F8	60	M73	49	02/28-29/08	05/29/08	22.5	90-91	2
F16	32				09/22/05			4
F16	52				05/24/07	19.9		4
F16	75	M6	80	01/13-14/09	04/15/09	22.7	91-92	3
F23*	21				05/30/06			3
F23	45	M27 or M29[f]	78 107	02/19-25/08	05/23/08	23.8	87-93	3
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
F25	110				08/19/08	16.1		2
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*	28				07/09/08			1
F75	32				06/01/07			1
F75	55	M73	61	02/11/09	05/07/09	23	93	2
F93	56				08/07			2
F94*	46				05/27/09			3

[a] Ages of females were estimated at litter birth dates. Ages of males were estimated around the dates the pairs consorted.
[b] Consort pairs indicate pumas that were observed together based on GPS data or VHF location data.
[c] Estimated birth dates were indicated by GPS data of mothers at nurseries or by back-aging cubs to approximate birth date.
[d] Observed number of cubs do not represent litter sizes as some cubs were observed when they were 5 to 16 months old after postnatal mortality could have occurred in siblings. Only cub tracks were observed with F28.
[e] Asterisk (*) indicates first probable litter of the female, based on 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 10. Summary for individual adult puma survival and mortality, December 8, 2004 to July 31, 2009, 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 as far as Unaweep Canyon.
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 02-20-09	934	Dead. Born on study area; offspring of F3. M5 was independent of F3 by 13 months old, and dispersed from his natal area at about 14 months old. Established adult territory on northwest slope of Uncompahgre Plateau at the age of 24 months (protected from hunting mortality in buffer area) and ranged into the eastern edge of Utah (vulnerable to hunting). Killed by a puma hunter on 02-20-09 in Beaver Creek, Utah at age 54 months.
M6	02-18-05 to 07-31-09	1,624	Alive.
M27	03-10-06 to 05-07-09	1,154	Lost contact− failed GPS/VHF collar. Recaptured 12-02-07 & 01-22-08 by puma hunter/outfitter north of the study area. Possibly visually observed on study area with F23 on 02-25-08. Recaptured by a puma hunter/outfitter 12-11-08 & 12-28-08 north of the study area. Photographed by a trail camera on the study area (Big Bucktail Canyon) on 5 occasions: 03-27-09, 04-02-09, 04-15-09, 04-24-09, & 05-07-09.
M29	04-14-06 to 02-25-09	1,048	Lost contact− failed GPS/VHF collar. Possibly visually observed on study area with F23 on 02-25-08. Recaptured on study area 02-25-09, but could not be safely handled to change faulty GPS collar.
M32	04-26-06 to 07-31-09	1,192	Alive.
M51	01-07-07 to 03-20-09	803	Alive. Lost contact− failed GPS/VHF collar.
M55	01-21-07 to 07-31-09	922	Alive.
M71	01-29-08 to 07-31-09	549	Alive.
M73	02-21-08 to 07-31-09	526	Alive.
M100	03-27-09 to 07-31-09	126	Alive.
F2	01-07-05 to 08-14-08	1,315	Dead; killed by another puma (sex of puma unknown; male suspected) 08-14-08. Estimated age at death 92 months.
F3	01-21-05 to 01-15-09	1,455	Lost contact− failed GPS/VHF collar.
F7	02-24-05 to 08-03-08	1,256	Dead 08-03-08; killed by U.S., W.S. agent for predator control of depredation on domestic sheep. Estimated age at death 107 months.
F8	03-21-05 to 07-31-09	1,593	Alive.
F16	10-11-05 to 07-31-09	1,389	Alive.
F23	02-05-06 to 07-31-09	1,272	Alive.
F24	01-17-06 to 09-03-08	960	Lost contact− failed GPS/VHF collar.
F25	02-08-06 to 07-31-09	1,269	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	Dead; killed by another puma (sex of puma unknown) 07-29-08. Estimated age at death 60 months.
F50	12-14-06 to 03-26-07	102	Dead of natural causes 03-26-07; probably injury or illness-related; exact agent unknown. Estimated age at death 30 months.
F54	01-12-07 to 08-18-07	218	Dead; killed by a male puma while in direct competition for prey (i.e., mule deer fawn) 08-18-07. Estimated age at death 49 months.
F70	01-14-08 to 07-31-09	564	Alive.
F72	02-12-08 to 07-31-09	535	Alive.
F75	03-26-08 to 07-31-09	492	Alive.
F93	12-05-08 to 07-31-09	238	Alive.
F94	12-19-08 to 07-31-09	224	Alive.
F96	01-28-09 to 07-31-09	184	Alive.
F104	05-21-09 to 07-31-09	71	Alive.

Table 11. 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 $n \geq 5$ individual pumas were monitored in the interval. Puma deaths in this analysis pertained only to pumas that died of natural causes. Pumas that were killed by people, a non-natural cause (i.e., F7 for depredation control 8/3/2008 and M5 killed by a puma hunter off the protected study area and buffer zone 2/20/2009) were right censored.

Period of interest	**Females**			**Males**		
	S	**SE**	***n***	***S***	**SE**	***n***
Annual 8/1/2005 to 7/31/2006	1.000	0.0000	10	0.667*	0.2222*	6*
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	0.831	0.0986	14	1.000	0.0000	7
Annual 8/1/2008 to 7/31/2009	0.875	0.1031	13	1.000	0.0000	8
Hunting season 11/1/2005 to 3/31/2006	1.000	0.0000	6	na	na	4
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
Hunting season 11/1/2008 to 3/31/2009	1.000	0.0000	11	1.000	0.0000	8

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

Table 12. Summary of subadult puma survival and mortality, December 2004 to July 2009, Uncompahgre Plateau, Colorado.

Puma I.D.	Monitoring span	No. days	Status
M5	09-16-05 to 06-30-06	308	M5 was offspring of F3, born August 2004. Independent and dispersed from natal area at 13 months old. Established adult territory on northwest slope of Uncompahgre Plateau at the age of 24 months (protected from hunting mortality in buffer area) and ranged into the eastern edge of Utah (vulnerable to hunting). Killed by a puma hunter on 02-20-09 in Beaver Creek, Utah at about 54 months old.
M11	06-21-06 to 12-02-07	529	M11 was offspring of F2, born May 2005. Independent at 13 months old. Dispersed from natal area at 14 months old. Moved to Dolores River valley, CO, by 12-14-06. Killed by a puma hunter on 12-02-07 when about 30 months old.
F23	01-04-06 to 02-04-06	31	Alive. Captured on the study area when about 17 months old. Survived to adult stage; gave birth to first litter at about 21 months old.
M31	04-19-06 to 04-26-06	7	M31's estimated age at capture was 20 months. Dispersed to northern New Mexico and was killed by a puma hunter on 12-11-08 in Middle Ponil Creek, Cimarron Range. He was about 52 months old.
M49	03-26-07 to 10-01-07	189	M49 was offspring of F50, born July 2006. Orphaned at about 9 months old, when F50 died of natural causes. Dispersed from his natal area at about 10 months old and ranged on the northeast slope of the Uncompahgre Plateau. When M49 was about 15 months old, he shed his expandable radiocollar on about 10-01-07 at a yearling cow elk kill on the northeast slope of the Uncompahgre Plateau. He was killed by a puma hunter in Blue Creek in the protected buffer zone north of the study area on 01-24-09; he was about 29 months old.
F52	01-10-07 to 05-15-07	125	F52 dispersed from study area as a subadult by Jan. 16, 2007. F52's last VHF aerial location was Crystal Creek, a tributary of the Gunnison River east of the Black Canyon 05-15-07. She was treed by puma hunters on 12-29-08 on east Huntsman Mesa, southeast of Powderhorn, CO. She was about 41-43 months old and could have been in her adult-stage home range. GPS collar nonfunctional.
F66	08-23-07 to 11-05-07 11-25-08 to 06-03-09	74 190	F66 was offspring of F30, born July 2007. Lost contact; her cub collar quit after 11-05-07. Recaptured as an independent subadult on her natal area 11-25-08 when 16 months old. F30 was killed by a puma when F66 was 12 months old, within the age range of normal independence. F66 died of injuries to internal organs that caused massive bleeding attributed to trampling by an elk or mule deer on about 05-28-09 when she was 23 months old. Her range partially overlapped her natal area.
M69	01-11-08 to 04-07-08	87	M69 was captured on the study area when about 14-18 months old. Emigrated from the study area as subadult by 03-19-08. Last VHF aerial location was southwest of Waterdog Peak, east side of Uncompahgre River Valley on 04-07-08. M69 was killed by a puma hunter on 11-06-08 in Pass Creek in the Snowy Range, WY when he was 24 to 28 months old.
F95	12-29-08 to 07-31-09	214	Alive. F95 is the offspring of F93, born about August 2007. She became an independent subadult by about 18 months old (02-11-09 aerial location). She has been ranging adjacent to and overlapping the northern portion of her natal area.

Table 13. Records of pumas that dispersed from the Uncompahgre Plateau study area, December 2004 to July 2009.

Puma I.D.	1st capture date on study area	1st capture location→kill or resite location (UTM, NAD27)	Estimated linear dispersal distance (km)*	Puma Information
M5	02-04-05	13S,240577Ex 4251037N→ 12S,665853Ex 4277125N	102.2	M5 was offspring of F3, born August 2004. Independent and dispersed from natal area at 13 months old. Established adult territory on northwest slope of Uncompahgre Plateau at the age of 24 months (protected from hunting mortality in buffer area) and ranged into the eastern edge of Utah (vulnerable to hunting). Killed by a puma hunter on 02-20-09 in Beaver Creek, Utah at about 54 months old.
M11	06-27-05	13S,248278Ex 4239858N→ 12S,741882Ex 4161575N	84.8	M11 was offspring of F2, born May 2005. Shed expandable radiocollar 10-24 to 11-08-05. Recaptured and re-collared 04-02-06. Independent at 13 months old. Dispersed from natal area at 14 months old. Moved to Dolores River valley, CO, by 12-14-06. Killed by a puma hunter on 12-02-07 when about 30 months old.
M31	04-19-06	12S,746919Ex 4225441N→ 13S,500000Ex 4050000N	329.8	M31's estimated age at capture was 20 months. Dispersed to northern New Mexico and was killed by a puma hunter on 12-11-08 in Middle Ponil Creek, Cimarron Range. He was about 52 months old.
M43	09-15-06	12S,760177Ex 4242995N→ 12S,739859Ex 4308557N	68.6	M43 was offspring of F7, born August 2006. He shed the expandable radiocollar 11-7 to 17-06, after which direct contact was lost. M43 was killed by a puma hunter 01-28-09 in Deer Creek, west slope of Grand Mesa, CO when he was 29 months old.
M49	12-05-06	12S,757241Ex 4258259N→ 12S,693350Ex 4274559N	66.1	M49 was offspring of F50, born July 2006. Orphaned at about 9 months old, when F50 died of natural causes. Dispersed from his natal area at about 10 months old and ranged on the northeast slope of the Uncompahgre Plateau. When M49 was about 15 months old, he shed his expandable radiocollar on about 10-01-07 at a yearling cow elk kill on the northeast slope of the Uncompahgre Plateau. He was killed by a puma hunter in Blue Creek in the protected buffer zone north of the study area on 01-24-09; he was about 29 months old.
M68	08-23-07	13S,257371Ex 4235231N→ 12S,711262Ex 4198681N	80.7	M68 was offspring of F30, born July 2007. He was orphaned at 12 months old when his mother was killed by a puma. He was killed by a puma hunter in the Disappointment Valley in southwest CO on 12-30-08; he was 17 months old.
M69	01-11-08	13S,248191Ex 4246810N→ 13T,378900Ex 4591990N	369.6	M69 was captured on the study area when about 14-18 months old. Emigrated from the study area as subadult by 03-19-08. Last VHF aerial location was southwest of Waterdog Peak, east side of Uncompahgre River Valley on 04-07-08. M69 was killed by a puma hunter on 11-06-08 in Pass Creek in the Snowy Range, WY when he was 24 to 28 months old.
F52	01-10-07	13S,258058Ex 4236260N→ 13S,319217Ex 4240467N	61.1	F52 was captured on the study area when about 18-20 months old. Dispersed from study area as a subadult by Jan. 16, 2007. F52's last VHF aerial location was Crystal Creek, a tributary of the Gunnison River east of the Black Canyon 05-15-07. She was treed by puma hunters on 12-29-08 on east Huntsman Mesa, southeast of Powderhorn, CO. She was about 41-43 months old and could have been in her adult-stage home range.

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

Table 14. Recorded deaths of non-marked pumas and of marked pumas struck by vehicles, in chronological order, on the Uncompahgre Plateau puma study area, Colorado, from 2004 to 2009.

Puma sex & ID if marked	Estimated age (mo)	Date recorded	Cause of death	General physical condition	Location & UTM NAD27
M	12	09-24-04	Vehicle collision	Good	Pleasant Valley, County Road 24 13S,252870Ex4227520N
F	49	07-28-05	Vehicle collision	Good Not pregnant or lactating	Highway 62 east of Dallas divide 13S,250000Ex4222500N
F F17	11	08-18-06	Vehicle collision	Good	Highway 550 south of Colona 13S,257602Ex4242185N
F	18-24	11-06-06	Vehicle collision	Good	Highway 550 east of Ridgway State Park 13S,259843Ex4235985N
F	6	01-30-07	Vehicle collision	Good	Highway 62 west of Dallas divide 12S,762286Ex4218992N
F	36	09-16-08	Asphyxia, lodged in fork of tree	Unknown	Davis Point, Roubideau Canyon 12S, 743718Ex4255277N
M	12-24	08-13-08	Vehicle collision	Good	Highway 145 west of Placerville 13S,756490Ex4212336N
F F61	18	11-13-08	Vehicle collision	Good	Highway 550 east of Ridgway State Park 13S,259843Ex4235985N
F	12	08-10-09	Vehicle collision	Good	Highway 145 east of Norwood 12S,745739Ex4222548N

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 ≤660 m apart**	**No. observations with mothers & cubs >660 m apart**
Nov. 9, 2005 to	Nov.		3	4	2−6	9	2
Mar. 29, 2006	Dec.		4	4	3−7	16	4
	Jan.		5	4	4−8	17	3
	Feb.		4	5	5−9	16	2
	Mar.		2	5	6−10	9	0
		Totals	18	4−5	2−10	67	11[b]
Nov. 7, 2006 to	Nov.		4	4	2−3	11	0
Mar. 22, 2007	Dec.		4	4	2−5	11	0
	Jan.		5	3	4−6	10	2
	Feb.		4	4	5−7	10	1
	Mar.		3	1	8	2	1
		Totals	20	1−4	2−8	44	4[c]
Nov. 13, 2007 to	Nov.		2	1	6	1	1
Feb. 14, 2008	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]
Nov. 6, 2008 to	Nov.		3	5	3-6	10	0
Mar. 20, 2009	Dec.		1	4	4-7	4	0
	Jan.		2	6	5-17	8	3
	Feb.		2	4	7-9	6	0
	Mar.		3	2	7-10	5	1
		Totals	11	2-6	3-17	33	4[e]

[a] All puma mothers wore GPS-radiocollars. At least 1 cub in the litter wore a VHF radiocollar.
[b] Mean = 1,097 m, *SD* = 313.95, range = 670−1,600.
[c] Mean = 1,606 m, *SD* = 1,665.39, range = 678−4,101.
[d] Mean = 1,341 m, *SD* = 542.34, range = 759−1,832.
[e] Mean = 2,608 m, *SD* = 3,360.56, range = 799-7,641.

Table 16. Numbers of GPS locations and spans of monitoring for pumas captured on the Uncompahgre Plateau, Colorado, December 2004 to July 2009.

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 07-15-08	1,643
M55	M	adult	01-21-07 to 04-22-09	1,887
M100	M	adult	03-27-09 to 06-30-09	318
F2	F	adult	01-07-05 to 08-14-08	3,516
F3	F	adult	01-21-05 to 05-14-08	3,344
F7	F	adult	02-24-05 to 08-03-08	3.922
F8	F	adult	03-21-05 to 10-10-06	1,541
F16	F	adult	10-12-05 to 05-13-09	3,157
F23	F	subadult,	01-04-06 to 02-04-06	113
		adult	02-05-06 to 04-22-09	1,083
F24	F	adult	01-17-06 to 07-25-07	1,812
F25	F	adult	02-09-06 to 06-26-09	3,398
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 08-18-08	723
F70	F	adult	01-14-08 to 04-29-09	1,486
F72	F	adult	02-12-08 to 06-23-09	1,186
F75	F	adult	03-26-08 to 06-03-09	1,112
F96	F	adult	01-28-09 to 04-29-09	235
F104	F	adult	05-29-09 to 08-19-09	274

[a] GPS collars on pumas were remotely downloaded at approximately 1-month intervals, except during winter 2008-2009 to summer 2009 due to shortage of technicians during hiring freeze to assist in airplane flights to obtain downloads and to capture pumas to replace GPS collars (lengthening the download interval saved battery power). The last date in *Dates monitored* includes last location from the last GPS data download acquired for an individual puma.

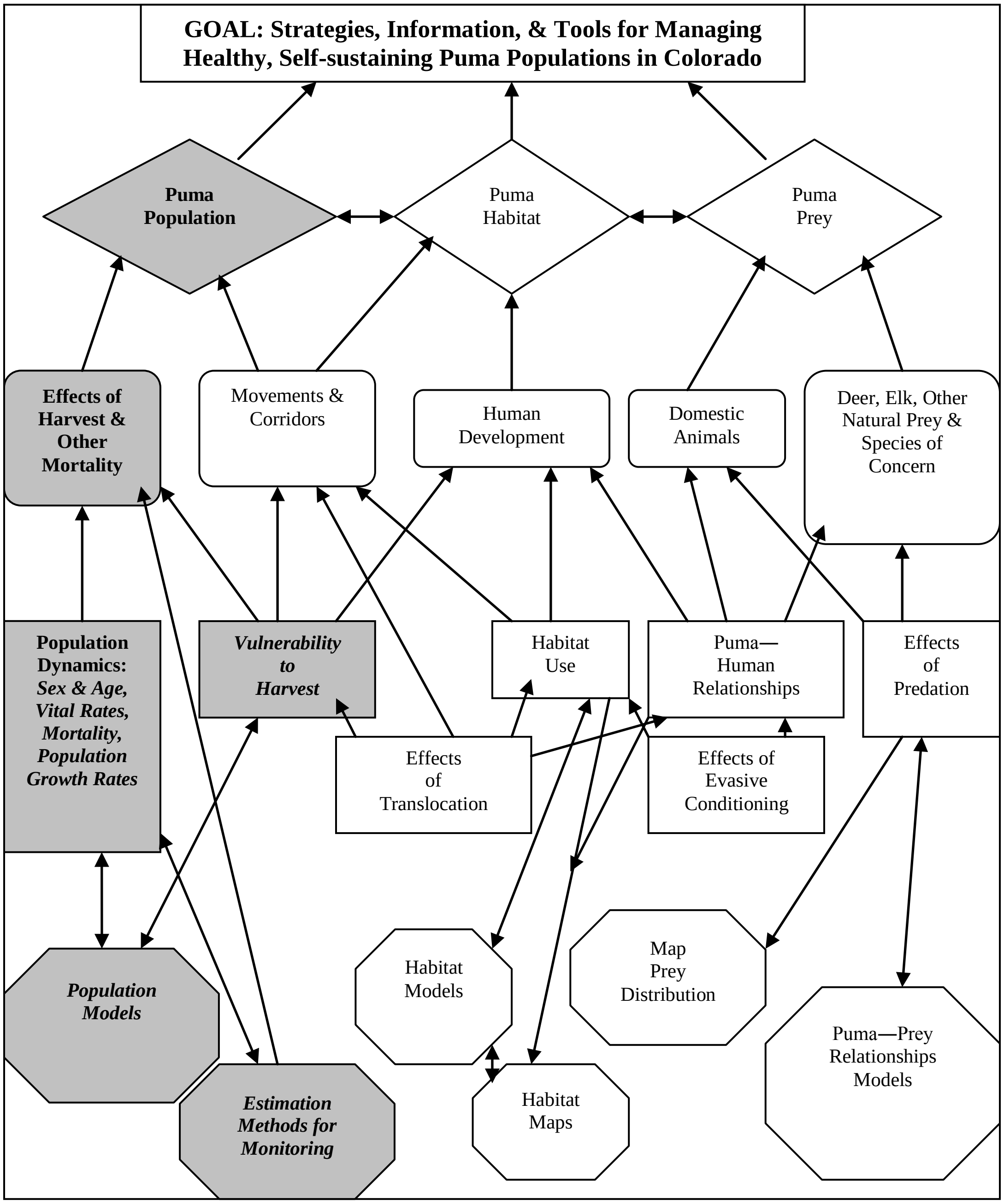

Figure. 1. An ecologically-based conceptual model of the Colorado Puma Research Program that provides the contextual framework for this and proposed puma research in Colorado. Gray-shaded shapes identify areas of research addressed by puma research on the Uncompahgre Plateau for the puma management goal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

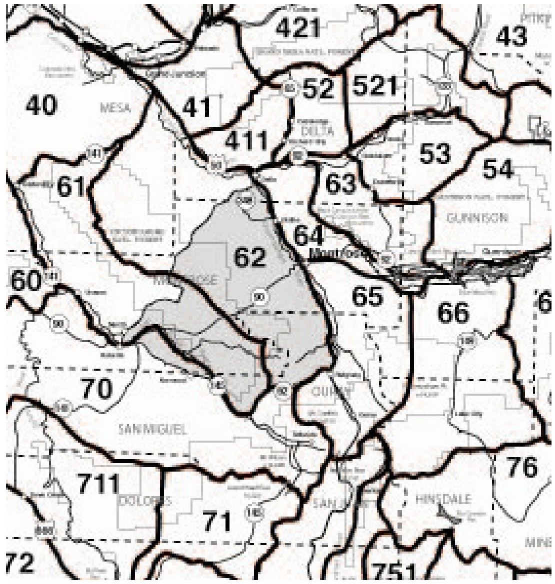

Figure 2. The puma study area on the southern half of the Uncompahgre Plateau, Colorado (shaded in gray) comprising the southern portions of Game Management Units (GMUs) 61 and 62 and a northern portion of GMU 70.

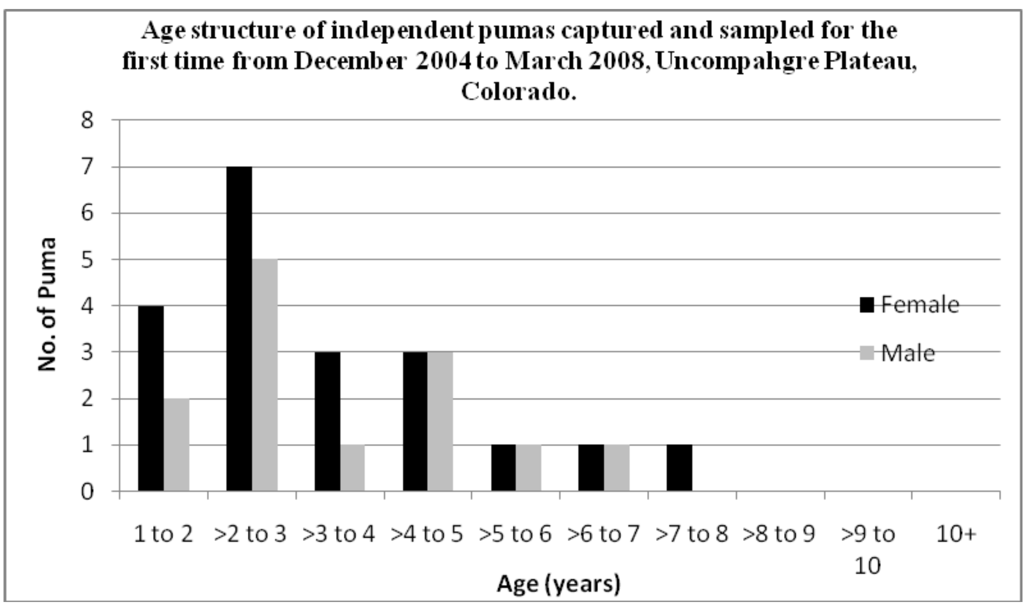

Figure 3. Age structure of independent pumas captured and sampled for the first time on the Uncompahgre Plateau, Colorado, December 2004 to May 2009.

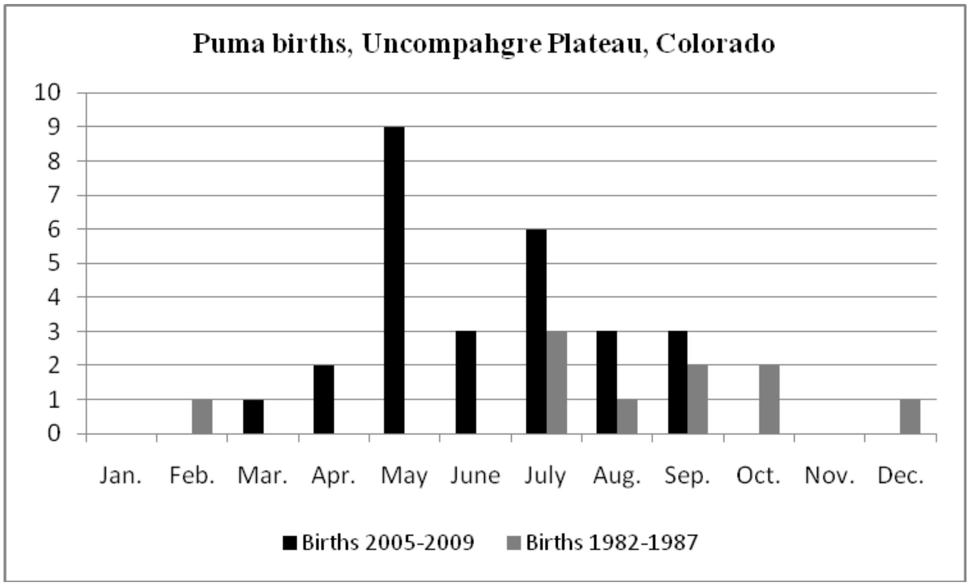

Figure 4. Puma births detected by month during the *reference period* (i.e., no puma hunting), 2005 to 2009 (n = 27 litters of 14 females; 26 of the litters were examined at nurseries when cubs were 26-42 days old and 1 litter confirmed by tracks of $\geq$2 cubs following GPS-collared mother F28 when cubs were ~42 days old), and during the earlier effort by Anderson et al. (1992:48; 1982 to 1987, n = 10 litters of 8 females, examined when cubs were <1-8 months old), Uncompahgre Plateau, Colorado.

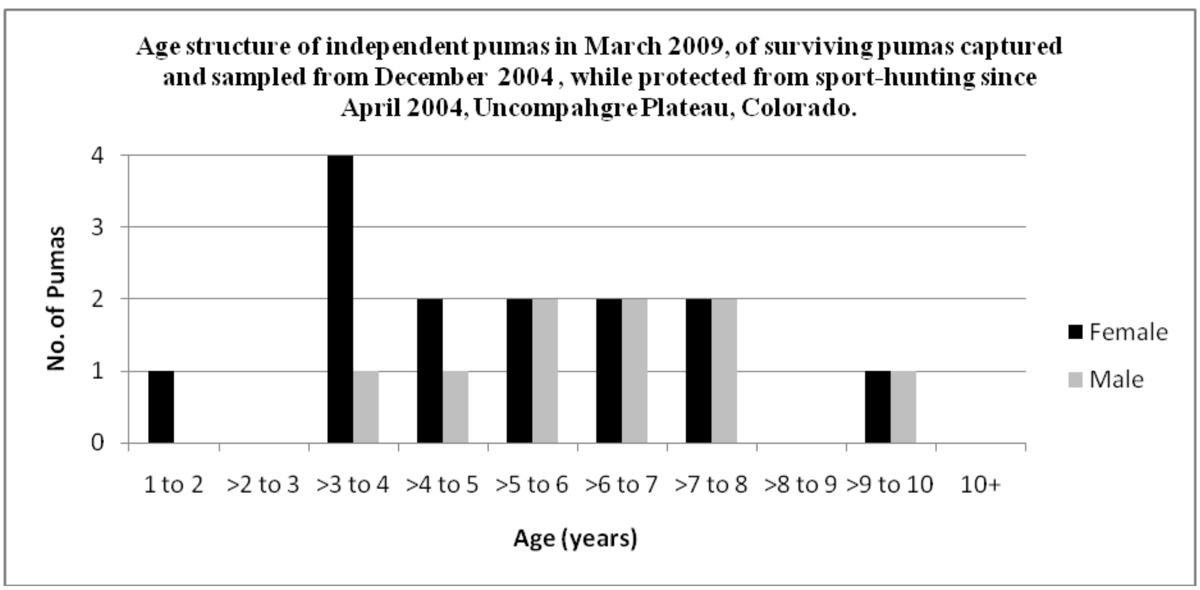

Figure 5. Age structure of surviving independent pumas captured and sampled on the Uncompahgre Plateau, Colorado in March 2009, and after protection from sport-hunting mortality since April 2004, which includes 5 hunting seasons (Nov. through Mar., 2004-05 to 2008-09). One human-caused mortality (F7 killed for depredation control 08-03-08) was documented in the radio- and GPS-collared sample of independent pumas on the study area. This age structure assumes that pumas F3, M29, and M51 were alive on March 31, 2009; they each had non-functional GPS collars and were detected alive as late as 1-15-09, 02-25-09, and 03-20-09, respectively. Mean ± *SD* of adult female and adult male ages, respectively: 5.21 ± 2.29 yr. (62.54 ± 27.42 mo.); 6.31 ± 1.87 yr. (75.67 ± 22.45 mo.).

APPENDIX A

Appendix A. Summary of individual puma cub survival and mortality, 2005 to 2009, 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. Killed by hunter in Beaver Creek, UT 02-20-09 at 4 ½ years old.	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 07-16 to 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).	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	Lost contact− shed radiocollar by 11-7 to 17-06. Treed, visually observed 03-01-07. Killed by a puma hunter 01-28-09 in Deer Creek, west slope of Grand Mesa, CO at 29 months old.	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.
M44	33	8-13-06	09-15-06 to 02-14-07	479	Lost contact− shed radiocollar by 10-27-06. Treed, visually observed 02-14-07; sibling (?) M56 also captured, sampled, & marked for 1st time. Killed by Wildlife Services for depredation control on 12-05-07, for killing 4 domestic sheep.	F7
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. Killed by a puma hunter in Blue Creek, northwest Uncompahgre Plateau 01-24-09 when ~29 months 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

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.
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
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	 324 434 538	Radiocollar malfunction. Tracks of 3 cubs observed with F16's tracks on 04-12-08, McKenzie Butte-Pinon Ridge Pass. 3 cubs observed with F16 on 08-08-08 by B. & T. Traegde. Dead. Died probably as independent subadult at 538 days old; struck by car on Hwy 550 mi. marker 111 N. of Ridgway, CO, euthanized by gunshot on 11/13/08.	F16
M62	34	7-14-07	08-17-07		Not radio-collared.	F24
M63	34	7-14-07	08-17-07		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

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.
F66	37	7-17-07	08-23-07 to 11-05-07	111	Radio-collared. Lost contact; last location 11/5/07. No signals after that date. F66 was photographed with one male sibling, either M67 or M68, & F30 on 5/31-6/1/08. F66 was recaptured and radio-collared as a subadult on 11/25/08. She died from massive trauma & bleeding of internal organs possibly resulting from being trampled by an elk or mule deer on about 05-28-09 as an independent subadult 23 months old.	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 05-31 to 06-01-08. Killed by a puma hunter in Disappointment Valley, CO 12-30-08 at 17 months old.	F30
F74	259	6-1-07	03-12-08 to 07-09-08	403	Radio-collared. Shed radiocollar between 7-9-08 and 7-15-08, probably while still dependent on mother F75.	F75
M76	30	5-19-08	06-18-08	~87	Not radio-collared. Probably dead; if not killed when sibling M79 was killed, then probably would starve to death.	F2
M77	30	5-19-08	06-18-08	~87	Not radio-collared. Probably dead; if not killed when sibling M79 was killed, then probably would starve to death.	F2
F78	30	5-19-08	06-18-08	~87	Not radio-collared. Probably dead; if not killed when sibling M79 was killed, then probably would starve to death.	F2
M79	30	5-19-08	06-18-08	87	Not radio-collared. Dead. Chewed-off anterior portions of the nasals, maxilla, palate, dentaries, and pieces of the braincase, with 6 or 9 portion of yellow ear-tag and intestines and bits of skin found ~45 m from mother F2's death site on 8/14/08. Cub death probably due to puma-caused infanticide with cannibalism at ~87 days old. Male puma scrapes, about 8, under a rock rim ~50m distance from cub remains, and made ~ time of pumas' deaths.	F2
F80	40	5-23-08	07-02-08		Not radio-collared. Apparently died before 2-4-09; no tracks found in association with F23 & siblings F81 & F97.	F23

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.
F81	40	5-23-08	07-02-08 to 07-29-09	424	Radio-collared. Last live location 7-29-09.	F23
F97	8 ½ mo.	5-23-08	02-04-09	354	Radio-collared. Lost contact after 05-12-09; shed collar at elk kill cache on Mailbox Park.	F23
M82	37	5-29-08	07-05-08 to 03-20-09 or 04-02-09	295-308	Radio-collared.	F8
M83	37	5-29-08	07-05-08		Not radio-collared. Apparently died; no tracks found in association with F8 & sibling M82 2-10-09.	F8
M84	36	6-5-08	07-11-08 to 02-11-09	251	Radio-collared 7-11-08 to 7-22-08; collar removed because of malfunction. Not radio-collared after 7-22-08. Eartag of M84 was found by E. Phillips on 8-25-08 when mother F70's GPS locations located here on either side of the eartag in the East fork Dolores Cyn. M84 recaptured radiocollared again 1-29-09 in Dolores Cyn. in association with F70 & F96's family. Shed radiocollar again about 2-11-09.	F70
F85	36	6-5-08	07-11-08		Radio-collared. Dead. Probably died of predation or infanticide about 10-1-08 near elk calf kill.	F70
F86	36	6-5-08	07-11-08 to 07-23 to 08-03-08	~48-59	Radio-collared 7-22-08. Dead. Radio-collar, orange ear-tag #86 with pinna with green tattoo #86 found by J. Timmer 9-1-08. F86 died ~7-23 to 8-3-08 when mother F70's GPS locations located her at F86 remains. Probable predation.	F70
M87	28	7-3-08	07-31-08		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
Male 7A	28-35	7-10-08	~08-07-08 to 08-14-08	28 to 35	Not radio-collared. F7's cubs died from starvation after they were orphaned. F7 was shot on 8-3-08 for depredating on domestic sheep.	F7
Male 7B	28-35	7-10-08	~08-07-08 to 08-14-08	28 to 35	Not radio-collared. F7's cubs died from starvation after they were orphaned. F7 was shot on 8-3-08 for depredating on domestic sheep.	F7
Female 7C	28-35	7-10-08	~08-07-08 to 08-14-08	28 to 35	Not radio-collared. F7's cubs died from starvation after they were orphaned. F7 was shot on 8-3-08 for depredating on domestic sheep.	F7

Appendix A continued

Puma I.D.	Estimated Age at capture (days)	Est. Birth date	Est. survival span from 1st capture to fate or last monitor date	Age to last monitor date alive or at death (days, birth to fate)	Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death	Mother I.D.
M91	35	8-19-08	09-29-08		Radio-collared.	F25
M92	35	8-19-08	09-29-08		Radio-collared.	F25
F95	16 mo.	June-07	12-29-08		Radio-collared. Survived to subadult stage.	F93
F98	4-5 mo.	Sep-Oct-08	2-12-09	23-24	Radio-collared. Died, probably killed by male puma (infanticide).	Unm.F
M99	5 mo.	Sep-Oct-08	2-27-09		Radio-collared. Last location 4-22-09 on Paterson Mt.	Unm.F
M101	35	4-15-09	05-20-09		Radio-collared.	F16
M102	35	4-15-09	05-20-09		Radio-collared.	F16
F103	35	4-15-09	05-20-09		Radio-collared.	F16
M105	38	5-7-09	06-14-09		Radio-collared	F75
F106	38	5-7-09	06-14-09		Not radio-collared; F75 returned to nursery during handling.	F75
M107	34	5-25-09	06-28-09		Not radio-collared; too small.	F94
F108	34	5-25-09	06-28-09		Shed radiocollar; fastener failed.	F94
M109	34	5-25-09	06-28-09		Not radio-collared; too small.	F94

[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 Simulations.

Research on the Uncompahgre Plateau Puma Project from December 2004 to July 2009 provides estimates of puma population structure and parameters for a model-based approach developed by CDOW biometrician P. Lukacs and Mammals Researcher K. Logan to examine options for the design of the remainder of this research, and as a preliminary assessment of the CDOW puma management assumptions.

Puma Population Modeling

Our puma population projections for the study area involved an age-structured, deterministic, discrete time model. The additive puma population model structure is:

N_{t+1} =
Adult Females = $(S_{AF} * N_{AFt} + S_{SF} * N_{SFt}) * (1 – H_{AFt+1})$ +
Adult Males = $(S_{AM} * N_{AMt} + S_{SM} * N_{SMt}) * (1 – H_{AMt+1})$ +
Subadult Females = $((r * S_C * N_{Ct}) * (1 – H_{SFt+1})) * PI_{SF}/E_{SF}$ +
Subadult Males = $(((1 − r) * S_C * N_{Ct}) * (1 – H_{SMt+1})) * PI_{SM}/E_{SM}$ +
Cubs = $L_{\tilde{y}} * AF_R * N_{AFt+1}$

Terms:
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).
r = Proportion of the subadult population that is female (e.g., 0.5; 1-0.5 = proportion of males).
PI/E = Ratio of progeny + immigrants/emigrants.
$L_{\tilde{y}}$ = Average litter size.
AF_R = Proportion of adult females giving birth to new litters each year.

Basic assumptions of the model include: 1) expected puma population projections and annual rates of increase (i.e., lambda) are conditional on the assigned puma population structure and demographic estimates, 2) no density dependent responses are built into the model. Density dependence might operate in puma population dynamics, with competition for food regulating adult female density and competition for mates regulating adult male density (Logan and Sweanor 2001), and 3) harvest is additive mortality.

We parameterized the model with data gathered on the pumas on the study area during the first 3.7 years. (Data from this past year, 2008-09 could not be used because decisions about harvest structure for the *treatment period* needed to be made June of that biological year). The starting population was the *minimum count* of pumas and attendant estimated sex and age structure made during November 2007 to March 2008 (Table B.1). 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 B.2). Some sex and age-stage specific estimates of survival (i.e., adult male, subadult male, subadult female) came from the literature

(Table B.2), because our current sample sizes (i.e., number of individuals and years) may not be adequate for realistic estimates (i.e., 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 B.2). We preferred using the population characteristics and parameter estimates gathered in the current research effort, because this is the puma population we intend to manipulate to assess current CDOW puma management strategies.

Table B.1. Minimum puma population count on Uncompahgre Plateau study area, Colorado, November 2007 to March 2008 (RY4). The minimum count involves counting all radio- and GPS-collared pumas, all other marked pumas, and all presumably unmarked pumas detected on the study area during the period. Presumed unmarked pumas could be marked with ear-tags and tattoos. Their tracks and movements could be separated from movements of radio- and GPS-collared pumas. Or they exhibited evidence that could separate them from other local marked pumas from their tracks (i.e., distinguishable by sex, number of cubs and/or relative size of cubs varied).

	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	20-21
	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.

Table B.2. Summary of preliminary puma population model parameter estimates obtained from the Uncompahgre Plateau Puma Project and from the 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 of both sexes 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.). This result supported Logan and Sweanor 2001:69, *n* = 148).
Proportion of adult females producing new litters each year	0.65	Proportion of adult females giving birth each year (n = 3 years for n = 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).

Puma Population Simulations

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 the puma research and management 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, expected to be 16% harvest of independent pumas. Various sex ratios of harvest composition were examined.
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. Various sex ratios of harvest composition were examined.
4) 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. Various sex ratios of harvest composition were examined.
5) Puma harvest at a 20% harvest level intermediate to the 16% stable growth and 28% decline phase with varying female to male sex structure of the harvest.
6) Puma harvest at the historic harvest level of 26% and sex ratio of 45 females:55 males on the study area during 1994-2003.

Results of Puma Population Simulations

The following tables contain the expected minimum population sizes for independent pumas and annual rates of population increase conditional upon the minimum number of independent pumas detected in Reference Year 4 (RY4) and the model input parameters and assumptions (given in Tables B.1 and B.2). The total number of independent pumas is probably higher in any particular scenario because we probably did not detect all of the independent pumas in RY4. Simulations involving harvest apply the harvest following *reference year* 5 (RY5) and starting with *treatment year* 1 (TY1) to assess what might be expected to occur within the current research structure on the Uncompahgre Plateau.

Our puma population simulation modeling suggest strategies to achieve increasing and declining puma populations contingent upon the set of assumptions and input demographic data. Moreover, results of this modeling effort constitute the first time that CDOW puma harvest assumptions have been evaluated by using Colorado-specific population data. Results could change as more quantitative population data are gathered and the puma population is manipulated during this research. Expected estimates of population growth were generally consistent with the current 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 following series of tables (B.3 – B.16) indicate results of the individual models, followed by notes on 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.

Table B.3.

Harvest Level	Year	Projected Minimum Puma Population Size: Adult Female	Adult Male	Subadult Female	Subadult Male	Cub	Independent Pumas: 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	1.37
	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.
*Lambda is the finite rate of population growth (Williams et al. 2002:136): $\lambda = 1 + (N_{t+1} - N_t) / N_t$

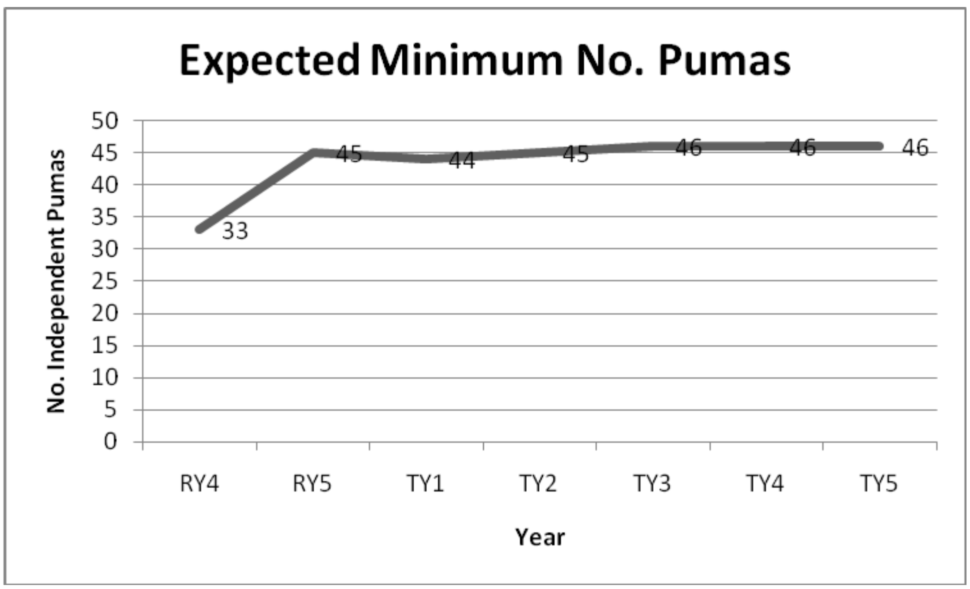

Figure B.1. Expected minimum number of independent pumas based on population simulations with 16% harvest of independent pumas comprised of 50% males and 50% females in the harvest in TY1 to TY5.

Table B.4.

Harvest Level	Year	Projected Minimum Puma Population Size: Adult Female	Adult Male	Subadult Female	Subadult Male	Cub	Independent Pumas: Total	Lambda
16% of independent pumas, harvest comprised of **40% females:60% males.**	RY4	16	8	5	4	20	33	
	RY5	18	10	9	8	33	45	1.37
	TY1	20	11	7	6	37	44	0.98
	TY2	21	10	9	7	39	46	1.05
	TY3	23	10	9	7	41	48	1.04
	TY4	24	10	9	7	44	51	1.05
	TY5	25	10	10	8	46	53	1.05

Note: The puma population is expected to increase.

Table B.5.

Harvest Level	Year	Projected Minimum Puma Population Size					Independent Pumas	
		Adult		Subadult				
		Female	Male	Female	Male	Cub	Total	Lambda
16% of independent pumas, harvest comprised of **45% females:55% males.**	RY4	16	8	5	4	20	33	
	RY5	18	10	9	8	33	45	1.37
	TY1	20	11	7	6	36	45	0.98
	TY2	20	11	8	7	37	46	1.04
	TY3	21	11	8	7	38	47	1.03
	TY4	21	12	8	7	39	49	1.03
	TY5	22	12	9	7	40	50	1.03

Note: The puma population is expected to increase.

Table B.6.

Harvest Level	Year	Projected Minimum Puma Population Size					Independent Pumas	
		Adult		Subadult				
		Female	Male	Female	Male	Cub	Total	Lambda
16% of independent pumas, harvest comprised of **55% females:45% males.**	RY4	16	8	5	4	20	33	
	RY5	18	10	9	8	33	45	1.37
	TY1	18	12	7	7	34	44	0.97
	TY2	17	13	7	7	31	44	1.00
	TY3	17	14	6	6	30	43	0.98
	TY4	16	14	6	6	29	42	0.98
	TY5	15	15	6	6	27	41	0.97

Note: The puma population is expected to decline slowly.

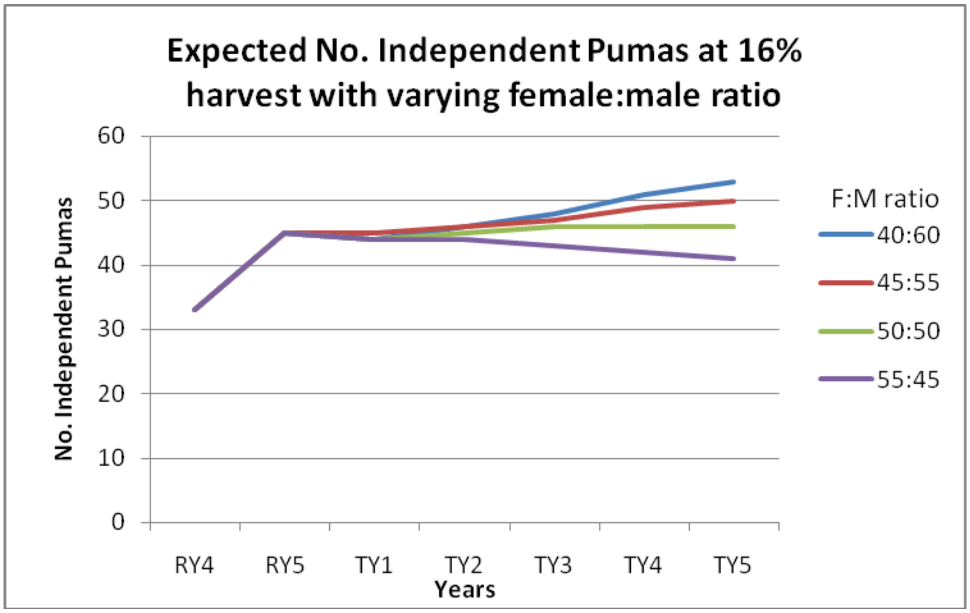

Figure B.2. Expected minimum number of independent pumas based on population simulations with 16% harvest of independent pumas comprised of varying female to male sex ratios in the harvest in TY1 to TY5. See tables B.3-6 (above) for quantities of results for each model. In reality, the ratio of females to males in the harvest may vary randomly on an annual basis, and the expected annual numbers of independent pumas may fall within the lower and upper population trend lines.

Table B.7.

Harvest Level	Year	Projected Minimum Puma Population Size					Independent Pumas	
		Adult		Subadult				
		Female	Male	Female	Male	Cub	Total	Lambda
No harvest.	RY4	16	8	5	4	20	33	
	RY5	18	10	9	8	33	45	1.37
	TY1	23	14	8	8	42	53	1.17
	TY2	27	17	11	10	49	64	1.22
	TY3	32	22	12	11	58	77	1.20
	TY4	38	27	15	14	69	92	1.20
	TY5	44	32	17	16	81	110	1.19

Note: Expected lambda for the modeled non-hunted puma population on the Uncompahgre Plateau are consistent with 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 yr.; *r* = 0.28, *n* = 4 yr.; *r* = 0.17, *n* = 4 yr.; *r* = 0.11, *n* = 7 yr.; Logan and Sweanor 2001:169-175). Puma population growth could be higher on the Uncompahgre Plateau because of higher quality habitat (i.e., greater vulnerable prey biomass), and if puma sources are nearby to the study area.

Table B.8.

Harvest Level	Year	Projected Minimum Puma Population Size					Independent Pumas	
		Adult		Subadult				
		Female	Male	Female	Male	Cub	Total	Lambda
15% of independent pumas, sexes are harvested equally.	RY4	16	8	5	4	20	33	
	RY5	18	10	9	8	33	45	1.37
	TY1	19	12	7	7	36	45	0.99
	TY2	19	12	8	7	35	47	1.04
	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 current the CDOW puma harvest assumption for a stable-to-increasing population, with slow growth attributed to equal harvest of females and males.

Table B.9.

Harvest Level	Year	Projected Minimum Puma Population Size					Independent Pumas	
		Adult		Subadult				
		Female	Male	Female	Male	Cub	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	1.37
	TY1	21	11	8	6	38	45	0.99
	TY2	22	10	9	7	39	47	1.06
	TY3	23	10	9	7	42	50	1.05
	TY4	25	11	10	8	45	53	1.06
	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.

Table B.10. Puma population simulation results, based on the minimum number of detected independent pumas in RY4, and harvest rate of 20% of independent pumas comprised of 50% females and 50% males applied to independent pumas as a treatment during TY1-TY5.

Harvest Level	Year	Projected Minimum Puma Population Size					Independent Pumas	
		Adult		Subadult				
		Female	Male	Female	Male	Cub	Total	Lambda*
20% of	RY4	16	8	5	4	20	33	
independent	RY5	18	10	9	8	33	45	1.37
pumas,	TY1	18	11	7	6	34	42	0.93
comprised of	TY2	17	11	7	6	31	41	0.97
50% females	TY3	16	11	6	6	30	40	0.96
& 50% males.	TY4	15	11	6	6	28	38	0.96
	TY5	15	11	6	5	27	36	0.96

Note: The puma population would be expected to decline.

Table B.11. Puma population simulation results, based on the minimum number of detected independent pumas in RY4, and harvest rate of 20% of independent pumas comprised of 40% females and 60% males applied to independent pumas as a treatment during TY1-TY5.

Harvest Level	Year	Projected Minimum Puma Population Size					Independent Pumas	
		Adult		Subadult				
		Female	Male	Female	Male	Cub	Total	Lambda
20% of	RY4	16	8	5	4	20	33	
independent	RY5	18	10	9	8	33	45	1.37
pumas,	TY1	20	10	7	5	36	42	0.93
comprised of	TY2	20	8	8	6	37	42	1.01
40% females	TY3	21	8	8	6	38	43	1.00
& 60% males.	TY4	21	8	8	6	39	43	1.01
	TY5	22	7	9	6	40	44	1.02

Note: The puma population would be expected to increase slowly.

Table B.12. Puma population simulation results, based on the minimum number of detected independent pumas in RY4, and harvest rate of 20% of independent pumas comprised of 45% females and 55% males applied to independent pumas as a treatment during TY1-TY5.

Harvest Level	Year	Projected Minimum Puma Population Size					Independent Pumas	
		Adult		Subadult				
		Female	Male	Female	Male	Cub	Total	Lambda
20% of	RY4	16	8	5	4	20	33	
independent	RY5	18	10	9	8	33	45	1.37
pumas,	TY1	19	10	7	6	35	42	0.94
comprised of	TY2	19	10	7	6	34	42	0.99
45% females	TY3	19	10	7	6	34	41	0.98
& 55% males.	TY4	18	9	7	6	34	41	0.99
	TY5	18	9	7	6	33	40	0.99

Note: The puma population would be expected to decline slowly. The ratio of 45% females and 55% males in the harvest is the average harvest sex ratio during 1994-2003.

Table B.13. Puma population simulation results, based on the minimum number of detected independent pumas in RY4, and harvest rate of 20% of independent pumas comprised of 55% females and 45% males applied to independent pumas as a treatment during TY1-TY5.

Harvest Level	Year	Projected Minimum Puma Population Size					Independent Pumas	
		Adult		Subadult				
		Female	Male	Female	Male	Cub	Total	Lambda
20% of independent pumas, comprised of **55% females & 45% males**.	RY4	16	8	5	4	20	33	
	RY5	18	10	9	8	33	45	1.37
	TY1	17	12	6	6	32	42	0.94
	TY2	15	12	6	6	28	40	0.99
	TY3	14	12	5	5	25	37	0.98
	TY4	12	12	5	5	22	34	0.99
	TY5	11	12	4	4	20	31	0.99

Note: The puma population would be expected to decline more rapidly.

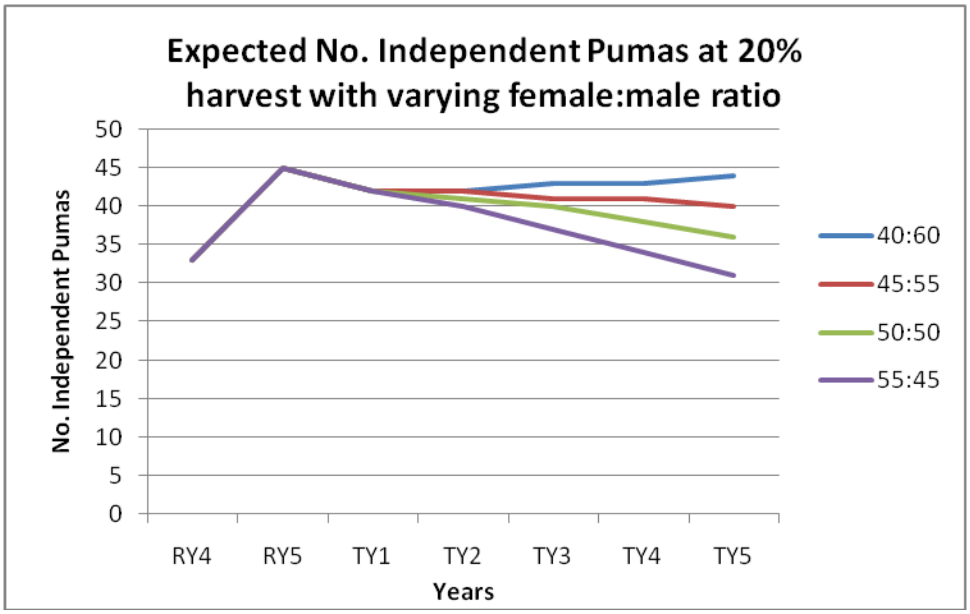

Figure B.3. A harvest level of 20% of independent pumas is expected to result in a declining population, except in the scenario consistently weighted heavily toward male harvest (i.e., 60%).

Table B.14.

Harvest Level	Year	Projected Minimum Puma Population Size					Independent Pumas	
		Adult		Subadult				
		Female	Male	Female	Male	Cub	Total	Lambda
28% of independent pumas, sexes are harvested equally.	RY4	16	8	5	4	20	33	
	RY5	18	10	9	8	33	45	1.37
	TY1	17	10	6	6	30	38	0.84
	TY2	14	9	6	5	25	33	0.88
	TY3	12	8	5	4	22	29	0.86
	TY4	10	7	4	4	18	25	0.86
	TY5	9	6	3	3	16	21	0.86

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

Table B.15.

Harvest Level	Year	Projected Minimum Puma Population Size					Independent Pumas	
		Adult		Subadult				
		Female	Male	Female	Male	Cub	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	1.37
	TY1	19	8	7	4	34	38	0.84
	TY2	18	6	7	5	32	35	0.93
	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.

Yet another harvest scenario to consider for the treatment period is application of the historic puma harvest on the study area. Puma mortality data for the study area during the 10 years previous 1994-2003 prior to the beginning of the study *reference period* was tabulated after carefully geo-referencing mortality locations on the study area (Logan 2008). 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 minimum expected puma population after year 5 of the *reference period* (i.e., RY5). A harvest of 14 pumas/yr. is a 26% harvest rate of the expected minimum independent puma population at the start of TY1.

Table B.16.

Harvest Level	Year	Projected Minimum Puma Population Size					Independent Pumas	
		Adult		Subadult				
		Female	Male	Female	Male	Cub	Total	Lambda
26% of independent pumas at start of TY1, comprised of **45% females & 55% males.**	RY4	16	8	5	4	20	33	
	RY5	18	10	9	8	33	45	1.27
	TY1	18	9	7	5	33	39	0.87
	TY2	17	8	7	5	30	36	0.93
	TY3	15	7	6	5	28	34	0.92
	TY4	14	6	6	5	26	31	0.93
	TY5	13	6	5	4	25	29	0.93

Note: As expected, results of this model indicate puma population decline. This simulation demonstrates the negative cost of uncertainty in puma management; in this case a puma population would decline where the intended management objective was for a stable-to-increasing population.

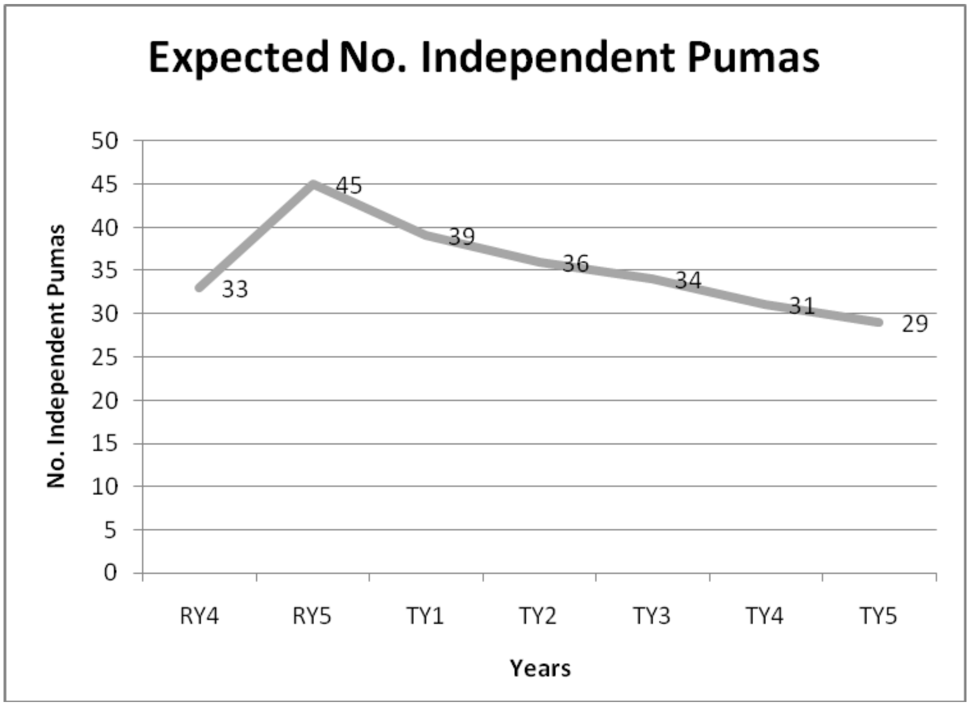

Figure B.4. Expected dynamics of a puma population with the historical harvest (1994-2003) rate on the Uncompahgre Plateau study area of 26% of the independent puma and sex ratio of 45% females to 55% males (see Logan 2008 for historical harvest data on the study area).

APPENDIX C

Collaborative project on disease surveillance in wild felids with College of Veterinary Medicine and Biomedical Sciences, Department of Microbiology, Pathology, and Immunology, Colorado State University.

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

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, 2005-2009.

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	+	-	-	+	-	+	-	++
UPCO7	F	3/3/2007	13S, 247645, 4246097	+	-	+	-	-	+	-	++
UPCO8	F	3/21/2005	12S, 727808, 4239029	I	-	-	-	-	+	-	++
UPCO4	M	1/28/2005	13S, 257565, 4239606	+	-	-	-	-	+	+	-
UPCO5	M	2/4/2005	13S, 240577, 4251037	-	-	+	+	-	+	-	-
UPCO6	M	2/18/2005	13S, 247399, 4254006	+	-	-	-	-	+	-	-
UPCO6	M	4/12/2008	13S, 257516, 4239696	+	-	-	NA	-	+	-	+
UPCO23	F	2/25/2008	12S, 723304, 4242231	-	-	-	NA	-	+	-	+
UPCO25	F	2/8/2006	13S, 258374, 4230480	+	+	-	+	-	+	-	-
UPCO28	F	3/23/2006	12S, 722868, 4240115	+	-	-	-	-	+	-	-
UPCO29	M	4/14/2006	12S, 723458, 4242340	+	+	-	+	-	+	-	++
UPCO31	M	4/19/2006	12S, 746919, 4225441	+	-	-	+	-	+	-	-
UPCO23	F	1/4/2006	12S, 730188, 4234861	-	-	-	+	-	-	-	-
UPCO27	M	3/10/2006	12S, 722339, 4245212	-	-	-	-	-	+	-	-
UPCO30	F	4/15/2006	13S, 248551, 4242095	-	-	+	-	-	+	-	-
UPCO50	F	12/14/2006	12S, 753639, 4260149	+	-	-	-	-	-	-	-
UPCO51	M	1/7/2007	13S, 238783, 4252390	+	-	-	-	-	+	-	-
UPCO52	F	1/10/2007	13S, 258058, 4236260	-	-	-	-	-	-	-	-
UPCO54	F	1/12/2007	13S, 252688, 4228050	+	-	-	-	-	+	-	-
UPCO55	M	1/21/2007	13S, 258133, 4228691	+	-	+	+	-	+	-	-
UPCO24	F	1/17/2006	12S, 737151, 4233273	+	+	-	+	-	+	-	-
UPCO69	M	1/11/2008	13S, 248191, 4246810	+	+	+	+	-	+	-	-
UPCO70	F	1/20/2008	13S, 247122, 4245760	+	+	+	+	-	+	-	+
UPCO71	M	1/29/2008	12S, 754611, 4256842	-	-	-	NA	-	-	-	-
UPCO72	F	2/12/2008	13S, 258294, 4234597	-	-	-	NA	-	+	-	-
UPCO73	F	2/21/2008	12S, 728576, 4241799	-	-	-	NA	-	+	-	+
UPCO74	F	3/12/2008	12S, 729678, 4239555	P	-	-	NA	P	P	-	-
UPCO75	F	3/26/2008	12S, 732894, 4239423	P	-	-	NA	-	+	-	+
UPCO72	F	7/20/2009	13S, 255400, 4229658	P	-	-	NA	-	+	+	NA
UPCO104	F	5/21/2009	12S, 745118, 4264721N	P	No swab	No swab	NA	-	+	-	NA
UPCO55	M	1/5/2009	13S, 239076, 4248637	+	-	-	NA	-	+	-	NA
UPCOF16	F	1/14/2009	13S, 256528, 4235500	P	-	-	NA	-	+	-	NA
UPCO66	F	11/25/2008	13S, 245901, 4247627	+	-	-	NA	-	+	-	NA
UPCO94	F	12/19/2008	12S, 758531, 4259824	-	-	-	NA	-	+	+	NA
UPCO96	F	1/28/2009	13S, 247764, 4246239	P	-	-	NA	-	+	-	NA
UPCO100	M	3/27/2009	12S, 749832, 4217148	P	-	-	NA	-	+	-	NA
UPCO82	M	2/10/2009	12S, 726732, 4243782	P	-	-	NA	-	+	-	NA
UPCO93	F	12/15/2008	12S, 751445, 4265985	+	-	-	NA	-	+	-	NA
UPCO71	M	1/29/2008	12S, 754611, 4256842	-	-	-	NA	-	-	-	-
UPCO72	F	2/12/2008	13S, 258294, 4234597	-	-	-	NA	-	+	-	-
UPCO73	F	2/21/2008	12S, 728576, 4241799	-	-	-	NA	-	+	-	+
UPCO74	F	3/12/2008	12S, 729678, 4239555	P	-	-	NA	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), NA (not applicable).

Colorado Division of Wildlife
July 2008 - June 2009

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
Federal Aid		:	Along the Urban-Exurban Front-range of Colorado
Project No.	N/A		

Period Covered: July 1, 2008 - June 30, 2009

Author: M.W. Alldredge

Personnel: E. Joyce, T. Eyk, K. Blecha, L. Nold, K. Griffin, D. Kilpatrick, M. Paulek, B. Karabensh, M. Miller, F. Quartarone, M. Sirochman, L. Wolfe, J. Duetsch, C. Solohub, J Koehler, L. Rogstad, R. Dewalt, J. Murphy, D. Swanson, T. Schmidt, T. Howard, D. Freddy CDOW; B. Posthumus, Jeffco Open Space; D. Hoerath, K. Grady, D. Morris, Boulder County Open Space; S. Oyler-McCance, USGS.

ABSTRACT

We continued 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 6 months post-deposition, but genotyping error rates have not yet been assessed. We are investigating degredation rates further by sampling feces in natural, uncontrolled, environments deposited at known times from known individuals. Sampling cougar feces in the field may be a feasible non-invasive sampling method to estimate cougar populations.

The use of telomeres as a method to determine the age structure of bear and cougar populations has been examined and will be investigated further in the coming year. Further refinement of the age-to-length relationship for both species is warranted based on preliminary results. In addition to this, length relationships relative to genetic relatedness and individual stressors will give further insight into interpreting results from future data.

This year capture efforts focused on re-collaring previously collared cougars, and capturing previously unmarked independent age cougars and cubs. We collared an additional 10 independent age cougars and also put VHF eartag transmitters on 8 cubs during the year. Mortality remained high over the year exceeding 40% for independent age cougars (predominantly human related) and exceeding 50% for cubs (predominantly starvation). Home-range patterns remained consistent to previous years. The effectiveness of aversive conditioning is still showing mixed results, which is likely a factor of the opportunistic nature of cougars using urban environments and a lack of habituation to them. Relocation of cougars as a management tool has had limited assessment, but given some success, still warrants

further investigation. Mule deer are the predominant prey in cougar diets, although males will also utilize elk regularly.

WILDLIFE RESEARCH REPORT

COUGAR 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

Section A: Genetics

1. Evaluate differences in DNA quantity from either a scat surface collection or a cross-sectional collection.
2. 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.
3. Evaluate temporal, environmental, and seasonal effects on fecal DNA quantity and quality for both controlled and uncontrolled conditions.

Section B: Telomeres

4. Evaluate the potential to develop a model for estimating age of bears and cougars based on telomere length.

Section C: Front-range cougars

5. Capture and mark independent age cougars and cubs to collect data to examine demographic rates for the urban cougar population.
6. Continued assessment of aversive conditioning techniques on cougars within urban/exurban areas, including use of hounds and shotgun-fired bean bags or rubber bullets.
7. Continue to assess relocation of cougars as a practical management tool.
8. Assess cougar predation rates and diet composition based on GPS cluster data.

SECTION A: GENETICS

INTRODUCTION

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 due to 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.

STUDY AREA

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.

METHODS

Fecal samples were collected from the 3 sibling cougars located at the Foothills Wildlife Research Facility. During the year the entire remaining sample of 60 feces per cougar were collected 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

Response variables that are being measured are number of incorrect identifications, allelic dropout rates (actual number of alleles that dropout in any given sample), and number of false alleles. The primary analysis is a logistic regression on the dichotomous identification variable, treating the three temperature regimes as covariates. Additional analyses summarize the rate at which alleles dropout and the occurrence of false alleles. A total of 60 scats have been collected and sub-sampled at each time period within treatment groups.

PCR and DNA sequencing is being done at the Rocky Mountain Center for Conservation Genetics and Systematics laboratory. Individual cougars are screened and genotyped using 9 -12 nuclear microsatellite loci isolated from domestic cat (Menotti-Raymond and O'Brien 1995, Menotti-Raymond et al. 1999). Three recent studies have used sets of these primers successfully on mountain lions (Ernest et al. 2000, Sinclair et al. 2001, Anderson et al. 2004). We will choose a set of these primers for our work. PCRs will be performed using a M13-tailed forward primer as described by Boutin-Ganache et al. (2001). Each 12.5μl reaction will contain 125μM each dNTP, 1X *Taq* buffer (Kahn et al. 1998), 0.034μM M13-tailed forward primer, 0.5μM non-tailed reverse primer, 0.5μM M13 dye-labeled primer with Beckman Coulter dyes D2, D3 or D4 (Proligo), and 0.31U *Taq* polymerase (Promega). The thermal profile for both the forward dye-labeled and the M13 dye-labeled reactions will be as follows with the appropriate annealing temperature varying by locus: preheat at 94°C for 1 min, denature at 94 ºC for 1 min, anneal for 1 min, and extend at 72 ºC for 1 min for 35 cycles. The PCR products will be diluted and run on the CEQ8000 XL DNA Analysis System (Beckman Coulter). All loci will be run with the S400 size standard (Beckman Coulter) and analyzed using the Frag 3 default method.

RESULTS AND DISCUSSION

Most of the remaining samples were collected this year and the majority of the samples were genotyped. Approximately 200 samples remain to be genotyped as collections at the greater time intervals will continue into November 2009. 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 6 months old. Genetic degradation appears to occur at a slower rate than initially expected. This would indicate that scat surveys for individual identification of cougars may be a viable non-invasive sampling technique.

SECTION B: TELOMERES

BY M. ALLDREDGE AND J. PAULI

INTRODUCTION

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

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

STUDY AREA

Genetic samples for black bears were obtained from blood collections taken from bears captured in Wyoming. Genetic samples for cougars were obtained from either blood or tissue samples taken from cougars in Colorado as part of either the Uncompahgre Plateau or Front-Range cougar studies.

METHODS

We quantified telomere length in cougar and bear tissue samples using a real-time quantitative polymerase chain reaction (Q-PCR) technique (Cawthon 2002). This method measures relative telomere lengths by determining the factor by which a sample DNA differs from an arbitrary reference DNA in its ratio of telomere repeat copy number (T) to single copy gene number (S). The T/S ratio of one individual relative to the T/S for another reflects relative differences in telomere length between individuals. This approach is highly accurate (Cawthon 2002), particularly for differentiating relative telomere length among individuals within a species (Nakagawa et al. 2004). In theory, any single copy gene sequence can be employed for standardization; we chose to use the single copy gene, 36B4, which was originally employed to develop this method for quantifying telomere length in humans (Cawthon 2002). Using genome data for eight species (carnivores, primates, birds, amphibians, ungulates, and rodents; accessible at http://www.ncbi.hlm.nih.gov/) and the computer program, ClustalX (version 1.81), we conducted a sequence alignment and have determined that the 36B4 gene is highly conserved across vertebrate taxa and appears to be a suitable internal standard for a wide range of species, including the cougars and black bears.

We ran telomere PCR and single-copy gene PCR on different 96-well plates; preparation of telomere and single-copy plates was identical except for the primers. We diluted extracted DNA with distilled water to 3 ng·µl-1. For each animal, we added 10 µl of diluted DNA to 2 adjacent wells. To generate a standard curve, we diluted DNA from an arbitrarily chosen animal to 1 ng·µl-1, 2.5 ng·µl-1, 4 ng·µl-1 and 6 ng·µl-1 and added 10 µl of each concentration to 3 adjacent wells. Between rows of samples, distilled water without template DNA was added to 2-4 wells as negative controls. Plates were sealed with a rubber cover, centrifuged briefly and heated in a thermocycler at 96˚ C for 10 minutes.

After cooling the plate for 10 minutes, we added the final PCR reagents. For the telomere PCR, the reagents included 2.25 µl distilled water and 12.5 µl SYBR Green PCR Master Mix (Applied Biosystems). For the single-copy PCR, reagents included 2.3 µl distilled water, 12.5 µl SYBR Green PCR Master Mix. The final primer concentrations were tel 1b, 100 nM; tel 2b, 900 nM; 36B4u, 300 nM and 36B4d, 500 nM. Primer sequences were: tel 1b, 5' CGG TTT GTT TGG GTT TGG GTT TGG GTT TGG GTT TGG GTT 3'; tel 2b, 5' GGC TTG CCT TAC CCT TAC CCT TAC CCT TAC CCT TAC CCT 3'; (Cawthon pers. comm.; Callicott and Womack 2006) 36B4d, 5' CCC ATT CTA TCA TCA ACG GGT ACA A 3'; and 36B4u, 5' CAG CAA GTG GGA AGG TGT AAT CC 3' (Cawthon 2002). After sealing the plate with a transparent adhesive cover, we briefly vortexed and centrifuged it.

We used an automated thermocycler (7500 Real-Time PCR System, Applied Biosystems) to perform Q-PCR. For telomeres, the reaction profile began with a 94˚ C incubation for 1 minute, followed by 40 repetitions of 1 second of denaturing at 96˚ C then 1 minute of annealing-extending at 54˚ C. For the single-copy PCR, the incubation lasted 10 minutes at 95˚ C, followed by 35 repetitions of 95˚ C for 15 seconds and 58˚ C for 1 minute. Using Applied Biosystems (ABI; Applied Biosystems Foster City, CA) software, we generated a standard curve to estimate the amount of T and S for each sample. From these values we calculated the T/S ratio for each individual.

RESULTS AND DISCUSSION

Amplification efficiencies were high for both the single copy gene and telomere in bear and cougar samples. Standard curves obtained for both species enabled a robust estimate of relative telomere length (Figure 1).

For both species, relative telomere length declined with increasing animal age (Figure 2). Because samples analyzed were obtained from blood, hair and muscle tissue, and since telomere length varies across tissue-types, preliminary regression analyses were limited to blood samples only. Although there is considerable variation in telomere lengths for age, an interesting and potentially relevant relationship between animal age and relative telomere length exists. For both species, additional samples of a particular tissue-type (e.g., blood) may help clarify the relationship between age and telomere length.

Additionally, obtaining reliable age estimates and assigning individuals to biologically relevant age classes could greatly improve the analysis. For this report, we used the median estimated age from the range of potential ages that were provided. Clearly, biologically meaningful age categories would strengthen this analysis. Research on marten has shown telomeric attrition was correlated with parasite load, and body condition (Pauli et al. *in prep*). Such additional individual-level information may be important covariates for these species as well. With additional samples and more information we may be able to better interpret the T/S results for both black bears and cougars.

SECTION C: FRONT-RANGE COUGARS

INTRODUCTION

At the local scale, efforts have been made to continue the cougar/human interaction study on the Front-Range of Colorado. Given that cougars currently coexist with humans within urban/exurban areas along Colorado's Front-Range, varying levels of cougar-human interaction are inevitable. The CDOW is charged with the management of cougars, with management options ranging from minimal cougar population management, to dealing only with direct cougar-human incidents, to attempted extermination of cougars along the human/cougar spatial interface. Neither inaction or extermination represents 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 it is necessary to directly test management prescriptions in terms of desired cougar population and individual levels of response.

Long-term study objectives for the Front-Range Cougar Research project 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 Cougar Management Guidelines Working Group (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. As a continuation from the pilot study efforts, we have continued to assess the effectiveness of aversive conditioning as a method to alter interaction rates between cougars and humans. We also continue to monitor relocated cougars to determine the effectiveness of relocation as a management tool.

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

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

STUDY AREA

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

METHODS

Baiting, using deer and elk carcasses, has been conducted throughout the year, with a focus on areas that do not allow the use of hounds. Bait sites are monitored using digital trail cameras to determine bait site activity. Cage traps were generally used for capture when cougars removed the bait and cached it. Beginning in November, 2008 and continuing through April, 2009, hounds were also used several times per week to capture cougars. Snares were used in situations where hounds could not be used and cougars would not enter cage traps. Captured cougars were anesthetized, monitored for vital signs, aged, measured, and ear-tagged. All independent cougars (> 18 months old) were fitted with GPS collars. All cubs greater than 15 kg (approximately 6 months or older) were ear-tagged with 22 g ear-tag transmitters. For detailed capture and handling procedures see the study plan APPENDIX I.

When cougars interact with humans and elicit a response from CDOW District Wildlife Managers (DWMs) they are potential candidates for aversive conditioning. However, only a subset of these will actually be conditioned and the remaining animals will not be treated in order to have a control group. At this time, we consider aversive conditioning treatments on cougars to potentially be: multiple captures and handling of cougars, single or multiple treatments using beanbags fired from a shotgun, single or multiple chases using hounds, and potential combinations of capture, hound chases, and beanbags. Initially, we want to assess situations and methods that are already being implemented by wildlife managers.

The most likely scenario are 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 individual to an adjacent open-space property or similar area. Following relocation 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 scenario that will occur are incidents in areas where a cougar can be directly conditioned or chased from the 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.

Cougars will only be relocated for management purposes, generally in conjunction with human conflict or livestock depredation. Research cougars that have been collared for other purposes of the study may also become part of the relocation group if their levels of human interaction warrant such a management action. In May, 2008, two research cougars were relocated approximately 30km after they returned to the city of Boulder following a short distance relocation. Because only a few cougars are relocated each year, we will collar and monitor all cougars that are relocated in the northeast region. Cougars will be ear-tagged and fitted with a telemetry collar (VHF, or GPS collars may be used depending on the situation).

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

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

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

We used the following protocol to investigate cougar GPS clusters in the field. For S_1 clusters, we investigated each cougar GPS location in the cluster by spiraling out a minimum of 20 m from the GPS waypoint while using the GPS unit as a guide, and visually 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. 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.

RESULTS AND DISCUSSION

Collared cougars from the previous year were captured and re-collared to replace exhausted batteries throughout the year. An additional 10 independent age cougars were also captured and collared during the year (Table 1). A total of 8 cubs were captured during the year and fitted with ear-tag transmitters (Table 2). Currently there are 13 independent age cougars in the study with functioning GPS collars, one of which is in Wyoming, one was a marked cub recently collared, and one was a rehabilitation cougar that was released in Pike forest.

Home ranges for collared cougars have been determined using minimum convex polygons (MCP) to depict the general pattern of use and potential overlap (Figure 4), but likely over-represent the actual area used by an individual. Home ranges exhibit similar patterns to previous years, being fairly linear in a north-south direction. Adult male home ranges are much larger than adult female home ranges. Subadult male home ranges are smaller than adult male home ranges, but are also characterized by large movements and significant overlap with adults (Figure 5). Female home ranges are smaller with sizes between 80 and 120 km^2. Female home ranges also have significant overlap, especially among related individuals (Figure 6).

Mortalities of collared cougars were high with 6 new mortalities during the 2008-09 year (Table 1). Causes of death included vehicle collision, unknown sources, and management or landowner euthanasia. Mortality of cubs was also high with 5 of 8 tagged kittens dying during the 2008-09 year (Table 2). In general, cause of death for cubs was related to malnutrition although vehicle collisions also occurred. All cubs were at least 3 months old prior to tagging and most cub mortality occurred in ages older than 6 months.

During 2008-09 there were an additional 4 cougars that entered the aversive conditioning treatment group (Table 1). In general these situations represented cases where a cougar killed a deer or other naturally occurring prey item within city limits or urban area. These situations did not demonstrate a cougar being habituated to these areas but more likely represented a cougar opportunistically taking prey in urban areas occurring on the edge of their home ranges.

Two cougars were relocated out of Boulder city during the 2008-09 year. The cougars, an older female (AF24) and a cub (AM29) were relocated together, although it was known they were not a family unit. The adult female did return to the Boulder area after about a month. The cub also returned to the Boulder area after 3 months and survived until he was approximately one year old. The one successful relocation from the previous year (AM14) is still successful with the cougar remaining in the same translocation area.

A considerable amount of effort was spent on investigating GPS clusters in an attempt to understand predator prey dynamics during the 2008-09 year with 445 GPS clusters being sampled. Primary actions at these sites averaged over individuals were day beds (5.6% ± 2.7%), predation (22.9% ± 11.7%), scavenging (0.7% ± 1.4%), hunting or traveling (38.4% ± 25.5%) or unknown (32.3% ± 25.3%) (Figure 7). Examining only S1 clusters (clusters with at least 2 locations within 200m) demonstrates 42.9% ± 19.9% of these sites having evidence of predation.

Mule deer were the primary prey items found at clusters with confirmed kills. Female cougar kill sites consisted of 45% adult mule deer, 16% fawn mule deer, 24% unknown age mule deer, 10% small prey items, and 5% unknown prey items (Figure 8). Male cougar kill sites consisted of 34% adult mule deer, 6% fawn mule deer, 22% unknown age mule deer, 22% adult elk, 3% calf elk, 4% unknown age elk, and 9% small prey items. Small prey items included coyote, porcupine, raccoon and domestic cats and dogs.

SUMMARY

Genetic analysis for cougar feces revealed that DNA is still present in samples after feces have been in controlled temperature environments for up to 6 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. We have added known-age samples collected from natural environments from known cougars marked in the front-range cougar project.

The use of telomeres as a method to determine the age structure of bear and cougar populations is promising and will be investigated further in the coming year. Further refinement of the age-to-length relationship for both species is warranted. In addition to this, length relationships relative to genetic relatedness and individual stressors will give further insight into interpreting results from future data.

In addition to re-collaring previously collared cougars, an additional 10 independent age cougars were collared during the year. We also put VHF eartag transmitters on 8 cubs during the year. Mortality remained high over the year exceeding 40% for independent age cougars and exceeding 50% for cubs. Home-range patterns remained consistent to previous years. The effectiveness of aversive conditioning is still showing mixed results, which is likely a factor of the opportunistic nature of cougars using urban environments and a lack of habituation to them. Relocation of cougars as a management tool has had limited assessment, but given some success, still warrants further investigation. Mule deer are the predominant prey in cougar diets, although males also utilize elk regularly.

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

Cougar ID	Sex	Age	Date	Location	Occurrence	Capture	Release Loc	Conditioning	Status
AM02	M	1	6/14/07	Lacey Prop.	Baiting	Cage	On-site	NA	Alive
		1.5	1/10/08	White Ranch	Capture effort	Hounds	On-site	NA	Alive
		1.5	2/9/08	Coal Creek	Intraspecific mortality				Dead
AM04	M	7	7/14/07	White Ranch	Baiting	Cage	On-site	NA	Alive
		7	10/17/07	Eldorado Springs	Livestock depredation	Cage	White Ranch	Beanbag	Alive
		8	4/29/08	Magnolia/Flagstaff	Replace Collar	Hounds	On-site	NA	Alive
		8	5/5/08	South Boulder	Seen in town	Free-dart	Lindsey	Beanbag	Alive
		8	8/4/08	North Boulder	Killed deer in town	Cage	Centennial Cone	Beanbag	Alive
		9	2/24/09	Boulder Canyon	Punctured intestine				Dead
AM06	M	5	11/21/07	Heil Valley Ranch	Capture effort	Hounds	On-site	NA	Alive
		6	12/30/08	Heil Valley Ranch	Replace Collar	Hounds	On-site	NA	Alive
AF03	F	4	11/29/07	Flagstaff	Deer kill	Cage	On-site	NA	Alive
AF01	F	2	12/17/07	Table Mesa	Deer kill	Cage	On-site	NA	Alive
AM05	M	2	12/19/07	White Ranch	Capture effort	Hounds	On-site	NA	Alive
AM07	M	1.5	12/26/07	Heil Valley Ranch	Capture effort	Hounds	On-site	NA	Alive
			4/19/08	Highway 7	Roadkill				Dead
AF08	F	1.5	12/26/07	Heil Valley Ranch	Capture effort	Hounds	On-site	NA	Alive
		3	6/18/09	West Horsetooth	Deer kill-remove collar	Cage	On-site	NA	Alive
AM09	M	1.5	12/28/07	Heil Valley Ranch	Capture effort	Hounds	On-site	NA	Alive
		2.5	12/27/08	Hwy 34 (mile 70)	Roadkill				Dead
AF10	F	7	1/15/08	Apex Open Space	Deer Kill	Cage	On-site	NA	Alive
			2/13/08	I-70	Roadkill				Dead
AF19	F	8+	3/4/08	Heil Valley Ranch	Capture effort	Hounds	On-site	NA	Alive
		8+	3/18/09	North Boulder	Deer Kill	Cage	Heil Valley Ranch	Beanbag	Alive
			4/13/19	Left Hand Canyon	Deer Kill	Cage	Heil Valley Ranch	NA	Alive
AF11	F	1.5	3/5/08	South Table Mesa	Deer Kill	Cage	On-site	NA	Alive
			6/10/08	US-40/Empire	Roadkill				Dead
AM20	M	4	3/6/08	White Ranch	Capture effort	Hounds	On-site	NA	Alive
			5/18/08	West of White Ranch	Livestock Depredation	Shot			Dead
AF15	F	6	3/18/09	Coffin Top	Capture effort	Hounds	On-site	NA	Alive
		7	4/2/09	Hall Ranch	Replace Collar	Hounds	On-site	NA	Alive
AF17	F	9+	3/29/08	Sugarloaf	Pet depredation	Cage	Within 1 mile	Beanbag	Alive
			5/20/08	Four-mile Canyon	Unknown mortality				Dead

Table 1 Cont.

AF12	F	2	5/8/08	N. Boulder	Deer Kill	Cage	US Forest Boulder Canyon	Beanbag	Alive
			5/29/08	N. Boulder	Livestock depredation	Cage	Near Ward	Beanbag	Alive
			2/13/09	N. Boulder	Deer Kill	Snare	None	Euthanized	Dead
AM13	M	2	5/8/09	Sugarloaf	Livestock depredation	Cage	On-site	Beanbag	Alive
			12/17/09	Heil Valley Ranch	Replace Collar	Hounds	On-site	NA	Alive
AM14	M	2	5/15/09	South Boulder	Seen under deck	Free-dart	Lindsey	None	Alive
			5/20/09	South Boulder	Deer kill	Free-dart	West of Rollinsville	Beanbag	Alive
			4/14/09	Rollins Pass	Replace Collar	Hounds	On-site	NA	Alive
AF34	F	1.5	12/5/08	Heil Valley Ranch	Capture effort	Hounds	On-site	NA	Alive
			3/18/09	N. Boulder	Deer kill	Cage	Heil Valley Ranch	Beanbag	Alive
AM18	M	1.5	12/24/08	Evergreen	Deer kill	Cage	Mt. Evans SWA	None	Alive
			3/14/09	Evergreen	Livestock depredation	Cage	None	Euthanized	Dead
AF16	F	3	12/29/08	Evergreen	Deer Kill	Snare	Flying J Open Space	None	Alive
			3/20/09	Evergreen	Livestock depredation	Cage	Mt. Evans SWA	Beanbag	Alive
AF45	F	5	1/2/09	Gold Hill	Deer kill	Cage	On-site	NA	Alive
AF40	F	1.5	1/27/09	White Ranch	Capture effort	Hounds	On-site	NA	Alive
AF24	F	10+	2/12/09	North Boulder	Deer Kill	Cage	Hall Ranch	None	Alive
			2/25/09	Hwy 7	Replace Collar	Hounds	On-site	NA	Alive
			4/4/09	North Boulder	Raccoon Kill	Free-dart	Heil Valley Ranch	None	Alive
			5/31/09	North Boulder	Encounter	Shot			Dead
AM31	M	1.5	12/31/08	Evergreen	Chicken coop	Hounds	On-site	None	Alive
			3/29-09	Conifer	Livestock depredation	Cage	Mt. Evans SWA	None	Alive
AF37	F	1.5	12/31/08	Evergreen	Chicken coop	Free-dart	On-site	None	Alive
			8/112/09	I-70	Roadkill				Dead
AM21*	M	1.5	8/29/09	N. Boulder	Encounter	Free-dart	Ward	None	Alive
AF32	F	1.5	9/28/09	Indian Hills	Livestock depredation	Cage	Within 1 mile	None	Alive
SW023	F	1	4/9/09		Rehab	Release	Pike forest	None	Alive

Table 2: Capture history, maternal relationship, aversive treatment and current status of all cubs capture as part of the Front-range cougar study.

Cougar ID	Sex	Age	Mother	Date	Location	Occurrence	Capture	Release Loc	Conditioning	Status
AF35	F	3	AF16	12/29/08	Evergreen	Deer Kill	Cage	Flying J Open Space		Alive
				12/31/08	Evergreen	Roadkill				Dead
AM36	M	3	AF16	12/29/08	Evergreen	Deer Kill	Cage	Flying J Open Space		Alive
				1/8/09	Evergreen	Starvation				Dead
AM30	M	8	AM01	1/30/09	S. Boulder	Deer Kill	Cage	On-site		Alive
AM38	M	8	AM01	1/30/09	S. Boulder	Deer Kill	Cage	On-site		Alive
				3/27/09	S. Boulder	Encounter	Free-dart	Lindsey	Beanbag	Alive
				3/30/09	S. Boulder	Pet Depredation	Free-dart	Centennial Cone	None	Alive
				4/9/09	Morrison	Encounter	Free-dart	None	Euthanized	Dead
AM29	M	6	Euth.	2/11/09	N. Boulder	Deer Kill	Free-dart	Hall Ranch	None	Alive
		12		6/15/09	N. Boulder	Encounter	Free-dart	Masonville	Beanbag	Alive
AM21*	M	12	Unkn	3/25/09	Table Mesa	Baiting	Cage	On-site	NA	Alive
AM25	M	12	Unkn	5/22/09	Indian Hills	Deer Kill	Cage	On-site	None	Alive
				9/13/09		Raccoon	Free-dart	Perforated intestine		Dead
AM41	M	12	Unkn	5/22/09	Indian Hills	Deer Kill	Free-dart	On-site	None	Alive
					Indian Hills	Encounter	Shot			Dead

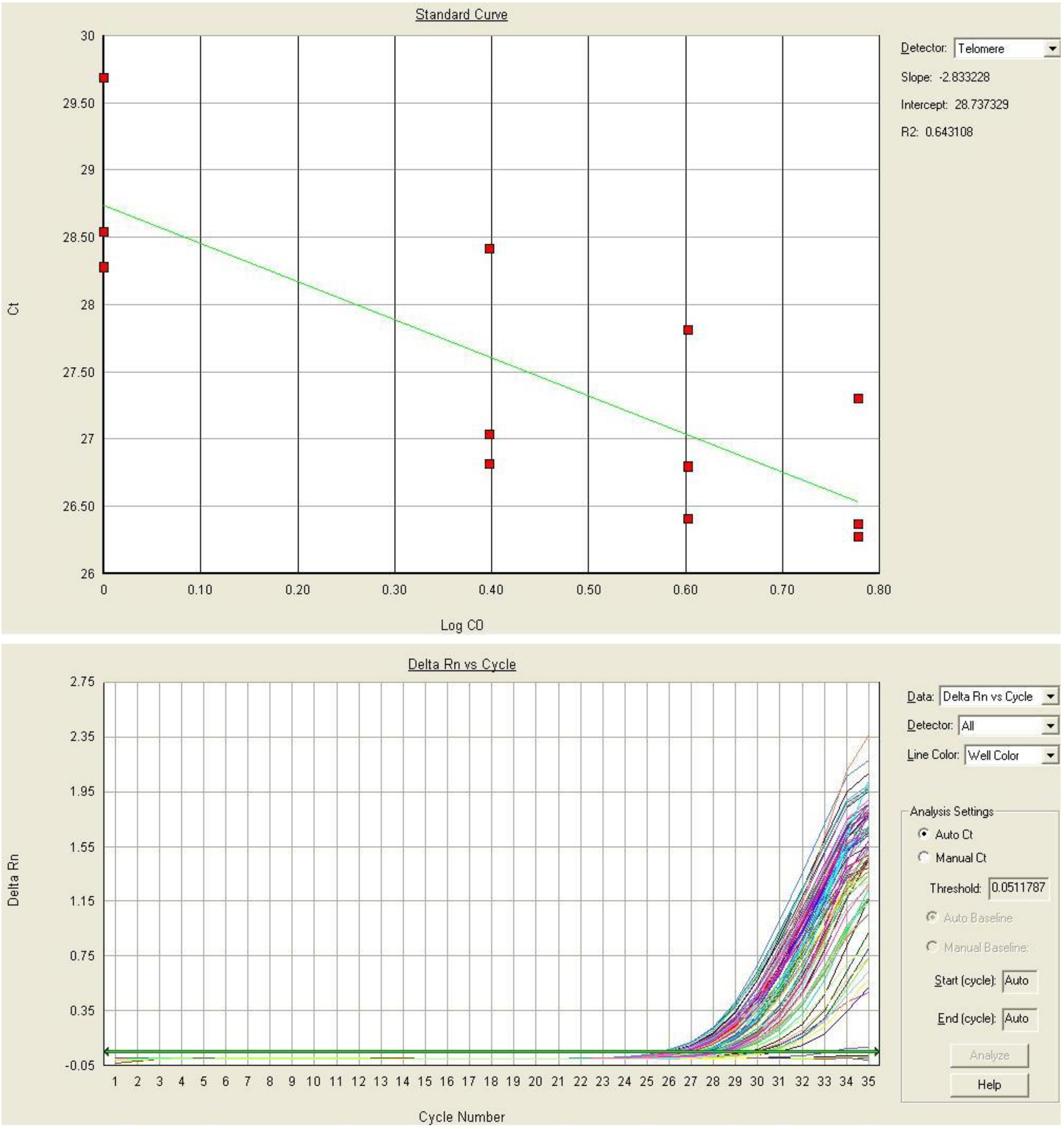

Figure 1. Example standard curve and amplification plot obtained from Q-PCR

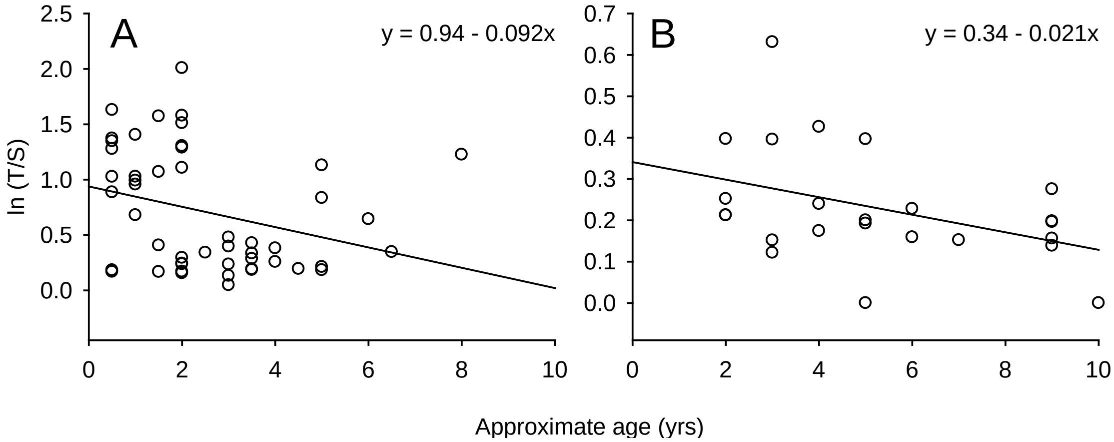

Figure 2. Linear relationship between age and telomere length for blood samples of cougars (A) and black bears (B) inhabiting Wyoming and Colorado.

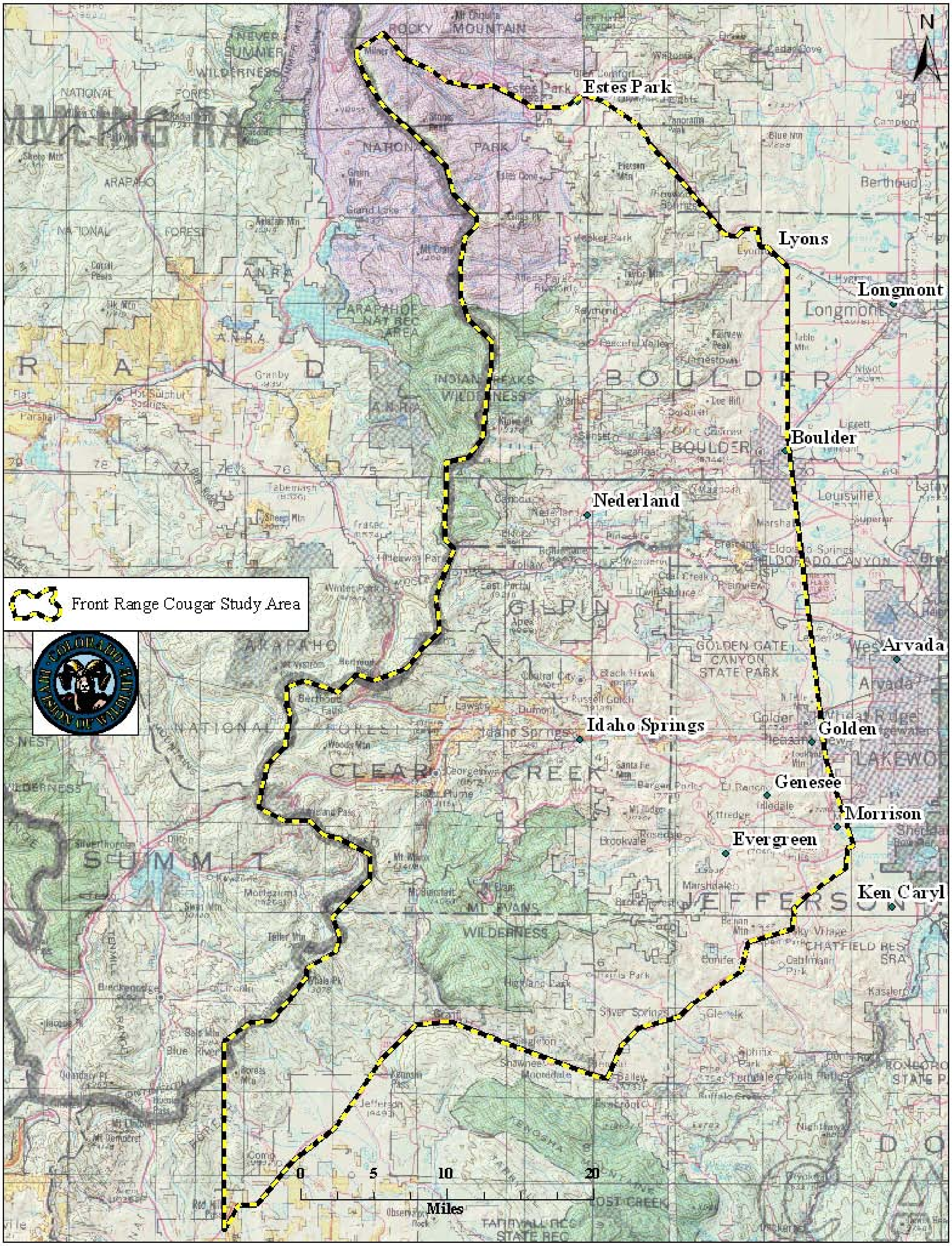

Figure 3: Study area boundary with the continental divide to the west, Highway 285 on the south, Highway 34 and 36 on the north, and the edge of the foothills on the east.

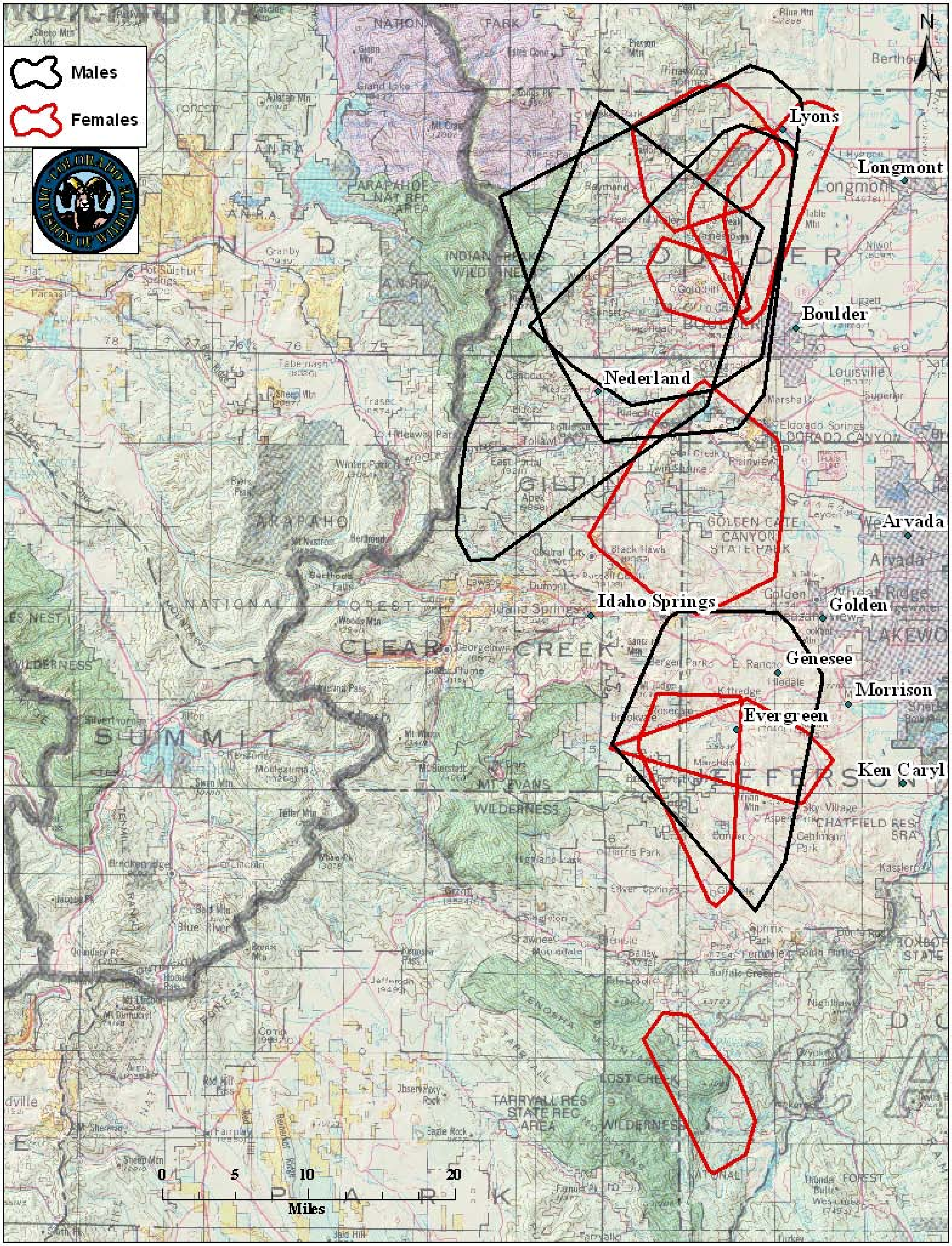

Figure 4: Male and female MCP homeranges for cougars with functioning GPS collars depicting the overlap in homeranges between males and females.

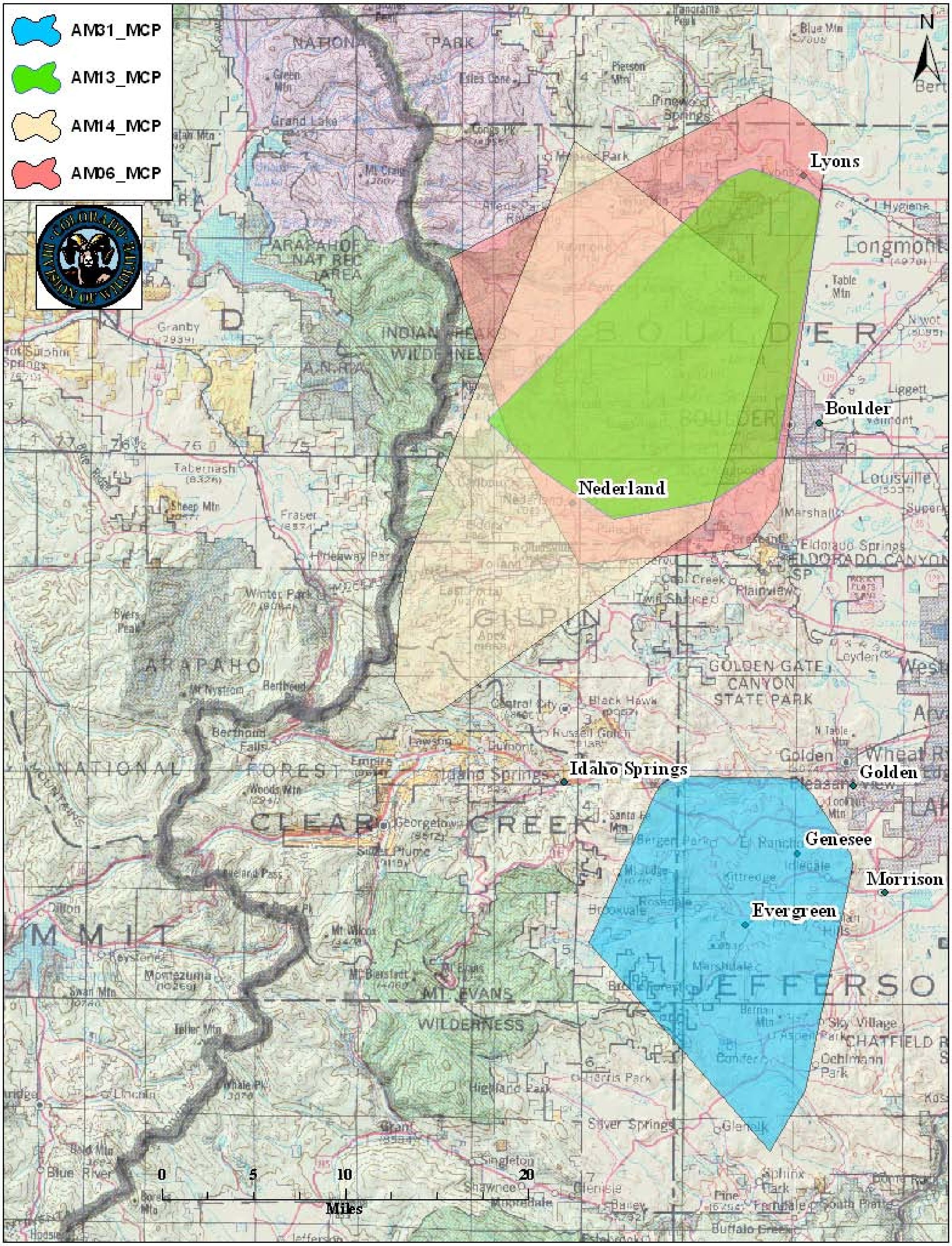

Figure 5: Homeranges for male cougars with functioning GPS collars. Homerange size for AM13 and AM14 appear large but this is primarily a factor of management related movement (AM14) or a change in the area of use (AM13).

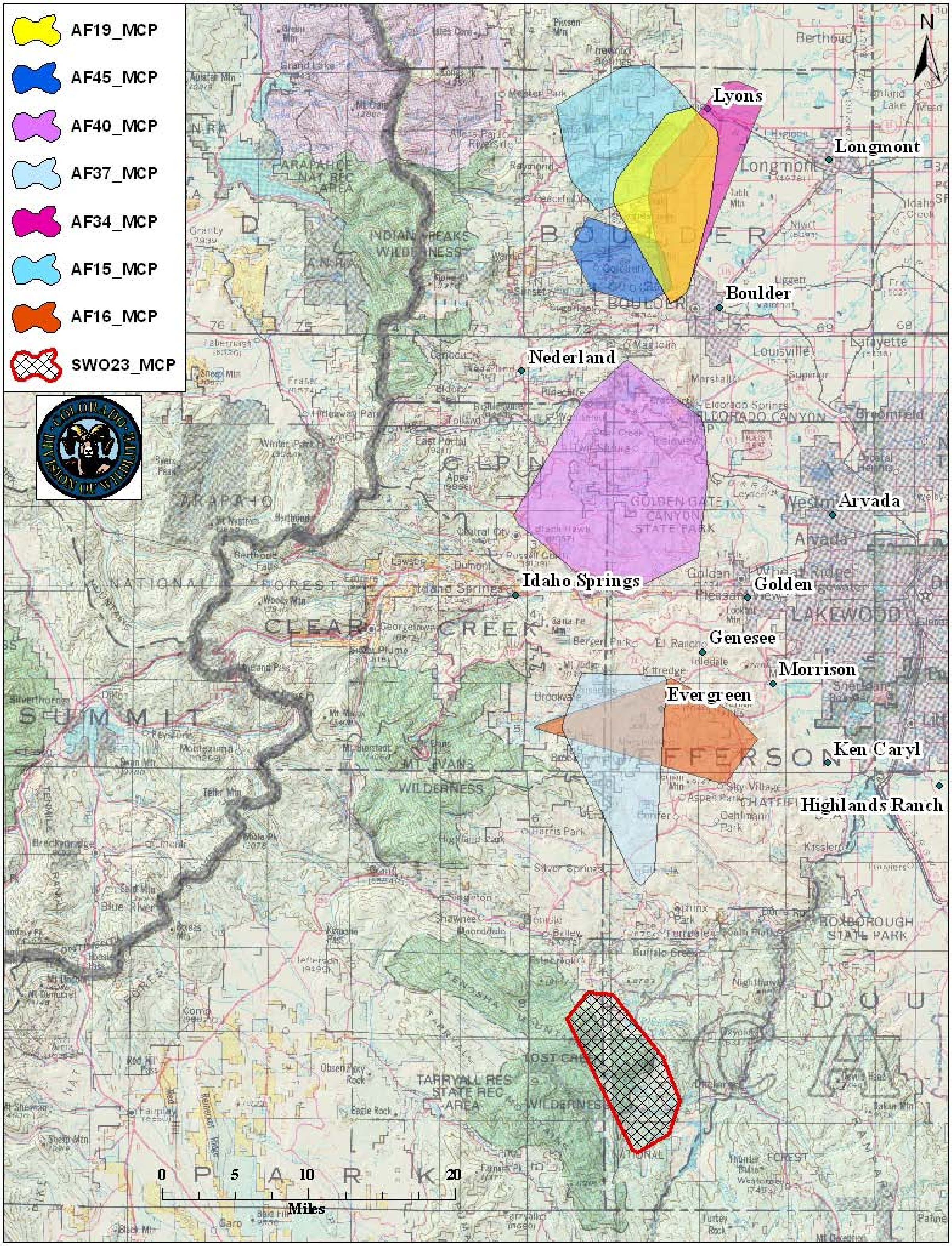

Figure 6: Homeranges for female cougars with functioning GPS collars. Female homeranges overlap one another, which may be related individuals.

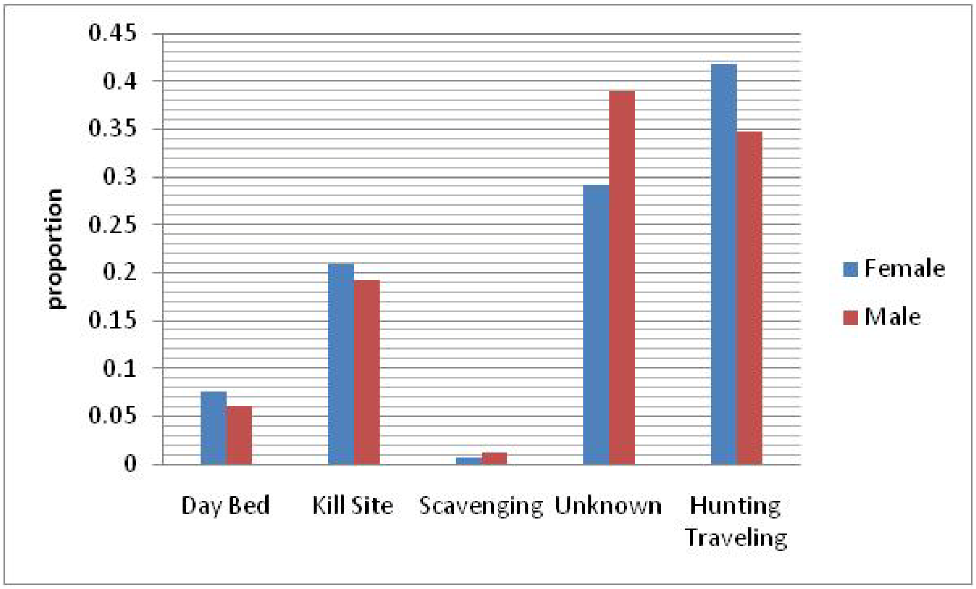

Figure 7: Proportional activities reported across all 445 GPS cluster sites investigated based on the number of points at the location, evidence of activity at the location, and distance to previous locations not associated with the cluster.

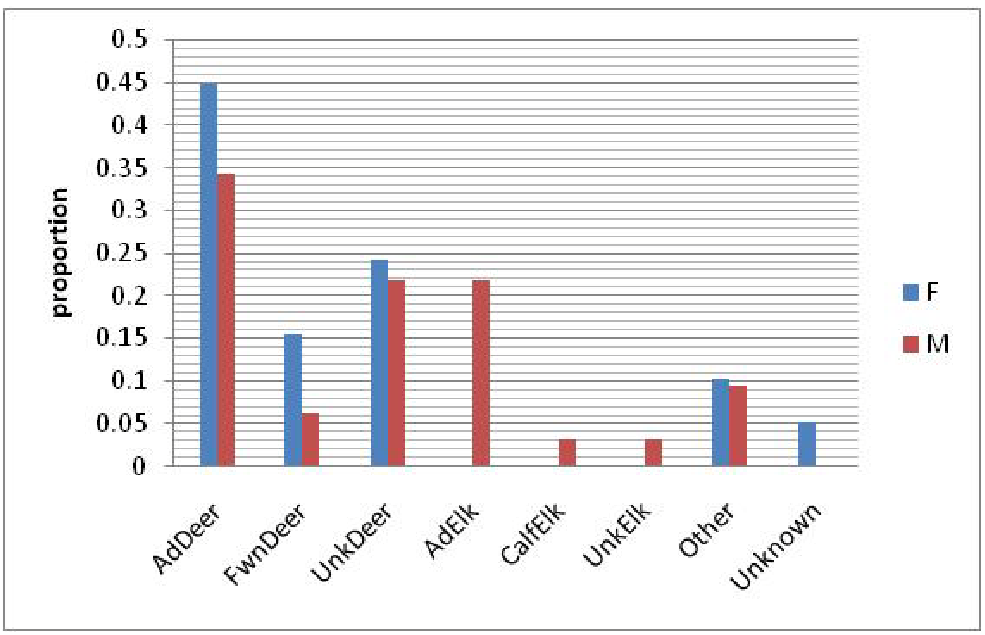

Figure 8: Proportion of prey items found at kill sites where evidence of prey was found. Category other is generally associated with small prey items such as coyote, porcupine, raccoon, and domestic cats and dogs.

Colorado Division of Wildlife
July 2008 – June 2009

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, 2008 – June 30, 2009

Author: Kay Horton Knudsen

Personnel: Kay Horton Knudsen, David J. Freddy, Michael W. Miller

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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 began employment with the Colorado Division of Wildlife on August 30, 2008.

David J. Freddy was the Mammals Research Team Leader and supervised the librarian until his retirement in December 2008. Michael W. Miller was the interim Mammals Research Team Leader from January-June 2009.

A progress report and current status of the Library are detailed below.

WILDLIFE RESEARCH REPORT

COLORADO DIVISION OF WILDLIFE RESEARCH LIBRARY SERVICES

KAY HORTON KNUDSEN

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 first task facing the new librarian was to sort 8 boxes of accumulated mail and re-activate the online Library catalog hosted by the vendor SirsiDynix. Discussions followed with the supervisor, other research managers, the Library committee and members of the Research staff on their vision and goals for the Library as well as their needs in the research arena. Meetings also took place with the governmental special librarians in Ft. Collins at the U.S. Forest Service, the National Wildlife Research Service (USDA's Animal and Plant Health Inspection Service), the U.S. Geological Survey as well as with the Natural Resources Librarian at Colorado State University's Morgan Library.

From these discussions it was determined the top priority was a new web-based integrated library system (ILS) and access to research databases for Colorado Division of Wildlife employees statewide. The ILS would include a library catalog and a circulation system as well as cataloging and serials check-in modules. Other items on the ILS wish list were a hosted system (server maintained at vendor's facility), federated searching (ability to search the catalog plus multiple databases with one search) and ability of the system to handle digital media. The librarian's research produced a list of 4 companies providing ILS service to special libraries (as opposed to public and academic libraries); a list of requirements was sent to each vendor and phone discussions and web demonstrations followed. A more extensive web demonstration was scheduled for the CDOW research managers and Library committee.

EOS International was chosen as the vendor of preference; contract negotiations and purchase orders were submitted and a final agreement was completed in December 2008. It was decided to initially purchase the basic modules (a hosted system with library catalog, circulation, cataloging and serials control) and delay other features until the system was up and running. Data migration from SirsiDynix to EOS took place in January 2009, library staff training in February and release of the Library website to CDOW staff in March 2009.

During this time, Library research databases were also investigated and demonstrated. Using the same evaluation procedure as with the ILS, it was decided to purchase access to BioOne, four of EBSCO's specialty databases (Environment Complete, Fish and Fisheries Worldwide, Wildlife and Ecology Studies Worldwide and SocIndex with Full Text) and the JSTOR Life Sciences collection. Through several of the print periodical subscriptions, the Library also has access to the publisher's full-text online archives. When the Library catalog was released to CDOW staff (authenticated through the WildNet staff network), access was also given to the research databases and the online journal archives.

The next step was training for CDOW staff on the various features of the new Library website. Group and individual sessions were held in Ft. Collins and at CDOW offices in Glenwood Springs, Grand Junction, Durango, Montrose and Colorado Springs. Demonstrations are planned at other staff meetings during the coming year. Handouts were created to assist staff with basic website use and the specialized database features such as creating subject and table of contents alerts.

Other projects in the Library this year included 1) massive physical cleaning and sorting of documents to determine the resources available and to make them accessible to the librarian, 2) cataloging of new material, 3) inclusion of PDF formats into the catalog's bibliographic file if PDF is available, 4) clean-up of bibliographic barcodes in the Library database, 5) renewal of print journal subscriptions based on discussions with research managers and consolidation of several periodical invoices into one and 6) cataloging of staff reprint articles following a request to research staff to provide copies of their publications (most often journal articles).   Work-study staff was hired from Colorado State University during part of Fall semester 2008 and all of Spring semester 2009 to assist in these efforts.

The librarian attended the Colorado Association of Libraries conference in Denver in November 2008, the exhibits area of the American Association of Libraries Mid-Winter meeting in Denver in January 2009, an EBSCO Train-the-Trainer session in Greeley in March 2009, a 5-day Wildlife Management Short Course offered at CSU in March/April 2009 and a Colorado InterLibrary Loan update meeting at Estes Park in April 2009.

Most document requests and reference questions received in the Library are from CDOW staff or from outside researchers (generally consultants and out-of-state natural resources employees). At this time the Library is not open on a walk-in basis to the general public. CDOW employees request journal articles or items from the Library collection; outside researchers most often want a copy of a CDOW publication. Therefore the immediate focus for Library staff resources will be on organizing and cataloging Colorado publications and obtaining documents per staff request. The chart below shows the number of reference questions and document requests handled by the librarian during the past year. Please note that 1 request from a CDOW staff member may be for multiple journal or book titles. For example, in September there was a request for 50 articles/ books on crawfish and in June a request for 40 titles on raptors.

	Reference Requests
August 2008	15
September 2008	21
October 2008	33
November 2008	14
December 2008	28
January 2009	33
February 2009	30
March 2009	35
April 2009	24
May 2009	13
June 2009	20

The Research Center Library holds 18,403 titles and 24,800 items (these are the multiple copies of a title); has 84 registered patrons (CDOW staff) and 252 items were checked out this year. There are 82 PDFs currently attached to title records in the Library catalog.

Usage statistics for the research databases are given in the chart below. For BioOne and JSTOR the statistics are for the number of successful full-text article requests; the Library did not subscribe to BioOne until late February. For EBSCO, the number shown is the total number of searches by CDOW staff.

	BioOne	EBSCO searches	JSTOR
January 2009	0	449	16
February 2009	0	1757	348
March 2009	7	610	532
April 2009	76	1492	266
May 2009	30	1321	208
June 2009	77	395	140
July 2009	55	1255	111

Prepared by ____________________________
Kay Horton Knudsen