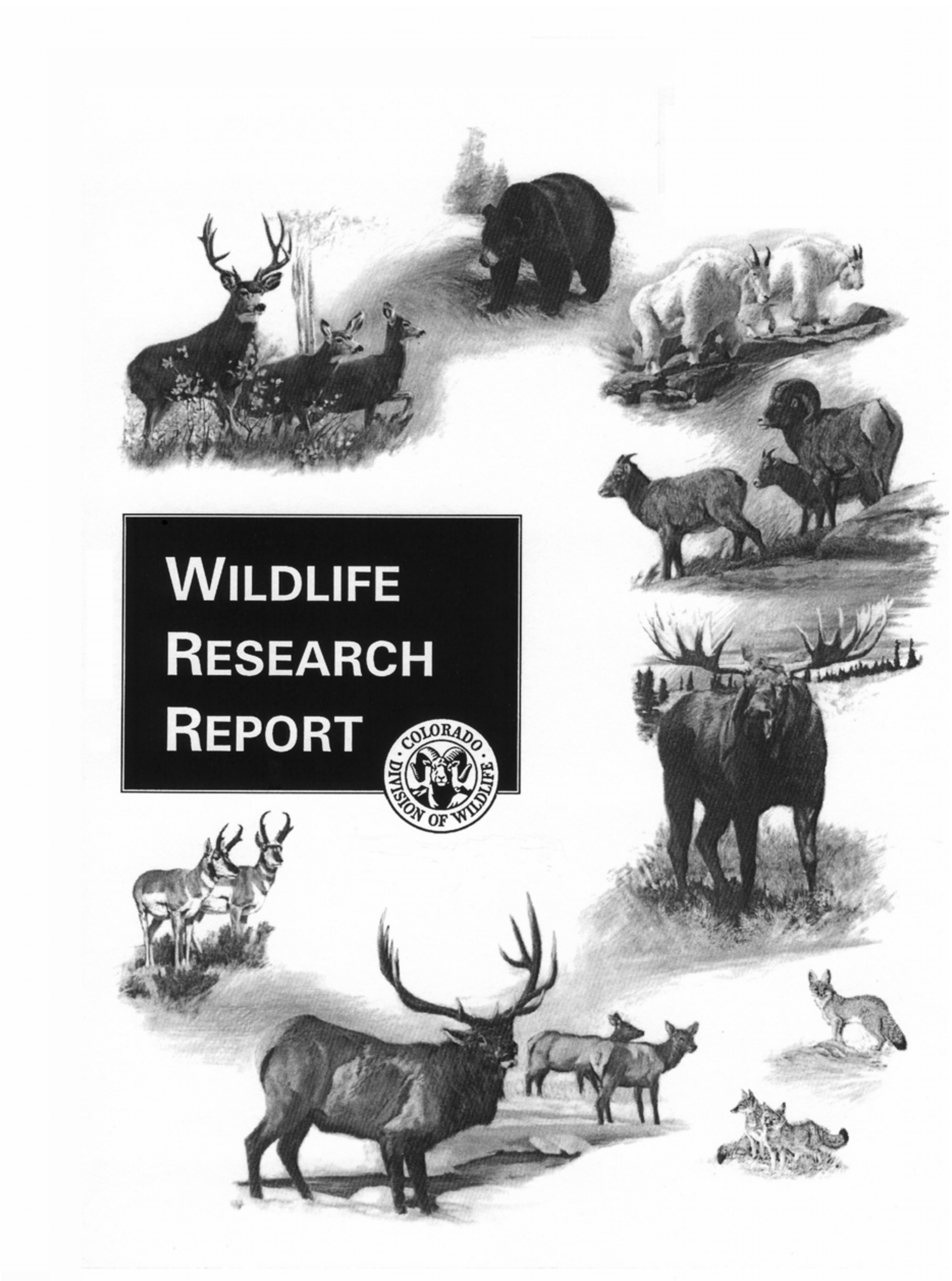
MAMMALS - JULY 2006



WILDLIFE RESEARCH REPORTS

JULY 2005 – JUNE 2006

MAMMALS PROGRAM

COLORADO DIVISION OF WILDLIFE
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Colorado Division of Wildlife
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WILDLIFE RESEARCH REPORT

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

Period Covered: July 1, 2005 - June 30, 2006

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ABSTRACT

In an effort to establish a viable population of 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 1999-2005, 204 lynx were released in Colorado. Fourteen additional animals (8 males: 6 females) were released in spring 2006 resulting in a total of 218 lynx reintroduced to southwestern Colorado. We documented survival, movement patterns, reproduction, and habitat-use through aerial (n = 8680) and satellite (n = 18, 963) tracking. Most lynx remained near the core release area in southwestern Colorado. From 1999-2006, there were 80 mortalities of released adult lynx. Approximately 31.3% were human-induced which were attributed to collisions with vehicles or gunshot. Malnutrition and disease/illness accounted for 21.3% of the deaths while 32.5% of the deaths were from unknown causes. 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 and 2005. Four dens with 11 kittens were found in 2006. Lynx CO04F07, a female lynx born in Colorado in 2004 was the mother of one of these litters which documented the first recruitment of Colorado-born lynx into the Colorado breeding population. From snow-tracking, the primary winter prey species (n = 426) were snowshoe hare (*Lepus americanus*, annual $\bar{x}$ = 75.1%, SE = 5.17) and red squirrel (*Tamiasciurus hudsonicus*, annual $\bar{x}$ = 15.3%, SE = 3.09); other mammals and birds formed a minor part of the winter diet. Mature Engelmann spruce (*Picea engelmannii*)-subalpine fir (*Abies lasiocarpa*) forest stands with 42-65% canopy cover and 15-20% conifer understory cover were 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. A study to evaluate snowshoe hare densities, demography and seasonal movement patterns among small and medium tree-sized lodgepole pine stands and mature spruce/fir stands was initiated in 2005 and will continue through 2009. Results to date have demonstrated that CDOW has developed 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 lynx 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. Release additional adult lynx captured in Canada in southwestern Colorado during spring 2006.
2. Complete winter 2005-06 field data collection on lynx habitat use, hunting behavior, diet, mortalities, and movement patterns.
3. Complete winter 2005-06 lynx trapping field season to collar Colorado born lynx and re-collar adult lynx.
4. Complete spring 2006 field data on lynx reproduction.
5. Summarize and analyze data and publish information as Progress Reports, peer-reviewed manuscripts for appropriate scientific journals, or CDOW technical publications.
6. Complete a study plan to evaluate snowshoe hare densities, demography and seasonal movement patterns among small and medium tree-sized lodgepole pine stands and mature spruce/fir stands.

INTRODUCTION

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

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

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

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

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

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

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

Southwestern 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. The Core Release Area is defined as areas bounded by the New Mexico state line to the south, Taylor Mesa to the west and Monarch Pass on the north and east and > 2900 m in elevation (Figure 1). 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

All 2006 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). Specific release sites were those used in earlier years of the project and were selected based on land ownership and accessibility during times of release (Byrne 1998). Lynx were transported from the Frisco Creek Wildlife Rehabilitation Center, where they were held from their time of arrival in Colorado, to their release site in individual cages. Release site location was 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.

Distribution and Movement Patterns

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.

To determine general movement patterns of reintroduced lynx, regular locations of released lynx were collected through a combination of aerial, satellite and ground radio-tracking. Locations were recorded in UTM coordinates and general habitat descriptions for each ground and aerial location were recorded.

Home Range

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

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

Survival

Survival was estimated as ragged telemetry data using the nest survival models in Program MARK (White and Burnham 1999).

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.

Snow-tracking

Locations from aerial- and satellite-tracking were used to help ground-trackers locate lynx tracks in snow. Snowmobiles, where permitted, were used to gain the closest possible access to the lynx tracks without disturbing the animal. From that point, the tracking team used snowshoes to access tracks. Once tracks were found, the ground crew back- or forward-tracked the animal if it was far enough away not to be disturbed. Back-tracking generally avoided the possibility of disturbing the lynx by moving away from the animal rather than towards the animal. However, monitoring of the lynx through radio-telemetry was used to assure that the ground crew was staying a sufficient distance away from the lynx in the event the lynx might double back on its tracks. Radio-telemetry was also used in forward-tracking to make sure the team did not disturb the animal. If it appeared the lynx began to move in response to the observers, the observers stopped following the tracks. If the lynx began to move and the movement did not appear to be a response to the observers, the ground crew continued following the track.

An attempt was made in Season 1 (February-May 1999) and Season 2 (December 1999-April 2000) to snow-track each lynx. In Season 3 (December 2000-April 2001), we attempted to snow-track all lynx within the Core Release Area. In tracking Season 4 (December 2001-April 2002), Season 5 (December 2002-April 2003), Season 6 (December 2003-April 2004), Season 7 (December 2004-April 2005) and Season 8 (December 2005-March 2006) we attempted to track all accessible lynx in the Core Release Area and some lynx north of the Core Release Area. Ground crews were instructed to track lynx only where it was safe to travel. Restrictions to safe travel included avalanche danger and extremely rugged terrain. Ground crews worked in pairs and were fully equipped for winter back-country survival.

Data Collection

For each day of tracking the date, lynx being tracked, slope, aspect, UTM coordinates, elevation, general habitat description, and summary of the days tracking were recorded. Aspect was defined as the direction of 'downhill' or 'fall line' on a slope. This is the direction along the ground in a dihedral angle between the horizontal and the plane of the ground surface. Units were compass degrees. Slope was defined as the dihedral angle between the horizontal and the plane of the ground surface (e.g., 45°).

Once a track was located there were 2 types of 'sites' that were encountered. Site I areas needed documentation but either did not reflect areas lynx selected for specific habitat features, or were sites that occurred too frequently to measure each in detail. These sites included the start and end of the track being followed, the location of scat, and short-duration beds defined as being small in size (approximating an area a lynx would crouch), and with little ice formed in the bed indicating little time spent there. Site II areas included areas that might reflect specific habitat features lynx selected for and included locations where the following were found: kills, start of chases, territory marks (e.g., spray sites, buried scat, scat placed on prominent locations), long-duration beds (encompasses an area where a lynx would have lain for an extended period, iced bottom), and road crossing (both sides of road). In addition, habitat plots were conducted along lynx travel routes if no other sites were sampled in the last hour.

At each of the 2 types of sites the date, lynx tracked, slope, aspect, forest structure class, UTM coordinates, and elevation were recorded. Forest structure classes included grass/forb, shrub/seedling, sapling/pole, mature, and old growth as defined in Table 1. For Site I areas, the only additional data that was collected was identification of what the site was used for (e.g., short-duration bed), and a brief description of the site. Habitat plots (see below) were conducted at Site II areas.

Description of the Habitat Plot

The habitat plot consisted of a 12 m x 12 m square defined by a series of 25 points placed in 5 rows of 5 with the center point being on the object that defined the site (e.g., a kill)(Figure 2). Each point was 3 m apart. The 12 m x 12 m sampling square exceeded the minimum requirement of 0.01 ha. recommended by Curtis (1959) for sampling trees.

Measurements taken at each of the 25 points included:

1. Snow depth - measured vertically by an avalanche probe marked in cm.
2. Understory - measured from top of snow to 150 cm above snow in a column of 3-cm radius around the avalanche probe. Because understory measurements were influenced by vegetation outside the perimeter of the 25 sampling points (12 m x 12 m) the area used for estimating undersory cover was 15 m by 15 m. At each point, crews recorded all shrubs, trees and coarse woody debris (CWD) that fell within this column and was visible above the snow. Crews also recorded number of branches of each species that fell within the column at 3 different height categories (0-0.5 m, 0.51-1.0 m, 1.01-1.5 m).

3. Overstory: measured at 150 cm above snow with a sighting tube. The tube was made of PVC pipe, with a curved viewing end and a crosshair made of wire on the opposite end. The sighting tube was attached to the avalanche probe used to measure snow depth. Species that hit the crosshair were recorded at each of the 25 points in the vegetation plot. Ganey and Block (1994) found this method of measuring canopy cover (with 20 sample points per plot; Laymon 1988) provided greater precision among observers.
4. Species composition: all the different species of tree or shrub that hit the crosshair of the sighting tube at each of the 25 points were recorded.
5. Tree composition of the vegetation plot was recorded by species and diameter at breast height (DBH). Snow depth was used in conjunction with this recorded DBH to estimate true DBH. Within the 12 m x 12 m square all conifers and deciduous trees were recorded by DBH size class (A = 0-6 in, B = 6.1-12 in, C = 12.1 -18 in, D = 18.1-24 in, E = > 24 in). Area for the tree composition analysis was 12 m x 12 m.

Understory was estimated as: 1) percent occurrence within the vegetation plot (number of points with understory/total number of points surveyed) and 2) mean percent occurrence and variance by species and height category over the total points sampled within the vegetation plot. Overstory was estimated as percent occurrence over the vegetation plot (number of points with overstory/total number of points surveyed).

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

A study plan was designed to evaluate the importance of young, regenerating lodgepole pine (*Pinus contorta*) and mature Engelmann spruce / subalpine fir stands in Colorado by examining density and demography of snowshoe hares that reside in each.

Specifically, the 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 density-estimation procedures available perform accurately and consistently using an innovative, telemetry augmentation approach as a baseline. Movement patterns and seasonal use of deciduous cover types such as riparian willow will be 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 2005 204 lynx were reintroduced into southwestern Colorado. An additional 14 lynx were released in April 2006 (6 females: 8 males), bringing the total number of lynx released in Colorado to 218 (Table 2). Lynx released in 2006 were captured in British Columbia and Yukon. These 14 lynx were released in the Core Release Area of southwestern Colorado at or near previously used release sites in southwestern Colorado. Lynx were released with 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 2007.

Distribution and Movement Patterns

A total of 8680 aerial VHF locations for all 218 reintroduced lynx have been collected to date (June 30, 2006). An additional 18,963 satellite locations have been collected. Most lynx released in 2006 remained in southwestern Colorado. The majority of surviving lynx from the entire reintroduction effort continue to use high elevation (> 2900 m), forested areas from New Mexico north to Gunnison, west as far as Taylor Mesa and east to Monarch Pass. Most movements away from the Core Release Area were to the north.

Numerous travel corridors have been 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. Such movement patterns have also been documented by native lynx in Wyoming and Montana (Squires and Laurion 1999).

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

Initial survival rate estimates for reintroduced lynx were completed, however, further analyses need to be conducted before estimates will be presented. As of June 30, 2006, CDOW was actively tracking 95 of the 138 lynx still possibly alive. There are 43 lynx that we have not heard signals on since at least June 30, 2005 and these animals are classified as 'missing' (Table 3). One of these missing lynx is a mortality of unknown identity, thus only 42 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 from 1999-2006 there are 80 known mortalities as of June 30, 2006. Causes of death are listed in Table 4. Starvation was a significant cause of mortality in the first year of releases only. Mortalities occurred throughout the areas through which lynx moved. Approximately 31.3% were human-induced which were attributed to collisions with vehicles or gunshot. Malnutrition and disease/illness accounted for 21.3% of the deaths while 32.5% of the deaths were from unknown causes (Table 4).

Reproduction

2003.-- Nine pairs of lynx were documented during the 2003 breeding season (March and April) from the 17 females we were monitoring. In May and June, 6 dens and a total of 16 kittens were found in the lynx Core Release Area in southwestern Colorado (Table 5, Figure 1). 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 dens were scattered throughout the Core Release Area, with no dens found outside the core area. All the dens were in Engelmann spruce/subalpine fir forests in areas of extensive downfall. Elevations ranged from 3240-3557 m. Field crews weighed, photographed, PIT-tagged the kittens and took hair 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.

Four of the 6 females that we know had kittens in summer 2003 were still with kittens at the end of April 2004. Two of those females still had 2 kittens with them at that time. Visual observations in February 2004 of one female with 2 kittens indicated all 3 were in good body condition. The mortality of female YK00F16 and her 1 kitten in October 2003 from plague was not due to poor habitat or prey conditions, and thus we might assume she would have raised the 1 kitten to this stage as well. Three probable kitten deaths from female YK00F19 were from 1 litter that most likely failed very early. Through snow-tracking in winter 2003-04 an unknown female (no radio frequency heard in the area of the tracks) we also documented 1-2 additional kittens born spring 2003 and still alive in winter 2004.

Of the 16 kittens we found in summer 2003, we documented the following by April 2004: 6 confirmed alive, 7 confirmed dead, and 3 some evidence dead. Although we tried, we were not able to capture any of the 6 surviving kittens to fit them with radio-collars for subsequent monitoring.

2004.-- In Spring 2004, 26 females from the releases in 1999, 2000 and 2003 had active radio-collars. Of these, we documented 18 possible mating pairs of lynx during breeding season. All 4 of the females that had kittens with them through winter 2003-04 bred again spring 2004; 2 with the same male they successfully bred with spring 2003. During May-June 2004 we found 11 dens and a total of 30 kittens (Table 6). At all dens the females appeared in excellent condition, as did the kittens. The kittens weighed from 250-770 grams. Three of the 11 females with kittens were from the 2003 releases (Table 6). Three additional litters were documented after denning season through either observation of a female lynx with kittens or snow-tracking females with kittens that were not one of the 11 females found on dens. From the size of the kittens they would have been born during the normal denning season in May or June. Nine additional kittens were observed from these litters for a total of 39 known kittens born in 2004. Two of these additional litters were documented from direct follow-ups to sighting made by the public and reported to CDOW.

Two females that had kittens in 2003 and reared at least part of their litters through March 2004, bred and had kittens again in 2004. Two of the litters documented by direct observation or snow-tracking are from females whose collars were no longer functioning. Seven kittens born in 2004 were captured at approximately 10-months of age and fitted with dual satellite/VHF collars. Six of the 7 were still alive and being monitored as of June 30, 2006. The cut collar of one kitten CO04M15 was left at the Silverton Post Office on October 25, 2005. We assume this lynx is dead.

2005.-- In spring 2005 we had 40 females from the releases in 1999, 2000, 2003 and 2004 that had active radio-collars. We documented 23 possible mating pairs of lynx during breeding season. During May-June 2005 we visited 16 dens and found a total of 46 kittens (Table 7). At all dens the females appeared in excellent condition, as did the kittens. An additional female (BC03F10) had a den we were not able to get to during May or June due to high water during spring run-off. Female BC03F03 was hit and killed on I-70 on 5/19/2005. She had 2 fetuses in her uterus, so would have contributed to reproduction this year had she lived.

We weighed, photographed, PIT-tagged the kittens and recorded sex. We also took blood samples from the kittens for genetic work in an attempt to confirm paternity. While we were working with the kittens the females remained nearby, often remaining visible to us. The females generally continued a low growling vocalization the entire time we were at the den. In all cases, the female returned to the den site once we left the area.

All of the 2005 dens were scattered throughout the high elevation areas of Colorado, south of I-70. Most of the dens were in Engelmann spruce/subalpine fir forests in areas of extensive downfall. Elevations ranged from 3117-3586 m. We weighed, photographed, and PIT-tagged the kittens, recorded sex and took hair samples from the kittens for genetic work in an attempt to confirm paternity. Four of the females would not leave the den until we reached out to pick up a kitten. While we were working with the kittens the females remained nearby, often remaining visible to us. The females generally continued a low growling vocalization the entire time we were at the den. In all cases, the female returned to the den site once we left the area.

One female, YK00F10 has had litters 3 years in a row. In 2003 she had 4 kittens and raised 2 through the winter. In 2004 she had 2 kittens and raised both through the winter, in 2005 she had 4 kittens again. She has had all 3 litters in the same general area and has had the same mate for 3 years. Eight additional females had their second litter in Colorado in 2005. Three females from the 2004 releases had litters in 2005. Year 2005 was the second consecutive year that we had females released the prior spring, find a territory and a mate within a year and produced live young. In reproduction season 2004 we had 3 females released in spring 2003 that also produced live young the next year. Of those 3, 2 successfully raised at least part of their litters through winter 2005.

Seven kittens born in 2005 were captured at approximately 10-months of age and fitted with dual satellite/VHF collars. One of the 7 was still alive and being monitored as of June 30, 2006.

2006.--In spring 2006, 42 females were being monitored. We found 4 dens in May and June 2006 with 11 kittens total (Table 8). Lynx CO04F07, a female lynx born in Colorado in 2004, was the mother of one of these litters which documented the first recruitment of Colorado-born lynx into the Colorado breeding population.

The percent of tracked females found with litters in 2006 was lower (0.095) than in the 3 previous years (0.413, SE = 0.032, Table 9). However, all demographic and habitat characteristics measured at the 4 dens that were found in 2006 were comparable to all other dens found (Table 9). 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).

Den Sites.--A total of 37 dens have been found from 2003-2006. All of the dens except one have been scattered throughout the high elevation areas of Colorado, south of I-70. In 2004, 1 den was found in southeastern Wyoming, near the Colorado border. Dens were located on steep ($\bar{x}_{slope} = 30^o$, SE=2^o), north-facing, high elevation ($\bar{x}$ = 3354 m, SE = 31 m) slopes (Figure 3). The dens were typically in Engelmann spruce/subalpine fir forests in areas of extensive downfall of coarse woody debris (Figures 4, 5, 6). All dens 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 other 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. All lynx captured in 2005 and 2006 were caught in box-traps. All captured lynx were fitted with new Sirtrack ™ dual VHF/satellite collars.

Seven adult lynx were captured from March 1999-June 30, 2006 because they were in poor body condition. Five of these lynx were successfully treated at the Frisco Creek Rehabilitation Center and re-released in the Core Release Area. One lynx, BC00F7, died from starvation and hypothermia. Lynx QU04M07 died on February 5, 2006 at the rehabilitation center. Necropsy results documented starvation as the cause of death that was precipitated by hydrocephalus and bronchopneumonia (unpublished data T. Spraker, CSUVTH). Two lynx were captured because they were in atypical habitat outside the state of Colorado. They were held at Frisco Creek Rehabilitation Center for a minimum of 3 weeks and re-released in the Core Release Area in Colorado. Prior to release these lynx were fitted with new Sirtrack ™ dual VHF/satellite collars.

In addition, 14 Colorado-born kittens were captured and collared at approximately 10-months of age. Seven 2004-born kittens were collared in spring 2005, and 7 2005-born kittens collared in spring 2006.

HABITAT USE

Landscape-scale daytime habitat use was documented from 7421 aerial locations of lynx collected from February 1999-June 30, 2005. Throughout the year Engelmann spruce / subalpine fir was the dominant cover used by lynx. A mix of Engelmann spruce, subalpine fir and aspen (*Populus tremuloides*) was the second most common cover type used throughout the year. Various riparian and riparian-mix areas were the third most common cover type where lynx were found during the daytime flights. Use of Engelmann spruce-subalpine fir forests and Engelmann spruce-subalpine fir-aspen forests was similar throughout the year. There was a trend in increased use of riparian areas beginning in July, peaking in November, and dropping off December through June.

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

Mean percent total overstory was higher for long bed and kill sites than travel or den sites (Figure 4). Engelmann spruce provided a mean of 35.87% overstory for kills and long beds, with travel sites averaging 28% and den sites having the lowest mean percent overstory of 23% (Figure 4). Mean percent subalpine fir or aspen overstory did not vary across use sites (Figure 4). Willow overstory was highly variable and no dens were located in willow overstory.

A total of 1841 site-scale habitat plots were completed in winter from December 2002 through April 2005. The most common understory species at all 3 height categories above the snow (low = 0-0.5m, medium = 0.51 - 1.0 m, high = 1.1 - 1.5 m) was Engelmann spruce, subalpine fir, willow (*Salix* spp.) and aspen (Figure 5). Various other species such as Ponderosa pine (*Pinus ponderosa*), lodgepole pine (*Pinus contorta*), cottonwood (*Populus sargentii*), birch (*Betula* spp.) and others were also found in less than 5% of the habitat plots. If present, willow provided the greatest percent cover within a plot followed by Engelmann spruce, subalpine fir, aspen and coarse woody debris for long beds, kills and travel sites. Areas documented in willow used by lynx are typically on the edge of willow thickets as tracks are quickly lost within the thicket. Den sites had significantly higher percent understory cover for all three height categories. Understory at den sites was primarily made up of coarse woody debris (Figure 5).

The most common tree species documented in the site-scale habitat plots was Engelmann spruce Figure 6). Subalpine fir and aspen were also present in >35% of the plots. Most habitat plots were vegetated with trees of DBH < 6" (Figure 6). As DBH increased, percent occurrence decreased within the plot. Although decreasing in abundance as size increased, most lynx use sites had trees in each of the DBH categories, indicating mature forest stands except for dens. Den sites had a broad spectrum of Engelmann spruce tree sizes, including > 18" but no large subalpine fir or aspen trees. While Engelmann spruce and subalpine fir occurred in similar densities for kills, long beds and travel sites, den sites had twice the density of subalpine firs found at all other sites (Figure 6).

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 400 kills were located from February 1999-April 2005. We collected 671 scat samples from February 1999-April 2004 that will be analyzed for content. In each winter, the most common prey item was snowshoe hare, followed by red squirrel (Table 10).

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 (Figure 7). This trend was repeated for percent understory at all 3 height categories (Figure 8) 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 (Figure 9).

SNOWSHOE HARE ECOLOGY

A study plan was completed to evaluate snowshoe hare densities, demography and seasonal movement patterns among small and medium tree-sized lodgepole pine stands and mature spruce/fir stands (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 2005, 204 lynx were released in the Core Release Area. The reintroduction effort was augmented with the release of 14 additional animals in April 2006, bringing the total to 218 lynx reintroduced to southwestern Colorado.

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. Dispersal movement patterns for lynx released in 2000 and subsequent years were similar to those of lynx released in 1999. 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 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. 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). Human-caused mortality factors such as gunshot and vehicle collision are currently the highest causes of death.

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. Reproduction in 2006 included a Colorado-born female giving birth to 2 kittens, documenting the first recruitment of Colorado-born lynx into the Colorado breeding population. Additional reproduction is likely to have occurred in all years from females we are 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 for an increasing population.

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. 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.

Snow-tracking of released lynx provided information on hunting behavior and diet through documentation of kills, food caches, chases, and diet composition estimated through prey remains. Snow-tracking results indicate the primary winter prey species are snowshoe hare and red squirrel, with other mammals and birds forming a minor part of the winter diet. 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). Caution must be used in interpreting the proportion of identified kills. Such a proportion ignores other food items that are consumed in their entirety and thus are biased towards larger prey and may not accurately represent the proportion of smaller prey items, such as microtines, in lynx winter diet. Through snow-tracking we have evidence that lynx are mousing and several of the fresh carcasses have yielded small mammals in the gut on necropsy. The summer diet of lynx has been documented to include less snowshoe hare and more alternative prey than in winter (Mowat et al., 1999). All evidence suggests reintroduced lynx are finding adequate food resources.

SUMMARY

From results to date it can be concluded that CDOW has developed release protocols that ensure high initial post-release survival, and on an individual level lynx have demonstrated they can survive long-term in areas of Colorado. It has also been documented that reintroduced lynx could exhibit site fidelity, engage in breeding behavior and produce kittens that are 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 for a population to sustain itself. Monitoring of reintroduced lynx will continue in an effort to document such viability.

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Table 1. Definitions of forest structure classes used to describe habitat sites (Thomas 1979).

Forest Structure Class	Definition
Grass/forb	The grass/forb stage is created naturally by a catastrophic event, such as wildfire, and is typified by the near complete absence of snags, litter or down material in the aspen and ponderosa pine types, or vice versa in the lodgepole or subalpine forest types.
Shrub/seedling	The shrub/seedling stage occurs when tree seedlings or shrubs grow up to 2.5 cm at diameter breast height (DBH), either naturally or artificially through planting.
Sapling/pole	The sapling/pole stage is a young stage where tree DBH's range from 2.5-17.5 cm with tree heights ranging 1.8-13.5 m. These trees are 5-100 years of age, depending on species and site condition.
Mature	The mature stage occurs when tree diameters reach a relatively large size (25-50 cm) and the trees are usually 90 or more years old. Forest stands begin to experience accelerated mortality from disease and insects.
Old-growth	The old-growth stage occurs when a mature stand is at advanced age (100 years for aspen or 200 years for spruce), is very slow growing, and has advanced degrees of disease, insects, snags, and down, dead material. An exception to this occurs in ponderosa pine and aspen types where these old-growth stands typically experience low densities of down dead material or snags.

Table 2. Lynx released in Colorado from February 1999 through June 30, 2006.

Year	Females	Males	TOTAL
1999	22	19	41
2000	35	20	55
2003	17	16	33
2004	17	20	37
2005	18	20	38
2006	6	8	14
TOTAL	115	103	218

Table 3. Status of adult lynx reintroduced to Colorado as of June 30, 2006.

	Females	Males	Unknown	TOTALS
Released	115	103		218
Known Dead	46	33	1	80
Possible Alive	69	70		138
Missing	20	24		43[a]
Tracking	49	46		95

[a] 1 is unknown mortality

Table 4. Causes of death for lynx released into southwestern Colorado from 1999-2006 as of June30, 2006.

Cause of Death	Number of Mortalities
Unknown	26
Hit by Vehicle	11
Starvation	10
Shot	9
Other Trauma	7
Probable Shot	5
Plague	5
Predation	3
Probable Predation	2
Illness	2
Total Mortalities	80

Table 5. Lynx reproduction documented in 2003.

Female	Release Year	Date Den Found	Number of Kittens		
			Females	Males	Total
BC00F8	2000	5/21/03	?	?	2
BC00F19	2000	5/26/03	1	1	2
YK00F16	2000	6/19/03	1	1	2
YK99F1	1999	6/10/03	2	1	3
YK00F19	2000	6/11/03	1	2	3
YK00F10	2000	5/31/03	2	2	4
		TOTAL	7	7	16

Table 6. Lynx reproduction documented in 2004.

Female ID	Release Year	Previous Litters	Date Den Found	Date Kittens Found	Number of Kittens		
					Females	Males	Total
YK00F2	2000		5/28/2004		3	1	4
AK00F2	2000		5/31/2004		2	1	3
YK00F1	2000		6/1/2004		3		3
YK00F15	2000		6/4/2004		1	2	3
BC00F14	2000		6/7/2004		1	2	3
BC00F18	2000		6/10/2004		4		4
YK00F10	2000		6/17/2004		1	1	2
BC03F02	2003		6/25/2004			2	2
BC03F10	2003		6/26/2004		2		2
BC03F09	2003		6/29/2004		1	1	2
YK00F7	2000		6/30/2004		1	1	2
YK99F1	1999		6/2004	Dec 2004			2
Unknown				Sept 2004			4
Unknown				Feb 2005			3
TOTAL					19	11	39

Table 7. Lynx reproduction documented in 2005.

Female ID	Release Year	Previous Litters	Date Den Found	Date Kittens Found	Number of Kittens		
					Males	Females	Total
AK00F02	2000	2004	5/21/2005		2	1	3
YK00F15	2000	2004	5/28/2005		1	1	2
YK00F10	2000	2003, 2004	6/1/2005		2	2	4
YK00F11	2000		6/9/2005			2	2
YK00F01	2000	2004	6/10/2005		2	1	3
YK00F07	2000	2004	6/14/2005		1	2	3
BC00F18	2000	2004	6/24/2005		1	1	2
BC03F02	2003	2004	5/25/2005		1	1	2
BC03F01	2003		5/27/2005		2	2	4
QU03F06	2003		6/5/2005		3		3
QU03F04	2003		6/14/2005		1	2	3
QU03F07	2003		6/16/2005		3	1	4
BC03F09	2003	2004	6/27/2005		1	1	2
BC03F10	2003	2004	6/2005	12/20/2005			2
BC04F01	2004		6/11/2005		2	1	3
BC04F03	2004		6/19/2005		1	3	4
BC04F05	2004		6/23/2005		3		3
BC04F04	2004			12/10/2005		1	1
TOTAL					26	22	50

Table 8. Lynx reproduction in 2006.

Female ID	Release Year	Year Born in Colorado	Previous Litters	Date Den Found	Number of Kittens		
					Males	Females	Total
AK00F15	2000		2004, 2005	5/21/2006	1	3	4
AK00F05	2000		2004	6/7/2006	1	2	3
BC03F10	2003		2004, 2005	6/9/2006	1	1	2
CO04F07		2004		6/17/2006	2		2
TOTAL					5	6	11

Table 9. Lynx reproduction summary statistics for 2003-2006.

Year	# Females Tracked	# Dens Found in May/June	% Tracked Females with Kittens	Additional Litters Found in Winter	Mean # Kittens/Litter	Total Kittens Found	Sex Ratio M/F
2003	17	6	0.353		2.67 (SE = 0.33	16	1.0
2004	26	11	0.462	2	2.83 (SE = 0.24)	39	1.5
2005	40	17	0.425	1	2.88 (SE = 0.18)	50	0.8
Mean 2003-05			0.413 (SE =0.032)				
2006	42	4	0.095		2.75 (SE = 0.47)	11	1.2
Mean 2003-06			0.334 (SE = 0.083)		2.78 (SE = 0.05)	TOTAL 116	1.14 (SE = 0.14)

Table 10. 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

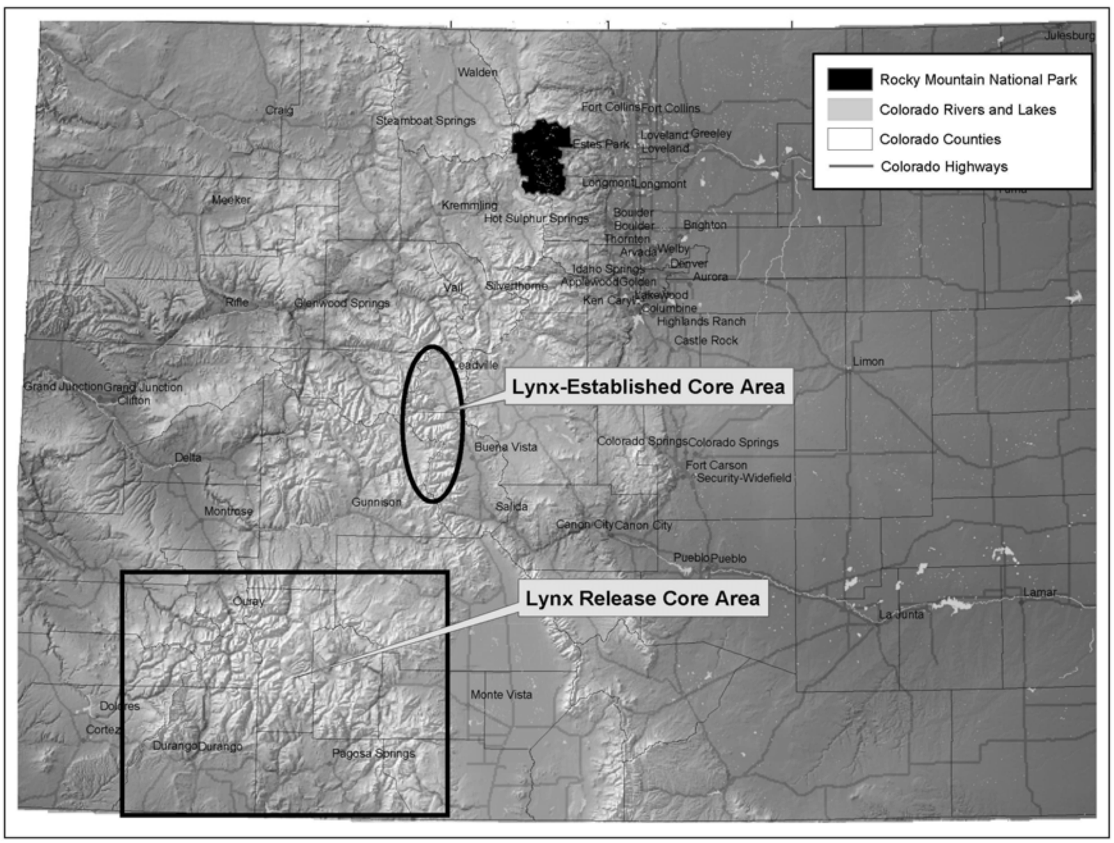

Figure 1. Lynx are monitored throughout Colorado and by satellite throughout the western United States. The lynx core release area, where all lynx were released, is located in southwestern Colorado. A lynx-established core use area has developed in the Taylor Park and Collegiate Peak area in central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

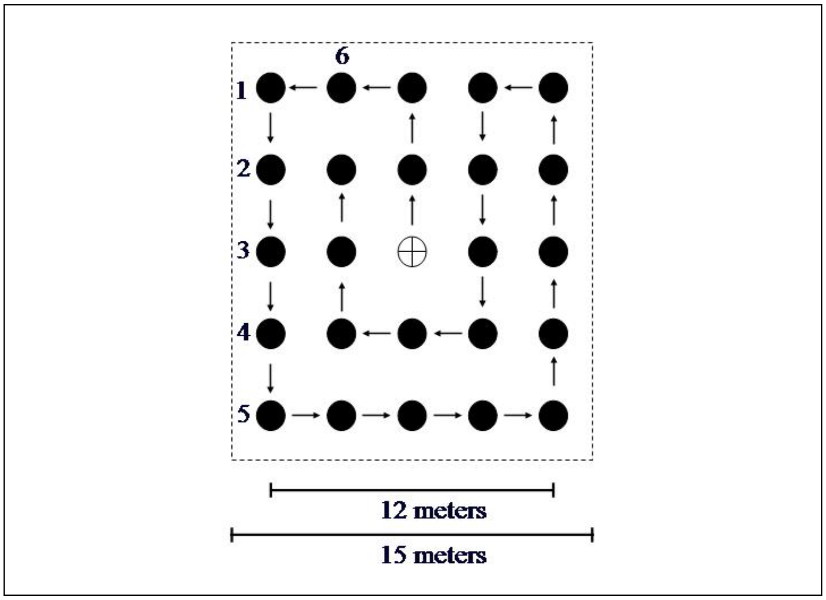

Figure 2. Design of site-scale habitat plot sampling plot. Each of the 25 points are 3 meters apart (the first 6 points are labeled 1-6). The object that triggered a habitat plot (e.g., kill) is the center point, depicted by the hollow circle. The actual pints encompass a 12 m x 12 m square but the understory and overstory data collected are influenced by vegetation occurring within a 15 m x 15 m square.

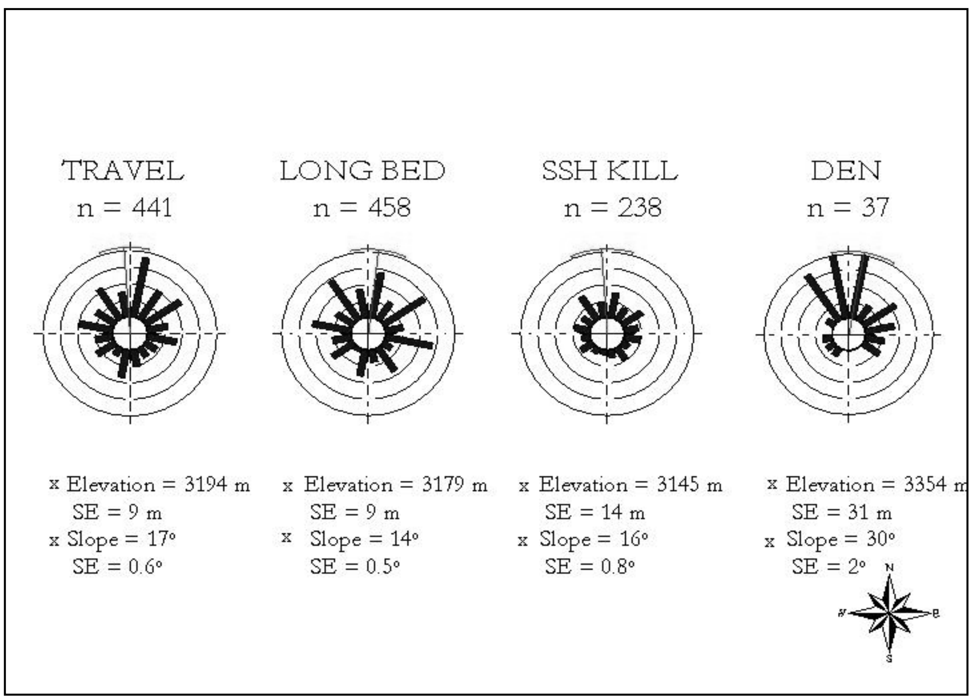

Figure 3. Frequency of aspect with mean vector and 95%confidence interval depicted as grey bars on graphs for 4 lynx use sites; dens, long beds, kills and travel as well as mean elevation and SE and mean slope and SE .

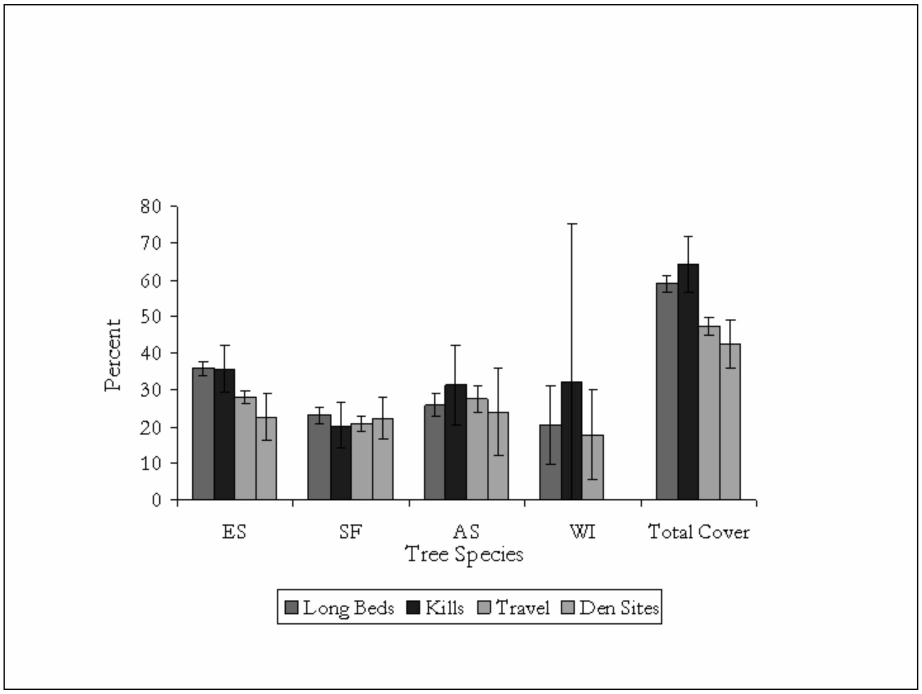

Figure 4. Mean percent overstory by tree species Engelmann spruce (ES), subalpine fir (SF), aspen (AS), willow (WI) and total cover for 4 different lynx use sites: long beds, kill sites, travel and den sites. Confidence intervals (95%) are depicted by error bars.

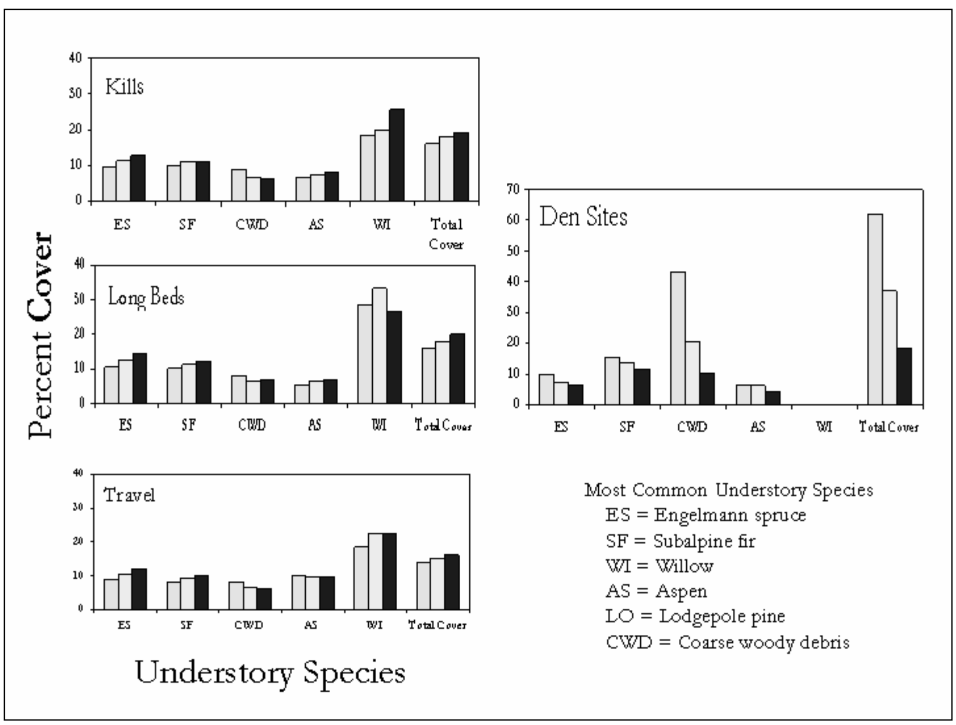

Figure 5. Mean percent understory by tree species Engelmann spruce (ES), subalpine fir (SF), coarse woody debris (CWD), aspen (AS), willow (WI), and total cover for 4 different lynx use sites: long beds, kill sites, travel, and den sites.

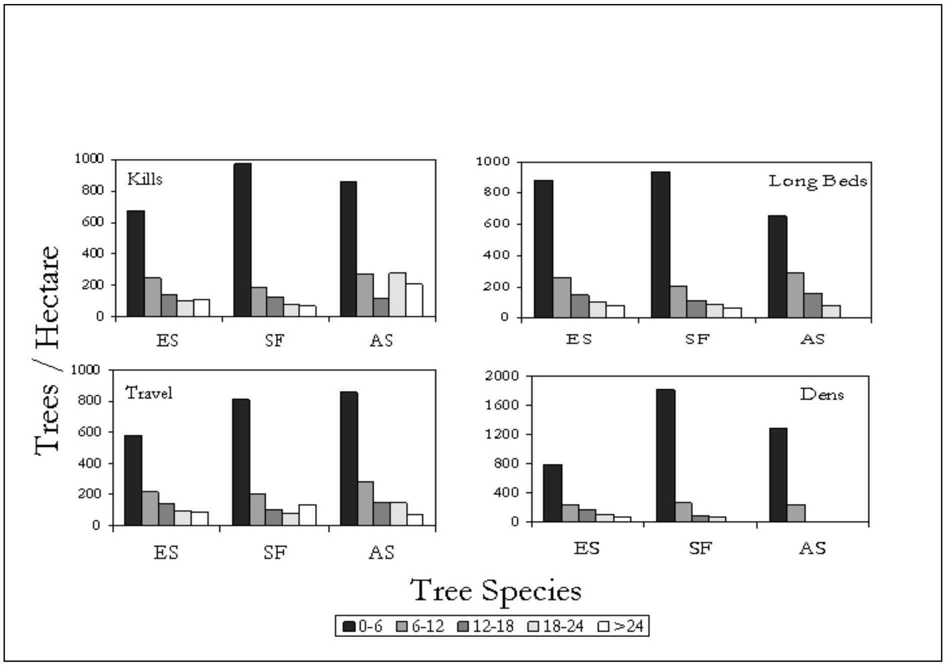

Figure 6. Mean tree density by species Engelmann spruce (ES), subalpine fir (SF), and aspen (AS) and dbh size class for 4 different lynx use sites**.**

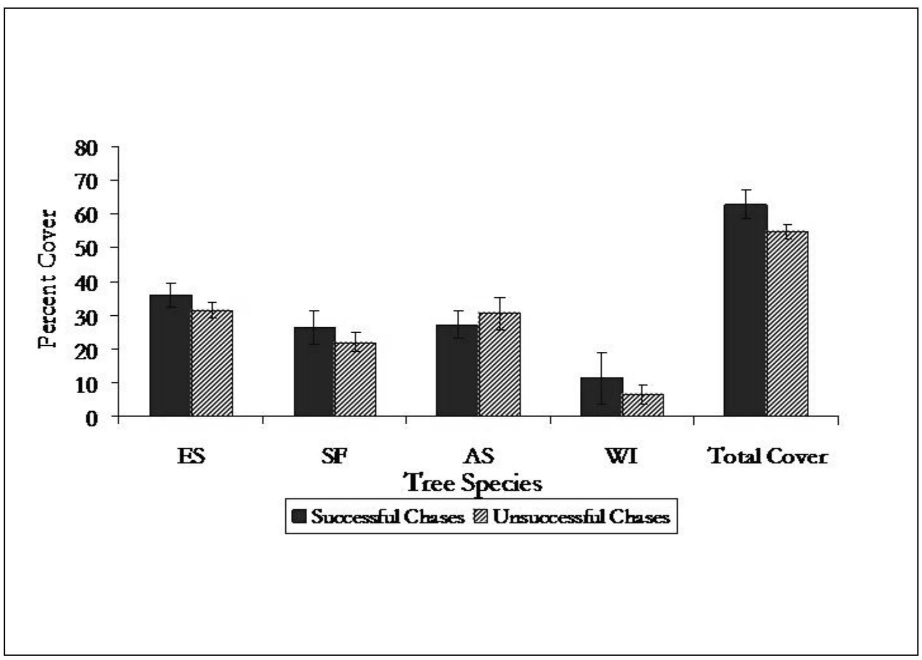

Figure 7. Mean percent overstory by tree species Engelmann spruce (ES), subalpine fir (SF), aspen (AS), willow (WI) and total cover for successful and unsuccessful snowshoe hare chases. Confidence intervals (95%) are depicted by error bars.

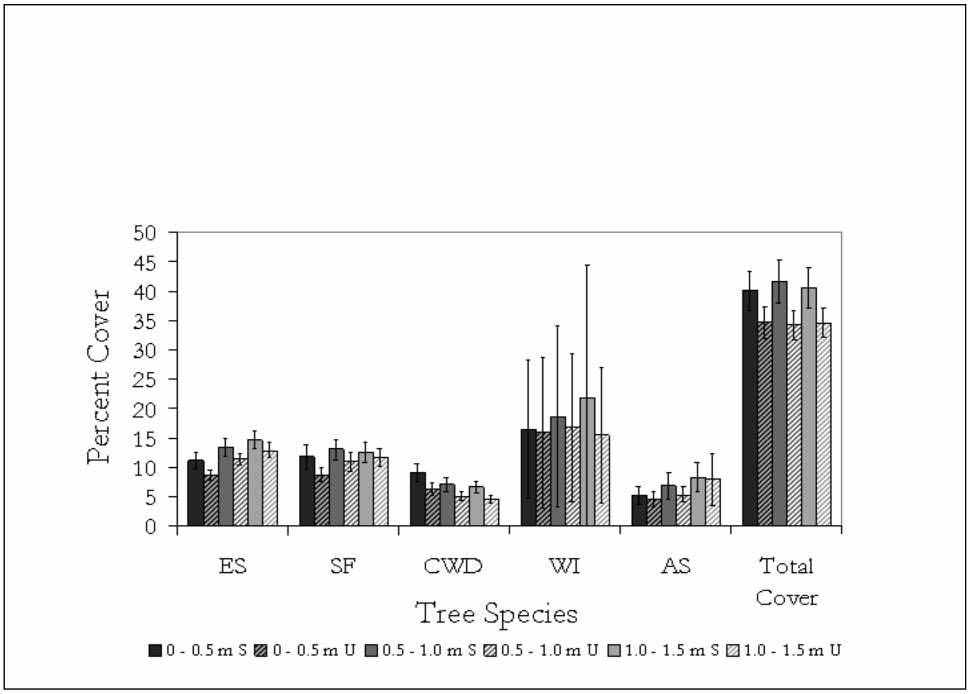

Figure 8. Mean percent understory by tree species Engelmann spruce (ES), subalpine fir (SF), apsen (AS), willow (WI), and total cover for 3 different understory height categories for successful and unsuccessful snowshoe hare chases. Confidence intervals (95%) are depicted by error bars.

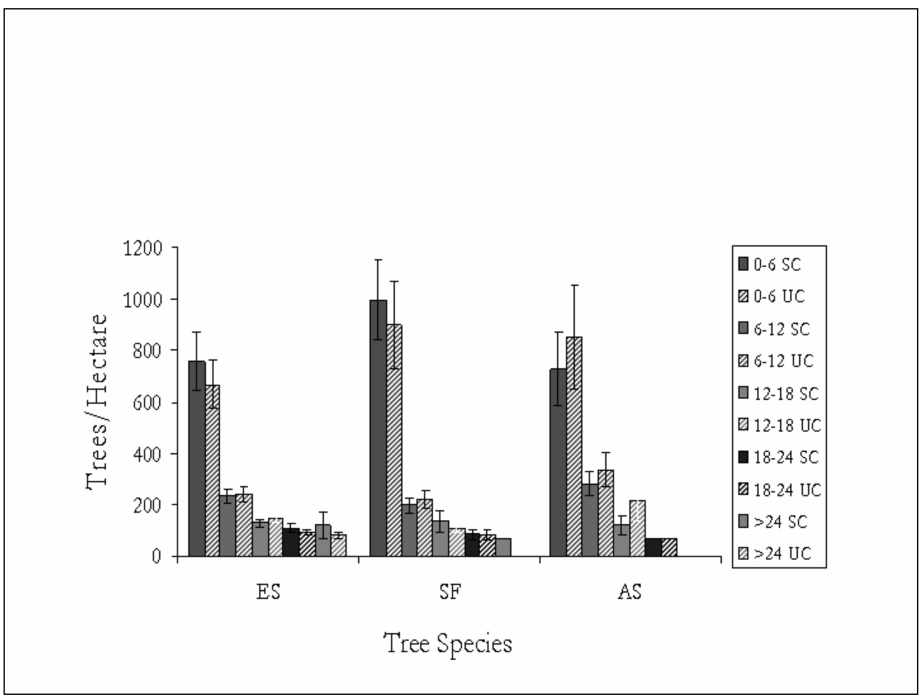

Figure 9. Mean tree density by species Engelmann spruce (ES), subalpine fir (SF), and aspen (AS) and 5 dbh size classes for successful chases (SC) and unsuccessful chases (UC) of snowshoe hares.

APPENDIX I

PROGRAM NARRATIVE STUDY PLAN
FOR MAMMALS RESEARCH
FY 2005-06 – FY 2009-10

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

Federal Aid Project No.: N/A :

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

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STUDY PLAN APPROVAL

Prepared by: ______________________________ Date: ____________________

Submitted by: ______________________________ Date: ____________________

Reviewed by: ______________________________ Date: ____________________

______________________________ Date: ____________________

______________________________ Date: ____________________

Reviewed by: ______________________________ Date: ____________________
Biometrician

Approved by: ______________________________ Date: ____________________
Mammals Research Leader

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

NEED

A program to reintroduce the threatened Canada lynx (*Lynx canadensis*) into Colorado was initiated in 1997. Since that time, 204 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 (T. Shenk, Colorado Division of Wildlife, unpublished data). Thus, as in the far north where the intimate relationship between lynx and snowshoe hares has captured the attention of ecologists for decades, it appears that the existence of lynx in Colorado and the 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. This has caused controversy where recommendations conflict with competing resource management goals. Accurate identification and detailed description of lynx-hare habitat in the southern Rocky Mountains would permit more informed and refined management recommendations.

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

Numerous investigators have sought to determine the relative importance of these distinctly different habitat types with regards to snowshoe hare ecology. Most previous evaluations were based on hare density or abundance (Bull et al. 2005), indices to hare density and abundance (Wolfe et al. 1982, Koehler 1990, Beauvais 1997, Miller 2005), survival (Bull et al. 2005), and/or habitat use (Dolbeer and

Clark 1975). Each of these approaches provides insight into hare ecology, but taken singly, none provide a complete picture and may even be misleading. For example, extensive use of a particular habitat type may not accurately reflect the fitness it imparts on individuals, and density can be high even in “sink” habitats (Van Horne 1983). A more informative approach would be to measure density, survival, and habitat use simultaneously in addition to recruitment and population growth rate through time. Griffin (2004) employed such an approach and found that summer hare densities were consistently highest in young, dense stands. However, he also noted that only dense mature stands held as many hares in winter as in summer. Furthermore hare survival seemed to be higher in dense mature stands, and only dense mature stands were predicted (by matrix projection) to impart a mean positive population growth rate on hares. Griffin’s (2004) study occurred in the relatively moist forests of Montana, which share many similarities but also many notable differences with Colorado forests including levels of fragmentation, species composition, elevation, and annual precipitation.

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

Pellet plot counts are typically conducted by laying out numerous rectangular or circular plots along transect lines randomly placed within a study site. All pellets occurring within the plot are counted and removed on an annual basis. The mean number of pellets per plot is then inserted into a regression equation that gives an estimate of hare density (Krebs et al. 1987). Estimates from this technique correlate well with density estimates derived from simultaneous mark-recapture studies occurring in the same area (Krebs et al. 2001, Murray et al. 2002, Mills et al. 2005, Homyack et al. 2006). However, because fecal deposition rates can vary by season and diet, and because pellet decomposition rates can vary with altitude, climate, aspect, precipitation, and cover type, region-specific, stand-specific, and/or season-specific equations should be developed before this technique is employed for a given area and season (Krebs et al. 2001, Prugh and Krebs 2004, Murray et al. 2005). Density estimates vary with plot size and shape, requiring equations specific to these geometric considerations as well (McKelvey et al. 2002). Pellet counts tend to yield more precise and unbiased density estimates when plots are visited and cleared more than once per year (e.g., plots cleared in the fall and then counted in the spring to estimate winter density) because variability in deposition and decomposition rates is reduced (Homyack et al. 2006). However, this requires considerably more work and expense than an annual survey. Some studies have conducted pellet plot counts without first clearing plots (e.g., Bartmann and Byrne 2001). This saves time and money, but requires the ability to discern fresh (this year) pellets from old pellets, which can be difficult and is generally not a recommended approach (Prugh and Krebs 2004, Murray et al. 2005).

Distance sampling is a well-developed method for estimating the density of objects in a given area (Buckland et al. 2001). In general, observers walk a pre-defined sampling transect and record each object of interest along with the perpendicular distance of that object from the transect line. This information is then used to develop a detection function which is in turn used to estimate density (Buckland et al. 2001). The method assumes all objects on the line are seen with certainty, objects are not double-counted, distance measures are accurate, and transect lines are located randomly within a study area (Buckland et al. 2001). Recently, distance sampling has been used to indirectly estimate hare density by first estimating the pellet group density of hares, then using fecal deposition and decomposition rates as a link back to hare density (Eriksson 2006). In general, distance sampling is more efficient than pellet plot counts as it does not require the tedious layout of hundreds of plots or counting individual pellets. This advantage is most recognizable in situations where pellet groups occur at low densities. Conversely, at extremely high densities, it may become difficult to distinguish pellet groups, and plots may be preferable (Marques et al. 2001). Regardless, distance sampling of pellet groups to estimate animal density also requires habitat and season specific decomposition and defecation rates, which can be difficult to obtain (Marques et al. 2001).

For this project, I have chosen to provide land managers with information relating demographic rates, as well as density, to stand characteristics. Thus, I will use mark-recapture techniques as data from such an approach can provide information on both density and demography. I will address the "effective trapping area" issue using a new approach that augments mark-recapture data with telemetry locations of animals using the grid.

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 (Figure 1). 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.

Specifically, I will 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). To maximize comparability, I will choose lodgepole stands so that all are generating from harvest or all are regenerating following fire. I also intend to identify which of the numerous density-estimation procedures available perform accurately and consistently using an innovative, telemetry augmentation approach as a baseline. I will assess movement patterns and seasonal use of deciduous cover types such as riparian willow. Finally, I will 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.

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.

OBJECTIVES

1) Compare telemetry-corrected estimates of density to those that would have been obtained from other commonly employed techniques used to convert population size estimated from a trapping grid to density (i.e., mean maximum distance moved, ½ mean maximum distance moved, ½ trap interval, nested grids, Program DENSITY). The purpose is to determine which common technique requiring less effort most consistently matches estimates from the intensive, telemetry-corrected approach.
2) Assess the relative value of the 3 stand types that purportedly provide high quality hare habitat by estimating and comparing survival, recruitment, finite population growth rate, and maximum (late summer) and minimum (late winter) snowshoe hare densities for each type.
3) Describe the timing, duration, and extent of broad-scale, seasonal movement patterns of snowshoe hares.
4) Relate specific vegetation, physical, and landscape characteristics of the 3 stand types to snowshoe hare density and demographics.

APPROACH

Hypotheses

1) In general, snowshoe hare density in Colorado will be relatively low ($\leq$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.

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 will be estimated using a variety of conventional techniques as well as a rigorous method that incorporates radio telemetry. The stand-specific demographic parameters will be estimated primarily from capture-mark-recapture methods. As such, apparent survival is defined as the probability that a marked animal alive and in the population at time i survives and is in the population at time $i + 1$. Apparent survival encompasses losses due to both death and emigration. Recruitment is the number of new animals in the population at time $i + 1$ per animal in the population at time i. New recruits can arise from on-site reproduction as well as immigration. The finite population growth rate is the number of animals in a given age class at time $i + 1$ divided by the number present at time i. Shifts in home range will be assessed by comparing the seasonal proportion of telemetry locations in deciduous habitats using multi-response permutation procedures (MRPP; Zimmerman et al. 1985, White and Garrott 1990).

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 will further characterize 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 will record physical covariates such as ambient temperature, precipitation, and snow depth at each stand during sampling periods as well as precipitation 1-3 years prior to sampling. Finally, I will calculate potentially important landscape metrics such as patch size and level of fragmentation.

Location--.Identification of a suitable study area for this project and others that may follow is ongoing. The general study area must consist of an interspersion of young lodgepole pine and mature spruce/fir forest juxtaposed closely with open, seasonal habitats such as riparian willow. Within this general area, 3 sites will be selected such that 1) the 3 stand types of interest (small and medium lodgepole, large spruce/fir) occur within each site, 2) sites are close enough geographically to minimize differences due to climate, weather, and topography, but are far enough apart to be considered independent (e.g., 3 sites might occur in 3 different, but adjacent drainages), 3) each stand type within a site is adjacent to a riparian area, and 4) stand types of interest occur within 1 km of an access road (for logistical purposes). Such an arrangement often occurs in east-west drainages where spruce/fir grows on the north-facing slope, lodgepole pine covers the south-facing slope, and a riparian/willow area with road access separates the two (Figure 2). Additionally, sites must 1) include stands of suitable size and shape to admit a 16.5-ha trapping grid, 2) be consistent in their management history (i.e., all lodgepole pine stands in all sites must be either thinned or un-thinned, all regenerating after fire or all regenerating after harvest), and 3) be consistent in their intensity of use by lynx (core areas or not).

I recently obtained the U.S. Forest Service R2VEG GIS database (newest, most detailed stand inventory information available statewide) and am currently working to objectively select a suite of potential study sites that satisfy the above-stated conditions. Depending on the number of potential sites within this suite, I will choose a small set of provisional study areas to ground-truth based on logistical considerations (e.g, housing, access). I will randomly select the final study sites from among those that appeared qualitatively suitable during ground-truthing. Prior to data collection I will more intensively sample the vegetation characteristics of the various stand types within the selected study sites to ensure that they represent intended conditions.

Sampling.--All trapping and handling procedures will be 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 will begin data collection on site 1 immediately following the second birth pulse in late July. Along with a crew of 5 technicians, I will deploy one 7 × 12 trapping grid (50-m spacing between traps; grid covers 16.5 ha) in each of the 3 stand types of interest following Griffin (2004) and Zahratka (2004). Grid locations and orientation will be chosen randomly within each stand subject to the logistical constraint that they must be within 1 km of a road. Traps will be deployed in all 3 stands in a single day. As traps are deployed, they will be locked open and "pre-baited" with apple slices and commercial rabbit chow. On days 2-4, the crew will continue pre-baiting, replacing apples and rabbit chow as necessary. The purpose of this extended pre-baiting is to maximize capture rates when trapping begins. This will minimize the number of trap-nights needed to capture the desired number of animals which in turn will minimize trapping-related stress as well as the likelihood that American marten (*Martes americana*) will key into trap lines and prey on entrapped hares, as has occurred in previous studies (J. Zahratka, personal communication). 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 seems reasonable.

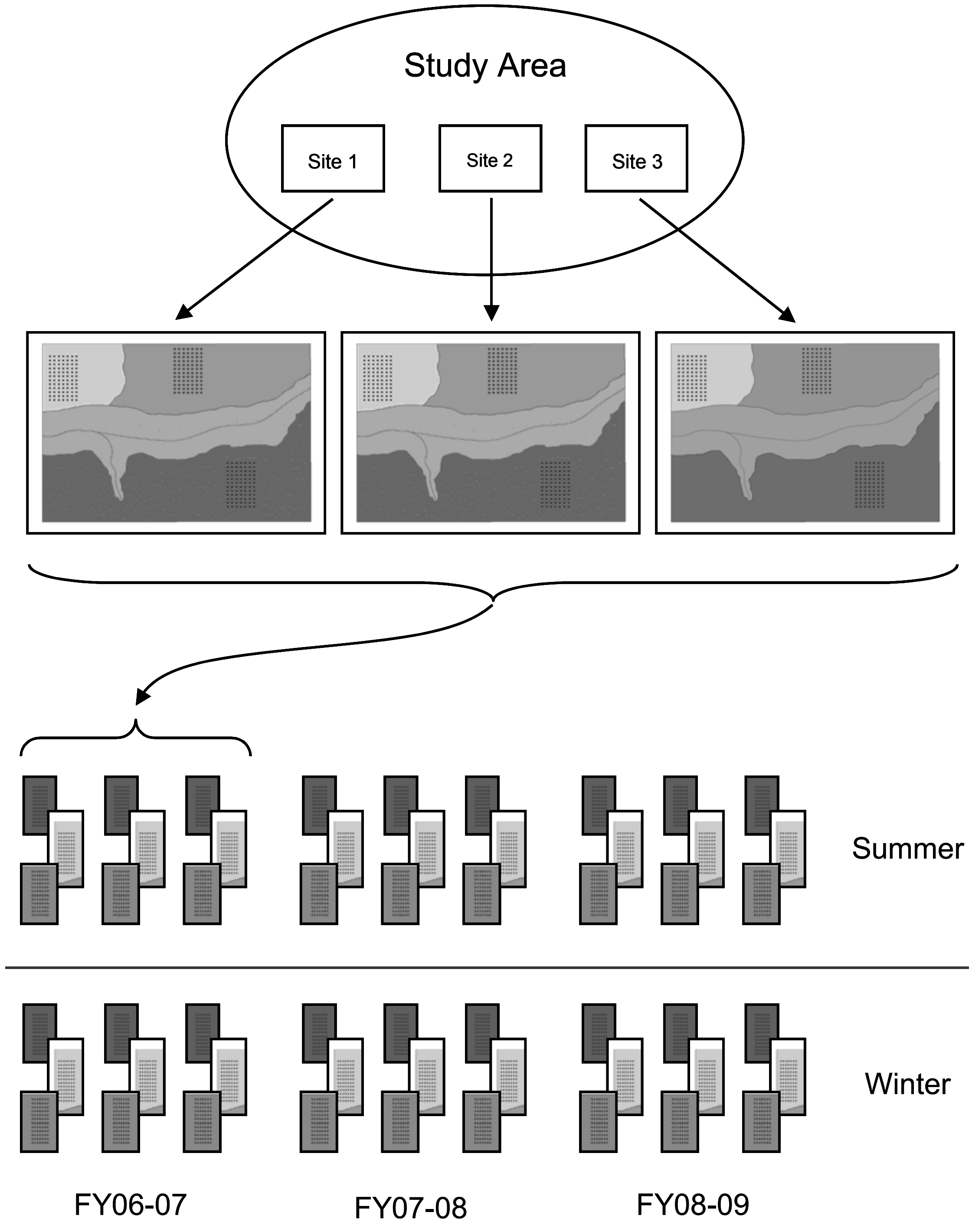

Figure 2. Experimental design for study of snowshoe hare density, demography, and movement. Within the study area, 3 sites, each consisting of 3 forest stand types (light to dark gray shades) and a riparian area (medium gray shade), will be sampled (dotted trapping grids) during late summer and late winter for 3 years.

Traps will be set on the afternoon of the 4th day and checked early each morning and again in the evening on days 5–9. By checking traps in both morning and evening I prevent hares from being entrapped >13 hours, which should minimize capture stress. Based on Zahratka (2004) and personal experience, I anticipate capturing up to 10–15 individual hares per grid. A crew of 2 people will work together on each grid to check traps and process captures as quickly as possible. All captured hares will be coaxed out of the trap and into a dark handling bag by blowing quick shots of air on them from behind. Hares will remain in the handling bag, physically restrained with their eyes covered, for the entire handling process. Each individual will be aged, sexed, marked with a passive integrated transponder (PIT) tag and temporary ear mark (to track PIT tag retention), then released. Aging will consist of assigning each individual as either juvenile (<1 year old, <1000 g) or adult (≥1 year old, ≥1000 g) based on weight. This criterion is accurate through the end of September at which point juveniles are difficult to distinguish from adults (K. Hodges, University of British Columbia; P. Griffin, University of Montana, personal communication). After the first day of trapping, all captured hares will be scanned for a PIT tag prior to any handling and those already marked will be recorded and immediately released. Traps and bait will be completely removed from the grid on day 10.

In addition to PIT tags and ear marks, I will radio collar 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 expect 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 will randomly select a starting trap location each morning and run the grid systematically from that point. Thus, the first several hares encountered (and collared) will be 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 will refrain from deploying the final 3 collars until days 4 and 5 of the trapping session.

Immediately following the removal of traps, the field crew will begin work locating each radio-collared hare 1–2 times per day for 10 days. Locations will be obtained by "homing" on a signal (Samuel and Fuller 1996, Griffin 2004) taking care not to push hares while approaching them. Technicians will record their location with hand-held GPS units (Garmin model 12XL) as soon as a visual of the collared hare is obtained or if the signal can be picked up by the receiver without an antenna. Using the same make and model collars, Griffin (2004) found that hares are usually within ~15m when the signal came be received without an antenna (Griffin 2004). I will test this assumption with my telemetry equipment over a variety of transmitter locations and orientations. Because hares are largely nocturnal (Keith 1964, Mech et al. 1966, Foresman and Pearson 1999), an effort will be made 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.

The crew will gather telemetry locations for radio-collared hares on site 1 for 8–9 days. Then the 10–day trapping procedure and 8 to 9–day telemetry work will be repeated on the 3 grids comprising site 2 (Figure 3). The cycle will be repeated once more for grids on site 3 (Figure 3). The entire process will be repeated during the following winter when densities should be at a minimum.

In summary, for any given 9-week sampling period, I will collect data from 9 total grids, 1 grid in each of 3 habitat types (stand types) across 3 sites. Sampling will occur during 2 such 9-week periods each year – once in late summer and once in late winter – and will continue for 3 years (Figure 2). During the interim between intensive trapping and telemetry work, a single technician and myself will attempt to gather 1–2 telemetry locations/hare/month in order to keep closer tabs on these individuals, determine more precisely when mortality occurs, and retrieve collars from dead hares. Telemetry work will also occur during "pre-baiting" days to determine which hares are still alive and immediately available to be sampled by the grid during the ensuing trapping period.

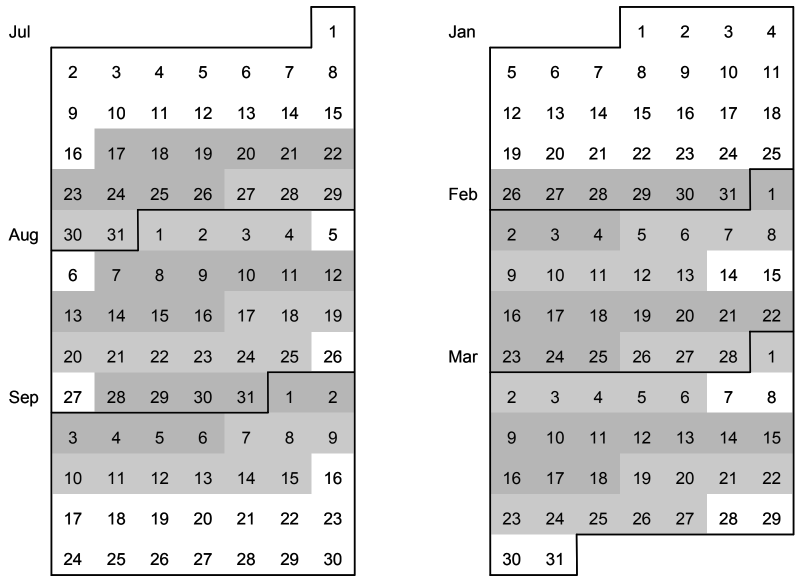

Figure 3. Approximate annual data collection schedule for trapping (■) and telemetry (■). Dates and weeks will change depending on calendar year and pay schedule. During telemetry work, the 6-person crew will be divided into 2 teams, only one of which will be working at any given time. Monthly locations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

Vegetation sampling at each stand will follow 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 9 live-trapping grids, I will lay out 5 × 5 grids (3-m spacing) of vegetation sampling points centered on 15 of the 84 trap locations (Figure 4). At each of the 25 vegetation sampling points, I will record: 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 [0.1 m] and winter [1.0 m] stem density; Barbour et al. 1999), 2) horizontal cover in 0.5-m increments above the ground up to 2 m (Nudds 1977), and 3) canopy cover [present or absent] using a densitometer. Additionally, at the center of all 15 vegetation sampling grid points (i.e., at the trap location), I will measure basal area using an angle gauge. These measurements will be gathered once at the start of the project, unless conditions change due to disturbance such as fire. Temperature will be monitored hourly at each grid during the 6-week intensive sampling periods using data loggers. During winter sampling periods, snow depth measurements will be recorded daily at the same 15 trap locations used to quantify the vegetative attributes of that stand.

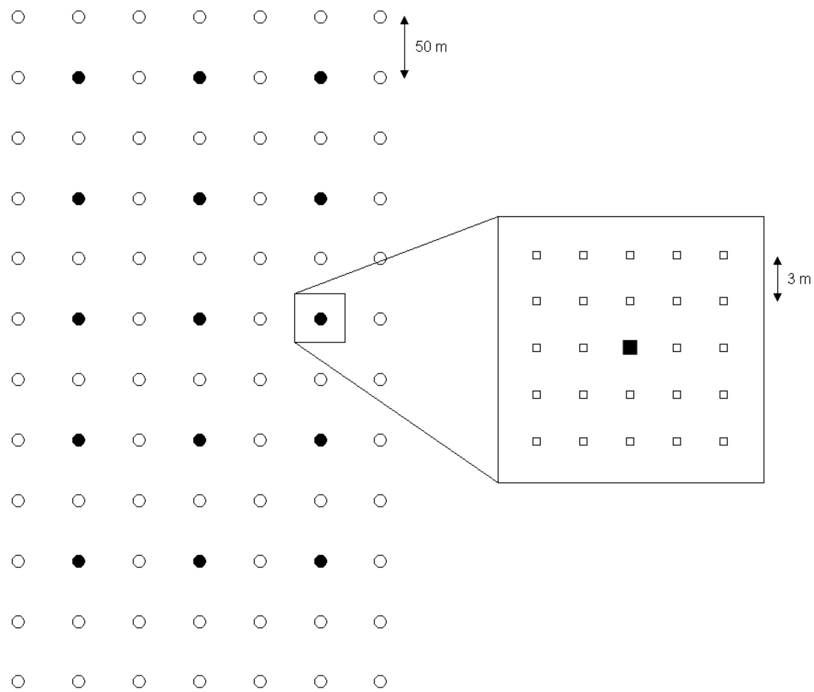

Figure 4. 15 trap locations (•) on 7 × 12 trapping grid where vegetation will be sampled by measuring stem density horizontal cover, and canopy cover at the 25 points on each 5 × 5 subgrid (inset). In addition, basal area will be measured at the trap location (■) on which each of the 15 subgrids are centered.

Data Analysis

Density.--I will assume that hare populations are demographically and geographically closed during the short 5-day mark-recapture sampling periods. To obtain a density estimate for each grid, I will use the Huggins closed capture model (Huggins 1989, 1991) in Program MARK (White and Burnham 1999) with some modifications. The basic Huggins estimator (no individual covariates) is based on the fact that if p_j is the probability that a hare in the population will be captured (and marked) for the first time on trapping occasion *j*, then $p^* = 1-(1-p_1)...(1-p_5)$ is the probability that an individual is captured at least once during a 5-day trapping period (i.e., $j = 1,\ldots,5$). Accordingly, the basic Huggins estimator for population size, $\hat{N}$, is $\hat{N} = M_{t+1}/p^*$ where M_{t+1} is the total number of hares captured. The estimator can be re-written to allow each of the M_{t+1} individuals captured to have their own p^*. In that case, $\hat{N} = \sum_{i=1}^{M_{t+1}} 1/p_i^*$. Presumably hares that reside near the edge of a grid encounter fewer traps and are less likely to be captured than hares residing near the center of a grid. To account for this, I will take advantage of the Huggins model with individual covariates to model p^* by using the logit link function of program MARK to model p_i^* as a function of d_i, where d_i is distance from the edge of the grid for hare *i* based on mean capture coordinates. A naïve density estimate for each grid would then be $\hat{D} = \hat{N}/A$ where *A* is the area of the grid. However, this gives full credit to all hares, even those whose home range only partially overlaps the grid, which results in a density estimate that is biased high. To correct for this bias, I will determine the proportion, $(\tilde{p}_k)$, of telemetry locations for each of the $k = 1,\ldots,10$ radio-collared hares that fall within the "naïve grid area." By incorporating data from multiple grids, a logistic regression model will be developed to estimate $\tilde{p}_i$ for all M_{t+1} animals captured on a grid based on distance from the edge of the grid for hare *i* (d_i). Replacing the numerator (i.e., 1) in the Huggins estimator with ($\tilde{p}_i$), gives a density estimate, $\hat{D} = \left(\sum_{i=1}^{M_{t+1}} \tilde{p}_i / p_i^* \right) \Big/ A$.

The above-stated approach assumes that radio-collared hares neither gravitate toward nor avoid the former grid area after the 5 days of trapping, 10–20 locations per hare is enough to provide a reasonable representation of the proportion of time they spend on the grid, and their use of the grid area is representative of other hares that were captured but not collared (i.e., that the logistic regression model of $\tilde{p}_i$ is a useful model). I contend that this type of estimate from grid-based trapping can be construed as a relatively unbiased estimate of density. Using these point estimates and their associated confidence intervals, I will compare hare density among seasons, years, and stand types. I will also compare these "true" density estimates to those that would have been obtained using other available methods such as ½ mean maximum distance moved (Wilson and Anderson 1985, Williams et al. 2002:314-315), full mean maximum distance moved (Parmenter et al. 2003), ½ trap interval (Parmenter et al. 2003), "nested grids" (White et al. 1982:120-131), and Program DENSITY (Efford et al. 2004).

Demography.--I will analyze mark-recapture data using Pradel temporal symmetry models (Pradel 1996, Nichols and Hines 2002) in a robust design framework (Williams et al. 2002:523-554), which will be available in Program MARK by summer 2006. Thus, I will treat summer and winter sampling occasions as primary periods, and the 5-day trapping sessions within each as secondary periods. The Pradel temporal symmetry models employ both forward and reverse-time evaluation of capture histories to provide estimates of apparent survival ($\hat{\phi}$) and seniority ($\hat{\gamma}$). Apparent survival, ϕ_i, is the probability that a marked animal alive and in the population at time *i* survives and is in the population at time *i* + 1. The seniority parameter, γ_i , is the reverse-time analogue of survival. Reading backward through a capture history, it is the probability that a marked animal alive and in the population at time *i* was alive and in the sampled population at time *i* − 1. If *N* is the number of animals present in the population, $N_i\phi_i \approx N_{i+1}\gamma_{i+1}$ and $N_{i+1} / N_i = \phi_i / \gamma_{i+1} = \lambda_i$. Also, if f_i is recruitment rate, or the number of recruits at time *i* + 1 per animal present at time *i*, then $N_{i+1} = N_i\phi_i + N_i f_i$. Rearranging and substituting into the previous equation gives $f_i = \phi_i \left(1/\gamma_i - 1\right)$. Thus, using Pradel models, one can estimate recruitment and finite population growth rate in addition to survival (Pradel 1996, Nichols and Hines 2002).

I will use Akaike's Information Criterion corrected for small sample size (AICc; Burnham and Anderson 1998) to determine whether models with time-dependent parameters or constant parameters are best supported by the data. I will derive estimates of the above-mentioned parameters from the best model or from model averaging. I anticipate pooling capture data across sites to obtain $\hat{\phi}_i$, $\hat{\lambda}_i$, and $\hat{f}_i$ for each stand type for each interval between primary sampling periods (5 estimates of each). I also anticipate simply estimating these parameters for "generic hares", treating both juveniles and adults as a single group or age class. Given that juveniles are morphometrically indistinguishable from adults by their first fall of life (K. Hodges, University of British Columbia; P. Griffin, University of Montana, personal communication), adult and juvenile survival rates are similar (Griffin 2004), and there is little evidence for age-specific differences in pregnancy rates or litter size (Dolbeer 1972), this approach seems justified. However, if I happen to capture sufficient numbers of juveniles and adults, the design I have laid out here allows for treating the age classes separately. This, in turn, may permit me to decompose the contribution that f_i makes to λ_i into the portion of that contribution due to on-site reproduction and that due to immigration (Nichols et al. 2000). Similarly, it may also be possible using my telemetry data to decompose apparent survival, ϕ_i , into emigration and mortality. Such fortuitous situations would facilitate the identification of source and sink habitats if they exist.

Seasonal Movements.--I will assess whether snowshoe hares seasonally shift their home ranges using the multi-response permutation procedure (MRPP; Zimmerman et al. 1985, White and Garrott 1990:134-135). Under this approach, telemetry locations are grouped by season (summer and winter), and an MRPP statistic is calculated as the weighted average of the distance between all possible pairs of locations within groups compared to the average distance between all possible pairs ignoring groups. The null hypothesis is that the distribution of locations is the same for both groups (seasons). Sufficiently small values of the test statistic suggest that within group distances are smaller than distances measured ignoring groups, which is evidence against the null in favor of a group (seasonal) effect. P-values are obtained by calculating the percentile of the observed test statistic relative to all possible test statistics that could be computed by re-arranging the data into all possible groups of 2. The MRPP procedure is sensitive and can detect even small changes in use of an area (White and Garrott 1990:136). I propose a priori that changes in proportional use of deciduous habitats <0.10 in magnitude are unlikely to be biologically significant.

Vegetation.--I will calculate mean stem density, horizontal cover, canopy cover, and basal area for each season–stand type as well as temperature, precipitation, snow depth information, and landscape metrics. These will be entered into the MARK design matrix as covariates to population size (~density) and survival in a random effects analysis. As such, I will be able to quantify the amount of variation in population size or survival that is due to differences in vegetation, landscape, or weather relative to the amount left to other causes.

Sample size.--I conducted power analyses to determine the probability of discerning meaningful differences in density and survival for hares occupying different stand types. For density, I postulated that foraging lynx likely do not discriminate among stands that differ by only a few hares. However, it seems probable that if hare density in one stand is twice that of another, a lynx would choose the former given the opportunity. Thus, I conducted power calculations to determine the probability of distinguishing differences in densities between 2 stand types in which one had twice the density of hares as the second. Specifically, using the Huggins closed capture model (Huggins 1989, Huggins 1991) in Program MARK, I specified the number of hares (N) present in each of 2 groups (i.e., 2 stand types), allowed capture (p) and recapture (c) probabilities to vary with time but constrained them to be equal and the same for each group, then simulated this scenario 1000 times for a range of realistic capture probabilities. For each simulation I calculated a 95% confidence interval for the mean difference in $\hat{N}$ between the 2 groups and determined the proportion of all simulations in which this confidence interval did not include zero. This proportion is the power, or probability of discerning a difference between the 2 groups when one actually exists. I compared 2-fold differences in density at the low (5 vs. 10 hares/grid) and high (15 vs. 30 hares/grid) end of the range of hare numbers and I expect to observe (Zahratka 2004). I also simulated the power to detect differences between 17 and 39 hares/grid, corresponding to recently published cut-points for low and high hare densities in the context of lynx conservation (Mills et al. 2005). Given capture/recapture probabilities I observed during winter 2005 (approximately 0.35–0.45), I expect to have reasonable power to detect 2-fold differences in density even if I encounter relatively few hares per grid (Figure 5).

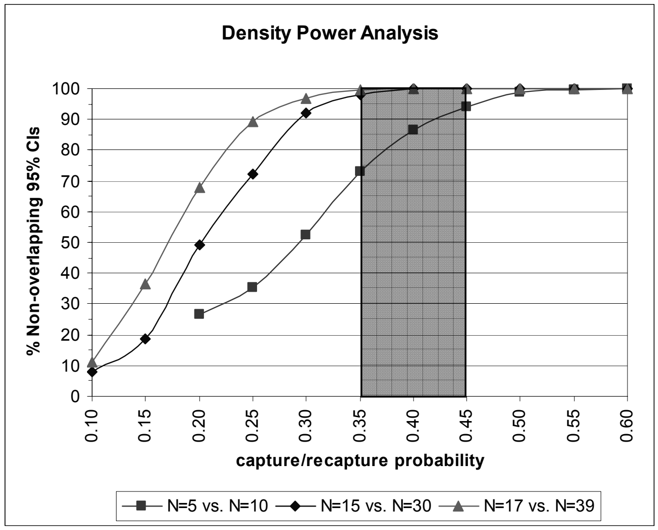

Figure 5. Power for distinguishing differences in snowshoe hare density between 2 habitat types when a difference actually exists. Gray area indicates the capture probability realized by the 3rd day of trapping during a pilot study in winter 2005. *N* indicates number of hares per grid, a range of roughly 0.1 (*N* = 5) to 0.7 hares/ha (*N* = 39).

I conducted power analyses for survival in a similar manner using the Huggins estimator (Huggins 1989, Huggins 1991) in a robust design framework (Williams et al. 2002:524-556). For this analysis, I specified 3 primary periods (e.g., 3 years) with 5 secondary occasions for each. I established either 30 or 45 hares in each of 2 groups (i.e., pooled an expected 10-15 hares/grid across the 3 grids in a given habitat type), specified a different survival rate for each, and allowed *p* and *c* to vary with time but constrained them to be equal and the same for each group as before. I then specified a general model that assumed survival rates varied among groups and a second, reduced model that assumed survival rates were the same for each group. After 1000 simulations under a given scenario of hare numbers, capture probabilities, and survival rates, I conducted a likelihood ratio test between each pair of general and reduced models. As before, I used the proportion of significant tests as an estimate of power to detect differences in survival.

I compared survival rates of 0.4 vs. 0.5, 0.3 vs. 0.5, and 0.2 vs. 0.5. These rates span the range of annual hare survival rates reported in the literature (Dolbeer 1972, Dolbeer and Clark 1975, Griffin 2004). Also, because each comparison is anchored at 0.5, these calculations provide a conservative estimate of power due to the nature of binomial probabilities. That is, I would be more likely to distinguish the difference between 0.1 and 0.2 than between 0.4 and 0.5 even though the difference in both cases is 0.1 because the sampling variance of the estimate for the same sample size is maximal at 0.5 and declines to 0 for survival rates of 0 or 1. Results indicate that I have ≥80% chance of discerning real differences in survival of ≥0.3 (Figure 6), but only 40-65% chance (depending on number of hares captured) of detecting a difference of 0.2, and very little chance of detecting differences smaller than 0.2. However, I plan to combine my telemetry data with my trapping data in the MARK Robust design model using separate groups for each data type. This should enhance my precision and power, thus making the prospect of detecting differences as small as 0.2 a possibility.

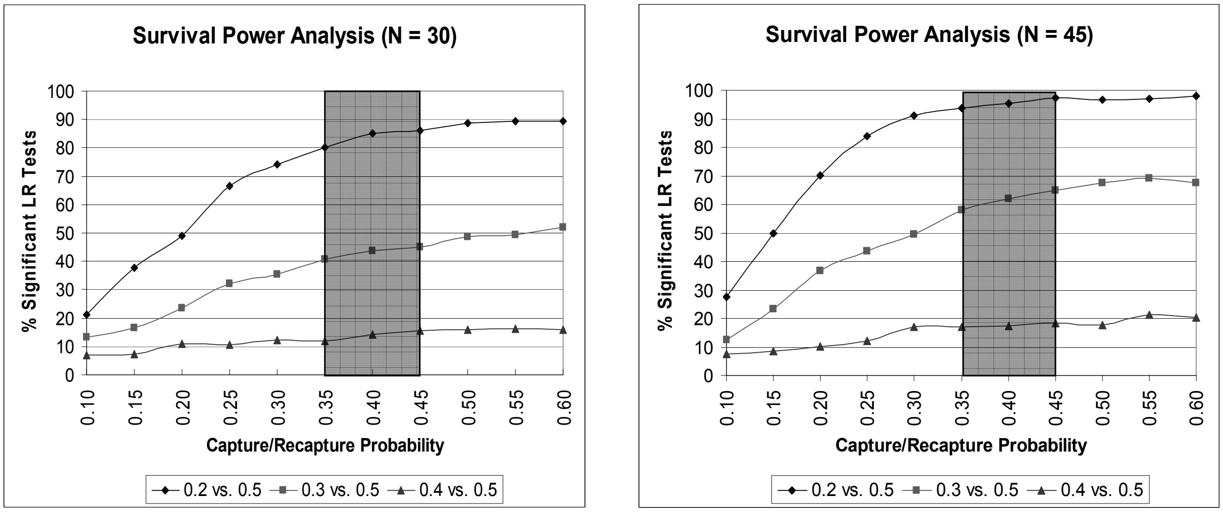

Figure 6. Power, or probability of distinguishing differences in snowshoe hare survival between 2 habitat types when differences actually exist. $N = 30$ (left) and $N = 45$ (right) correspond to reasonable estimates of the number of hares I expect to capture in each habitat type. Gray area indicates the capture probability realized by the 3rd day of trapping during a pilot study in winter 2005.

To complete a power analysis for $\hat{\lambda}$ requires running simulations of Pradel models in a robust design framework. This capability is not yet available in Program MARK, so such an analysis has not been completed. Sampling 15 vegetation plots per trapping grid provided reasonably precise characterizations of similar stands in similar locations during a previous study (Zahratka 2004). I trust this level of sampling will be adequate for the present study as well. If not, more plots can be established at a later date given that vegetative characteristics are unlikely to change appreciably over a few years.

Project Schedule

I will begin the first 9-week data collection period in mid July 2006. The first winter sampling period will begin in February 2007. Intensive sampling will occur across a total of 3 summer and 3 winter periods, with monthly telemetry work interspersed between the main sampling periods. All fieldwork will terminate with the winter 2009 sampling period. Analysis, write-up, and submission to journal outlets will occur during summer and Fall 2009. I plan to graduate during spring semester 2010.

Personnel

Jacob S. Ivan, Ph. D. student, Colorado State University will be the primary investigator responsible for the design and conduct of the study. Tanya M. Shenk, Mammals Research, Colorado Division of Wildlife, and Gary C. White, Professor, Colorado State University will serve as primary advisors. Also, as most lynx/hare habitat occurs on United States Forest Service (USFS) land, this project will require cooperation and coordination with USFS biologists and district rangers for permission and possibly logistical support (housing, campsites, trucks).

As presented here, this project will require an estimated minimum of 3,600 person-hours/year (5 technicians, 720 hours) in technician labor to complete the intensive 9-week sampling periods as well as 360 person-hours/year of technician labor to run the monthly telemetry operation. Thus, completion of the 3-year project will require an estimated minimum of 11,880 person-hours in addition to time spent by the primary investigator, advisors, and cooperators.

Estimated Annual Cost

	FY06-07	FY07-08	FY08-09
Personnel			
TFTE (5 techs, 360, $11.13/hr, 11.16% overhead)*	$ 22,270	$ 22,830	$ 23,410
TFTE (1 tech, 360 hours, $11.13/hr, 11.16% overhead)**	$ 4,454	$ 4,565	$ 4,679
Operating			
PURCHSERV (Ph.D. Stipend, tuition, minimal supplies)***	$ 27,500	$ 27,500	$ 27,500
SUPPLIES (bait, snowmobile repairs, handling supplies, etc.)	$ 4,000	$ 4,000	$ 4,000
EQUIPMENT (radio collars)	$ 11,500	$ 11,500	$ 11,500
Travel			
INSTTRAV	$ 1,500	$ 1,500	$ 1,500
VEHICLE LEASE/MILEAGE (3 vehicles, 5 months/year)**	$ 5,328	$ 5,328	$ 5,328
TOTAL COST	$76,552	$77,223	$77,917
TOTAL COST TO SSH BUDGET	$43,724	$44,395	$45,089

*Assumes 2.5% cost-of-living wage increase/year
**Telemetry work during interim between sampling periods
***Will be charged to budget centers other than lynx/snowshoe hare

EXPECTED RESULTS/BENEFITS

1) Seasonal density estimates and associated variability will help establish where Colorado lies on the continuum of hare densities reported in the literature. Whether densities are relatively high or low, stable or highly variable, or drastically different or roughly equal among cover types could influence future land management decisions as well as decisions regarding the lynx reintroduction process.
2) Combined with Zahratka (2004) and future research, density estimates from this project may elucidate the degree to which hare populations fluctuate or cycle in Colorado, a phenomenon of interest to wildlife ecologists and managers.
3) Comparison of “known” densities to those obtained from other commonly used methods will inform future research and monitoring programs which techniques are likely to produce results that are most consistently in agreement with the intensively derived estimates reported from this project. This knowledge will also enhance interpretation of previously reported hare densities in Colorado and elsewhere.
4) Assessment of density, demographic parameters, and their variability among habitat types will help identify which type(s) consistently support(s) high hare numbers and productivity. The current, conservative approach to lynx/hare conservation is to treat all potential habitat as equally and highly valuable, although this has not been substantiated scientifically, especially in Colorado. This project should determine if the current approach is justified or if there is a disparity in the value of different habitat types relative to lynx-hare conservation. If the latter is true, those charged with managing forests may be allowed more flexibility to accommodate competing resource uses while maintaining lynx/hare habitat.

5) Assessment of density and demographic parameters should help identify the general time period over which succession carries young, regenerating lodgepole pine stands into and then out of service as snowshoe hare habitat. It is apparent that stands in fresh clear cuts and mature lodgepole stands do not provide quality hare habitat (Zahratka 2004). The value of small and medium lodgepole stands to hares has not been quantified in Colorado and is of interest to resource managers.
6) Knowledge regarding the presence or absence of large-scale seasonal movements, and the extent to which this occurs will inform managers about the value of peripheral vegetation (other than conifer forest, such as riparian willow or aspen), will identify when and for how long peripheral vegetation is likely to be used, and will potentially identify other snowshoe hare management issues that have not received prior consideration.
7) A description and comparison of vegetation and landscape characteristics among the 3 stand types and their relationship to snowshoe hare demography and movement patterns should further aid land managers in creating and maintaining lynx/hare habitat.

RELATED FEDERAL PROJECTS

Given that the majority of lynx/hare habitat occurs on United States Forest Service land, this project will require cooperation with local ranger districts, regional biologists, and researchers within that agency. As soon as I have completed provisional study site selection, I will contact the appropriate collaborators to obtain permission, appropriate permits, etc.

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Colorado Division of Wildlife
July 2005 – June 2006

WILDLIFE RESEARCH REPORT

State of	Colorado	: Division of Wildlife
Cost Center	3430	: Mammals Research
Work Package	3001	: Deer Conservation
		Program Final Report Deer Conservation Research For 5-Year Federal Aid Grant W-185-R July 2001 – June 2006
Federal Aid Project	W-185-R	:

Period Covered: July 1, 2001 – June 30, 2006

Author: David J. Freddy, Mammals Research Leader, 1 June 2006

Principal Investigators: D. L. Baker, C. J. Bishop, E. J. Bergman, D. J. Freddy, and T. M. Pojar, Colorado Division of Wildlife; W. F. Andelt, N. T. Hobbs, and G. C. White, Colorado State University

ABSTRACT

This report highlights the accomplishments of mule deer research and associated activities conducted by the Colorado Division of Wildlife (CDOW) with the funding support of Federal Aid Grant W-185-R during the 5-year grant segment, July 2001-June 2006. Five major multi-year research projects addressing mule deer population limiting factors, habitat status, and habitat enhancements were designed, implemented, completed, and reported upon during this segment in response to addressing stakeholder interests that influenced the direction of mule deer management and research beginning in the late 1990s. Additionally, funding provided critical scientific and technical expertise quality control oversight for statewide deer hunter harvest surveys, statewide deer population databases, mule deer survival and population estimate management surveys, mule deer population modeling, and mule deer research projects. Funding also partially supported research projects addressing chronic wasting disease and fertility control in mule deer.

Research experiments provided strong evidence that habitat nutritional quality had a greater impact on net productivity of mule deer than did existing levels of coyote, cougar, and black bear predation and therefore, future research and management efforts should focus on improving the nutritional capabilities of senescent pinyon-juniper winter ranges for deer. Research also provided strong evidence that the timing and rate of breeding were within normal ranges for mule deer and therefore concerns about the breeding cycle could be dismissed as a major contributor to declining performance of mule deer populations. Comparative assessments of vegetation inside and outside sagebrush and mountain brush exclosures indicated that after 40 to 50 years of protection from ungulate herbivory, woody species increased in cover dominance with only minor changes in herbaceous cover. Increasing plant species diversity in these types of winter ranges will probably not be accomplished by excluding herbivory. In a highly scrutinized public experiment, research and management expertise co-demonstrated that methods used by Colorado to estimate mule deer population size and to develop

population management models provided reliable information to adequately guide mule deer harvest management decisions.

From activities supported by this Grant during this segment, principal investigators published 15 peer-reviewed scientific articles pertaining to mule deer for prominent wildlife research journals with an additional 4 manuscripts currently in review with journals, provided 18 annual CDOW Wildlife Research Reports summarizing yearly progress of projects, and provided 13 presentations at prominent professional workshops or symposia. The cumulative impact of this programmatic effort provides Colorado the basis to progress and proactively sustain the mule deer resource in an increasingly demanding and complex landscape, social, and political environment. The relative success of mule deer management in Colorado reflects the positive synergy between the terrestrial research and management sections in sharing expertise, financial resources, manpower, and common goals.

WILDLIFE RESEARCH REPORT

PROGRAM FINAL REPORTDEER CONSERVATION RESEARCH
FOR 5-YEAR FEDERAL AID GRANT W-185-R
JULY 2001 – JUNE 2006

DAVID J. FREDDY
Mammals Research Leader

PROGRAM NEED

During the late 1990s, the Colorado Division of Wildlife (CDOW) was challenged by sportsmen and other stakeholders to investigate potential causes of declining numbers of mule deer in Colorado. Additionally, sportsmen were critical of methods used to estimate numbers of mule deer and subsequently did not trust the CDOWs assessment of the overall status of mule deer in Colorado. The concerns of stakeholders gained the attention of the Colorado Legislature which directed CDOW to prepare a document to address causes of the mule deer decline and outline a plan of action to reverse the perceived trend in mule deer populations. That document was prepared for the legislature in 1999 (Gill et al. 2001) and established the direction and objectives for mule deer management and research beginning in 1999.

Research objectives and program implementation were outlined and initiated in 1999 with most of the research effort directed at the Uncompahgre Plateau mule deer population which was of high concern to various stakeholders. This Federal Aid Grant Final Report highlights the accomplishments of the research pertaining to the mule deer program that was conducted from July 1, 2001 through June 30, 2006 and wholly or partially supported by Federal Aid Grant funds.

PROGRAM NARRATIVE OBJECTIVES

The primary Program Narrative research objectives were:

I. Identify factors limiting the growth of mule deer populations.
II. Assess methods to reduce impacts of limiting factors.
III. Improve and evaluate statewide systems and technical methods used to determine status of mule deer populations.
IV. Assess the impacts of chronic wasting disease on mule deer populations.
V. Develop alternative approaches to control over-abundant urban-exurban mule deer populations.

RESULTS

Objective I. Factors Limiting Growth of Mule Deer Populations.

Initially, stakeholders expressed concern that statewide declines in mule deer populations were caused by low pregnancy rates in adult females due to inadequate numbers of mature bucks to breed females, and by low recruitment of neonatal fawns due to excessive predation on neonates. Two primary projects were funded to focus on: 1) estimating pregnancy and fetal rates in adult female mule deer; and, 2) estimating survival rates of neonate fawn mule deer.

Result Highlights:

- Pregnancy and fetal rates were determined with ultrasonography and PSPB blood values to be within normal limits for the Poudre River and Uncompahgre Plateau mule deer in 1998 and 1999. Therefore, numbers of mature mule deer bucks were adequate to assure acceptable rates and timing of breeding for adult female deer.

- Survival of radio-collared neonatal fawns from birth in June to December averaged 0.50 during 3 years from 1999 through 2001. This rate of neonate survival was only marginally adequate to assure population growth. Primary cause of death in neonates was sick/starve implicating inadequate nutrition for either adult does or neonates. Predation on neonates by canids, ursids, and felids occurred but not at rates considered to be limiting the population. Coyotes were the primary predator accounting for about 13% of the neonate deaths.

Resulting Peer-Reviewed Publications:

ANDELT, W.F., T.M. POJAR, AND L.W. JOHNSON. 2004. Long-term trends in mule deer pregnancy and fetal rates in Colorado. Journal of Wildlife Management 68:542-549.

POJAR, T.M., AND D.C. BOWDEN. 2004. Neonatal mule deer fawn survival in west-central Colorado. Journal of Wildlife Management 68:550-560.

Associated Annual Wildlife Research Progress Reports Available from the Colorado Division of Wildlife Research Library, Fort Collins, Colorado:

POJAR, T.M., AND D.C. BOWDEN. 2002. Mule deer life-cycle-neonatal fawn survival. Colorado Division of Wildlife, Wildlife Research Report July: 47-63.

POJAR, T.M. 2003. Mule deer life-cycle-neonatal fawn survival. Colorado Division of Wildlife, Wildlife Research Report July: 55.

Objective II. Assess Methods to Reduce Impacts of Limiting Factors.

A widespread debate throughout the western states in the late 1990s was whether mule deer were declining primarily due to predation from perceived abundant coyote, cougar, and black bear populations or if the decline was due to long-term losses in habitat quality and availability which negatively affected mule deer nutrition and subsequent recruitment and survival. Both predation and habitat quality were judged by various stakeholders to be the ‘cause’ of declining mule deer in Colorado and specifically the Uncompahgre deer population. Although painting the picture that the mule deer decline was caused by one major factor versus another major factor oversimplified the situation, such a dichotomy of thought quickly helped focus thrusts for potential research and management actions. The case for predation was assessed by Ballard et al. (2001) in their influential overview of predation and deer populations. The potential effects of habitat deterioration resulting from successional senescence of important plant communities and direct losses of habitat space due to human encroachment was argued by deVos, Jr. et al. (2003) in their overview of mule deer conservation strategies.

As this debate evolved, Colorado was fortunate to have developed a strong working relationship with the Idaho Department of Fish and Game in our mutual attempts to address causes of the mule deer decline. The research sections of these 2 agencies decided to cooperatively investigate whether predation or habitat was the cause of the mule deer decline. Idaho, because of political, social, and legal aspects, was more capable of addressing the impacts of predation on mule deer than was Colorado and therefore, Idaho designed and implemented an intensive experimental reduction of coyote and cougar populations to measure the impacts of such actions on mule deer net recruitment (Hurley et al. 2002, Hurley et al. 2005). To compliment Idaho’s efforts, Colorado designed and implemented a series of experiments to measure the impacts of improving the nutritional quality of habitats on mule deer net recruitment (Bishop and White 2000).

Three primary projects were funded to focus on: Phase 1A) effect of enhanced nutrition on mule deer population parameters; Phase 1B) long-term effects of herbivory on sagebrush and mountain brush winter ranges; and Phase 2A) effects of landscape habitat alterations within senescent old-growth pinyon-juniper winter ranges to enhance mule deer population parameters.

Result Highlights:

Phase 1A

- Survival of fawns receiving an enhanced nutrition treatment from December through April had an over-winter survival rate of 0.89 which was higher ($P \leq 0.001$) than the survival rate of 0.65 for control fawns not receiving enhanced nutrition. The over-winter survival period was 15 December to 15 June during 3 years, 2001-02, 2002-03, 2003-04, and survival rates were based on 240 6-month old fawns with 120 fawns captured and radio-collared in each of the control and treatment areas. The effect of enhanced nutrition was highly evident even with the presence of ongoing predation by coyotes and cougars.

- Survival rates of fetuses to neonate and through 1-year of age that were born to adult females receiving enhanced winter nutrition were 0.46 and higher ($P \leq 0.001$) than survival rate of 0.28 for fetuses born to adult females not receiving enhanced nutrition. Survival rates were over 3-years, 2002-2004, and based on 276 fawns monitored across 293 adult females that were radio-collared of which, 154 adults received vaginal implant transmitters to aid in capture and monitoring neonate survival. Ultrasonography was used to determine *in-utero* fetal rates.

- Body condition on about 1 March, as estimated from percent body fat and depth of longissimus dorsi muscle via ultrasonographpy, was better ($P \leq 0.001$) in adult females receiving enhanced winter nutrition (n = 78) than for control adult females not receiving enhanced nutrition (n= 76). Serum thyroid hormone levels were also higher in adult females receiving enhanced nutrition compared to control adult females not receiving better nutrition. Pregnancy and fetal rates were similar (0.95 and 1.80 fetuses per female) for adult females receiving and not receiving enhanced nutrition.

- The finite rate of population increase, λ, was 1.20 for those deer receiving enhanced nutrition. For those deer not receiving enhanced nutrition, the finite rate of increase was 1.04 indicating a stable or slightly increasing population. The nutrition enhancement therefore, had a dramatic effect on deer population performance, indicating habitat quality was ultimately limiting the population that was also subject to natural levels of predation. In comparison, intensive control of coyote and cougar populations in Idaho had marginal positive impacts on survival rates of neonate fawns, 6-month old fawns, and adult mule deer and ultimately, net population growth (Hurley et al. 2005).

- These enhanced nutrition experimental results provided a foundation for focusing deer management efforts on improving habitat quality in Colorado's pinyon-juniper mule deer winter ranges rather than trying to intensively control or reduce coyote and/or cougar populations.

Phase 1B

- Excluding herbivory from semi-arid sagebrush and mountain brush plant communities resulted in increased dominance by shrub species and only minor changes in herbaceous species in non-grazed compared to adjacent grazed areas. Comparisons were based on measurements made in summer 2000 at 17 permanently fenced exclosures in western Colorado where ungulate herbivory was excluded for 40 to 50 years. Improving herbaceous and overall species diversity within established shrub dominated habitats will not likely occur by excluding grazing.

Phase 2A

- Evaluating the effects of landscape alterations within senescent old-growth pinyon-juniper winter ranges on mule deer population performance parameters was initiated in 2004-05 as a pilot study and precursor to full-scale study implementation. Over-winter fawn survival was estimated on 2 critical pinyon-juniper winter range habitat treatment evaluation areas on the Uncompahgre Plateau in 2004-05. Both areas were found to be logistically adequate for future work and fawn survival was 0.84 to 0.96 on both sites (n = 25 radio-collared fawns per site).

- A project study plan for evaluating landscape habitat treatments was completed in 2005. Full-scale 4-year implementation began during winter 2005-06 as over-winter fawn survival, adult female body condition, and mule deer density were estimated among 8 habitat treatment evaluation areas (each 10-20 km^2 in size) on the Uncompahgre Plateau. Pinyon-juniper habitat areas were categorized as controls (non-treated and senescent), pre-treatmeant (treated to reduce density of pinyon-juniper during last 10-15 years), and treatment (receiving additional habitat enhancements during this study). Initial survival rate estimates ranging from 0.76 to 0.88 suggest over-winter fawn survival may vary among habitat treatment levels. Estimates of deer density reaffirmed that deer densities in the northern study areas were lower (4-8 deer/km^2) than densities in the southern study areas (19-57 deer/km^2). Continued estimation of deer performance parameters over the next 3 years should allow detecting whether altering senescent pinyon-juniper habitats improves mule deer net productivity.

Resulting Peer-Reviewed Publications:

BISHOP, C.J., G.C. WHITE, D.J. FREDDY, AND B.E. WATKINS. 2003. How habitat quality affects hunting. Mule Deer 8:18-20.

BISHOP, C.J., D.J. FREDDY, G.C. WHITE, B.E. WATKINS, T.R. STEPHENSON, AND L.L. WOLFE. 2006 In Review. Using vaginal implant transmitters to aid in capture of neonates from marked mule deer. Journal of Wildlife Management.

MANIER, D.J., AND N.T. HOBBS. 2006. Large herbivores influence the composition and diversity of shrub-steppe communities in the Rock Mountains, USA. Oecologia 146:641-651.

SCHULTHEISS, P.C., H. VAN CAMPEN, C.J. BISHOP, L.L. WOLFE, AND B. PODELL. 2006 In Review. Malignant catarrhal fever associated with ovine herpesvirus-2 in free-ranging mule deer (*Odocoileus hemionus*) in Colorado. Journal of Wildlife Disease.

Associated Annual Wildlife Research Progress Reports Available from the Colorado Division of Wildlife Research Library, Fort Collins, Colorado:

BERGMAN, E.J., C.J. BISHOP, D.J. FREDDY, AND G.C. WHITE. 2005. Pilot evaluation of winter range habitat treatments on over-winter mule deer fawn survival. Colorado Division of Wildlife, Wildlife Research Report July: 24-35.

BERGMAN, E.J., C.J. BISHOP, D.J. FREDDY, AND G.C. WHITE. 2006 In Press. Evaluation of winter range habitat treatments on over-winter mule deer fawn survival. Colorado Division of Wildlife, Wildlife Research Report July: Available September 2006.

BISHOP, C.J. AND G.C. WHITE. 2002. Effect of nutrition and habitat enhancements on mule deer recruitment and survival rates. Colorado Division of Wildlife, Wildlife Research Report July: 65-79.

BISHOP, C.J., D.J. FREDDY, AND G.C. WHITE. 2002. Pilot study: use of ultrasound and vaginal implants. Colorado Division of Wildlife, Wildlife Research Report July: 81-92.

BISHOP, C.J. G.C. WHITE, D.J. FREDDY, AND B.E. WATKINS. 2003. Effect of nutrition and habitat enhancements on mule deer recruitment and survival rates. Colorado Division of Wildlife, Wildlife Research Report July: 33-54.

BISHOP, C.J. G.C. WHITE, D.J. FREDDY, AND B.E. WATKINS. 2004. Effect of nutrition and habitat enhancements on mule deer recruitment and survival rates. Colorado Division of Wildlife, Wildlife Research Report July: 21-43.

BISHOP, C.J. G.C. WHITE, D.J. FREDDY, AND B.E. WATKINS. 2004. Effect of nutrition and habitat enhancements on mule deer recruitment and survival rates. Colorado Division of Wildlife, Wildlife Research Report July: 21-43.

BISHOP, C.J. G.C. WHITE, D.J. FREDDY, AND B.E. WATKINS. 2005. Effect of nutrition and habitat enhancements on mule deer recruitment and survival rates. Colorado Division of Wildlife, Wildlife Research Report July: 37-65.

BISHOP, C.J. G.C. WHITE, D.J. FREDDY, AND B.E. WATKINS. 2006 In Press. Effect of nutrition and habitat enhancements on mule deer recruitment and survival rates. Colorado Division of Wildlife, Wildlife Research Report July: Available September 2006.

Associated Presentations at Professional Workshops/Symposia:

BISHOP, C.J., G.C. WHITE, D.J. FREDDY, AND B.E. WATKINS. 2001. Effects of nutrition and habitat enhancements on mule deer fawn recruitment: preliminary results. Fourth Western States and Provinces Deer and Elk Workshop, August 1-3, Wilsonville, Oregon, USA.

BISHOP, C.J., G.C. WHITE, D.J. FREDDY, AND B.E. WATKINS. 2003. Effects of enhanced winter nutrition of free-ranging mule deer on fawn recruitment and recruitment. Fifth Western States and Provinces Deer and Elk Workshop, May 21-24, Jackson, Wyoming, USA.

BISHOP, C. J., G. C. WHITE, D. J. FREDDY, AND B. E. WATKINS. 2004. The effect of habitat quality on mule deer fawn survival and recruitment: interim report. Society for Range Management 57th Annual Meeting, January 24–30, Salt Lake City, Utah, USA.

BISHOP, C. J., G. C. WHITE, D. J. FREDDY, AND B. E. WATKINS. 2004. Effect of enhanced nutrition of free-ranging mule deer on fawn survival and recruitment rates. The Wildlife Society 11th Annual Conference, September 18–22, Calgary, Alberta, Canada.

BISHOP, C. J., G. C. WHITE, D. J. FREDDY, AND B. E. WATKINS. 2005. Effect of enhanced nutrition of free-ranging mule deer on population performance. Sixth Western States and Provinces Deer and Elk Workshop, May 16–18, Reno, Nevada, USA.

BISHOP, C. J., G. C. WHITE, D. J. FREDDY, AND B. E. WATKINS. 2005. Effect of enhanced nutrition on mule deer population performance in pinyon-juniper habitat. Ecology and Management of Pinyon-Juniper and Sagebrush Communities Workshop, May 16–19, Montrose, Colorado, USA.

<u>III. Improve and Evaluate Statewide Systems and Technical Methods Used to Determine Status of Mule Deer Populations</u>.

Monitoring the status of mule deer in Colorado has advanced due to the synergy of the research section developing population monitoring systems and terrestrial management section implementing those monitoring systems as appropriate on a statewide basis. Developing, implementing, and maintaining, statistically rigorous systems to estimate statewide hunter harvest of mule deer, population densities and size for selected deer populations, adult female and fawn survival rates for selected populations, and developing future research projects requires scientific input, oversight and periodic evaluations. Additionally, proper evaluation requires a rigorously maintained and updated database containing statewide mule deer population data. As part of a multi-functional quality control process, the CDOW obtains oversight of key statewide mule deer research and management activities via a contract to a qualified individual through this Federal Aid Grant.

Result Highlights:

- Provided annual assistance to maintaining and improving statewide deer hunter harvest survey sampling systems and harvest data acquisition.

- Provided annual maintenance and oversight of the DEAMAN (Deer-Elk-Antelope-Management) database representing 20 years of statewide data acquisition and storage. Included updating data files, updating user's manual, converting DEAMAN operating system to Windows 2000 and then Windows XP, and facilitating the conversion of DEAMAN to a server-based operating system.

- Provided 1- and 3-day training workshops in 2002 and 2004 in population modeling and use of DEAMAN for up to 18 terrestrial management biologists. Provided annual support to up to 18 management biologists in their day-to-day use of DEAMAN and associated population modeling spreadsheet analyses.

- Provided annual assistance to management biologists in analyzing survival rates of adult female and fawn mule deer and estimates of population density and size within 5 key deer populations used to critically assess the statewide trends mule deer.

- Provided critical technical expertise and credibility to designing and implementing a public demonstration experiment to evaluate the reliability of Colorado's methods to estimate mule deer population size and to model mule deer populations.

- Provided scientific and technical expertise annually to all facets of the mule deer research program inclusive of experimental designs and approaches to addressing mule deer population estimation techniques, habitat enhancement studies, and spatial analyses of deer as related to the spread of chronic wasting disease.

- Senior or co-authored multiple peer-reviewed publications regarding mule deer research and statewide management in Colorado and provided scientific comment and expertise and several professional workshops pertaining to mule deer and other ungulate research and management.

Resulting Peer-Reviewed Publications:

BISHOP, C.J., G.C. WHITE, D.J. FREDDY, AND B.E. WATKINS. 2005. Effect of limited antlered harvest on mule deer sex and age ratios. Wildlife Society Bulletin 33:662-668.

BOWDEN, D.C., G.C. WHITE, A.B. FRANKLIN, AND J.L. GANEY. 2003. Estimating population size with correlated sampling unit estimates. Journal of Wildlife Management 67:1-10.

FREDDY, D.J., G.C. WHITE, M.C. KNEELAND, R.H. KAHN, J.W. UNSWORTH, W.J. DEVERGIE, V.K. GRAHAM, J.H. ELLENBERGER, AND C.H. WAGNER. 2004. How many mule deer are there? Challenges of credibility in Colorado. Wildlife Society Bulletin 32:916-927.

MASON. R., L.H. CARPENTER, M. COX, J.C. DEVOS, JR., J. FAIRCHILD, D.J. FREDDY, J.R. HEFFELFINGER, R.H. KAHN, S.M MCCORQUODALE, D.F. PAC, D. SUMMERS, G.C. WHITE, AND B.K. WILLIAMS. 2006 In Press. A case for standardized ungulate surveys and data management in the western United States. Wildlife Society Bulletin.

WHITE, G.C. 2004 In Press. Correcting counts: techniques to de-index. Wildlife Research.

WHITE, G.C., D.J. FREDDY, R.B. GILL, AND J.H. ELLENBERGER. 2001. Effect of adult sex ratio on mule deer and elk productivity in Colorado. Journal of Wildlife Management 65: 436-444.

WHITE, G.C., AND B.C. LUBOW. 2002. Fitting spreadsheet population models to multiple sources of observed data. Journal of Wildlife Management 66:300-309.

Associated Annual Wildlife Research Progress Reports Available from the Colorado Division of Wildlife Research Library, Fort Collins, Colorado:

FREDDY, D.J. 2002. Deer aerial survey population estimation Rangely deer data analysis unit D-6, GMU 10. Colorado Division of Wildlife, Wildlife Research Report July: 117-168.

WHITE, G.C. 2002. Improved population modeling-DEAMAN system administration. Colorado Division of Wildlife, Wildlife Research Report July: 93-102.

WHITE, G.C. 2003. Multispecies Investigations: consulting services for mark-recapture analysis. Colorado Division of Wildlife, Wildlife Research Report July: 189-196.

WHITE, G.C. 2004. Multispecies Investigations: consulting services for mark-recapture analysis. Colorado Division of Wildlife, Wildlife Research Report July: 151-161.

WHITE, G.C. 2005. Multispecies Investigations: consulting services for mark-recapture analysis. Colorado Division of Wildlife, Wildlife Research Report July: 67-75.

Associated Presentations at Professional Workshops/Symposia:

FREDDY, D.J., G.C. WHITE, M.C. KNEELAND, V.K. GRAHAM, W.J. DEVERGIE, J.H. ELLENBERGER, J.W. UNSWORTH, C.H. WAGNER, P.M. SCHNURR, V.W. HOWARD, JR., AND T.S. BICKLE. 2001. Estimating mule deer populatin size using Colorado quadrat system corrected for Idaho mule deer sightability: a sportsmen's issue. Fourth Western States and Provinces Deer and Elk Workshop, August 1-3, Wilsonville, Oregon, USA.

FREDDY, D.J. 2005. Moderator: Session on Representative Strategies. International Association of Fish and Wildlife Agencies Ungulate Data Gathering, Analysis, and Use Workshop, 19 May. Reno, Nevada, USA.

WATKINS, B.E., J.H. OLTERMAN, AND T.M. POJAR. 2001. Mule deer survival studies on the Uncompahgre Plateau, Colorado 1997-2001. Fourth Western States and Provinces Deer and Elk Workshop, August 1-3, Wilsonville, Oregon, USA.

WAGNER, C.H., B.E. WATKINS, J. VAYHINGER, AND S. STEINERT. 2001. Summary of mule deer survival studies in Colorado, 1997-2001. Fourth Western States and Provinces Deer and Elk Workshop, August 1-3, Wilsonville, Oregon, USA.

WHITE, G.C. 2001. Effect of adult sex ratio on mule deer and elk productivity in Colorado. Fourth Western States and Provinces Deer and Elk Workshop, August 1-3, Wilsonville, Oregon, USA.

WHITE, G.C. 2005. Featured Speaker: Theoretical considerations and practical implications. International Association of Fish and Wildlife Agencies Ungulate Data Gathering, Analysis, and Use Workshop, 19 May. Reno, Nevada, USA.

IV. Assess the Impacts of Chronic Wasting Disease on Mule Deer Populations.

Chronic wasting disease (CWD) in mule deer has been a focal point of various research efforts within the CDOW since the early 1990s. Research on CWD was proposed to be funded within this Federal Aid 5-Year Grant. Partial funding from Federal Aid occurred during 2001 but after that year, funding for CWD was obtained from sources other than the Federal Aid Grant. As such, research potentially occurring while Federal Aid funding was in effect was limited to supporting activities associated with publications.

Resulting Peer-Reviewed Publications:

GROSS, J.E., AND M.W. MILLER. 2001. Chronic wasting disease in mule deer: disease dynamics and control. Journal of Wildlife Management 65:205-215.

MILLER, M.W., AND E.S. WILLIAMS. 2002. Detecting PrP^{CWD} in mule deer by immunohistochemistry of lymphoid tissues. Veterinary Record 151:610-612.

WILLIAMS, E.S., AND M.W. MILLER. 2002. Chronic wasting disease in deer and elk in North America. *Revue Scientifique et Technique Office International des Epizooties* 21:305-316.
WILLIAMS, E.S., M.W. MILLER, T.J. KREEGER, R.H. KAHN, AND E.T. THORNE. 2002. Chronic wasting disease of deer and elk: a review with recommendations for management. Journal of Wildlife Management 66:551-563.
WOLFE, L.L., M.M. CONNER, T.H. BAKER, V.J. DREITZ, K.P. BURNHAM, E.S. WILLIAMS, N.T. HOBBS, AND M.W. MILLER. 2002. Evaluation of antemortem sampling to estimate chronic wasting disease prevalence in free-ranging mule deer. Journal of Wildlife Management 66:564-573.

Associated Annual Wildlife Research Progress Reports Available from the Colorado Division of Wildlife Research Library, Fort Collins, Colorado:

Miller, M.W. 2002. Chronic wasting disease in mule deer; monitoring and management. Colorado Division of Wildlife, Wildlife Research Report July: 113-116.

Associated Presentations at Professional Workshops/Symposia:

Conner, M.M. 2005. Increasing the efficacy of chronic wasting disease detection via selective and targeted sampling. Sixth Western States and Provinces Deer and Elk Workshop, May 16–18, Reno, Nevada, USA.

V. Develop Alternative Approaches to Control Over-abundant Urban-exurban Mule Deer Populations.

An increasing problem with mule deer in Colorado and other states is localized over-abundance of deer in urban-exurban areas. Deer have successfully invaded highly developed human habitats where increasing incidences of browsing damage to lawns, ornamentals, and gardens, and vehicle-deer collisions created the need for some form of deer population control. In these urban-exurban situations, traditional hunting or even highly controlled hunting or culling may not be feasible or socially acceptable. The potential to develop and use hormonal fertility control to reduce net recruitment of deer into these localized populations was recognized by CDOW during the 1990s. Research was initiated to test available hormonal therapies using captive mule deer at the CDOW Foothills Wildlife Research Facility. A portion of this fertility control research was supported by this Federal Aid Grant. After late 2002, other sources of funding were applied to continue this research.

Resulting Peer-Reviewed Publications:

Baker, D.L., M.A. Wild, M.M. Conner, H.B. Ravivarapu, R.L. Dunn, and T.M. Nett. 2004. Gonadotropin-releasing hormone agonist: a new approach to reversible contraception in female deer. Journal of Wildlife Diseases 40:713-724.

Associated Annual Wildlife Research Progress Reports Available from the Colorado Division of Wildlife Research Library, Fort Collins, Colorado:

Baker, D.L. 2002. Evaluation of GnRH-PAP as a long-term fertility control agent in female mule deer. Colorado Division of Wildlife, Wildlife Research Report July: 103-112.

SUMMARY

Five major multi-year research projects addressing mule deer population limiting factors, habitat status, and habitat enhancements were designed, implemented, completed, and reported upon during this segment. Furthermore, funding partially supported research projects addressing chronic wasting disease and fertility control in mule deer. Additionally, funding provided critical scientific and technical expertise quality control oversight for statewide deer hunter harvest surveys, statewide deer population databases, mule deer survival and population estimate management surveys, mule deer population modeling, and mule deer research projects.

LITERATURE CITED

BALLARD, W.B., D. LUTZ, T.W. KEEGAN, L.H. CARPENTER, AND J.C. DEVOS, JR. 2001. Deer-predator relationships: a review of recent North American studies with emphasis on mule and black-tailed deer. Wildlife Society Bulletin 29:99-115.

BISHOP, C.J., AND G.C. WHITE. 2000. Effects of habitat enrichment on mule deer recruitment and survival rates-a program study plan narrative. Colorado Division of Wildlife, Wildlife Research Report July: 135-180.

DEVOS, JR., J.C., M.R. CONOVER, AND N.E. HEADRICK (EDITORS). 2003. Mule deer conservation: issues and management strategies. Berryman Institute Press, Utah State University, Logan, USA.

GILL, R.B., T.D.I BECK, C.J. BISHOP, D.J. FREDDY, N.T. HOBBS, R.H. KAHN, M.W. MILLER, T.M. POJAR, AND G.C. WHITE. 2001. Declining mule deer populations in Colorado: reasons and responses. Colorado Division of Wildlife Special Report 77. Fort Collins, Colorado, USA.

HURLEY, M.A., M. SCOTT, AND J.W. UNSWORTH. 2002. Influence of predators on mule deer populations. Federal Aid in Wildlife Restoration, Job Progress Report, Project W-160-R-28. Idaho Department of Fish and Game, Boise, USA.

HURLEY, M.A., J.W. UNSWORTH, P. ZAGER, E.O. GARTON, AND D.M. MONTGOMERY. 2005. Mule deer survival and population response to experimental reduction of coyotes and mountain lions. Sixth Western States and Provinces Deer and Elk Workshop, May 16–18, Reno, Nevada, USA.

Prepared by ____
David J. Freddy, Mammals Research Leader

Colorado Division of Wildlife
July 2005 – June 2006

WILDLIFE RESEARCH REPORT

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

Period Covered: July 1, 2005 – June 30, 2006

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

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

ABSTRACT

We measured mule deer (*Odocoileus hemionus*) population parameters in response to a nutrition enhancement treatment to evaluate the relative importance of habitat quality as a limiting factor of mule deer in western Colorado during November 2000 – January 2005. We conducted preliminary data analyses upon completion of field work. We found strong evidence that enhanced nutrition increased fawn recruitment to the yearling age class. During 2002–2004, fetus-neonate survival from 1 March–15 December was higher ($\chi^2_1 = 3.846$, $P = 0.050$) for treatment fawns ($S(t) = 0.528$, SE = 0.027) than control fawns ($S(t) = 0.401$, SE = 0.025). During 15 December–15 June, 2001–2004, the overwinter survival rate of fawns was greater ($\chi^2_1 = 18.781$, $P < 0.001$) in the treatment unit ($S(t) = 0.895$, SE = 0.029) than in the control unit ($S(t) = 0.655$, SE = 0.044). Using a staggered entry survival process with data combined over years, survival of treatment fetuses to 1 year of age ($S(t) = 0.458$, SE = 0.031) was 0.18 higher ($\chi^2_1 = 13.20$, $P < 0.001$) than survival of control fetuses to 1 year of age ($S(t) = 0.276$, SE = 0.026). The finite rate of population increase, λ, was 1.20 for treatment deer and 1.04 for control deer. Our preliminary results provided a foundation for focusing deer management efforts on improving habitat quality in western Colorado pinyon-juniper (*Pinus edulis-Juniperus osteosperma*) ecosystems with corresponding research efforts to quantify the effects of habitat manipulations on deer performance. During the past year, we monitored post-treatment adult doe survival, identified a set of publications to be completed for submission to scientific journals, initiated final data analyses corresponding to the set of publications, and worked on or completed several manuscripts. A manuscript on the effectiveness of vaginal implant transmitters was accepted for publication in the Journal of Wildlife Management, and a manuscript documenting malignant catarrhal fever in the deer population was submitted to the Journal of Wildlife Diseases. The lead investigator also wrote a portion of a book chapter regarding the effects of excessive herbivory on mule deer populations.

WILDLIFE RESEARCH REPORT

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

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

P. N. OBJECTIVE

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

SEGMENT OBJECTIVES

1. Radio-monitor and measure post-treatment survival of the sample of radio-collared mule deer adult does.
2. Identify a set of publications to be generated from the research.
3. Initiate final data analyses to support preparation of manuscripts.
4. Prepare manuscripts for submission to scientific journals for publication.

INTRODUCTION

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

We designed and implemented a field experiment where we measured deer population responses to a nutrition enhancement treatment to further understand the causative factors underlying observed deer population dynamics. We conducted the study on the Uncompahgre Plateau in southwest Colorado, where several predator species were present in abundant numbers: coyotes (*Canis latrans*), mountain lions (*Felis concolor*), and bears (*Ursus americanus*). In addition to predation, myriad diseases in combination have proximately affected survival of the Uncompahgre deer population (Pojar and Bowden 2004, B. E. Watkins, Colorado Division of Wildlife, unpublished data). Predator numbers were not manipulated in any manner during the course of the study. All factors were left constant with the exception of deer nutrition. Deer nutrition was enhanced by providing supplemental feed to deer occupying a treatment area during winter. We measured December fawn recruitment and overwinter fawn survival in response to the treatment to determine whether deer nutrition was ultimately more limiting than predation or disease. A second phase of research was initiated in 2005 to quantify deer population parameters in response to manipulations of pinyon-juniper (*Pinus edulis*-*Juniperus osteosperma*) habitat (Bergman et al. 2006). The objective of this research is to determine whether habitat can be effectively improved for mule deer by introducing disturbance into late-seral pinyon-juniper stands.

STUDY AREA

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

METHODS

Refer to Bishop et al. (2005) for field methodology employed during 2000–2005. During fiscal year 2005-06, we continued to monitor radio-collared adult female deer occupying the two experimental units. Our primary research efforts were focused on data analysis and the preparation of manuscripts for publication in scientific journals. The lead investigator completed additional coursework in mathematical statistics, data analysis, and animal nutrition. We submitted or intend to submit the following manuscripts for publication:

1. Effect of enhanced nutrition on the population performance of free-ranging mule deer. Journal of Wildlife Management.
    a. A separate publication may be submitted to Science focused on the documentation of coyote predation as a compensatory mortality factor during winter.
2. Using vaginal implant transmitters to aid in capture of neonates from marked mule deer. Journal of Wildlife Management.
3. Evaluation of overdispersion in survival analyses of neonate mule deer associated with sibling fawns. Journal of Wildlife Management.
4. Evaluation of serum thyroid hormone levels as an indicator of body condition during late winter. Journal of Wildlife Management.
5. Evaluation of mule deer age and sex ratios as a response variable in field research. Journal of Wildlife Management.
6. Bovine viral diarrhea isolation and seroprevalence in a free-ranging mule deer (*Odocoileus hemionus*) population in southwest Colorado. Journal of Wildlife Diseases.
7. Malignant catarrhal fever associated with ovine herpesvirus-2 in free-ranging mule deer (*Odocoileus hemionus*) in Colorado. Journal of Wildlife Diseases.

8. Spatial patterns in mortality causes of neonatal mule deer across a land use gradient in southwest Colorado. (This could go to several different journals or be published as an internal CDOW publication.)
9. Disease assessment in a Colorado mule deer population following a decline. Journal of Wildlife Diseases (or internal CDOW publication).

RESULTS AND DISCUSSION

A comprehensive presentation and discussion of preliminary results was provided by Bishop et al. (2005). These results have not changed and therefore we do not repeat them here. The following manuscript was accepted for publication (Appendix I):

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

The following manuscript was submitted for publication (Appendix II):

Schultheiss, P. C., H. Van Campen, T. R. Spraker, C. J. Bishop, L. L. Wolfe, and B. Podell. Malignant catarrhal fever associated with ovine herpesvirus-2 in free-ranging mule deer (*Odocoileus hemionus*) in Colorado. Journal of Wildlife Diseases.

The following book chapter was completed and currently undergoing external peer review:

Watkins, B. E., C. J. Bishop, E. J. Bergman, A. Bronson, B. Hale, D. W. Lutz, B. F. Wakeling, and L. C. Carpenter. Habitat guidelines for mule deer: Colorado Plateau Ecoregion. Mule Deer Working Group, Western Association of Fish and Wildlife Agencies.

The lead investigator completed the following courses to assist with data analysis and manuscript preparation: mathematical statistics (2), population dynamics, population analysis, wildlife nutrition, and animal metabolism. A data bootstrap analysis in SAS was initiated to quantify the degree of overdispersion in our neonate survival data. Overdispersion represents extra-binomial variation in sample data arising from violations of independence. Functionally, undetected overdispersion will result in overly precise variance estimates, and ultimately, incorrect inference. Our neonate samples were subject to independence violations because all captured siblings were routinely radio-collared and treated as independent sample units. A known fates analysis will be conducted using Program MARK to quantify the effect of the nutrition enhancement treatment on various stages of fawn survival while simultaneously accounting for temporal variation and individual heterogeneity (i.e., fawn weight and hind foot length). Once these analyses are completed, we will write and submit manuscripts accordingly. The remaining manuscripts will then be handled in order of priority. Our anticipated timeline is detailed below.

Draft manuscripts completed in FY 06-07:

1. Effect of enhanced nutrition on the population performance of free-ranging mule deer. Journal of Wildlife Management.
2. Evaluation of overdispersion in survival analyses of neonate mule deer associated with sibling fawns. Journal of Wildlife Management.
3. Evaluation of serum thyroid hormone levels as an indicator of body condition during late winter. Journal of Wildlife Management.

Draft manuscripts completed in FY 07-08:

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

The final proposed manuscript related to disease assessment will be completed as time allows.

SUMMARY

Enhanced winter nutrition of free-ranging deer caused an increase in both fetus-neonate survival and overwinter fawn survival, resulting in higher yearling recruitment (Bishop et al. 2005). Overwinter adult doe survival increased as a result of the treatment, but annual survival was more similar among treatment and control adult does. Combining all parameter estimates into a deterministic population model, the treatment population indicated an exceptionally high rate of increase ($\lambda = 1.20$) while the control population ($\lambda = 1.04$) was indicative of the overall Uncompahgre deer population during 2000–2004. The nutrition enhancement treatment was artificial in the sense that we applied it only to test whether habitat quality was ultimately more limiting than predation or other factors. Our results to do not provide support for managing deer populations with nutrition supplements because our treatment delivery approach could not be applied to a large number of animals over a large area. Rather, our results provide a foundation for focusing deer management efforts on improving habitat quality in western Colorado pinyon-juniper ecosystems with corresponding research efforts to quantify the effects of habitat manipulations on deer. We are presently in the process of conducting final data analyses and preparing and submitting manuscripts for publication in scientific journals.

LITERATURE CITED

BALLARD, W. B., D. LUTZ, T. W. KEEGAN, L. H. CARPENTER, AND J. C. DEVOS, JR. 2001. Deer-predator relationships: a review of recent North American studies with emphasis on mule and black-tailed deer. Wildlife Society Bulletin 29:99–115.

BERGMAN, E. J., C. J. BISHOP, D. J. FREDDY, AND G. C. WHITE. 2006. Evaluation of winter range habitat treatments on over-winter survival and body condition of mule deer. Federal Aid in Wildlife Restoration Project W–185–R, Job Progress Report. Wildlife Research Report, Colorado Division of Wildlife, Fort Collins, USA.

BISHOP, C. J., G. C. WHITE, D. J. FREDDY, AND B. E. WATKINS. 2005. Effect of nutrition and habitat enhancements on mule deer recruitment and survival rates. Federal Aid in Wildlife Restoration Project W–185–R, Job Progress Report. Wildlife Research Report, Colorado Division of Wildlife, Fort Collins, USA.

CONNOLLY, G. E. 1981. Limiting factors and population regulation. Pages 245–285 *in* O. C. Wallmo, editor. Mule and black-tailed deer of North America. University of Nebraska Press, Lincoln, USA.

GILL, R. B., T. D. I. BECK, C. J. BISHOP, D. J. FREDDY, N. T. HOBBS, R. H. KAHN, M. W. MILLER, T. M. POJAR, AND G. C. WHITE. 2001. Declining mule deer populations in Colorado: reasons and responses. Colorado Division of Wildlife Special Report Number 77. Denver, USA.

POJAR, T. M., AND D. C. BOWDEN. 2004. Neonatal mule deer fawn survival in west-central Colorado. Journal of Wildlife Management 68:550–560.

UNSWORTH, J. W., D. F. PAC, G. C. WHITE, AND R. M. BARTMANN. 1999. Mule deer survival in Colorado, Idaho, and Montana. Journal of Wildlife Management 63:315–326.

Prepared by ________________________

Chad J. Bishop, Wildlife Researcher

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

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

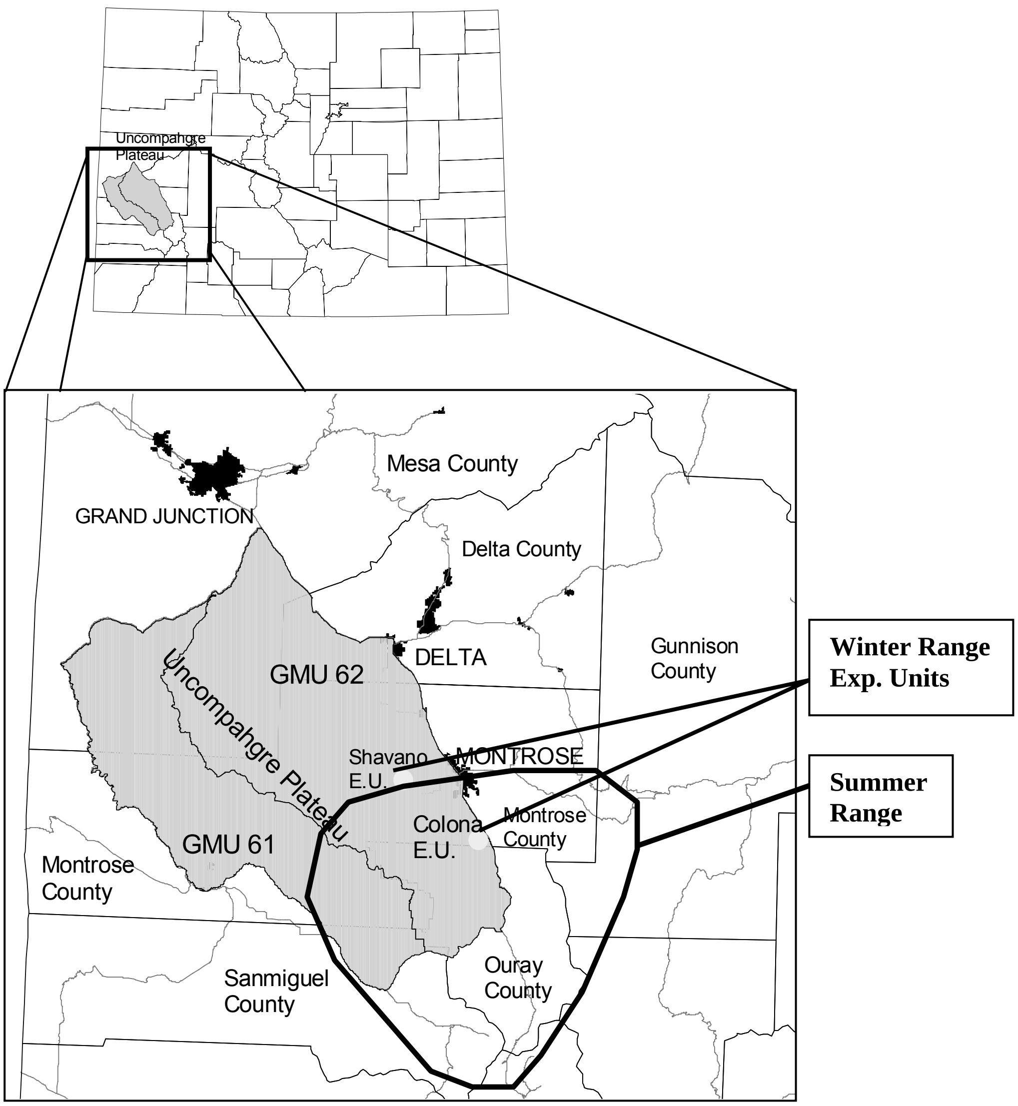

Figure 2. Location of Colona and Shavano (Units A and B) experimental units on the Uncompahgre Plateau, southwest Colorado; and location of the summer range study area encompassing the southern Uncompahgre Plateau and adjacent San Juan Mountains.

APPENDIX I

The following manuscript (referenced here by Abstract) was accepted for publication by the Journal of Wildlife Management.

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

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

ABSTRACT

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

APPENDIX II

The following manuscript (referenced here by Abstract) was submitted to the Journal of Wildlife Diseases.

MALIGNANT CATARRHAL FEVER ASSOCIATED WITH OVINE HERPESVIRUS-2 IN FREE-RANGING MULE DEER (*Odocoileus hemionus*) IN COLORADO

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

ABSTRACT

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

Colorado Division of Wildlife
July 2005 – June 2006

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	W-185-R	:

Period Covered: July 1, 2005 - June 30, 2006

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

Personnel: L. Baeten, D. Baker, B. Banulis, J. Boss, A. Cline, D. Coven, M. Cowardin, K. Crane, B. deVergie, K. Duckett, D. Hale, C. Harty, E. Joyce, R. Lockwood, J. McMillan, M. Michaels, G. Miller, M. Miller, M. Sirochman, T. Sirochman, R. Swygman, C. Tucker, B. Watkins, L. Wolfe, M. Zeaman CDOW, L. Carpenter - Wildlife Management Institute, D. Felix - Olathe Spray Service, P. Johnston and R. Swisher - Quicksilver Air

ABSTRACT

We designed and initiated a multi-year, multi-area study to assess the impacts of landscape level winter range habitat improvement treatments on mule deer population performance on the Uncompahgre Plateau and adjacent valleys in southwestern Colorado. During this first year, we measured all response variables on 5 study areas. 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 high (mean survival rate of 0.82 (.036 SE)) for the winter of 2005-2006. Preliminary evidence suggests that areas that have received habitat treatments may positively influence survival. However, based on estimates of total body fat for adult female deer, there was no apparent distinction between our habitat treatment study areas. Point estimates of deer density on the 5 study areas during the winter of 2005-2006 confirmed the latitudinal trend that areas on the northern portion of the Uncompahgre Plateau typically have lower deer densities than the southern portion of the Plateau. Due to overlap of 95% confidence intervals for our deer density estimates, a refinement of sampling techniques will be implemented for future years of this study.

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

1. To assess whether mechanical/chemical habitat treatments increase over-winter fawn survival.
2. To assess whether mechanical/chemical habitat treatments increase the local carrying capacity of deer, measured through deer density.
3. To assess whether the impacts of enhancing mule deer habitat via mechanical/chemical habitat treatments can be detected through improvement of adult doe body condition.

SEGMENT OBJECTIVES

1. Capture and radio-collar the minimum necessary sample (n=25) of 6 month-old fawns during November through early January in each of 5 study areas.
2. Measure overwinter 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/control cross-over design with *ad libitum* pelleted food supplements as a substitute for instantaneous high quality habitat improvements (Bishop et al. 2004). The primary hypothesis behind this research concerned the interaction between predation and nutrition. If supplemental forage treatments improved over-winter fawn survival (i.e. if predation did not prevent an increase), then it could be concluded that over-winter nutrition was the primary limiting factor on populations. As such, preliminary evidence suggests that nutrition enhancement treatments increased fawn survival by as much as 20% (C.J. Bishop, personal communication). This research effectively identified some of the underlying processes in mule deer population regulation, but did not test the effectiveness of acceptable habitat management techniques. Due to the undesirable effects of feeding wildlife (e.g. artificially elevating density, increased potential for disease transmission and cost), a more appropriate technique for achieving a high quality nutrition enhancement needs to be assessed.

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

STUDY AREA

At the onset (Bergman et al. 2005, Appendix I), we identified 2 pairs of treatment/control 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/control units could not be further than 10km apart, but needed to have adequate buffer to minimize the movement of animals between the treatment and control areas.
2) Control 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.

A 5th study area (Shavano Valley, 20 km^2) was added to increase the level of inference that could be drawn from this study. The existing treatments on this 5th area occurred on two occasions. During the late 1960's, parts of this area was anchor chained. During the early 2000's, these areas were retreated with rollerchopping. In total, ~14.5 km^2 were treated out of the 20 km^2 within this study area.

The high density treatment area is located on Billy Creek State Wildlife Area (approximately 20km south of Montrose, CO). The high density control 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 control area is located on Sowbelly and Tatum draws (approximately 25km west of Delta, CO and approximately 8km from Peach Orchard Point). Both of the low density study areas are located in GMU 62 (DAU D-19). Shavano Valley was also located in GMU 62 (DAU D-19) to the west of Montrose, CO (see figure of study areas in Appendix I).

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. Fawns were fitted with radio collars made of vinyl belting and equipped with mortality sensors, which after remaining motionless for 4 hours, increase the pulse rate of received signals. To make fawn collars temporary, one end of the collar was cut in half and reattached using rubber surgical tubing; fawns shed the collars after approximately 6 months.

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 composition, an additional 30 adult female deer were captured via helicopter net-gunning and fitted with permanent radio-collars, also having mortality sensors, in late February within each of 2 study areas; our low density control area and on our high density treatment area. 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 this first year of data, plus data collected during a pilot year. In addition to including individual covariates (fawn sex and mass), we wished to explore the role of habitat treatment history on survival. Due to the preliminary nature of these analyses and the ongoing status of the habitat treatment work, we did not attempt to rank individual study areas. Rather, our analyses were conducted such that areas were included and compared using two different approaches. With the first approach, areas were included as either treated or untreated. The second approach allowed for 3 levels of habitat treatment intensity (untreated, single treatment or ongoing treatments).

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

RESULTS AND DISCUSSION

Minimum necessary sample sizes were met in all study areas for all components of this research (n = 25 fawns per area, n = 30 adult females for body condition). Capture related mortalities occurred on 3 of 188 occasions (1.6%, 1 of 127 fawns, 2 of 61 does). Mean mass of all fawns was 36.3 kg (Table. 1).

Compared to results from other research throughout the west, as well as on the Uncompahgre Plateau, estimates of fawn survival for the winter of 2005-2006 were high (Unsworth et al. 1999, Bishop et al. 2004). Across our 5 study areas, estimated survival rates ranged between 0.76 (.085 SE) and 0.88 (.065), with mean survival rate of 0.82 (.036) (Table 2). While these rates are lower than those measured during the pilot year of this research, they remain higher than average (Bergman et al. 2005). Based on anecdotal climate information, we suspect that winter conditions during these past two winters have been much milder than what historically is considered an average winter.

Preliminary survival models indicate that the single most influential parameter affecting overwinter fawn survival has been fawn mass as was documented by Bishop et al. (2004). Additionally, the survival model composed solely of fawn mass was also the most parsimonious of all models (Table 3). However, based on ΔAIC_c scores, there was minimal differentiation between models also including sex and study area (with study area being classified as either treatment or control). While model weights preliminarily indicate that study area treatment history is not the strongest variable influencing survival, our data suggests that habitat treatments positively influence survival. While models including study area treatment intensity were consistently within a ΔAICc score of 3 of the most supported model, the weights for these models were quite low. We feel the lack of support for these models is an artifact of the preliminary nature of these analyses and the small number of study areas included. When categorized by treatment intensity, 7 study areas are split into 3 categories. When categorized as treatment/control, 7 study areas are split into 2 categories. As the study progresses and more study areas are included, a treatment intensity effect is likely to be more supported, if an intensity effect exists.

Similar to the trend observed with overwinter survival, late winter body condition estimates for adult females during the winter of 2005-2006 were higher than those collected during previous winters on the Uncompahgre Plateau (Bishop et al. 2004 and C.J. Bishop, personal communication). However, based on estimates of total body fat, there was no apparent distinction between our study areas. While significant differences ($p = .009$) in the levels of the T3 hormone (nmol/l) were observed between study areas, this did not appear to translate to differences in body condition or survival (Table 4). Based on blood samples drawn at the time of capture, differences in pregnancy rates, based on PSPB and prevalence of disease titers (BT and EHD) between study areas were not observed. Overall, pregnancy rates were high in both study areas (BCSWA = 29/29, Sowbelly = 27/29). Titers for BT were observed at low/moderate rates in both study areas (BCSWA = 8/29, Sowbelly = 7/29), as were titers for EHD (BCSWA = 8/29, Sowbelly = 5/29).

Point estimates of deer density on the 5 study areas during the winter of 2005-2006 confirmed the latitudinal trend that has been historically observed (i.e. areas on the northern portion of the Uncompahgre Plateau typically have lower deer densities than the southern portions of the Plateau) (Fig. 1). However, there was almost universal overlap of 95% confidence intervals between study areas, weakening any conclusions that can be drawn from these data. Based on these results, a refinement of sampling techniques is needed and more resources need to be directed towards density estimation. In particular, during future years we will increase the total number of flights and the overall percent of the population marked in each high density study area (Fig. 2).

SUMMARY

Survival rates for mule deer fawns across our study areas averaged 82% with a measured high of 88% and measured low of 76%. Overall body condition parameter estimates for late-winter adult female deer were high, highlighting the general mild winter conditions that were observed throughout deer winter range in southwestern Colorado. Preliminary evidence of higher deer survival in treatment areas was observed, but data were not strong enough to draw strong conclusions at this preliminary stage. Estimates of total deer density across our study areas are in line with historical estimates, however, overall precision of our estimates need to be improved before habitat treatment effects can potentially be detected.

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Table 1. Mass (mean ± SE) and sex of mule deer fawns captured on the Uncompahgre Plateau from late-November through early-January of each year. All fawns were captured by baited drop-nets or helicopter net-gunning.

		Mean Mass		
Area	**Year**	**Males**	**Females**	**Total**
BCSWA	2004	36.8 (12)	35.6 (13)	36.1 (26)
Sowbelly	2004	35.4 (10)	34.7 (15)	35.0 (25)
BCSWA	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)

Table 2. Overwinter mule deer fawn survival rates for study areas across the Uncompahgre Plateau, 2005-2006. Study areas designated with asterisks are areas where fawns were captured above winter range in the transitional habitat zone. Fawns from this zone were expected to winter on the Sowbelly study area. However, 12 of these deer wintered on a separate study area, 5 wintered on Sowbelly and 8 were ultimately censored due to collar failure. Sample size equals 25 fawns in each area.

Area	$\hat{S}$ (S.E.)
BCSWA	0.83 (.076)
Buckhorn	0.76 (.088)
Shavano	0.76 (.085)
Peach Orchard	0.88 (.065)
Sowbelly*	1.00 (.000)
Other*	0.83 (.108)

Table 3. Preliminary survival model results for radio collared fawns from the winters of 2004-2005 and 2005-2006. Models including year as a covariate were not competitive, based on ΔAIC_c values.

Model	**AICc**	**ΔAICc**	ω_i
Mass	300.152	0.00	0.313
Mass + Sex	301.182	1.03	0.187
TreatmentControl + Mass	301.237	1.09	0.182
TreatmentControl + Mass + Sex	302.164	2.01	0.114
TreatmentIntensity + Mass	302.808	2.66	0.083
TreatmentIntensity + Mass + Sex	303.789	3.64	0.051
TreatmentControl	305.199	5.05	0.025
Sex	305.570	5.42	0.021
Treatment Intensity	306.755	6.60	0.012
Area	307.578	7.43	0.008
TreatmentIntensity + Sex	308.652	8.50	0.004

Table 4. Late-winter body condition estimates for female adult mule deer from 2 study areas on the Uncompahgre Plateau, 2005-2006. Parameters designated with an asterisk indicate a significant difference ($p \leq .05$) existed between study areas. Sample sizes were 29 does in each area. Mean T3 and T4 samples are reported in nmol/l.

	Area	
Parameter	**BCSWA**	**Sowbelly**
% Body Fat	**8.80% (2.02 S.E.)**	**9.81% (2.88 S.E.)**
T3*	**1.12 (0.28 S.E.)**	**1.41 (0.51 S.E.)**
T4	**70.69 (20.94 S.E.)**	**79.97 (15.80 S.E.)**

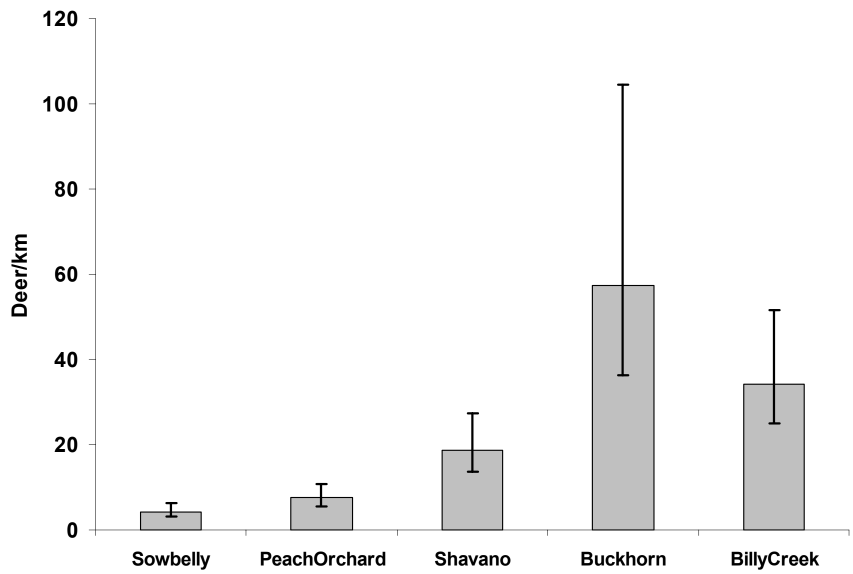

Figure 1. Deer density estimates, based on helicopter mark-resight flights, in all study areas, 2005-2006. Density estimates confirmed *a priori* expectations of latitudinal gradients from low in the northern (Sowbelly) to high in the southern (Billy Creek) study areas, based on historical density information. During future years of the study, between year variation within each study area will help identify treatment effects.

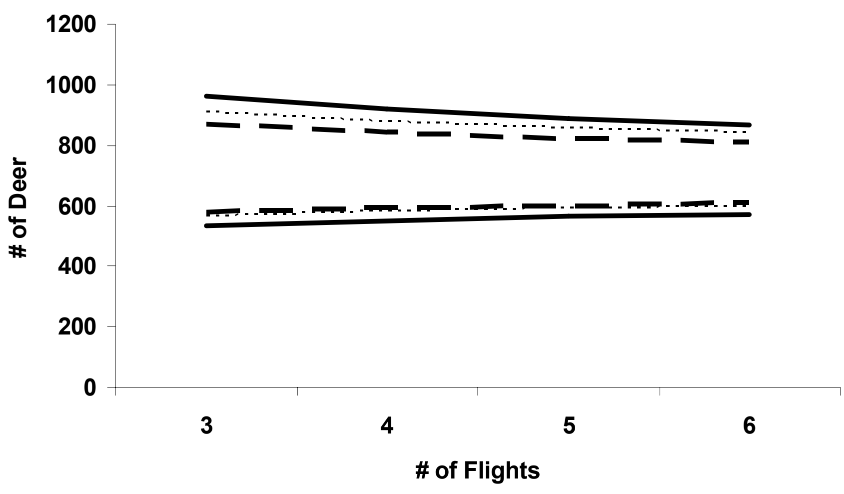

Figure 2. Simulated precision of mark-resight density estimates for areas with high deer densities. Different lines represent estimates of precision for varying percentages of the population marked. Bold solid lines depict estimates for 5% of the population, small dotted lines depict estimates for 7.5% of the population and bold dashed lines depict estimates for 10% of the population marked. During future years, six sampling flights will occur. We will also attempt to increase the proportion of the population marked via temporary marking techniques.

APPENDIX I

PROGRAM NARRATIVE STUDY PLAN
FOR MAMMALS RESEARCH
FY 2005-06 - 2008-09

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	:

Evaluation of Winter Range Habitat Treatments on Overwinter Survival and Body Condition of Mule Deer.

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Study Plan Approval

Prepared by:____________________ Date:____________

Submitted by:____________________ Date:____________

Reviewed by:____________________ Date:____________

____________________ Date:____________

____________________ Date:____________

Reviewed by:____________________ Date:____________

Biometrician

Approved by:____________________ Date:____________

Mammals Research Leader

PROGRAM NARRATIVE STUDY PLAN

FOR MAMMALS RESEARCH

Evaluation of winter range habitat treatments on over-winter survival and body condition of mule deer.

A research study proposal submitted by:
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A. NEED

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 demonstrated a tendency to show large fluctuations. Several dramatic declines have been observed since the turn of the 19^{th} century (Connolly 1981, Gill 2001, Hurly and Zager 2004). In summary, a general increase in mule deer populations was observed as early as the 1920's, with subsequent peak numbers being observed during the 1940's through the early-1960's. A subsequent decline occurred during the late-1960's through the 1970's. An increase was again observed during the 1980's before the most recent and pressing decline occurred during the early-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.

Management efforts to regulate populations have traditionally encompassed a number of approaches including predator control, interspecific/intraspecific competition and efforts to regulate habitat. Of specific interest to this study, state and federal land management agencies have conducted large scale habitat treatments under the guise of improving habitat quality for wildlife over the past 40 years. Many treatments have attempted to directly increase the quality of winter range for mule deer. Additionally, programs such as the Habitat Evaluation Program (HEP) (USFWS 1976) have been developed to assess habitat quality for different species, including mule deer. However, experimental research connecting mule deer population performance to actual habitat quality has been minimal (Kie et al. 1980, Kie 1984). As such, habitat evaluation programs that measure the productivity and availability of browse species, as well as assess cover quality, cannot be directly translated into deer population performance. The nature of the relationship between improving habitat quality and population performance needs to be concretely established to facilitate future habitat management efforts and before habitat evaluation programs can reliably be used to predict deer response to habitat management.

Past Research

As a result of the numerous objectives and challenges surrounding mule deer management, considerable amounts of energy and money have been invested in assessing the role of different factors on mule deer populations. During the past 15 years the role of predation and habitat quality as limiting factors have been experimentally tested in a number of ways (Bartmann et al. 1992, Hurly and Zager 2004, Bishop et al. 2005). Initial work conducted in Colorado used experimental manipulation to test the hypothesis of compensatory mortality. Results from this work demonstrated that density played an ultimate role in population performance, whereas the function of predators was found to be a proximate source of mortality. More recently, collaborative research conducted by the Colorado Division of Wildlife and Idaho Fish and Game has further assessed the roles of predators and habitat on over-winter fawn survival. In Idaho, the effect of predator removal on over-winter fawn survival was experimentally tested by applying different levels of predator control to different study areas. No positive effect on fawn survival was observed through these experiments and significant changes in population trends were not observed (M. Hurly, personal communication).

In Colorado, the role of forage quality and quantity on over-winter fawn survival was tested using a treatment/control cross-over design with *ad libitum* pelleted food supplements as a substitute for instantaneous high quality habitat (Bishop et al. 2005). The primary hypothesis behind this research concerned the interaction between predation and nutrition. If supplemental forage treatments improved over-winter fawn survival (i.e. if predation did not prevent an increase), then it could be concluded that over-winter nutrition was the primary limiting factor on populations. As such, preliminary evidence suggests that nutrition enhancement treatments increased fawn survival by as much as 20% (C.J. Bishop, personal communication). This research effectively identified some of the underlying processes in mule deer population regulation, but did not test the effectiveness of acceptable habitat management techniques. Due to the undesirable effects of feeding wildlife (e.g. artificially elevating density, increased potential for disease transmission, cost and manpower), a more appropriate technique for achieving a high quality nutrition enhancement needs to be assessed. Based on this past research, there is an increasing amount of evidence that habitat plays the central role in mule deer population performance.

Mule Deer Response

Mule deer can be expected to respond to effective habitat improvements at variable rates and in a number of ways. A basic assumption of how mule deer respond to improved habitat quality is that fawn survival is elevated in higher quality areas for as long as a treatment effect is maintained. However, fawn survival is highly variable and also has the ability to remain exceptionally high for short periods under optimum weather conditions. Therefore, an alternative scenario is that a pulse of very high survival would be followed by an increase in density and a subsequent return to moderate survival rates. In this case, habitat treatment effects would be observed primarily through increased deer density. However, uncertainty regarding the impact of habitat improvement efforts also exists due to the difficulty in determining if treatment effects are actually delivered to deer. While increases in forage quality and quantity improve survival if they are present at *ad libitum* levels, as suggested by supplemental feeding, the levels attained via landscape manipulations may be effectively too low to detect. In this case, the use of over-winter fawn survival as the sole parameter for determining if a treatment was delivered may be inappropriate and the potential for making a Type II error would be high. Therefore, a more sensitive measurement of treatment effect may be rooted in the body condition of adult female mule deer. As observed in past research (C.J. Bishop, personal communication), an effect of providing *ad libitum* food as a substitute for habitat improvement was an increase from 4% to 10% in estimable total body fat. With landscape level manipulations increases would be expected to be substantially smaller, though still measurable. While a direct link between adult body condition and fawn survival hasn't been made, body condition can serve as an indicator of whether a landscape treatment was delivered.

B. OBJECTIVES

1. To conduct a one-year pilot study to assess the logistical feasibility of the proposed study herein and to gather preliminary data to improve the study's efficiency and experimental design (completed during 2004-2005).
2. To determine if habitat improvement efforts change the density and biomass of preferred mule deer browse species.

3. To determine experimentally (assuming a positive increase occurs under objective 2) whether enhancing mule deer nutrition during winter and early-spring via mechanical/chemical habitat treatments increases over-winter fawn survival.
4. To determine experimentally (assuming a positive increase occurs under objective 2) whether enhancing mule deer nutrition during winter and early-spring via mechanical/chemical habitat treatments increases the local carrying capacity of treatment areas, measured through deer density.
5. To assess whether the impacts of enhancing mule deer habitat via mechanical/chemical habitat treatments (assuming a positive increase occurs under objective 2) can be detected through measurement of adult doe body condition.

Null Hypotheses

a. Landscape level treatments on mule deer winter range do not increase the density and biomass of preferred mule deer browse species.
b. Over-winter survival of fawns in habitat treatment areas is not different from survival of fawns in non-treated control areas.
c. Mid-winter density of deer in habitat treatment areas is not different from mid-winter density of deer in non-treated control areas.
d. Late-winter body condition of adult female deer in habitat treatment areas is not different from late-winter body condition of adult female deer that occupy non-treated control areas.

C. EXPECTED RESULTS

A need for information relating mule deer population response to habitat improvement efforts currently exists. This study, measuring over-winter fawn survival on a total of six treatment areas and two control areas, will evaluate whether traditional habitat management approaches have measurable population level impacts on mule deer. We will accomplish this by monitoring over-winter mule deer fawn survival, total deer density and adult female body condition in relation to controlled habitat treatments. Across much of the mule deer range in North America, and substantiated by historical data for the Uncompahgre Plateau, resource limitation for deer typically occurs on winter range (Carpenter and Wallmo 1981, C. J. Bishop, unpublished data). If a population level response (change in survival or density) is detected during this study, then we will establish that certain landscape management practices are beneficial to mule deer. If a population level response (change in survival or density) is not detected during this study, yet a change in adult female body condition is detected, we can deduce that current habitat management efforts do impact mule deer populations. However, under this scenario, if treatments impact population performance parameters, these responses occur over longer time periods and at finer scales than we are capable of detecting. If neither a population level response (change in survival or density) nor a change in adult female body condition is detected during this study, we will know that our current habitat management practices are in need of refinement in order to more efficiently benefit mule deer.

D. APPROACH

1. Pilot Study

One winter of pilot data collection has occurred. The reasons for using this first winter as a pilot study were two-fold:
1) *To determine feasibility of capture and monitoring in the chosen study areas.* One control study area is located in an area that historically has had low deer densities, has never received habitat treatments and is not close in proximity to agricultural lands (see Experimental Approach and Habitat Manipulations). It was unknown if deer densities were high enough to meet minimum sample size requirements in this area. Due to the remote location of this study site, helicopter net-gunning (Barrett et al. 1982, van Reenen 1982) is the only feasible capture technique. Helicopter net-gunning can become cost prohibitive in low

density areas, emphasizing the need to test this approach prior to committing to four additional years. In a separate study area, densities of both deer and elk are traditionally higher, possibly due to the extensive number of habitat treatments and higher proximity to agricultural fields (hay, alfalfa and/or grass). Because this second area is easily accessible from roads, baited drop nets (Ramsey 1968, Schmidt et al. 1978, Bartmann et al. 1992) are the preferred method of capture. However, the feasibility and efficiency of drop nets also needed to be evaluated in light of elk presence. By assessing these potential problems through a pilot study, we improved the efficiency and design of this final research study design.
2) *To collect one year of data in both high and low density areas prior to instituting an experiment in the treatment areas.* This will allow us to improve our estimates of process variation in fawn survival, because fawn survival has been shown to vary significantly among areas and years (Unsworth et al. 1999, Bishop et al. 2005).

Based on results of our pilot study, our ability to meet adequate sample size requirements in the low density area was confirmed. Deer densities were sufficiently high to allow helicopter net-gunning to occur at lower capture rates. All deer were captured within 1.5 days of capture effort. Concerns over non-target capture of elk in the high density area were also addressed during the pilot study. Elk presence in the study area and around drop-nets during the time of capture was moderate to high. However, capture of elk was minimized (i.e. limited to a single animal) and there were no threats to human safety, animal safety or destruction of equipment. The confounding of capture methods did not introduce measurable bias into our results as no capture myopathy mortalities occurred. The need to assess process variation in over-winter fawn survival was justified; measured survival rates in both study areas were high relative to reported rates (low density $\hat{s} = 0.96$ (UCI = 0.963, LCI = 0.956), high density $\hat{s} = 0.84$ (UCI = 0.829, LCI = 0.851)).

2. Experimental Approach

a. <u>Experimental Units</u>

During the next 4 years, we will measure all response variables on a total of 8 study areas. Due to the abundance of mechanical treatments across the Uncompahgre Plateau (see Habitat Manipulations) and in surrounding valleys, we were unable to randomly select which areas could be maintained as controls (i.e. areas already having received a mechanical treatment could not be used as a control). As such, a mixed design with paired treatment/controls, with additional pre-treated areas was necessary. Four areas on or near the Uncompahgre Plateau were selected as the treatment/control experimental units (Fig. 1). These 4 experimental areas are stratified into known high density and low density areas. Within each stratum, one area has been identified as a treatment area while the other will be maintained as a control area (Table 1). The selection process for these experimental units followed several strict guidelines:
1) Treatment/control units could not be further than 10km apart, but needed to have adequate buffer to prevent/minimize the movement of animals between the treatment and control areas.
2) Control 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.
5) Elk presence and density, relative to deer density, needed to be consistent across all study areas. Data collection throughout the pilot year of this study confirmed that while elk are present, elk density appears to be highly correlated with deer density on all study areas. In light of potential elk response to habitat treatments during this study, the general presence/absence of elk on each study area will be noted during weekly monitoring activities.
As mentioned above, we will also measure over-winter fawn survival on a 5th, pre-treated, study area each winter (Table 1). This 5th study area was added to increase the level of inference that could be drawn from this study. As such, the 5th study area will randomly change between 4 areas with existing treatments on an annual basis (Fig. 1 & Table 1). The existing treatments on these 4 areas were

conducted within the last 10 years and were primarily composed of roller-chopping or hydro-ax disturbances (Appendix 1). Pre-treated study areas were selected using a stratified, random sampling approach, without replacement. Study areas were stratified by identifying locations with known treatment histories between the previously identified treatment/control pairs (i.e. between Sowbelly and Billy Creek). Areas identified where then buffered to minimize the capture and marking of deer that might move away from the targeted treatments and the year which they will be included in the study was randomly assigned, without replacement. Regardless of type (control, treatment or pre-treated), all study areas were initially drawn such that they include the targeted treatments, but also account for geographical features that likely serve as natural barriers to movement. As such, our hypotheses will be tested on 6 treatment areas over a 4 year period.

<u>b. Response Variables</u>

To allow for competing hypotheses in regards to potential treatment effects, 3 primary response variables will be measured.

1) To determine if habitat treatments elicit a chronic survival response with a long-term population level effect, we will measure over-winter fawn survival in all experimental units ($\text{s-fawns}_{treatment}$ vs. $\text{s-fawns}_{control}$). Based on past research, treatment effects can elicit as much as a 20% increase in survival. Power calculations were structured such that minimum sample size requirements will provide adequate power to detect a similar response.

2) To determine if habitat treatments elicit a brief survival response with a long-term population level effect, we will estimate deer density to determine if there is a difference in carrying capacity between treatment and control experimental units. Because mule deer may respond to habitat change at variable rates, we may not be able to detect differences in fawn survival, but estimating deer density will still allow us to determine if habitat treatment efforts have a population level effect (i.e. assuming $\text{s-fawns}_{treatment} = \text{s-fawns}_{control}$, then we will test $\text{Density}_{control}$ vs. $\text{Density}_{treatment}$)

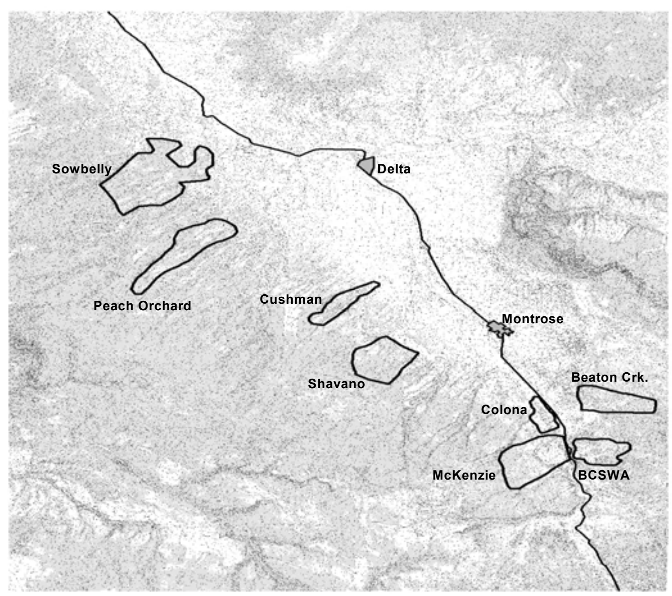

Figure 1. Experimental units shown in relation to the towns of Delta and Montrose, CO and the Uncompahgre Plateau. Low deer density areas include Sowbelly and Peach Orchard study areas, high deer density units include all other study areas. Beaton Creek and Sowbelly will be maintained as experimental controls, while Peach Orchard Point and BCSWA will be treatment areas. Cushman, Shavano, Colona and McKenzie depict areas that will be included as additional, pre-treated areas.

Table 1. Schematic and temporal representation of experimental units and their designation as high/low density, treatment/control and random treatment areas. The pilot study received no treatments to allow for the assessment of capture methods as well as to confirm the relative similarity in survival between strata as well as treatment/control areas. Areas designated as control units will not receive any mechanical treatments during this study, areas classified as pre-treated have received treatments during the past 10 years, but will receive no further treatments during this study. Areas classified as treatment areas will receive directed chemical and mechanical disturbance during the next 4 years.

	Low Density		High Density		
Year	Low Quality	High Quality	Low Quality	High Quality	Old Treament
Pilot	Control			Control	
1	Control	Treatment	Control	Treatment	Shavano
2	Control	Treatment	Control	Treatment	Colona
3	Control	Treatment	Control	Treatment	McKenzie
4	Control	Treatment	Control	Treatment	Cushman

3) To determine if habitat treatment efforts are effectively delivered, we will measure late-winter body condition of adult female deer. In the situation that a population level effect is not present, this final response variable will allow us to determine if the lack of response was due to a lack of statistical power (i.e. too small of a sample) or if it was due to a lack of a treatment effect (i.e. assuming $\text{s-fawns}_{\text{treatment}} = \text{s-fawns}_{\text{control}}$ and $\text{Density}_{\text{control}} = \text{Density}_{\text{treatment}}$, then we will test $\text{BodyCondition}_{\text{control}}$ vs. $\text{BodyCondition}_{\text{treatment}}$).treatments during this study. Areas classified as treatments will receive directed chemical and mechanical disturbance during the next 4 years.

3. Sample Size / Power Calculations

All sample size and power calculations were structured with an alpha level of 0.05 and a beta level of 0.30 ($\alpha = 0.05$ and power = $1- \beta = 0.70$). The number of flights and percent of population marked for density flights were estimated via simulation data, using historical data (C.J. Bishop, unpublished data, B. Banulis, personal communication, B. Watkins, personal communication). Point estimates and estimates of variance for each response variable were extracted from existing literature or unpublished data. For over-winter fawn survival, estimates of $\hat{s} = 0.44$ and SD = 0.217 (Unsworth et al. 1999), and the desire to detect a 20% difference in survival allowed us to calculate a minimum adequate sample size of 25 fawns per experimental unit (Fig. 3). We wish to have enough power to detect a 1.5% difference in total estimable body fat between treatment and control does during the late-winter period. Based on existing experimental data, differences of as much as 6% have been detected between treatment and control animals (treatment does = 10.39%, SD = 3.30, control does = 4.00%, SD = 2.47; C.J. Bishop, unpublished data). Again using $\alpha = 0.05$ and $\beta = 0.30$, and using a standard deviation of 2.61 (computed by removing group and year effects), a minimum sample size requirement of 30 does/area will be needed each year (Fig. 4). For density estimation purposes, but due to logistical constraints, the number of density flights will vary by area and the number of marks will vary by both area and flight. In low density areas, substantial gains in estimate precision are made by increasing both the total number of flights and the number of marked deer in the population (Fig. 5). However, due to the financial limitations of marking large numbers of deer with radio collars in this area, we will make it a priority to maximize the number of flights. Based on financial constraints, this will be 6 flights in the low density areas. As needed, and if logistical constraints permit, we will also try to temporarily mark groups of deer. If this

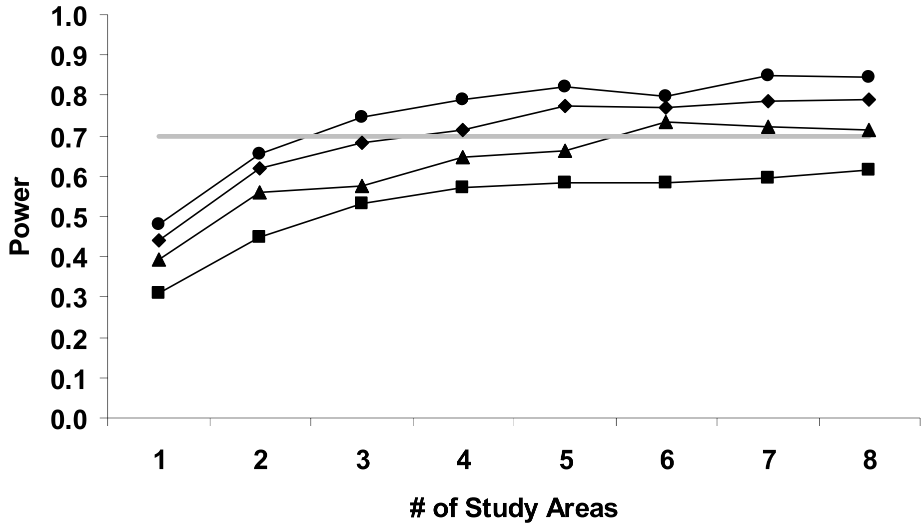

Figure 3. Expected power, based on simulation, of detecting a 20% (*d* = 0.20) difference in fawn survival across study areas at an α-level of 0.05. Different lines represent different samples sizes with squares, triangles, diamonds and circles representing 20, 25, 30 and 35 fawns/area. Estimated power for 25 fawns/area, using 6 treatment areas is 0.713.

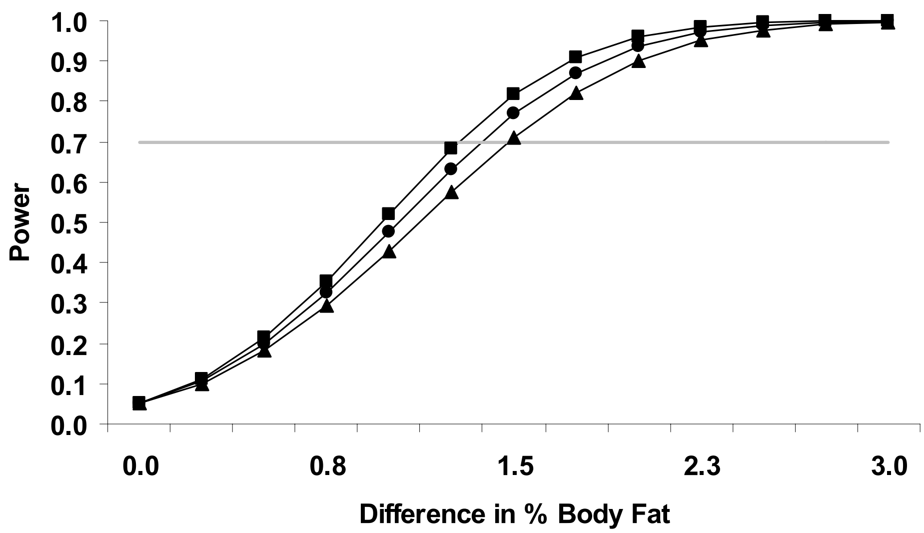

Figure 4. Expected power when detecting differences in estimable total body fat between treatment and control does during late-winter. Different lines represent different sample sizes with triangles, circles and squares representing 30, 35 and 40 does/area. Estimated power for detecting a 1.5% difference in body fat with 30 does/area is 0.710.

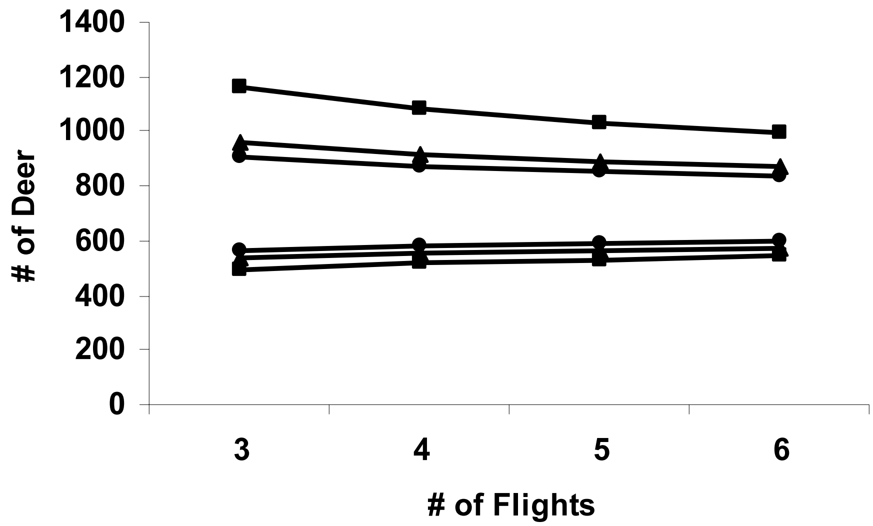

Figure 5. Expected relationship, based on simulation, between number of flights and precision of total number of deer estimated in low deer density areas. Different lines represent precision estimates from populations with different numbers of deer marked. Lines with squares represent populations with 2.5% of the population marked, lines with triangles represent populations with 5% of the population marked and lines with circles represent populations with 7.5% of the population marked.

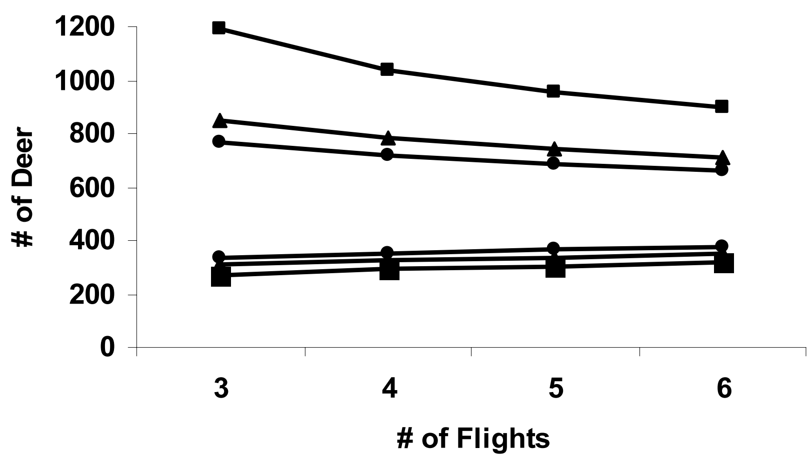

Figure 6. Expected relationship, based on simulation, between number of flights and precision of total number of deer estimated in high deer density areas. Different lines represent precision estimates from populations with different numbers of deer marked. Lines with squares represent populations with 2.5% of the population marked, lines with triangles represent populations with 5% of the population marked and lines with circles represent populations with 7.5% of the population marked.

latter approach is taken, we will attempt to increase the number of marks to 7.5% of the population. In high density study areas, the impact of increasing the number of marks in the population appears to be higher than that of increasing the number of flights (Fig. 6). As such, we will make it a priority to maximize the number of marks in each of these study areas, but we will limit the number of flights to 3 per area.

4. Procedures

a. Capture and Handling Methods

Twenty-five mule deer fawns will be captured and radio-collared in each of the experimental units. In the high density areas, we will attempt to capture all fawns with baited drop-nets (Ramsey 1968, Schmidt et al. 1978, Bartmann et al. 1992). If needed, helicopter net-gunning will be used to complete the necessary sample. In the low density units, all fawns will be captured via helicopter net-gunning (Barrett et al. 1982, van Reenen 1982). The confounding of area and capture methods should not be a problem, as indicated by our pilot study and by White and Bartmann (1994) who found no significant difference in survival of fawns 2 and 4 weeks after capture by these 2 methods for samples of 86 and 79 fawns. Captures will occur between mid-November and late-December of each year. Additionally, 30 adult doe deer will be captured via helicopter net-gunning in each experimental unit. Adult does will be captured late-February for body condition scoring purposes.

All deer will be fitted with radio collars made of vinyl belting and equipped with mortality sensors, which after remaining motionless for 4 hours, increase the pulse rate of received signals. Permanent collars will be placed on females, while temporary collars will be placed on fawns. To make fawn collars temporary, one end of the collar will be cut in half and reattached using rubber surgical tubing; fawns will shed the collars after approximately 6 months. Fawn collars will be reused annually, reducing costs after the initial year of the full-scale study.

b. Survival Monitoring

On a daily basis, from December through May, we will monitor the radioed fawns in order to document live/death status. This will allow us to estimate date and proximate cause of death. Daily monitoring will be done from the ground to maximize efficient collection of mortalities and assessment of cause specific mortality. Weekly aerial telemetry flights will be scheduled to insure that all deer are heard at least once a week, allowing weekly survival estimates for each experimental unit. While estimation of weekly survival rates for does is not a high priority for this study, we will attempt to monitor does for live/dead status as the same rate as fawns.

c. Body Condition Scoring

Methods employing the use of ultrasonography to predict total body fat have been established for moose, elk and mule deer (Stephenson et al. 1998, Cook 2000, Stephenson et al. 2002). For each adult female deer captured during late-winter, body condition will be assessed using an *in vivo* approach. Specifically, we will measure maximum rump fat thickness and thickness of the longissimus dorsi (loin) muscle using a portable ultrasonography machine. Each deer will also be scored using a subjective condition score developed for elk (Cook 2000). In conjunction, these measurements will allow for calculation/estimation of total percent body fat of each animal.

d. Density Estimation

During late-winter (late-February) of each field season we will estimate deer density on each of our study areas. Modified mark-resight techniques, via helicopter quadrats and/or randomized search patterns will be used for density estimation (Gill 1969, Bartmann et al. 1986, Kufeld et al. 1980, Freddy et al. 2004). For density estimation purposes, all deer that are captured will be collared with radio transmitters modified with color coded neck band material that identify groups of deer by method of capture (see Capture and Handling Methods). Additionally, as needed, we will mark adult deer <1 week prior to density estimation flights with a temporary mark to increase the number of marks in the population to be sampled. Temporary marks will consist of paint that is applied to the backs of deer at bait sites via paintballs. According to these marking techniques, we will have up to 3 groups of deer marked in each study area (neckband color #1 = drop-net (group 1), neckband color #2 = helicopter net-gun (group 2), body paint marks = temporary (group 3)). As such, we will be able to estimate resight probabilities, improving precision of density estimates. Additionally, because groups will be defined by capture method, we will be able to estimate resight biases that are associated with capture technique.

Prior to density estimation, the winter range for deer within each study area will be estimated. A quadrat for each study area will be defined prior to each flight by estimating a 95% adaptive kernel polygon from all deer locations collected prior to our helicopter flights. Once generated, all quadrat boundaries will be modified to accommodate nearby (<500m) topographical and geographical features that may serve as natural movement barriers to deer. For quadrats ≤ 10 km^2, we will attempt to count all deer within the quadrat on each flight. Upon initiation of each flight in these areas, quadrat boundaries will be flown prior to systematically covering the remainder of the study area. For those study areas with quadrats that exceed 10 km^2, we will create unique random flight paths for each flight. Random flight paths will be generated by overlaying these larger areas with a 1 km^2 grid. Each cell within the grid will be uniquely identified and a sample of 10 cells will be randomly selected (without replacement). These 10 cells will then be used to create a flight path. Flight paths will incorporate all randomly selected cells, but cells will be incorporated in the most efficient and continuous order possible (i.e. cells will not be flown in the order that they were selected). Deer observed in the process of flying between randomly selected cells will be counted and utilized in the sample for that flight. Each study area will be flown 3-6 times/winter. Weather permitting, flights will be flown on consecutive days. Total population estimates for the quadrat will be generated using program NOREMARK (White 1996).

e. <u>Habitat Manipulations</u>

Each of the experimental areas was selected based on its habitat treatment history. The low density treatment area (Peach Orchard Point, see Experimental Units and Location of Work) received a variety of mechanical treatments between 1999 and the present. Additionally, much of this area is located on Escalante State Wildlife Area. The high density treatment area (Billy Creek State Wildlife Area, see Experimental Units and Location of Work) received a series of anchor-chaining treatments during the 1970's. This area has also received continual treatment since that time in the form of weed control and agricultural grass/hay production for big game purposes. Part of each treatment area is located on a State Wildlife Area (SWA). SWA's are managed by the Colorado Division of Wildlife, and thus, management authority is controlled by the agency conducting this research. In addition to the existing manipulations, each of these treatment areas will receive additional habitat improvement efforts in the form of weed eradication and/or further mechanical disturbance. During the first year of treatments, efforts will be primarily directed at removing noxious/non-native weeds. During subsequent years, treatments will be mechanical in nature. Due to the relatively small areas and the need for a more surgical approach to delivering mechanical treatments, the primary tool for delivering treatments will be the contracted use of a hydro-ax. The motivation for a lag effect in the application of mechanical treatments stems from two objectives:

1) Without the initial removal of weeds, the application of mechanical disturbance can facilitate the spread of non-preferred plant species. Such a sequence of events would limit the intended increase in native browse species and could potentially take the form of a negative treatment.

2) A lag effect in mechanical disturbance will allow for a more spatially precise application of treatments. With 1 year of knowledge on deer movement and space use across the treatment areas, a more effective disturbance design can be applied.

An assessment of our habitat improvement efforts will also be incorporated into this study. This assessment will follow a 2 step approach. First, in order to compare between study areas, we will randomly sample each study area to estimate total cover and browse via cover and density plots. Second, in order to assess whether our treatment efforts impacted the vegetative landscape, we will sample our specific treatment areas for percent cover and percent browse before treatments occur and again at the end of study.

f. Statistical Analyses

We will test for differences between experimental units and years using the generic statistical model:

$$y_{i(jk)} = \mu + \alpha_j + \beta_k + \alpha\beta_{jk} + \epsilon_{i(jk)},$$

where y_{ijk} = parameter of interest (e.g., over-winter fawn survival or adult female body condition) for the i^{th} individual in treatment combination jk; $i = 1, 2, ..., n_{jk}$ (individual); $j = 1, 2, ..., 8$ experimental units; $k = 1, 2, 3, 4$ years; $\alpha\beta_{jk}$ = interactions among experimental units and years; and $\epsilon_{i(jk)}$ = random error associated with y_{ijk}. A similar model will be used to analyze density on each experimental unit. For survival analyses, a logit transformation will be used. Estimation of year effects will allow for quantification of process variation in survival throughout the study. Additional covariates, such as gender and body mass, will also be incorporated into the linear model.

5. Project Schedule

FY2004-05	Pilot Results/Revised Program Narrative	8/1/2005
FY2005-06	Progress Report	8/1/2006
FY2006-07	Progress Report	8/1/2007
FY2007-08	Progress Report	8/1/2008
FY2008-09	Completion Report	8/1/2009

6. Estimate annual Cost

Fiscal Year	Equipment/ Supplies	Rental Services	Operating	Vehicles	FTE Requirements PFTE	TFTE	Total Costs
2005-2006	$35,940	$107,633	$31,200	$12,805	1.0	2.0	$282,719
2006-2007	$37,018	$110,862	$32,136	$13,190	1.0	2.0	$291,201
2007-2008	$38,129	$114,188	$33,100	$13,585	1.0	2.0	$299,937
2008-2009	$39,273	$117,613	$34,093	$13,993	1.0	2.0	$308,935

7. Personnel

Eric J. Bergman, Mammals Researcher, Project Leader, Colorado Division of Wildlife
Chad J. Bishop, Mammals Researcher, Project Co-Leader, Colorado Division of Wildlife
David J. Freddy, Mammals Research Leader, Colorado Division of Wildlife
Gary C. White, Professor of Wildlife Biology, Colorado State University

E. LOCATION OF WORK

This study will be conducted on the Uncompahgre Plateau and adjacent valleys in southwestern Colorado. The high density treatment area is located on Billy Creek State Wildlife Area (approximately 20km south of Montrose, CO). The high density control area is located around Beaton Creek (approximately 15km south of Montrose, CO and approximately 5km north of Billy Creek State Wildlife Area). Both of these 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 control area is located on Sowbelly and Tatum draws (approximately 25km west of Delta, CO and approximately 8km from Peach Orchard Point). Both of these study areas are located in GMU 62 (DAU D-19). The pre-treated areas are also located in GMU 62 (DAU D-19) to the west and southwest of Montrose, CO. These areas, largely based on drainages, will be in the areas of Shavano Valley, Colona, McKenzie Buttes and Cushman Creek and will be incorporated into the study during years 1,2,3, and 4, respectively.

F. RELATED FEDERAL PROJECTS

This study is the second phase to a mule deer/habitat relationship study that began in 2000 (described above and in Bishop et al. 2005).

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Colorado Division of Wildlife
July 2005 – June 2006

WILDLIFE RESEARCH REPORT

State of	Colorado	: Division of Wildlife
Cost Center	3430	: Mammals Research
Work Package	3001	: Deer Conservaton
Task No.	5	: Multispecies Investigations Consulting Services for Mark-Recapture Analysis
Federal Aid Project:	W-185-R	:

Period Covered: July 1, 2005 - June 30, 2006

Author: G. C. White

Personnel: C. Bishop, D. J. Freddy, T. M. Shenk, L. Stevens, R. Kahn, F. Pusateri, E. O'Dell, D. Martin, P. Schnurr, K. Navo, B. Andelt, D. Finley, A. Linstrom, K. Strohm, P. Conn.

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ABSTRACT

Progress towards meeting the objectives of this job include:

1. Consulting assistance to Colorado Division of Wildlife (CDOW) on harvest surveys, terrestrial inventory systems, and population modeling procedures was provided. Assistance with estimation of spring and fall turkey, spring snow goose, sharp-tailed and sage grouse, chukars, ptarmigan, Abert's squirrels, and general small game harvest was provided, and programs and harvest estimates provided to CDOW via email and CD ROM. Computer code written in SAS to compute these estimates and display results graphically was also provided. Computer code was also written in SAS to estimate the compliance rate of Colorado small game license holders with the Harvest Information Program.

2. The CDOW DEAMAN software package for the storage, summary, and analysis of big game population and harvest data was revised further as a Windows XP program. A User's Manual has been provided to terrestrial biologists via the WWW at http://www.cnr.colostate.edu/~gwhite/deaman. I met with the CDOW software group to discuss conversion of DEAMAN to a central server application.

3. Consultation with CDOW Terrestrial Biologists in the use of DEAMAN and population modeling procedures continued. Numerous questions were answered via meetings with biologists, and via email.

4. A paper comparing the population levels of swift foxes in eastern Colorado to a previous study in cooperation with CDOW was submitted to Southwestern Naturalist: Martin, D. J., G. C. White, and F. M. Pusateri. 2006. Monitoring swift fox populations in eastern Colorado. Southwestern Naturalist. Submitted.

5. A paper on the use of vaginal implant transmitters in cooperation with CDOW was submitted and accepted for publication in the Journal of Wildlife Management: Bishop, C. J., D. J. Freddy, G. C.

White, B. E. Watkins, T. R. Stephenson, and L. L. Wolfe. 2006. Using vaginal implant transmitters to aid in capture of neonates from marked mule deer. Journal of Wildlife Management. In Press.

6. A paper resulting from Dan Walsh's M.S. project in cooperation with CDOW was submitted to Ecological Applications: Walsh, D. P., G. C. White, T. E. Remington, and D. C. Bowden. 2006. Population Estimation of Greater Sage-Grouse. Ecological Applications. Submitted.

7. A paper resulting from Sherri Huwer's M.S. project in cooperation with CDOW was submitted to the Journal of Wildlife Management: Huwer, S. L., D. R. Anderson, T. E. Remington, and G. C. White. 2006. Evaluating the importance of forbs to sage-grouse using human-imprinted chicks. Journal of Wildlife Management. Submitted.

8. A paper on mountain sheep populations in Rocky Mountain National Park was submitted and accepted for publication in the Wildlife Society Bulletin: McClintock, B. T., and G. C. White. 2006. Bighorn sheep abundance following a suspected pneumonia epidemic in Rocky Mountain National Park. Wildlife Society Bulletin. In Press.

9. A paper on extending the mark-resight estimator using a beta-binomial distribution was submitted and accepted in the Journal of Agricultural, Biological, and Ecological Statistics: McClintock, B. T., G. C. White, and K. P. Burnham. 2006. A robust design mark-resight abundance estimator allowing heterogeneity in resighting probabilities. Journal of Agricultural, Biological, and Ecological Statistics. In Press.

10. A paper resulting from the May, 2005 Elk and Deer Workshop was submitted and accepted for publication in the Wildlife Society Bulleting: Mason, J. R., L. H. Carpenter, M. Cox, J. C. Devos, J. Fairchild, D.J. Freddy, J. R. Heffelfinger, R. H. Kahn, S. M. McCorquodale, D. F. Pac, D. Summers, G. C. White, and B. K. Williams. 2006. A case for standardized ungulate surveys and data management in the western United States. Wildlife Society Bulletin. In Press.

11. A paper describing the use of closed captures models to estimate population size with Program MARK was submitted and accepted for publication in Environmental and Ecological Statistics: White, G. C. 2006. Closed population estimation models and their extensions in program MARK. Environmental and Ecological Statistics. In Press.

12. A paper on the application of multistate models in Program MARK was submitted and accepted for publication in the Journal of Wildlife Management: White, G. C., W. L. Kendall, and R. J. Barker. 2006. Multistate survival models and their extensions in program MARK. Journal of Wildlife Management. In Press.

13. A paper on the estimation of female grizzly bears was submitted to the Journal of Agricultural, Biological, and Ecological Statistics: Cherry, S., G. C. White, K. A. Keating, M. A. Haroldson, C. C. Schwartz. 2006. Evaluating estimators of the numbers of females with cubs-of-the-year in the Yellowstone grizzly bear population. Journal of Agricultural, Biological, and Ecological Statistics. Submitted.

14. A paper on the survival of mule deer in the Bridger Mountains, Montana, was submitted and accepted for publication in the Journal of Wildlife Management: Pac, D. F., and G. C. White. 2006. Survival and cause-specific mortality of mule deer in the Bridger Mountains, Montana. Journal of Wildlife Management. In Press.

15. A paper on the impact of limited antlered harvest on mule deer sex and age ratios in cooperation with CDOW was published in the Wildlife Society Bulletin: Bishop, C. J., G. C. White, D. J. Freddy, and B. E. Watkins. 2005. Effect of limited antlered harvest on mule deer sex and age ratios. Wildlife Society Bulletin 33: 662–668.

16. A paper on estimation of nest survival was submitted and accepted for publication in Studies in Avian Biology: Heisey, D. M., T. L. Shaffer, and G. C. White. 2006. The ABCs of nest survival: theory and application from a biostatistical perspective. Studies in Avian Biology. In Press.

17. A paper on the estimation of the area of black-tailed prairie dog colonies in eastern Colorado in cooperation with CDOW was published in the Wildlife Society Bulletin: White, G. C., J. R. Dennis, and F. M. Pusateri. 2005. Area of black-tailed prairie dog colonies in eastern Colorado. Wildlife Society Bulletin 33:265–272.

18. A paper in response to a critique by Sterling Miller was published in the Wildlife Society Bulletin in cooperation with CDOW: White, G. C., J. R. Dennis, and F. M. Pusateri. 2005. Response to: Overestimation bias in estimate of black-tailed prairie dog abundance in Colorado. Wildlife Society Bulletin 33:1452–1455.

19. A paper on methodologies to obtain more rigorous population monitoring data was published in Wildlife Research: White, G. C. 2005. Correcting wildlife counts with detection probabilities. Wildlife Research 32:211–216.

20. A paper on the procedures to monitor swift fox populations in eastern Colorado was published in the Journal of Wildlife Management: Finley, D. J., G. C. White and J. P. Fitzgerald. 2005. Estimation of swift fox population size and occupancy rates in eastern Colorado. Journal of Wildlife Management 69:861–873.

21. A research study to examine the impact of nutrition on the decline of mule deer fecundity during the last 20 years was continued in cooperation with Chad Bishop and CDOW. Portions of this work will serve as his doctoral dissertation in addition to his full-time duties as a researcher with CDOW.

22. A graduate research project (M. S.) was continued in cooperation with CDOW to evaluate line transect methodology for estimating pronghorn populations in eastern Colorado. The graduate student is Aaron Linstrom, and the project is in addition to his full-time duties as a biologist with CDOW.

23. A graduate research project (Ph. D.) in cooperation with CDOW to develop statistical models to monitor puma and black bear populations in Colorado based on checks of harvested animals and DNA and/or radio-tracking data was continued. The graduate student is Paul Conn.

24. A graduate research project (M. S.) in cooperation with CDOW to evaluate methods of redistributing elk in and around Great Sand Dunes National Park was started and then discontinued. The student, Greg Davidson, switched his work to evaluate habitat use by elk on the Grand Mesa.

25. Development of the design of a monitoring system for white-tailed prairie dogs in western Colorado and eastern Utah was continued in cooperation with CDOW with P. Schnurr, K. Navo and B. Andelt.

26. Design of a monitoring system for black-tailed prairie dogs in eastern Colorado in cooperation with CDOW was continued. This effort is in cooperation with Francie Pusateri and Eric O'Dell of CDOW.

WILDLIFE RESEARCH REPORT

CONSULTING SERVICES FOR MARK-RECAPTURE ANALYSES

GARY C. WHITE

P. N. OBJECTIVE

Provide expert biostatistical and experimental design services to the Colorado Division of Wildlife, Wildlife Programs Branch.

SEGMENT OBJECTIVES

1. Provide biostatisitical support to implement and analyze CDOW hunter harvest surveys.

2. Provide professional oversight, critiques, and analytical support to CDOW terrestrial management and avian and mammals research sections.

3. Convey to CDOW research and management sections new and pertinent information obtained in various collaborative projects conducted with other agencies and entities.

RESULTS, DISCUSSION, SUMMARY

See ABSTRACT for summary of key activities and publications.

Prepared by: ________________________________
Dr. Gary C. White, Department of Fish, Wildlife, and Conservation Biology
Colorado State University

Colorado Division of Wildlife
July 2005 – June 2006

WILDLIFE RESEARCH REPORT

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

Period covered: July 1, 2005—June 30, 2006

Author: K. A. Logan.

Personnel: K. Logan, S. Waters, B. Bavin, B. Simpson, K. Crane, T. Mathieson, M. Caddy, and T. Smith of CDOW, J. Bauer of Colorado Cooperative Fishery and Wildlife Research Unit, J. Kane, V. Johnson, S. Young, and J. McNamara of U.S.D.A. Wildlife Services, volunteers, cooperators including: private landowners, U.S. Forest Service, Bureau of Land Management, and Colorado State Parks, with financial support received from The Howard G. Buffett Foundation and Safari Club International Foundation.

ABSTRACT

Research continued on puma population characteristics and dynamics on the Uncompahgre Plateau. Puma capture efforts resulted in a total of 36 puma captures (14 adults [1 adult female captured twice], 4 subadults, 14 cubs, and 2 adult or subadult males [1 captured twice] but not handled) with 20 radio-collared pumas within the study area as of July 2006. Efforts to capture, sample, and mark pumas with the use of trained dogs extended from November 21, 2005 to May 26, 2006. This resulted in 14 puma captures, including 1 adult female, 1 subadult female, 2 adult males, and 1 subadult or adult male captured and processed for the first time. Two other males were captured (one of them twice), but were not handled for safety reasons. The remainder was recaptures of previously marked pumas, including 2 adult females (1 recaptured twice), 1 adult male, 1 subadult male, and 1 male cub. We substantially increased puma capture efforts with ungulate carcasses to bait pumas into cage traps. From August 2, 2005 to June 27, 2006, we used 77 road-killed mule deer, 3 road-killed elk, 3 puma-killed mule deer, and 1 puma killed elk at 23 different sites. This resulted in 11 puma captures, including 4 adult females, 1 adult male, and 1 male cub captured and processed for the first time, and 3 adult females, 1 subadult male, and 1 male cub that were recaptured. Eleven other puma cubs (4 males, 7 females) from 4 litters were captured by hand at nurseries and processed for the first time. We investigated 4 puma mortalities: one adult male was killed by another male puma, 2 cubs (1 male, 1 female) were killed and eaten by other pumas, and 1 female cub died due to the expandable radiocollar she was wearing. To date, 14 pumas (5 males, 9 females) have been monitored with GPS collars, yielding 113 to 1,784 locations per puma, and a total of 13,139 GPS locations. We began quantifying the frequency that puma mothers are away from their cubs during the Colorado puma hunting season (Nov. through Mar.) as a preliminary assessment of potential vulnerability of mothers to harvest. Radio-collared members (mothers and cubs) of 5 families were located 79 times during fixed-wing flights from November 9, 2005 to March 29, 2006. Mothers

were apart from their cubs >600 m during 12 of those occasions (15.2%). Preliminary comparisons between our current puma research on the Uncompahgre Plateau (~21 months duration) and results of the Anderson et al. (1992) puma research on the plateau (~7 years duration 1981-1988) are made where appropriate. We collaborated with colleagues to develop 3 proposals to contribute to the Colorado puma management program. Proposed work includes: testing genetic techniques for non-invasive methods to estimate puma numbers using mark-recapture methods and models, developing state-wide puma habitat models and maps, and assessing puma health. In addition, we will resume quantifying puma use frequencies of ungulates, and considering how research of pumas on developed areas on the Uncompahgre Plateau can contribute to the CDOW's efforts to study puma-human interactions on the Colorado Front Range.

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— all to improve the Colorado Division of Wildlife's (CDOW) model-based approach to managing pumas in Colorado.

SEGMENT OBJECTIVES

1. Continue gathering data on puma population sex and age structure.
2. Continue gathering data for estimates of puma reproduction rates.
3. Continue gathering data to estimate puma sex and age-stage survival rates.
4. Continue gathering data to estimate agent-specific mortality rates.
5. Continue gathering data on puma movements for the development of sampling methods for mark-resight or recapture population estimates that might involve sampling puma DNA-genotypes, trail cameras, or direct observations.
6. Begin gathering data on spatial relationships of puma mothers to their cubs during the Colorado puma hunting season as a preliminary assessment of the vulnerability of puma mothers to sport-hunting harvest.
7. Evaluate other data sources that could come from this research that can be developed into other puma research relevant to CDOW biologists and managers.

INTRODUCTION

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

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

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

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

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

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

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

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

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

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

While all projects cannot be addressed concurrently, understanding their relationships to one another is expected to help individual projects maximize their benefits to other projects that will assist the CDOW to achieve its strategic goal in puma management (Fig.1).

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

The highest-priority management needs are being addressed with this intensive population study that focuses on puma population dynamics using sampled, tagged, and GPS/radio-collared puma. Those objectives include:

1. Describe and quantify puma population sex and age structure.
2. Estimate puma population vital rates, including: birth rates, age-stage-specific survival rates, emigration rates, immigration rates.
3. Estimate agent-specific mortality rates.
4. Improve the CDOW's model-based management approaches with Colorado-specific data from objectives 1―3. Consider other useful models.

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

TESTING ASSUMPTIONS AND HYPOTHESES

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

1. Recreational puma hunting management in Colorado Game Management Units (GMUs) is guided by a model to estimate allowable harvest quotas to achieve one of two puma population objectives: 1) maintain puma population stability, or 2) cause puma population decline (CDOW, Draft L-DAU Plans, 2004). 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 deemed 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 (J. Apker, Carnivore Management Specialist, CDOW, Monte Vista). This assumption is based upon information with variable levels of uncertainty (e.g., small sample sizes, data from habitats dissimilar to Colorado). The key assumption is that the CDOW can manage puma population growth through recreational hunting: for a stable puma population hunting removes the annual increment of population growth (i.e., as estimated from estimates of population density, structure, and λ.; for a declining population, hunting removes more than the annual increment of population growth. Parameters influencing λ include population density, sex and age structure, female age-at-first-breeding, age-specific natality, sex- and age-specific survival, immigration and emigration. A descriptive study will ascertain these population parameters in an area that appears typical of puma habitat in western Colorado and will yield defensible population parameters based upon contemporary Colorado data. This study will be conducted in a 5-year *reference period* (i.e., absence of recreational hunting) to allow puma life history traits to interact with the main habitat factors that appear to influence puma population growth (e.g., prey availability and vulnerability, Pierce et al. 2000, Logan and Sweanor 2001). Contingent upon results in the *reference period*, a subsequent 5-year *treatment period* is planned. The *treatment period* will involve the use of controlled recreational hunting to manage the puma population into a decline phase.

H_{1a}: Population parameters measured 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 $\lambda = 1.15$, which is currently assumed in the CDOW's model-based management.

H_{1aA}: Population parameters measured during a 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 yield an estimated annual adult plus subadult population growth rate that will be substantially lower (i.e., ≥ 50% lower, $\lambda \leq 1.075$) than the assumed $\lambda = 1.15$.

H_{1b}: Population parameters during a 5-year *treatment period* (controlled puma hunting) will differ substantially from those measured during the preceding 5-year *reference* period (hunting closure) and will yield an estimated annual adult plus subadult population growth rate that will be approximately $\lambda \doteq 0.8$ for at least the first 2 years of the *treatment period*. Hunting-caused mortality will be strongly additive, and will require removal of the annual growth increment (of adults plus subadults) plus 20% (e.g., assume $\lambda = 1.15$, so, $0.15 \times 0.2 + 0.15 = 0.18$; $0.18 \times 100 =$ 18% annual harvest of adults plus subadults).

H_{1bA}: Population parameters during a 5-year *treatment period* (controlled puma hunting) will not differ substantially from those measured during the preceding 5-year *reference* period (hunting closure), and the adult plus subadult population will not decline on average as a result of hunting mortality. Hunting-caused mortality, reproduction, immigration, and emigration might be compensatory.

2. Considering limitations (i.e., methods, number of years, assumption violations) to the Colorado-specific studies on puma densities cited above (Currier et al. 1977, Anderson et al. 1992, Koloski 2002), managers assume that puma population densities in Colorado are within the range of those quantified in more intensively studied populations in Wyoming (Logan et al. 1986), Idaho (Seidensticker et al. 1973, Alberta (Ross and Jalkotzy 1992, and New Mexico (Logan and Sweanor 2001). The CDOW assumes density ranges of 2.0—4.6 puma/100 km^2 to extrapolate to Data Analysis Units to guide the model-based quota-setting process. Likewise, managers assume that the population sex and age structure is similar to puma populations described in the intensive studies. Using capture,

mark, re-capture techniques developed and refined during the study to estimate the puma population, the following will be tested:

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

3. 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_{2b}: 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 puma will cause an older age structure in harvest-age puma (i.e., adults and subadults) as suggested by the work of Anderson and Lindzey (2005) in Wyoming and Stoner (2004) in Utah.

H_{2c}: As hunting is re-instated in the *treatment period*, the age structure of harvested puma and the harvest-age puma in the population will vary 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 useful for estimating puma population abundance, evaluation of management alternatives, and effects of management prescriptions.
2. Testing assumptions about puma populations, currently used by CDOW managers, will help those managers to biologically support and adapt puma management based on Colorado-specific estimated puma population characteristics, parameters, and dynamics.
3. Methods for estimating puma abundance (capture-mark-recapture) of known reliability will allow managers to "ground truth" modeled populations and estimate effects of management prescriptions designed to achieve specified puma population objectives in targeted areas of Colorado. Ascertaining puma numbers and densities during the project will require development of reliable monitoring techniques based on capture-mark-recapture methods and models. Potential methods include direct and DNA genotype capture-recapture. 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 when 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 pinon-juniper covered foothills starting from about 1,700 m elevation to the spruce-fir and aspen forests growing to the highest elevations of about 3,000 m. Mule deer (*Odocoileus hemionus*) and elk (*Cervus elaphus*) are the most abundant wild ungulates available for puma prey. There are cattle and domestic sheep raised on summer ranges on the study area. Year-round human residents live along the eastern and western fringe of the area, and there is a growing summer residential presence especially on the southern end of the plateau. A highly developed road system makes the study area well accessible for puma research efforts. A detailed description of the Uncompahgre Plateau is in Pojar and Bowden (2004).

METHODS

Reference and Experimental Treatment Periods

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

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

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

During the *treatment period*, years 6—10, experimentally structured recreational puma hunting will occur on the same study area with the intent of causing a decline phase in the puma population by 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 population suppression (CDOW, Draft L-DAU Plans, 2004). Theoretically, puma survival will be influenced mainly by recreational hunting, which will be quantified by agent-specific mortality rates of radio-collared puma.

The portion of adults and subadults in the population will be reduced by approximately 20% in year 6 and 20% more in year 7. The 20% change was identified by Division managers that requested enumeration tools that might detect 20% changes in puma populations. For managers, detecting the magnitude of puma population decline phases is probably more important that detecting the magnitude of population increase phases. This will also allow quantification of puma population characteristics and vital rates and initial tests of enumeration methods during a decline phase.

Additional reductions may be made to test enumeration methods and other hypotheses that may be related to effects of hunting (i.e.,: relative vulnerability of puma sex and age classes to hunting, variations in puma population structure due to hunting) and puma-prey interactions (i.e., lines of research identified in the Colorado Research Program, Fig. 1). Those decisions can be made later in project development and as late as years 8―10. The killing of tagged and collared puma during the *treatment period* will not hamper operational needs (as it would during the start-up years), because by the beginning of this period, a large majority of independent puma in the population will be marked, and sampling schemes will be formalized.

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

Field Methods

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

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

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

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

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

A cage trap will be used to capture adults, subadults, and large cubs when puma can be lured into the trap using road-killed or puma-killed ungulates (Sweanor et al. 2005). Efficiency of the trap might be enhanced by using an automated digital call box that emits puma vocalizations (Wildlife Technologies, Manchester, NH). A cage trap will be set only if a target puma scavenges on the lure (i.e., an unmarked puma, or a puma requiring a collar change). Researchers will continuously monitor the set cage trap from about 1 km distance by using VHF beacons on the cage and door. This allows researchers to be at the cage to handle captured puma within 30 minutes. Puma will be immobilized with Telazol injected into the caudal thigh muscles with a pole syringe. Immobilized puma will be restrained and monitored as described above. If non-target animals are caught in the cage trap, we will open the door and allow the animal to leave the trap.

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

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

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

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

Adult and subadult female pumas will be fitted with GPS collars (approximately 400 g each, Lotek Wireless, Canada). Initially, GPS-collars will be programmed to fix and store puma locations at 4 times per day to sample daytime, nighttime, and crepuscular locations (i.e., 0:00, 06:00, 12:00, 19:00). GPS locations for puma will provide precise, quantitative data on puma movements mainly to provide data to formalize study designs, to test assumptions for capture-mark-recapture methods for this project, and to assess the relevance of puma DAU boundaries. The GPS-collars also will provide basic information on puma movements and locations to design other pilot studies in this program on vulnerability of puma to sport-harvest, habitat use, and predation frequency on mule deer and elk.

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

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

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

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

Analytical Methods

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

Reproductive Rates: Reproductive rates will be estimated for GPS- and VHF-collared female puma directly (Logan and Sweanor 2001). Genetic paternity analysis will be used to ascertain paternity for adult male puma (Murphy et al. 1998). Methods will be tested in Dr. M. Douglas's Laboratory (Colorado State University, Department of Fishery and Wildlife Biology).

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

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

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

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

Because the precision of estimates for small populations is sensitive to the probability of capture (White et al. 1982, Pollock et al. 1990), our operational goal will be to achieve capture probabilities of at least 0.5 for each animal per capture occasion. Capture simulations using MARK software (Cooch and White 2004) indicate that greater capture probabilities and more capture occasions yield more precise estimates. The capture probability for the simplest closed model [M(o)], which assumes that every member of the population has the same probability of capture *(p)* for each sampling period, suggest that for a population of 30 animals (i.e., adults plus subadult puma, which might be present by the end of year 2, see Puma Capture above) *p* must equal 0.5 for 3 capture occasions to attain a coefficient of variation (*V)* of 0.1. If 6 capture occasions are used, then a *p* of 0.3 might yield a *V* of 0.09.

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

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

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

<u>Functional Relationships</u>: Graphical methods will be used to examine functional relationships between puma density and vital rates, relationships between puma density estimated with direct capture-recapture methods (i.e., houndsmen teams) and possibly later (depending upon funding) by using estimates from DNA genotype or other mark- recapture methods. Linear regression procedures and coefficients of determination can be used to assess these functional relationships if data for the response variable are normally distributed and the variance is the same at each level. If the relationship is not linear, data is non-normal, and variances are unequal, we will consider appropriate transformations of the data for regression procedures (Ott 1993). Non-parametric correlation methods, such as Spearman's rank

correlation coefficient, can also be used to test for monotonic relationships between puma abundance and other parameters of interest (Conover 1999).

Statistical analyses will be performed using SYSTAT and SAS software. The risk of committing a type I error (i.e., rejecting a null hypothesis that is actually true) will be controlled at alpha = 0.10 because we will normally have small population sizes (typical of studies of large obligate carnivores). The higher alpha level will increase the probability of detecting a change and reduce the risk of a type II error (i.e., failing to reject a null hypothesis that is false). For managers, the risk of a type II error is probably more important.

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 2005 to July 2006. Our searches to detect puma presence covered the entire study area, but, we allocated most of our effort in areas where we consistently found tracks that we thought were of unmarked pumas. Less effort was allocated to the northeast and southwest areas where we found little or no evidence of pumas. We made 36 puma captures during the period (10 adult females [1 adult female captured twice], 4 adult males, 1 subadult female, 2 subadult males, 14 cubs, and 3 adult or subadult males [1 captured twice] but not handled). As our main method to capture, sample, and mark adult and subadult pumas, we used trained dogs from November 21, 2005 to May 26, 2006. Those efforts resulted in 82 search days, 149 puma tracks detected, 43 pursuits, and 14 puma captures (Table 1). Puma capture efforts with dogs in this period was similar to our efforts in the last (first) report period (Table 2). Only the number of pumas captured for the first time is lower in this period (7 vs. 11). These included 2 males (1 of them captured twice) that could not be handled for safety reasons (Table 3). It is possible that we captured 1 or both of those male pumas in subsequent capture efforts. Moreover, we substantially increased our puma capture efforts by using ungulate carcasses and cage traps from August 2005 to June 2006. We used 77 road-killed mule deer, 3 road-killed elk, 3 puma-killed mule deer, and 1 puma killed elk at 23 sites to capture pumas 11 times (Tables 4, 5, 6). Pumas scavenged 16 of 80 (20%) of the road-killed ungulate carcasses we used for bait. A total of 11 pumas were captured, sampled, and marked for the first time by using dogs and cage traps, (Table 5), including 1 cub caught with its mother in a cage trap (Table 7). Eleven recaptures of 10 marked pumas were made with the use of dogs and cage traps; GPS/VHF collars were replaced as needed (Table 6). We captured, sampled, and marked 11 other cubs in 4 litters that were captured by hand at nurseries (Table 7).

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 as it is in this current study. Although our current puma research on the Uncompahgre Plateau has been underway for only about 21 months (compared to 7 years of Anderson et al. 1992), there might be some useful preliminary comparisons between the 2 efforts that we can begin to make in this annual report. 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 become robust, and illuminate new knowledge for pumas in Colorado.

In the first 2 winters of puma capture efforts with dogs (1981-82 and 1983), Anderson et al. (1992:33) attempted to capture pumas in 32 and 59 days, respectively, compared to our efforts of 78 and 82 days (2004-05 and 2005-06). In the first winter, they captured 3 female pumas for the first time with an effort of 10.6 days per capture, compared to our 11 pumas (5 males, 6 females) captured for the first time, and an effort of 7.1 days per capture. In the second winter, they captured 7 pumas (4 males, 3 females) for the first time with an effort of 8.4 days per capture, compared to our 7 pumas (5 males, 2 females) captured for the first time with an effort of 11.7 days per capture. In the 7 winters of the

Anderson et al. (1992) study, the average effort was 91.1 days per winter (range = 32 to 136) resulting in average capture effort of 13.9 days per capture. Other capture efforts and results between the 2 studies are not comparable, because Anderson et al. (1992) did not attempt to capture pumas using cage traps or at nurseries like we are (e.g., in about the first 25 months, Anderson et al. captured 11 pumas; we captured 37 pumas in about 20 months).

Puma mass recorded by Anderson et al. (1992:86) for puma 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 the current study, mass for pumas ≥ 24 months old averaged 59.3 kg for 7 males (*SD* = 9.3, range 40 to 68 kg) and 39.7 kg for 8 females (*SD* = 4.8, range = 32 to 46). Sexual dimorphism has been described for puma throughout the species range (Young and Goldman 1946) and has been explained as the result of sexual selection (Logan and Sweanor 2001:109).

Segment Objective 2

We observed 12 puma cubs produced by 5 females (Table 7). Eleven of the cubs were examined at nurseries when the cubs were 29 to 37 days old; the sexes were 4 males and 7 females. A twelfth cub was caught in a cage trap when he was about 183 days (~6 mo.) old. No evidence of siblings was found during that event. The 5 litters were born in May (1), June (1), August (1), and September (2). Puma F3 has produced 2 litters; 1 in August 2005 and 1 in September 2006; for a birth interval of 13 months. Puma M6 is a candidate sire of F3's September 2006 litter; he and F3 consorted during June 22—24, 2005 (based on their joint GPS location data). From those consorting dates to the estimated birth date, the estimated gestation period for F3's litter was 93—95 days.

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). So far in our current research, for 7 postnatal litters about 26 to 42 days old from 7 individual females, the mean (±*SD*) and extremes of litter sizes were 2.57 ± 0.79, 2 to 4. Sexes of the 18 cubs we examined in 7 litters aged about 26 to 42 days old were 6 males and 12 females.

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. So far, the monthly distribution of puma births we have observed in the current study is: May (3), June (2), August (2), September (2). Considering an average 92-day gestation period (Anderson 1983:33, Logan and Sweanor 2001), breeding of pumas that produced these litters occurred from February through June. Anderson's observation of two 12-month birth intervals for one female (Anderson et al. 1992:48) compares with our sole observation of a 13-month birth interval for F3 (above).

Segment Objective 3 & 4

From December 2, 2004 (start of our research) to June 30, 2006, we monitored 7 adult male and 10 adult female pumas to quantify survival and agent-specific mortality rates (Table 8). One adult male is known to have died. M4 was about 37 to 45 months old when he was killed by an unidentified male puma along the southeast boundary of the study area. We lost contact with 2 adult males; 1 due to GPS/VHF collar failure (M6). Evidence in the field suggests that M6 might still be alive. The other male (M31) was classified as an adult at first capture because his estimated age was 25 months. However, he might still be in the latter part of the subadult stage and could have moved away from the study area. Our radiotelemetry flights beyond the boundaries of the study area have yet to locate him. All adult female pumas have survived. Adult pumas with which we have lost contact might be recaptured on the study area as our research efforts continue.

Twenty puma cubs (8 males, 12 females) have been monitored by radiotelemetry (Table 10). Two males (M5, M11) are known to have survived to the subadult stage. Two cubs (F13, M22) were killed and eaten by other pumas. F35 died 1 week after we marked her probably as a result of starvation caused when the radiocollar transmitter box got caught in her mouth. We lost contact with 9 cubs (5 females, 4 males) because they shed their expandable radiocollars. Of those 9, three females (F10, F12, F14) subsequently disappeared from the family groups (i.e., we were unable to find tracks of them with other family members) and are believed to have died. As this study proceeds, some cubs with which we have lost contact will probably be re-captured or re-observed, and thus, provide more complete survival information.

Anderson et al. (1992:50) reported on the fates of 21 radio-collared pumas (11 < 24 months old, 10 ≥ 24 months old) from a total of 49 in the previous study where pumas were not hunted. Yet, 19 of those pumas died due to human causes, attributed to: legal kill outside the study area (7), capture-related (6), predator management (3), illegal kill (2), and suspected predacide (1). Other causes of mortality included, intraspecies strife (1) and disease (1). Actual age-stage and annual survival rates and agent-specific survival rates from our current effort will be compared with the Anderson et al. (1992) data set at a later date when we have greater samples, duration in research time, and more complete fate data (i.e., pumas currently without functional collars) to make such comparisons meaningful. Differences might be illuminated. For example, research of a puma population in New Mexico that was not hunted for 10 years indicated that the major cause of death for both sexes and all age stages of pumas was intraspecifies strife, cannibalism, and infanticide (Logan and Sweanor 2001).

We have monitored the fates of 3 subadult pumas so far (Table 9). Males M5 and M11 were born on the study area, entered the subadult stage at about 13 months old, and have dispersed from their natal areas. F23 was captured as a subadult, survived to the adult stage, and has given birth to her first litter. Anderson et al. (1992) found that all 9 radio-collared male pumas dispersed from their natal areas, and 2 of 6 radio-collared females did not disperse from their natal areas (A. E. Anderson, Sep. 1993, errata for Anderson et al. 1992:61). Mean ± *SD* and range of dispersal distances (km) for 8 males, aged 10 to 13 months old at dispersal, were 86.2 ± 51.3, 23 to 151. For 4 females, aged 11 to 31 months old at dispersal, mean ± *SD* and range of dispersal distances (km) were 37.0 ± 15.3, 17 to 54 (Anderson et al. 1992:63). Although we have observed 2 male pumas disperse from natal areas, and no females disperse, our current research is too short in duration and samples too small yet to make meaningful comparisons with Anderson's earlier effort, particularly regarding offspring dispersal rates, distances moved, and philopatry. Dispersal and philopatry have been explained as life history strategies in pumas that assist gene flow, colonization, population maintenance, and individual survival and reproductive success (Logan and Sweanor 2001). Thus, such strategies would be expected to be conserved, and thus expressed in puma populations at different times and 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 estimate those parameters.

Segment Objective 5

Fourteen adult pumas (5 males, 9 females) were fit with Lotek 4400S GPS collars since field research began in December 2004. The collars are programmed to fix 4 locations per day (00:00, 06:00, 12:00, and 19:00). The number of GPS locations per individual puma ranged from 113―1,784 (Table 11). Activity areas for GPS-collared pumas during this report period were estimated (Table 12) with fixed kernel and minimum convex polygon home range estimators (ArcView 3.2 Animal Movement Extension), and mapped (Fig. 2). In addition, 1 adult female (F30), 1adult male (M32), and 1 independent male (M31, i.e., subadult or adult) were monitored with VHF radiocollars. The number of locations for those 3 pumas were not sufficient to estimate the size of activity areas (Table 13), however, their activity areas or locations are mapped on Fig. 2.

Anderson et al. (1992) provided an exhaustive analysis of seasonal puma home ranges and movements using data collected from VHF-collared animals during 1982 to 1988. We have not yet conducted an exhaustive analysis of adult puma home ranges and movements with the GPS data from our current puma research efforts in the past 21 months. Instead, we provide only limited descriptive information in Table 13 and Fig. 2. Given the different types of location data and analytical methods, only broad descriptive comparisons might be made between the 2 studies at this time. Elemental similarities in home range attributes of pumas in the Anderson et al. (1992) research and our current effort, include: current home ranges of some puma overlap extensively with home ranges of puma documented by Anderson et al (1992), home ranges of male and female pumas are large, male home ranges are larger that female home ranges, male home ranges overlap multiple female home ranges, female home ranges overlap other female home ranges sometimes extensively, male home ranges overlap other male home ranges to a lesser extent than female home ranges. These characteristics are generally similar for pumas in other populations that have been studied with adequate intensity and duration (Beier and Barrett 1993, Logan and Sweanor 2001), and reflect behavioral tactics of male and female pumas that might contribute to individual survival and reproductive success (Logan and Sweanor 2001).

Segment Objective 6

To investigate the potential that puma hunters might detect puma mothers away from their cubs, we started 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 fare game in Colorado, unless they are accompanied by 1 or more cubs. Mothers that are caught away from their cubs could be legally harvested. Such incidents would result in cubs being orphaned. Orphaned cubs that ≤ 6 months old could have a survival rate (to the subadult stage) of < 0.05. Orphaned cubs 7 to 12 months old might have a survival rate (to the subadult stage) of about 0.7 (K. Logan, unpublished data).

From November 9, 2005 to March 29, 2006 we located 4 to 5 radio-collared families of puma mothers and cubs from fixed-wing aircraft 79 times (Table 14).To assess whether mothers were apart or in close association with cubs, we needed to consider error in aerial locations. We recovered 7 puma radiocollars that we located from the airplane and fixed with GPS and then fixed the actual locations of collars on the ground with GPS. Range of location error was 20 to 520 m (mean = 282.86, *SD* = 164.75). We decided to use distances greater than the extreme high range of location error (520 m) as the metric to decide if puma mothers might be detected away from their cubs by hunters. Sixty-seven (84.8%) of observations located mothers and cubs ≤ 500 m apart, within the extreme margin of location error. Mothers were ≥ 650 m from their cubs during 12 (15.2%) of the observations (mean distance = 1,060 m, *SD* = 325.99, range = 650 to 1,600). Anderson et al. (1992:70-71) recorded 69 instances of simultaneous aerial locations of 7 pairs of puma mothers and dependent young. They reported that mothers and young were together in 21 (30.4%) of those instances, and they were 1 to 2.2 km apart in 48 (69.6%) of those instances.

Segment Objective 7

Three proposals were developed with colleagues in the CDOW and Colorado State University to meet some of the objectives of the Uncompahgre Plateau puma population research and to enhance the state-wide puma management program. CDOW and our CSU colleagues are currently seeking funding to support the proposals.

A proposal titled: *A Non-invasive Method to Estimate Puma Populations based on DNA Genotype Mark-recapture*, was developed in collaboration with geneticist Dr. Marlis Douglas (CSU). We propose to use the intensively studied puma population on the Uncompahgre Plateau for gathering genetic material to develop and test molecular techniques as a means of individually genotyping puma. If successful, the methods will be used in the field and laboratory to estimate the puma population on the

Uncompahgre Plateau study area. As part of our current puma capture protocol, we collect puma tissues (i.e., integument, blood, feces, hair) and archive them with Dr. Douglas, who will lead the genetics research.

We developed a proposal titled: *Colorado Puma Habitat Models and Maps* in collaboration with Dr. Kevin Crooks, Dr. Dave Theobald, and Dr. Ken Wilson (CSU) to develop puma habitat models and maps for the entire state of Colorado. Furthermore, we are collaborating with Dr. Crooks to assess if the GPS data currently available on pumas from this project can be used to develop a graduate degree program that investigates puma habitat use on the Uncompahgre Plateau.

We collaborated with Dr. Sue VandeWoude (CSU) to develop a pilot study titled: *Puma concolor immune health― Relationship to management paradigms and disease.* Tissue samples (i.e., blood, saliva, feces) from pumas we capture are collected and shipped to her laboratory for pending analysis.

Intensive effort to quantify puma use rates on ungulates by investigating puma GPS clusters was suspended in this report period, because we discovered in our work last year that such effort was time consuming and distracted some members of our research team from our principal objectives pertaining to puma population dynamics. Yet, our work last year proved the reliability of the GPS technology to allow us to gather quantitative information on ungulate prey use rates by pumas. In that effort, 7 GPS-collared adult pumas (3 males, 4 females) used 61 mule deer and 48 elk at 139 puma GPS clusters we investigated. In contrast, when Anderson et al. (1992) studied the pumas during 1981 to 1988, they found 68 mule deer and 3 elk used by pumas. These differences might reflect a greater number and distribution of elk currently on the Uncompahgre Plateau (~1,500 elk in GMU 62 vs. 9,663 elk in E20, sources Anderson et al. 1992:15, CDOW unpubl. 2004 post-hunt elk estimate, respectively), and poses new questions about the impact of puma predation on mule deer as a function of greater availability of elk. Consequently, the CDOW has provided additional support for a 6-month temporary technician to gather such data during the next year. An assessment will be made at the end of that work on whether we should expand the effort to investigate year-round puma use rates of ungulates on the Uncompahgre Plateau.

We will evaluate the potential for collaborative research on puma-human relationships on the Uncompahgre Plateau with the developing CDOW puma-human research on the Colorado Front Range. To date, we have gathered location data on 6 (4 adult females, 2 adult males) GPS-collared pumas that have activity areas on the developed southeast portion of our study area, which includes: Fairway Pines, Loghill Village, and Fisher Creek subdivisions, numerous other private homes, Fairway Pines golf course and driving range, all adjacent to Ridgeway State Park (Fig. 3). This is the same area that Anderson et al. (1992:80) received 17 useable questionnaires on puma observations from residents, and also had some radio-collared puma frequenting these same developments. Linking puma-human research on the Uncompahgre Plateau and Front Range provides opportunities for increasing sample size (i.e., puma numbers, study sites) and observing variation in puma-human relationships.

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 20 months of effort, 36 pumas (14 adults, 3 subadults, 19 cubs) have been captured, sampled, marked, radio-collared and released to quantify vital rates and puma population dynamics in a *reference* situation (i.e., without sport-hunting off-take). Data on research efforts and puma capture, fates, reproduction, and activity areas are presented. As of July 2006, 20 radio-collared puma are within the study area. Fourteen adult pumas were fit with GPS collars, yielding 113 to 1,784 locations per puma. We started investigating the potential vulnerability of puma mothers to capture by hunters while away from their cubs. Preliminary comparisons of aspects of puma biology and ecology were made between our new research effort on the Uncompahgre

Plateau and that of Anderson et al. (1992) in GMU 62 during 1981 to 1988. Research efforts for year 3 will focus on increasing numbers and distribution of sampled, marked, and GPS/radio-collared pumas on the study area, especially in the northeast and southwest portions of the study area where we have been finding relatively little evidence of pumas, possibly due to low density. Efforts will resume to estimate frequency of puma use of mule deer and elk on the Uncompahgre Plateau. Puma GPS location data will be used to: design enumeration methods in the field, develop and test puma habitat models and maps, and develop research on puma-ungulate relationships on the Uncompahgre Plateau contingent upon funding and support. We will increase our efforts to obtain outside funding for other projects we have proposed on puma genetics, puma habitat use, modeling, and mapping, and puma diseases. We will consider incorporating pumas on the Uncompahgre Plateau to address questions pertaining to research on puma-human relationships on the Colorado Front Range. All of these projects should enhance the Colorado puma research and management programs.

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Table 1. Summary of puma capture efforts with dogs from November 21, 2005 to May 26, 2006, Uncompahgre Plateau, Colorado.

Month	No. Search Days	No. & type of puma tracks found[a]	No. & type of pumas pursued	No. & I.D. or type of pumas captured
November	4	12 tracks: 2 male, 9 female, 1 unspecified sex	0 pursuits	0 captures
December	18	16 tracks: 10 male, 4 female, 2 unspecified sex	5 pursuits: 4 males, 1 female	2 pumas captured 3 times: M5 recaptured, 1 male captured twice but not handled[b]
January	19	50 tracks: 15 male, 23 female, 12 cub	11 pursuits: 4 males, 4 females, 3 cubs	3 pumas captured: F23, F24, 1 male not handled
February	19	39 tracks: 11 male, 14 female, 9 cub, 5 unspecified sex	9 pursuits: 2 males, 3 females, 4 cubs	1 puma captured: F8 recaptured
March	7	11 tracks: 2 male, 5 female, 4 cub	7 pursuits: 1 male, 3 females, 3 cubs	2 pumas captured: M27, F8 recaptured
April	7	11 tracks: 3 male, 5 female, 3 cub	9 pursuits: 3 males, 4 females, 2 cubs	3 puma captured: M29 & M31 captured, M15 recaptured
May	8	10 tracks: 5 male, 5 female	2 pursuits: 1 male, 1 female	2 pumas captured: F24 recaptured, M1 recaptured
TOTALS	82	149 tracks found: 48 male, 65 female, 28 cub, 8 unspecified sex	43 pursuits: 15 males, 16 females, 12 cubs	14 captures: 3 males & 2 females captured for the 1st time, 2 different males captured 3 times but not handled, 1 male recaptured, 2 females recaptured 3 times, 1 subadult male recaptured, 1 subadult or adult male recaptured, 1 male cub recaptured

[a] Puma hind-foot tracks with plantar pad widths >50 mm wide are assumed to be male; ≤50 mm are assumed to be female.
[b] Pumas are not handled for a variety of safety reasons: tree to dangerous to climb for researchers, puma treed near river, creek or cliff, puma might fall from tree after drug induction.

Table 2. Summary of puma capture efforts with dogs, December 2004 to May 2006, Uncompahgre Plateau, Colorado.

Period	Track detection effort	Pursuit effort	Puma capture effort	Effort to capture a 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 (minus M1, F3, & large female) 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

Table 3. Pumas that were captured with aid of dogs, but were not handled for safety reasons, from December 2005 to January 2006, Uncompahgre Plateau, Colorado.

Puma sex	Age stage	Capture date	Location	Comments
Male	subadult or adult	12-04-05	Roatcap Mesa	Puma climbed to top of huge Ponderosa pine tree. This puma might be M32.
Male	subadult or adult	12-05-05	Cushman Creek	This puma was the same animal caught 12-04-05. Climbed tall spruce tree on a ledge.
Male	adult	01-22-06	San Miguel River Canyon	Puma climbed Ponderosa pine tree beside the river. This puma might be M29.

Table 4. Summary of puma capture efforts with ungulate road-kill baits, puma kills, and cage traps from August 2, 2005 to June 27, 2006, Uncompahgre Plateau, Colorado.[a]

Month	No. of Sites	Puma activity & capture effort results
August	4	Male puma scavenged a mule deer on 8-20-05. Cage trap set 8-20 & 8-21-05; puma did not return.
September	7	Male puma scavenged a mule deer on 9-16-05; subadult M5 was recaptured there and was fit with a VHF collar (he had shed the expandable collar he wore as a cub).
October	10	Puma F16 captured 10-11-05 at an elk kill. Puma scavenged mule deer on 10-17-05. Cage trap set 10-18 and 10-19-05; puma did not return.
November	12	Puma F16 recaptured 11-1-05 at a mule deer kill; her faulty GPS collar was replaced. Puma F16 scavenged a mule deer on 11-27-05. No attempt to recapture her.
December	1	No puma activity detected.
January	2	No puma activity detected.
February	9	Puma F25 and cub M26 captured 2-8-06 at a mule deer kill. Puma F7 scavenged a mule deer on 2-26 & 2-17-06. No attempt to recapture her. Puma F3 scavenged a mule deer on 2-26-06. No attempt to recapture her.
March	11	Male puma completely scavenged a mule deer over the weekend of 3-18 & 19-06. Female puma completely scavenged a mule deer over the weekend of 3-18 & 19-06. Female puma scavenged a mule deer 3-21 to 3-23-06; puma F28 was captured there 3-23-06. Pumas F3 & cub F21 scavenged a mule deer 3-23 to 3-27-06. No attempt was made to recapture the pumas. Female puma completely scavenged a mule deer over the weekend of 3-25 & 26-06. Puma F7 was recaptured at a mule deer she scavenged on 3-30-06; her GPS collar was replaced.
April	11	Puma F30 captured 4-15-06 at a mule deer kill. Male puma scavenged a mule deer on 4-20-06. Cage trap was set 4-20 & 4-21-06; puma did not return. Male puma scavenged the same mule deer on 4-26-06; M32 was captured there on 4-26-06. Puma F2 and cubs F9 & M11 scavenged a mule deer on 4-2-06. Cub M11 was recaptured on 4-2-06 and fit with a VHF collar. F2 was recaptured there 4-3-06 and her GPS collar was replaced.
May	0	No fresh road-killed ungulate carcasses were available.
June	3	No puma activity.

[a] We used 77 road-killed mule deer, 3 road-killed elk, 3 puma-killed mule deer, and 1 puma-killed elk at 23 different sites. Of the road-killed ungulate baits, 16 of 80 (20.0%) were scavenged by pumas.

Table 5. Adult and subadult pumas captured for the first time, sampled, tagged, and released from October 2005 to April 2006, Uncompahgre Plateau, Colorado.

Puma I.D.	Sex	Estimated Age (mo.)	Mass (kg)	Capture date	Capture method	Location
F16	F	33	42	10-11-05	Cage trap	Ridgeway Reservoir Dam, Ridgeway State Park
F23	F	17	42	01-04-06	Dogs	San Miguel River Canyon
F24	F	57	38	01-17-06	Dogs	Horsefly Creek (west)
F25	F	80	46	02-08-06	Cage trap	Loghill Mesa
M27	M	55	61	03-10-06	Dogs	Big Bucktail Creek
F28	F	33	43	03-23-06	Cage trap	Big Bucktail Creek
M29	M	80	65	04-14-06	Dogs	Big Bucktail Creek
F30	F	33	34	04-15-06	Cage trap	Wildcat Canyon
M31	M	25	40	04-19-06	Dogs	Craig Draw
M32	M	56	57	04-26-06	Cage trap	Spring Creek

Table 6. Pumas recaptured with dogs and cage traps, September 2005 to May 2006, Uncompahgre Plateau, Colorado.

Puma I.D.	Recapture date	Mass kg	Estimated Age (mo.)	Capture Method	Process
M5	09-16-05	39	13	Cage trap	Re-collared
F16	11-01-05	42	34	Cage trap	Re-collared
M5	12-30-05	Observed	16	Dogs	None
F8	02-07-06	Observed	32	Dogs	None
F8	03-21-06	Observed	33	Dogs	None
F7	03-30-06	35	69-77	Cage trap	Re-collared
M11	04-02-06	32	10	Cage trap	Re-collared
F2	04-03-06	43	64	Cage trap	Re-collared
M15	04-13-06	23	9.5	Dogs	Re-collared
F24	05-17-06	Observed	61	Dogs	None
M1	05-26-06	Observed	51	Dogs	None

Table 7. Puma cubs sampled August 2005 to June 2006 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)
F17	F	Sept. 22, 2005	34	2.5	F16	32
F18	F	Sept. 22, 2005	34	2.0	"	"
M19	M	Sept. 22, 2005	34	2.0	"	"
M20	M	Sept. 22, 2005	34	2.1	"	"
F21[b]	F	Sept. 26, 2005	37	2.8	F3[c]	49
M22[b]	M	Sept. 26, 2005	37	2.8	"	"
M26[d]	M	Aug. 2005	183	12.0	F25	74
F33	F	May 30, 2006	31	1.9	F23	21
F34	F	May 30, 2006	31	1.9	"	"
F35	F	May 30, 2006	31	2.2	"	"
F36	F	June 9, 2006	29	1.9	F28	36
M37	M	June 9, 2006	29	2.1	"	"

[a] Estimated age of cubs sampled at nurseries is based on the starting date for GPS location foci for mothers at nurseries.

[b]Puma M6 is a candidate sire of cubs F21 & M22; he consorted with F3 (based on their joint GPS location data) during June 22—24, 2005. This would indicate a gestation period of 93—95 days.

[c]F3 gave birth to a previous litter in August 2004. From that litter, offspring M5 survived to independence. Birth interval is 13 months (Aug. 2004 to Sept. 2005).

[d]Estimated age of M26 was based on morphometric comparisons with known-age cubs (Logan and Sweanor 2001, and unpublished data, i.e., ~6 mo. ≈183 days). He was initially captured in a cage trap with his mother F25 on Feb. 8, 2006.

Table 8. Summary for individual adult puma survival and mortality, December 2004 to June 2006, Uncompahgre Plateau, Colorado.

Puma I.D.	Monitoring span	No. days	Status: Alive/Lost contact/Dead; Cause of death
M1	12-08-04 to 06-30-06	569	Alive.
M4	01-28-05 to 12-28-05	333	Dead; killed by a male puma.[a]
M6	02-18-05 to 02-22-06	369	Lost contact— failed GPS/VHF collar.
M27	03-10-06 to 06-30-06	112	Alive.
M29	04-14-06 to 06-30-06	77	Alive.
M31	04-19-06 to 04-26-06	7	Lost contact.[b]
M32	04-26-06 to 06-30-06	65	Alive.
F2	01-07-05 to 06-30-06	539	Alive.
F3	01-21-05 to 06-30-06	525	Alive.
F7	02-24-05 to 06-30-06	491	Alive.
F8	03-21-05 to 06-30-06	466	Alive.
F16	10-11-05 to 06-30-06	262	Alive.
F23	02-05-06 to 06-30-06	146	Alive.
F24	01-17-06 to 06-30-06	164	Alive.
F25	02-08-06 to 06-30-06	142	Alive.
F28	03-23-06 to 06-30-06	99	Alive.
F30	04-15-06 to 06-30-06	76	Alive.

[a] Puma M4 died at the estimated age of 37—45 months old.

[b] Puma M31 estimated age at capture was 25 months, at the lower margin of puberty. But he might have been a dispersing subadult, instead of an adult. He may have moved away from the study area. No VHF signals have been received of M31 in the area surrounding the study area as of 07-29-06.

Table 9. Summary of subadult puma survival and mortality, December 2004 to June 2006, Uncompahgre Plateau, Colorado.

Puma I.D.	Monitoring span	No. days	Status: Alive/Survived to adult stage/ Lost contact/Dead; Cause of death
M5	09-16-05 to 06-30-06	287	Alive; dispersed from natal area.
M11	06-21-06 to 06-30-06	7	Alive; dispersed from natal area.
F23	01-04-06 to 02-04-06	31	Alive; survived to adult stage; gave birth to first litter at ~21 months old.

Table 10. Summary for individual puma cub survival and mortality, December 2004 to July 2006, Uncompahgre Plateau, Colorado.

Puma I.D.	Estimated Age at capture (days)	Estimated survival span from 1st capture to fate or last monitor date	Age to last monitor date alive or at death	Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/Dead; Cause of death	Mother I.D.
M5	183	02-04-05 to 06-30-06	22 mo.	Survived to subadult stage by 09-16-05; independent at ~13 mo. old. Dispersed from natal area by 09-29-05 at 13 mo. old .	F3
F9	31	06-27-05 to 4-19-06	329 days	Lost contact— shed radiocollar 04-19-06—04-26-06.	F2
F10	31	06-27-05 to 11-20-05—12-29-05	207—246 days	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	06-27-05 to 07-11-06	14 mo.	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.	F2
F12	42	07-01-05 to 12-08-05—01-26-06	245—294 days	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	07-01-05 to 08-28-05	100 days	Dead; killed and eaten by a puma (sex unspecified).	F7
F14	26	07-22-05 to 02-07-06—03-10-06	226—257 days	Lost contact— shed radiocollar 01-20-06—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	07-22-05 to 06-06-06	345 days	Lost contact— shed radiocollar 06-06-06—06-14-06.	F8
F17	34	10-26-05 to 06-06-06	257 days	Lost contact— shed radiocollar 06-06-06—06-14-06.	F16
F18	34	10-26-05 to 06-30-06	281 days	Alive.	F16
M19	34	10-26-05 to 07-27-06	306 days	Lost contact— shed radiocollar 07-27-06—08-02-06.	F16
M20	34	10-26-05 to 05-24-06	244 days	Lost contact— shed radiocollar 05-24-06—05-25-06.	F16
F21	37	11-02-05 to 06-30-06	277 days	Alive.	F3
M22	37	11-02-05 to 12-21-05—12-22-05	86—87 days	Dead; killed and eaten by male puma 12-21-05—12-22-05.	F3
M26	183	02-08-06 to 03-21-06	224 days	Lost contact— shed radiocollar 03-21-06—03-24-06.	F25
F33	31	06-30-06 to 07-31-06	62 days	Alive.	F23
F34	31	06-30-06 to 07-31-06	62 days	Alive.	F23
F35	31	06-30-06 to 07-07-06	38 days	Dead; research-related fatality.[a]	F23
F36	29	07-08-06 to 07-28-06	49 days	Alive.	F28
M37	29	07-08-06 to 07-28-06	49 days	Alive.	F28

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

Table 11. Numbers of GPS locations for adult puma on the Uncompahgre Plateau, Colorado, December 2004 to June 2006.

Puma I.D.	Sex	Age stage	Dates monitored [a]	No. locations	Acquisition rate average, range, n[b]
M1	M	adult	12-08-04 to 06-21-06	1,784	77, 73—84, 13
M4	M	adult	01-28-05 to 12-28-05[e]	910	70, 57—84, 10
M6	M	adult	02-18-05 to 11-23-05[f]	926	84, 73—93, 9
M27	M	adult	03-11-06 to 06-21-06	316	77, 67—84, 3
M29	M	adult	04-14-06 to 07-27-06	287	68, 63—75, 3
F2	F	adult	01-07-05 to 07-12-06	1,664	75, 43—90, 18
F3	F	adult	01-21-05 to 07-26-06	1,649	76, 55—88, 17
F7	F	adult	02-24-05 to 07-26-06	1,423	67, 26—86, 17
F8	F	adult	03-21-05 to 07-05-06	1,328	70, 48—81, 14
F16	F	adult	10-12-05 to 07-03-06	833	76, 58—90, 10
F23	F	subadult,	01-04-06 to 02-04-06	113	79, 45—92, 6
		adult	02-05-06 to 07-17-06	511	
F24	F	adult	01-17-06 to 06-14-06	523	88, 86—93, 5
F25	F	adult	02-09-06 to 07-12-06	551	78, 68—87, 5
F28	F	adult	03-24-06 to 07-07-06	321	74, 61—89, 4

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

Table 12. Estimated use areas of GPS-collared pumas on the Uncompahgre Plateau, Colorado, 2005 to 2006.[a]

Puma I.D.	No. locations	Time span	No. months	95% Fixed kernel (km^2)	50% Fixed kernel (km^2)	100% Minimum convex polygon (km^2)
M1	1,083	07-01-05 to 06-21-06	12	988.1	189.1	1,129.0
M4[b]	481	07-01-05 to 12-28-05	5	208.8	29.6	318.5
M6[c]	465	07-01-05 to 11-23-05	4.8	550.8	67.3	542.0
M27	316	03-11-06 to 06-21-06	3.3	452.0	40.3	504.0
M29	220	04-14-06 to 06-30-06	2.5	276.1	14.0	288.3
F2	1,173	07-01-05 to 06-30-06	12	67.6	6.9	183.0
F3	1,079	07-01-05 to 06-30-06	12	84.3	11.7	194.0
F7	1,058	07-01-05 to 06-30-06	12	110.4	16.2	139.0
F8	1,043	07-01-05 to 06-30-06	12	84.1	7.7	215.0
F16	825	10-12-05 to 06-30-06	8.6	39.9	4.8	74.3
F23	566	01-04-06 to 06-30-06	5.9	109.2	13.0	226.0
F24	574	01-17-06 to 06-30-06	5.5	26.8	2.4	111.7
F25	453	02-09-06 to 06-30-06	4.7	105.5	16.1	115.9
F28	306	03-24-06 to 06-30-06	3.2	86.2	14.8	114.8

[a] Use areas were estimated by using the Animal Movement extension in ArcView 3.2.
[b] Puma M4 died on 12-28-05; he was killed by a male puma.
[c] Puma M6's GPS collar malfunctioned on 11-23-05. His last VHF location was fixed on 02-22-06. The VHF beacon failed after that date.

Table 13. VHF-radio-collared independent pumas on the Uncompahgre Plateau, Colorado, 2006.

Puma I.D.	Sex	Age stage	Dates monitored	No. locations
F30	F	Adult	04-15-06 to 06-28-06	11
M31	M	Adult or subadult	04-09-06 to 04-26-06	2
M32	M	Adult	04-26-06 to 06-28-06	6

Table 14. Summary of puma mother and cub associations by distance (m) during fixed-wing flights, November 9, 2005 to March 29, 2006.

Month	No. flights	No. puma families[a]	Ages of cubs (mo.)	No. observations with mothers & cubs ≤500 m apart	No. observations with mothers & cubs >600 m apart[b]
Nov.	3	4	2—6	10	2
Dec.	4	4	3—7	16	4
Jan.	5	4	4—8	16	4
Feb.	4	5	5—9	16	2
Mar.	2	5	6—10	9	0
Totals	18	4—5	2—10	67	12

[a] All puma mothers wore GPS-radiocollars. At least 1 cub in the litter wore a VHF radiocollar.
[b] Mean = 1,060 m, *SD* = 325.99, range = 650—1,600.

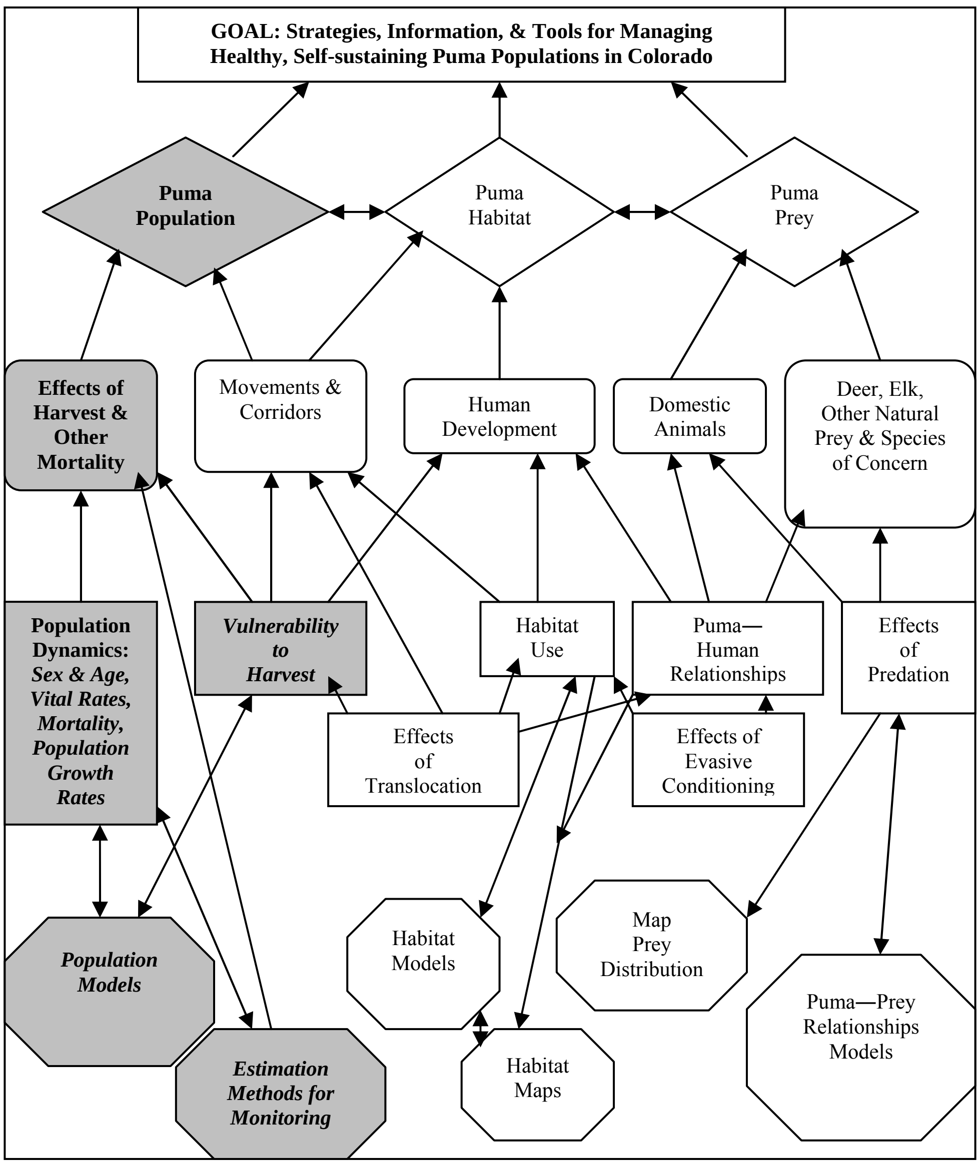

Figure. 1. An ecologically-based conceptual model of the Colorado Puma Research Program that provides the contextual framework for this and proposed puma research in Colorado. Gray-shaded shapes identify areas of research addressed by this report for the puma management goal (at top).

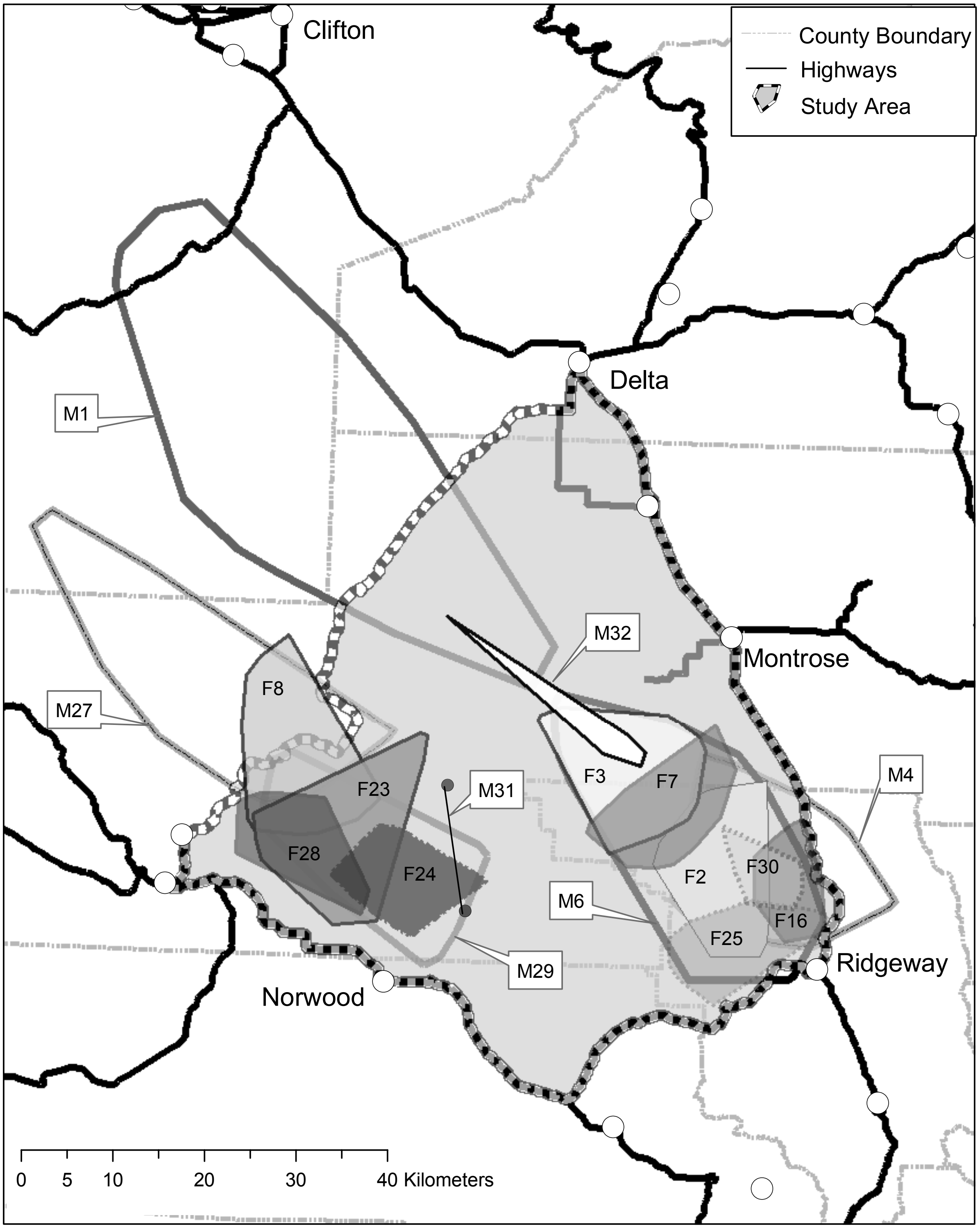

Figure 2. The Uncompahgre Plateau Puma Study Area with activity areas of GPS- and VHF- radio-collared pumas depicted with 100% Minimum Convex Polygons (for ease of viewing), and 2 locations of one independent puma for which we lost contact (M31), 2005 to 2006.

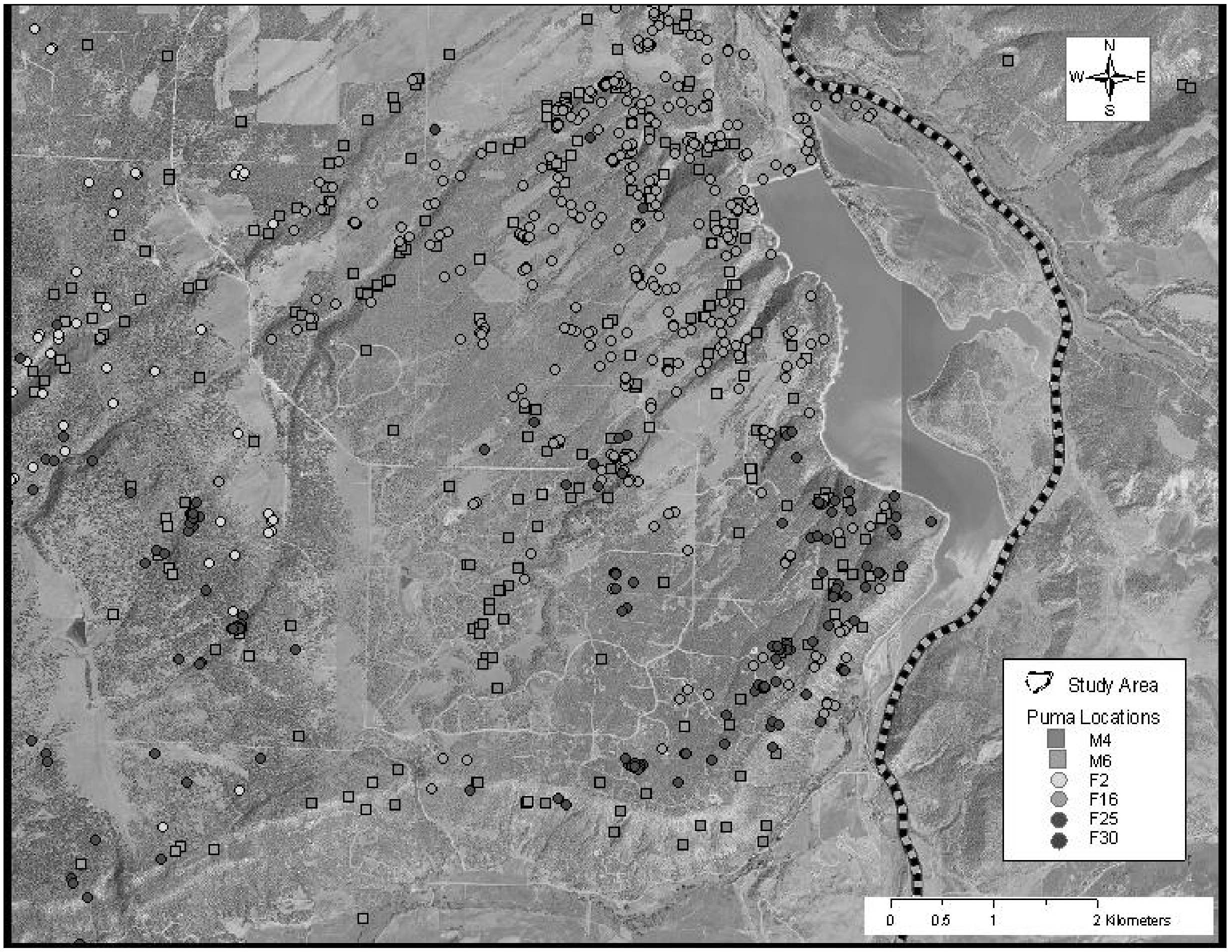

Figure 3. Locations of 6 GPS-collared pumas on the human-developed southeast portion of the Uncompahgre Plateau puma study area, 2005-2006, intended only to show potential for developing research on puma-human relationships on this study area and the Colorado Front Range.

Colorado Division of Wildlife
July 2005 – June 2006

WILDLIFE RESEARCH REPORT

State of	Colorado	: Division of Wildlife
Cost Center	3430	: Mammals Research
Work Package No.	7210	: Customer Services/Research Support
Task No.	1	: Library Services

Federal Aid Project: N/A :

Period Covered: July 1, 2005 – June 30, 2006

Author: J. A. Boss

Personnel: J. A. Boss, B. C. Jones, and A. R. Taylor.

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

During the Segment, the following were accomplished:

850 Publications acquired by the Research Center Library for the use of Colorado Division of Wildlife (CDOW) employees, cooperators, wildlife educators, and the public. These publications include books, interlibrary loan materials, periodicals, and newsletters.

2,297 Items of information delivered to CDOW employees, cooperators, wildlife educators, and the public, resulting from requests and literature searches.

775 Items of information cataloged into the electronic catalog, which including duplicates and additional volumes, expanded the Research Center Library inventory to 25,104 items.

1,441 Items of information entered into the electronic catalog for the maintenance of the inventory and circulation system of the Research Center Library.

1,232 Items checked-out by CDOW employees, cooperators, wildlife educators, and the public indicating use of library services.

3,436 Items of information delivered that are produced by the CDOW employees, cooperators, wildlife educators, and the public. These items include CDOW and other publications (2,938), research articles by CDOW personnel (274), and CDOW federal aid reports (224).

WILDLIFE RESEARCH REPORT

COLORADO DIVISION OF WILDLIFE RESEARCH LIBRARY SERVICES

JACQUELINE A. BOSS

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 by implementing the SirsiDynix Horizon library automation system via an Application Service Provider (ASP) model (project began in June 2002). By joining the Automation System Colorado Consortium (ASCC) we were able to take advantage of a LSTA grant written by the Colorado State Library staff, which facilitated the implementation of this system.

2. Continue to develop, improve, and implement the CDOW Research Center Library web-site (started in June 2004) by implementing the SirsiDynix horizon system online to serve broader spectrum of patrons of the CDOW Research Center Library.

3. Continue to attend ASCC meetings and participate in SirsiDynix Horizon online classes to enhance utilization of the SirsiDynix system.

SUMMARY OF LIBRARY SERVICES

Maintain and Build Electronic Catalogs of all Research Library Holdings

775 — Total number of items cataloged during this period of time. This includes not only acquisitions, but also older materials from the library collection being entered into the electronic catalog for the first time. Among the acquisitions are Federal Aid: Job Progress Reports and manuscripts written by CDOW researchers and other employees.

1,441 — Total number of items of information added to the electronic circulation system during this period. This includes not only the above mentioned newly cataloged items, but also newly acquired serials, volumes, additional copies, and other items being assigned scanning numbers for the electronic circulation system for the first time.

$239,772 — Estimated value of the 25,104 items in the Research Center Library collection as of June 30, 2006. The project to determine the value of the library collection began in May 2000. As time permits, the value of books already in the collection is determined, and added to the already “estimated value.” Each month’s addition of values of older materials, plus the new materials, increases the value of the Library collection. Not included in the “assumed value” of the Library collection are all of the periodicals, older materials, and government documents, which continue to be a large part of the collection, thus the “estimated value” of the Library collection continues to grow month by month.

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