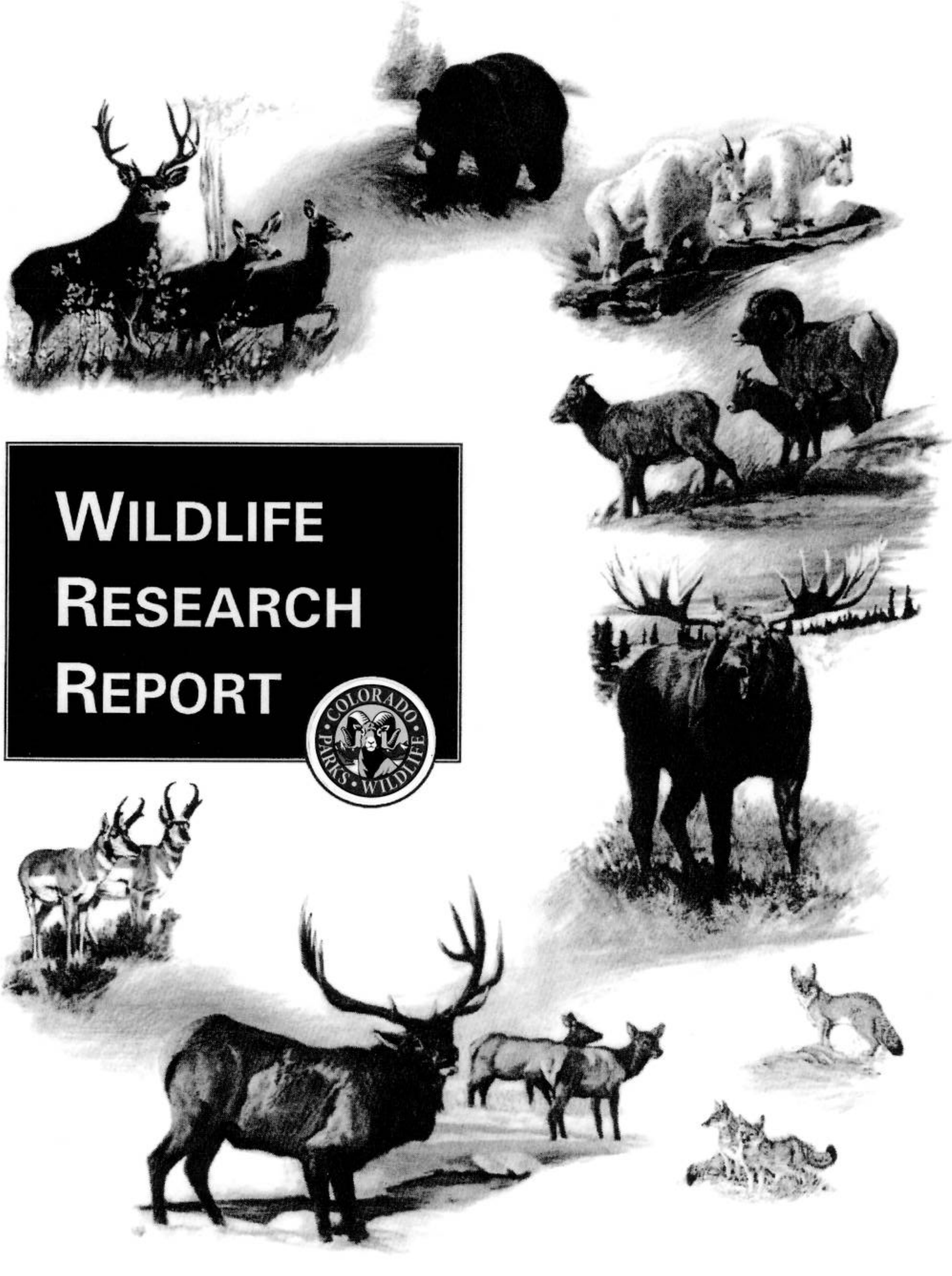
MAMMALS - JULY 2011



WILDLIFE RESEARCH REPORT

COLORADO PARKS & WILDLIFE

WILDLIFE RESEARCH REPORTS

JULY 2010 – JUNE 2011

MAMMALS PROGRAM

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

The Wildlife Reports contained herein represent preliminary analyses and are subject to change.
For this reason, information MAY NOT BE PUBLISHED OR QUOTED
without permission of the Author(s).

STATE OF COLORADO
John Hickenlooper, *Governor*

DEPARTMENT OF NATURAL RESOURCES
Mike King, *Executive Director*

PARKS AND WILDLIFE COMMISSION

Tim Glenn, *Chair*……Salida
Gary Butterworth, *Vice Chair*……Colorado Springs
Mark Smith, *Secretary*……Center
David Brougham……Denver
Chris Castilian……Denver
Dorothea Farris……Carbondale
Allan Jones……Meeker
Bill Kane……Basalt
Gaspar Perricone……Denver
Jim Pribyl……Boulder
John Singletary……Pueblo
Robert Streeter……Fort Collins
Lenna Watson……Grand Junction
Dean Wingfield……Yuma
Mike King, Executive Director, *Ex-officio*……Denver
John Salazar, Dept. of Agriculture, *Ex-officio*……Denver

DIRECTOR'S LEADERSHIP TEAM

Rick Cables, Director
Ken Brink, Steve Cassin, Greg Gerlich, Marilyn Gallegos Ramirez,
Susan Hunt, Gary Thorson, Jeff Ver Steeg

MAMMALS RESEARCH STAFF

Chad Bishop, Mammals Research Leader
Mat Alldredge, Wildlife Researcher
Chuck Anderson, Wildlife Researcher
Eric Bergman, Wildlife Researcher
Jake Ivan, Wildlife Researcher
Heather Johnson, Wildlife Researcher
Ken Logan, Wildlife Researcher
Kay Knudsen, Librarian
Margie Michaels, Program Assistant

Colorado Division of Parks and Wildlife
July 1, 2010 – June 30, 2011

TABLE OF CONTENTS
MAMMALS WILDLIFE RESEARCH REPORTS

SUPPORT SERVICES

Colorado Division of Parks and Wildlife
July 2010–June 2011

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of Parks and Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	0638	:	Wolverine Conservation
Task No.:	N/A	:	Assessing the efficacy of monitoring wolverine on a regional scale using occupancy and abundance estimation
Federal Aid Project No.	N/A		

Period Covered: July 1, 2010 – June 30, 2011

Author: J. S. Ivan

Personnel: M. Schwartz, USFS Rocky Mountain Research Station; M. Ellis, University of Montana

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

ABSTRACT

The wolverine (*Gulo gulo*) has a circumpolar distribution comprised mostly of tundra and boreal forest. However, its current range extends southward in peninsular fashion to the Cascades and Rocky Mountains of the conterminous United States. Recently the U.S. Fish and Wildlife Service ruled that the North American wolverine in the contiguous U. S. is a candidate species for protection under the Endangered Species Act. Thus, there is considerable interest in identifying monitoring schemes capable of detecting declines in wolverine populations over a large scale. We used spatially explicit simulations in which wolverine were sampled on a virtual landscape to quantify our ability to detect declines using robust-design occupancy estimation. We systematically varied 1) the number of sample units surveyed, 2) the number of visits made to each unit in the sample, and 3) the rate of population decline and computed the power to detect declines under various scenarios. Initial results indicate that occupancy estimation may work well for detecting large declines (50% decline over 10 years), but power to detect less catastrophic declines was low. Approximately 100 sample units would need to be surveyed to have adequate power to detect a 50% decline over 10 years. A census (350 sample unit) would be needed to ensure decent power for detecting smaller declines. Power increases as number of visits to each sample unit increases from 2 to 3 per survey season, but making more than 3 visits does not increase power substantially. If confronted with design tradeoffs that lead to having a better detection probability vs. those that allow for more units to be sampled, it is better to increase detection probability and survey fewer units. Future simulations will address the power to detect increases in population size in addition to declines, and we will attempt to compare power to detect declines using abundance estimation with that obtained using occupancy estimation.

WILDLIFE RESEARCH REPORT

ASSESSING THE EFFICACY OF MONITORING WOLVERINE ON A REGIONAL SCALE USING OCCUPANCY AND ABUNDANCE ESTIMATION.

JACOB S. IVAN

P. N. OBJECTIVE

Assess power for detecting trends in wolverine population growth using occupancy and abundance estimation.

SEGMENT OBJECTIVES

1. Build code to simulate realistic distribution and space use of wolverine on the landscape.
2. Build code to realistically simulate sampling the wolverine population using an occupancy framework.
3. Build code to analyze data "collected" via occupancy surveys.
4. Summarize results of 100s of iterations of randomly generated wolverine distributions and subsequent occupancy surveys; plot power to detect trends against various scenarios intended to reflect the range of conditions expected for both the sampling and process portions of the simulation.

INTRODUCTION

The wolverine (*Gulo gulo*) has a circumpolar distribution comprised mostly of tundra and boreal forest. However, its current range also extends southward in peninsular fashion to the Cascades and Rocky Mountains of the conterminous United States. Recently the U.S. Fish and Wildlife Service ruled that the North American wolverine in the contiguous U. S. was a candidate for protection under the Endangered Species Act (U.S. Fish and Wildlife Service 2010). Therefore, considerable interest exists in identifying monitoring schemes capable of detecting declines in wolverine populations over a large scale. Colorado Parks and Wildlife (CPW) has expressed interest in potentially pursuing a wolverine reintroduction, and monitoring program would be an integral part of such an effort. Additionally, with minor modifications, the simulation approach outlined here could be used to inform current Canada lynx (*Lynx canadensis*) monitoring efforts in Colorado. Thus, the work described here holds benefits for wolverine conservation in general as well as current and future CPW projects.

Estimating abundance or occupancy are 2 means around which a monitoring scheme for wolverines could be constructed. Within these general approaches, there are numerous sampling methods that could be employed in the field. For instance, individual identification necessary for abundance estimation can be obtained from pelage patterns (Royle et al. 2011), scat samples (Flagstad et al. 2004, Ulizio et al. 2006), hair snags (Mulders et al. 2007), or a combination of methods (Magoun et al. 2011). Similarly, occupancy information can be obtained via aerial track surveys (Magoun et al. 2007, Gardner et al. 2010), remote cameras (R. Inman, Wildlife Conservation Society, unpublished data) or any genetic sampling technique. In all cases, the models used to estimate abundance and/or occupancy are the same; field methods only change the probability of detecting (and potentially identifying an individual(s) and the cost of obtaining those detections. Our aim was to use simulation to generically estimate power for detecting population declines of interest in the Northern Rockies. Simulations are spatially explicit, sampling occurs randomly and we are currently using robust design occupancy models to look at power. Here we report only on our initial simulations using occupancy estimation.

METHODS

Simulated landscape and wolverine distribution

All simulations were programmed in R (R Core Development Team 2011), with calls to C++ (Stroustrup 1997), RMARK (Laake and Rexstad 2011), and MARK (White and Burnham 1999) as necessary. The simulation landscape included Idaho, western Montana, and northwest Wyoming (Figure 1). We overlaid this landscape with a raster dataset depicting "persistent spring snow" as this layer adequately captures the bioclimatic niche of wolverines (Copeland et al. 2010). Each 500-m pixel in the raster could take values 1 to 7 depending on the number of years from 2000-2006 that snow was present between April 24 and May 15 in that pixel. At the beginning of each iteration of the simulation, we randomly dispersed home range centers across the landscape subject to the following constraints based on wolverine ecology (Figure 2):

1) Home range centers (points) were required to fall within the spring snow layer.
2) Male home range centers were required to be >12.5 km apart.
3) Female home range centers were required to be >8.5 km apart.
4) Female home range centers could fall within male buffers, and transient males could fall within resident male or female buffers.

Once home range centers were distributed, we temporarily assigned each animal a bivariate normal utilization distribution scaled to match UD estimates from the literature. To impart more realism in these UDs, we multiplied the bivariate normal kernel for each animal by the underlying spring snow layer, then divided each pixel value in the resulting product by the total of all values for that animal to recreate a probability distribution. Functionally this process produces a center-weighted UD in which mass is piled up over pixels with higher values of persistent spring snow. Each animal's UD was different depending on the underlying configuration of spring snow.

We began each simulation with 200 males, 200 females, and 100 transients for a total of 500 wolverines in the Northern Rockies landscape. Our simulated population size was based on available wolverine abundance information and expert opinion. We then simulated a 10%, 20%, or 50% decline in this population over 10 years by randomly removing individuals from the landscape at each time step.

Simulated Sampling

To simulate collection of occupancy data, we overlaid a sampling grid of 225km^2-cells (n = 385 total cells) across the landscape. This cell size corresponds roughly to the home range size of female wolverine. At the beginning of each year, we computed the probability of at least 1 wolverine being available to sample in each cell on any given occasion for each cell in sampling grid:

$$p(\geq 1 \text{ wolverine present in cell } j) = 1 - \left[\prod_{i=1}^{w} (1 - p(\text{individual}_i \text{ is present}))\right]$$

where w = total number of wolverines in the simulation. For each visit within a given year, we drew a random uniform number (i.e., U(0,1)) and compared this number to the product: $p(\geq 1$ wolverine available$)p($wolverine detected | available$)$. If the random number was less than this product, wolverine were detected in that cell on that visit (occasion) and we entered a "1" in the encounter history for that cell-occasion. Otherwise, we entered a "0." We proceeded to sample in this manner for each visit to each cell for each year of the simulation. This results in a vector of 0s and 1s (i.e., an encounter history) for each cell that is 10x in length where "x" is the number of visits made during each of 10 years. For each unique landscape and declining wolverine population, we created several different datasets using this general sampling process. We specified detection probability, $p($wolverine detected | available$)$, to be either 0.2 or 0.8 and specified the number of visit to each cell in a year to be 2, 3, 4, 5, 6, or 7. This results in $2 \times 6 = 12$ datasets for each simulated population decline. We also considered the situation in which surveys could only be accomplished every other year, which resulted in another 12 datasets in which no data were collected during even years.

Analysis of simulated data

For each simulated dataset we used the R (R Development Core Team 2011) package RMARK (Laake and Rexstad 2011) to construct a robust design occupancy model (MacKenzie et al. 2006, p. 183-224) for fitting in program MARK(White and Burnham 1999). We allowed the occupancy (use) parameter (ψ_t) as well as colonization (γ_t) and extinction (ε_t) to vary through time in an unconstrained manner, but constrained detection probability (p) to be constant to reflect how it was simulated. This resulted in 10 estimates of probability of occupancy, or use, from each dataset. We then fit a random effects trend model to these 10 data points (also using the RMARK interface for MARK to account for covariance between estimates; Figure 4), and retained the slope of the trend line along with 95% confidence interval for that slope. When the 95% confidence interval for the slope of the trend line did not include zero, we considered a trend detected, otherwise a trend was not detected. The number of times a trend was detected out of the total simulations is an estimate of the power of the approach to identify the specified declines given the number of visits and detection probability specified.

RESULTS

As expected, initial results indicate that occupancy estimation should work well for detecting large declines (50% decline over 10 years, $\lambda = 0.933$) when detection probability is high ($p = 0.8$). Under these conditions, power was 80% when sampling 50 units, regardless of the number of visits, and approached 100% when sampling 100 units (Figure 5, "continuous sampling" panels). Power declined some, but was still respectable, even when detection probability was low ($p = 0.2$). In that case a power of 0.8 could be achieved with 4-6 visits to 100 sample units. Power to detect a 20% decline over 10 years ($\lambda = 0.977$) was diminished, however, especially when detection probability was low. For instance, in order to achieve 80% power, even with high detection probability, would require surveys in an estimated 300 sample units. There is no realistic chance of detecting minor declines (e.g., 10% over 10 years, $\lambda = 0.989$) using occupancy estimation (Figure 5).

Not surprisingly, power declines when sampling occurs every other year rather than annually (Figure 5, "gap sampling" panels). However, if detection probability is high, adequate power (0.8) can be achieved to detect a 50% decline over 10 years if such a scheme is implemented in a reasonable number of sample units (100), even with as few as 2-3 visits. Ability to detect smaller declines (20% or 10% over 10 years) is poor regardless of detection probability, number of sample units or number of visits (Figure 5, "gap sampling" panels).

Generally, we found that when detection probability is high, power increases as number of visits to each sample unit increases from 2 to 3 per survey season, but making more than 3 visits does not increase power substantially. However, when detection probability is low, gains can be realized by making more visits. This result re-confirms a well-documented phenomenon unique to occupancy estimation (MacKenzie et al. 2006, p. 168). Also, if confronted with design tradeoffs that lead to having a better detection probability vs. those that allow for more units to be sampled, it is always better to increase detection probability and survey fewer units.

DISCUSSION

Our initial simulations suggest that occupancy estimation may work well in a monitoring context if the survey techniques employed have relatively high detection probability and interest lies only in detecting sharp declines in the population. Future work on this project will focus on determining the effects of varying the size of sample units, using alternate starting population sizes, detecting increasing trends rather than decreasing, and making sure that detection and occupancy estimates match well with recently collected pilot data (R. Inman, unpublished data). Additionally, we will incorporate cost functions into the modeling effort and investigate how well occupancy estimation compares to abundance estimation, which can be accomplished by sampling with hare snares or by photographing unique throat patch patterns via remote camera

LITERATURE CITED

Aubry, K. B., G. M. Koehler, and J. R. Squires. 2000. Ecology of Canada lynx in southern boreal forests. Pages 373-396 *in* L. F. Ruggiero, K. B. Aubry, S. W. Buskirk, G. M. Koehler, C. J. Krebs, K. S. McKelvey, andJ. R. Squires, editors. Ecology and conservation of lynx in the United States. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado, USA.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. 2nd edition. Springer, New York.

Copeland, J. P., K. S. McKelvey, K. B. Aubry, A. Landa, J. Persson, R. M. Inman, J. Krebs, E. Lofroth, H. Golden, J. R. Squires, A. Magoun, M. K. Schwartz, J. Wilmot, C. L. Copeland, R. E. Yates, I. Kojola, and R. May. 2010. The bioclimatic envelope of the wolverine (Gulo gulo): do climatic constraints limit its geographic distribution? Canadian Journal of Zoology-Revue Canadienne De Zoologie 88:233-246.

Devineau, O., T. M. Shenk, G. C. White, P. F. Doherty, P. M. Lukacs, and R. H. Kahn. 2010. Evaluating the Canada lynx reintroduction programme in Colorado: patterns in mortality. Journal of Applied Ecology 47:524-531.

Dolbeer, R. A., and W. R. Clark. 1975. Population ecology of snowshoe hares in the central Rocky Mountains. Journal of Wildlife Management 39:535-549.

Flagstad, O., E. Hedmark, A. Landa, H. Broseth, J. Persson, R. Andersen, P. Segerstrom, and H. Ellegren. 2004. Colonization history and noninvasive monitoring of a reestablished wolverine population. Conservation Biology 18:676-688.

Gardner, C. L., J. P. Lawler, J. M. Ver Hoef, A. J. Magoun, and K. A. Kellie. 2010. Coarse-Scale Distribution Surveys and Occurrence Probability Modeling for Wolverine in Interior Alaska. Journal of Wildlife Management 74:1894-1903.

Getz, W. M., S. Fortmann-Roe, P. C. Cross, A. J. Lyons, S. J. Ryan, and C. C. Wilmers. 2007. LoCoH: Nonparameteric Kernel Methods for Constructing Home Ranges and Utilization Distributions. Plos One 2.

Getz, W. M., and C. C. Wilmers. 2004. A local nearest-neighbor convex-hull construction of home ranges and utilization distributions. Ecography 27:489-505.

Hodges, K. E. 2000a. The ecology of snowshoe hares in northern boreal forests. Pages 117-161 *in* L. F. Ruggiero, K. B. Aubry, S. W. Buskirk, G. M. Koehler, C. J. Krebs, K. S. McKelvey, andJ. R. Squires, editors. Ecology and conservation of lynx in the United States. University Press of Colorado, Boulder, Colorado, USA.

_____. 2000b. Ecology of snowshoe hares in southern boreal and montane forests. Pages 163-206 *in* L. F. Ruggiero, K. B. Aubry, S. W. Buskirk, G. M. Koehler, C. J. Krebs, K. S. McKelvey, andJ. R. Squires, editors. Ecology and conservation of lynx in the United States. University Press of Colorado, Boulder, Colorado, USA.

Ivan, J. S. 2011. Density, demography, and seasonal Movement of snowshoe hares in central Colorado. Dissertation, Colorado State University, Fort Collins, Colorado, USA.

Laake, J. L., and E. Rexstad. 2011. RMark - an alternative approach to building linear models in MARK. *in* E. Cooch, andG. C. White, editors. Program MARK: A gentle introduction.

MacKenzie, D. I., J. D. Nichols, J. A. Royle, K. H. Pollock, L. L. Bailey, and J. E. Hines. 2006. Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence. Academic Press, Oxford, UK.

Magoun, A. J., C. D. Long, M. K. Schwartz, K. L. Pilgrim, R. E. Lowell, and P. Valkenburg. 2011. Integrating Motion-Detection Cameras and Hair Snags for Wolverine Identification. Journal of Wildlife Management 75:731-739.

Magoun, A. J., J. C. Ray, D. S. Johnson, P. Valkenburg, F. N. Dawson, and J. Bowman. 2007. Modeling wolverine occurrence using aerial surveys of tracks in snow. Journal of Wildlife Management 71:2221-2229.

McKelvey, K. S., K. B. Aubry, and Y. K. Ortega. 2000. History and distribution of lynx in the contiguous United States. Pages 207-264 *in* L. F. Ruggiero, K. B. Aubry, S. W. Buskirk, G. M. Koehler, C. J. Krebs, K. S. McKelvey, andJ. R. Squires, editors. Ecology and conservation of lynx in the United States. University Press of Colorado, Boulder, Colorado, USA.

Mulders, R., J. Boulanger, and D. Paetkau. 2007. Estimation of population size for wolverines Gulo gulo at Daring Lake, Northwest Territories, using DNA based mark-recapture methods. Wildlife Biology 13:38-51.

Pebesma, E. J. 2004. Multivariable geostatistics in S: the gstat package. Computers & Geosciences 30:683-691.

Royle, J. A., A. J. Magoun, B. Gardner, P. Valkenburg, and R. E. Lowell. 2011. Density Estimation in a Wolverine Population Using Spatial Capture-Recapture Models. Journal of Wildlife Management 75:604-611.

Ruediger, B., J. Claar, S. Gniadek, B. Holt, L. Lyle, S. Mighton, B. Naney, G. Patton, T. Rinaldi, J. Trick, A. Vendehey, F. Wahl, N. Warren, D. Wenger, and A. Williamson. 2000. Canada lynx conservation assessment and strategy. 2nd edition. R1-00-53, U.S. Department of Agriculture, Forest Service, U.S. Department of Interior, Fish and Wildlife Service, Bureau of Land Management, National Park Service, Missoula, Montana, USA.

Service, U. S. F. a. W. 2010. Endangered and threatened wildlife and plants: 12-month finding on a petition to list the North American wolverine as endangered or threatened. Federal Register.

Shenk, T. M., and R. H. Kahn. 2010. The Colorado lynx reintroduction program. Colorado Division of Wildlife.

Stroustrup, B. 1997. The C++ Programming Language. 3rd edition. Addison Wesley Longman, Reading, MA, USA.

Team, R. D. C. 2011. R Foundation for Statistical Computing, Vienna, Austria.

Theobald, D. M., and T. M. Shenk. 2011. Areas of high habitat use from 1999-2010 for radio-collared Canada lynx reintroduced to Colorado. Colorado State University.

Ulizio, T. J., J. R. Squires, D. H. Pletscher, M. K. Schwartz, J. J. Claar, and L. F. Ruggiero. 2006. The efficacy of obtaining genetic-based identifications from putative wolverine snow tracks. Wildlife Society Bulletin 34:1326-1332.

White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46 Supplement:120-138.

Yee, T. W. 2010. The VGAM package for categorical data analysis. Journal of Statistical Software 32:1-34.

_____. 2011.

Zahratka, J. L., and T. M. Shenk. 2008. Population estimates of snowshoe hares in the southern Rocky Mountains. Journal of Wildlife Management 72:906-912.

Zuur, A. F., E. N. Ieno, N. J. Walker, A. A. Saveliev, and G. M. Smith. 2009. Mixed Effects Models and Extensions in Ecology with R. Springer, New York, New York, USA.

Prepared by ____

Jake S. Ivan, Wildlife Researcher

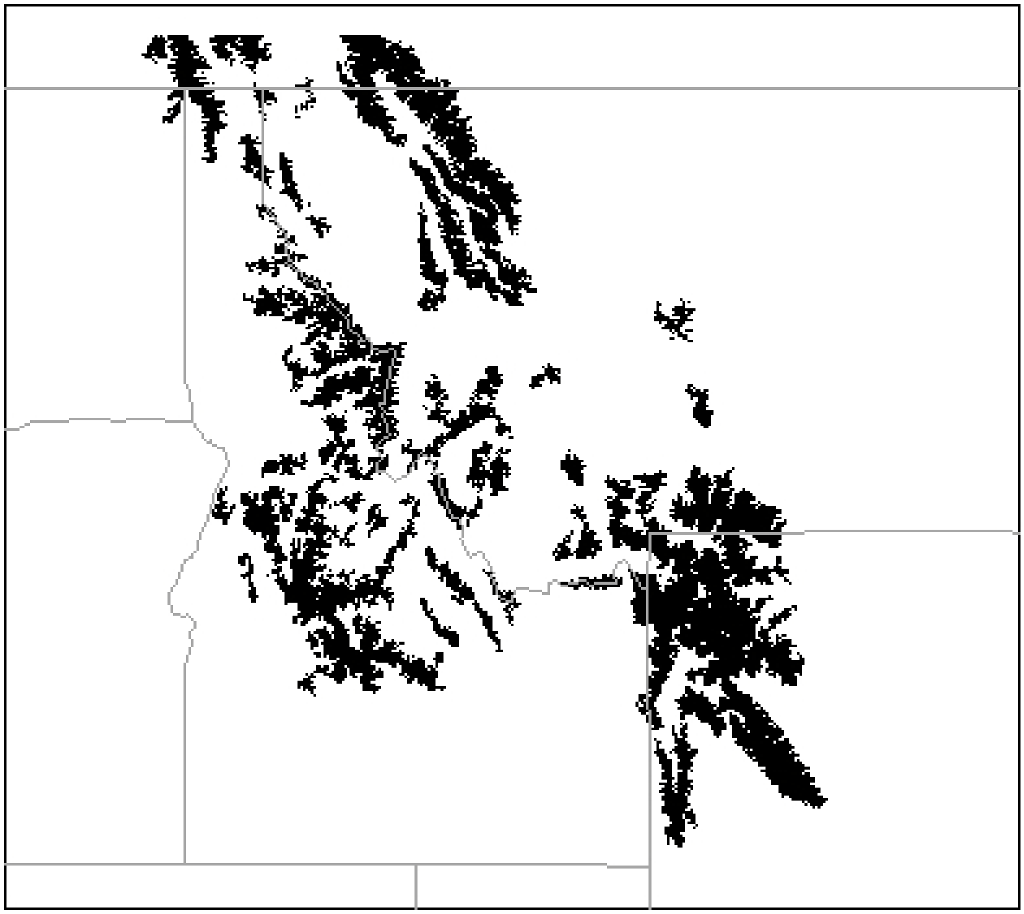


Figure 1. Study area for simulation including montane regions of Idaho, western Montana, and northwest Wyoming. Black polygons indicate primary wolverine habitat defined as areas with snowcover between April 24 and May 15 during at least 1 year from 2000-2006.

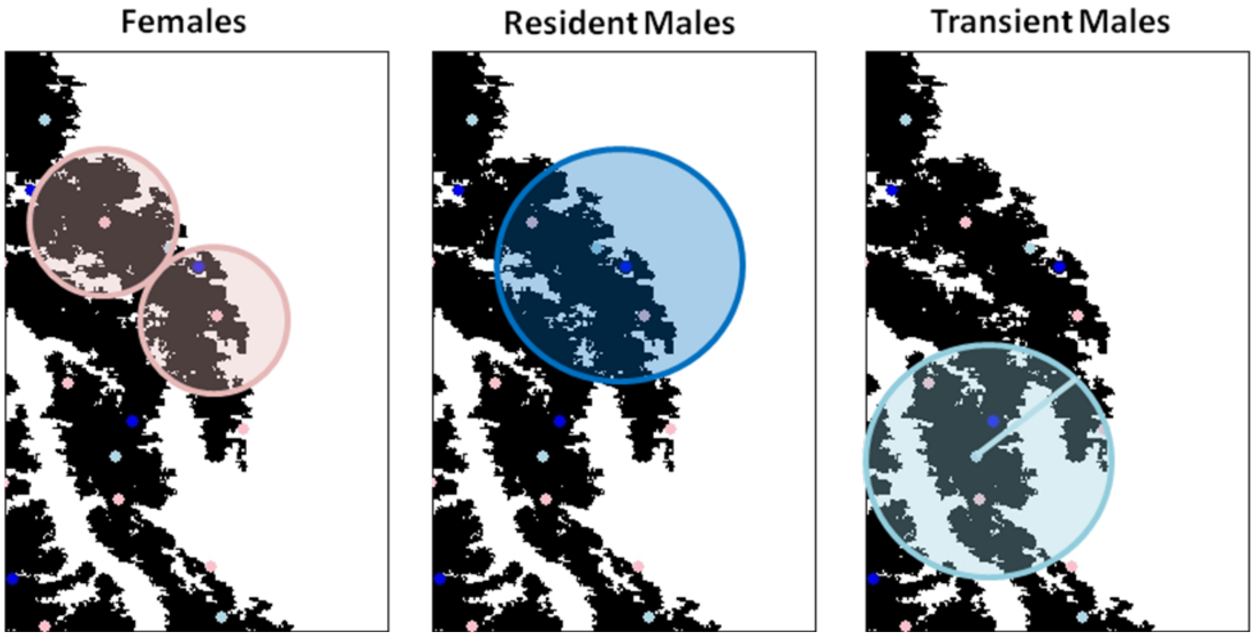


Figure 2. Example distribution of home range centers for male, female, and transient wolverines on the virtual landscape. Home range centers were required to fall within the spring snow layer, and intrasexual territorialty was enforced, except for transient individuals. The buffer around male home range centers was 12.5 km; female buffers were 8.5 km.

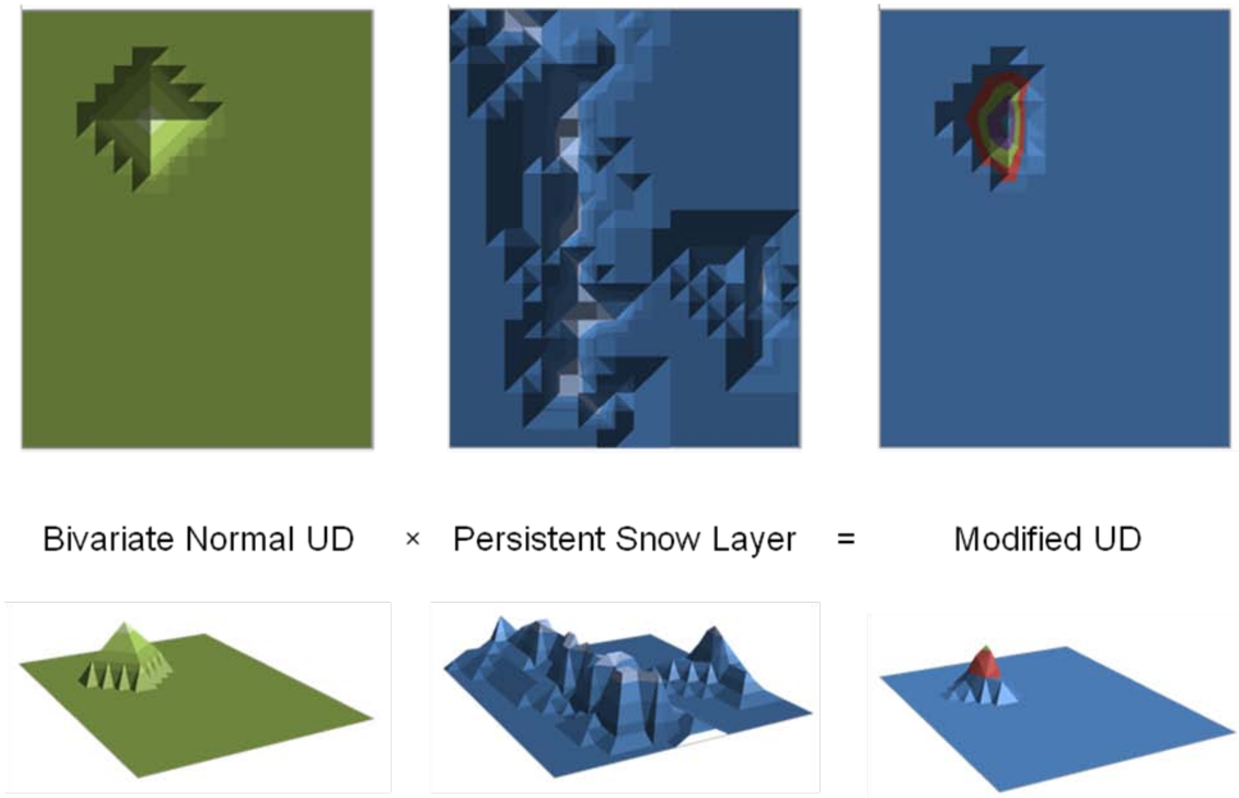


Figure 3. Simulated utilization distributions (UDs) for each individual were created by positioning a bivariate normal UD directly over each home range center (see Figure 2) then multiplying by the underlying persistent snow layer to form a modified, more realistic UD unique to each individual.

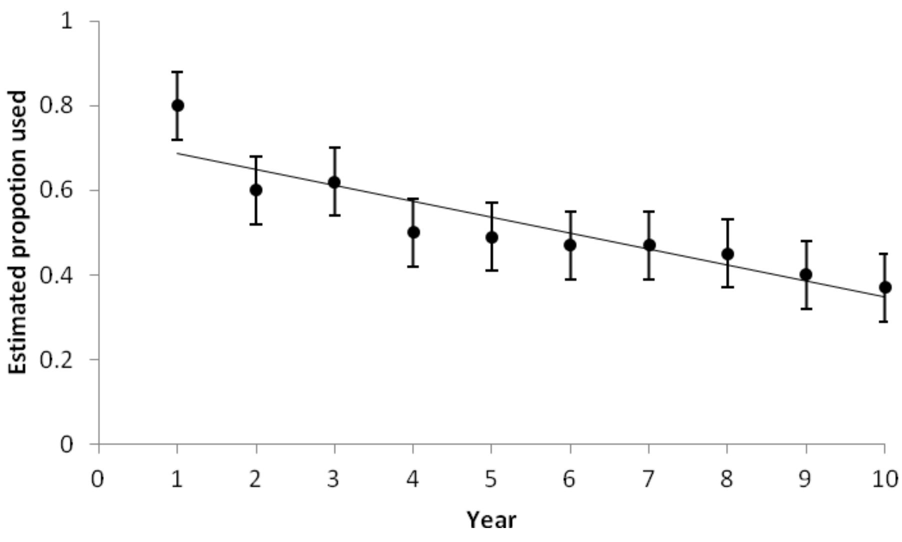


Figure 4. Example output from a single simulation: estimates of occupancy over a 10-year period fitted with a linear random effects model. If the 95% confidence interval on the slope of the linear trend did not include zero, then we concluded that a trend had been detected. The percentage of iterations in which trends were detected out of the total iterations provided a measure of power.

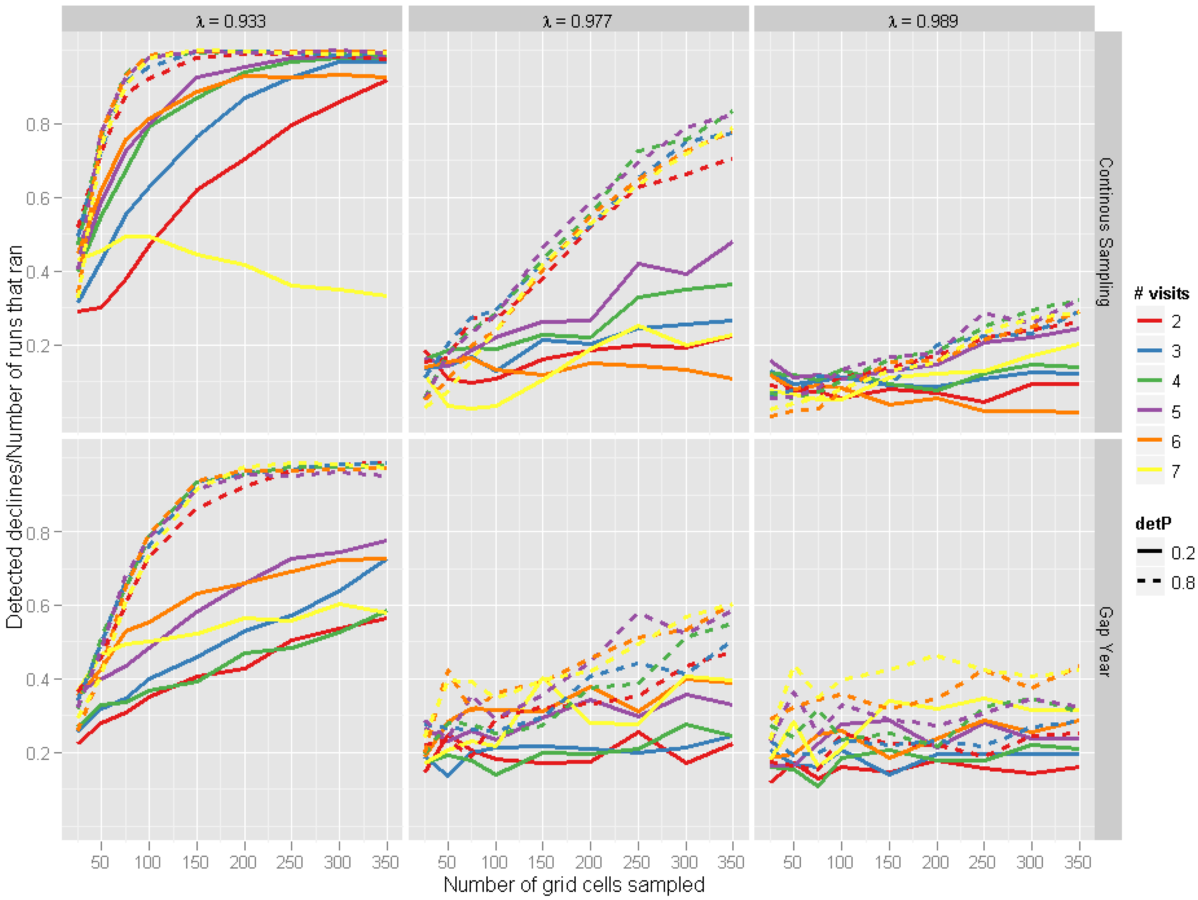


Figure 5. Power to detect population declines of 50% (λ=0.933), 20% (λ=0.977), and 10% (λ=0.989) using occupancy estimation. Curves represent 2 levels of detection probability (0.2 and 0.8) and varying number of visits annually to a sampled unit (2, 3, 4, 5, 6, 7). Top 3 panels depict estimates of power when occupancy surveys occur annually; bottom 3 panels depict power when surveys are conducted biannually. Note that the lowest power to detect a 50% decline with annual sampling is apparently realized with 7 visits to each sampling unit. This result is counterintuitive, and likely due to a coding error. It will be addressed in future simulations.

Colorado Division of Parks and Wildlife
July 2010–June 2011

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of Parks and Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	0670	:	Lynx Conservation
Task No.:	N/A	:	Monitoring Canada Lynx in Colorado Using Occupancy Estimation: Initial Implementation in the Core Lynx Research Area
Federal Aid Project No.	N/A		

Period Covered: July 1, 2010 – June 30, 2011

Author: J. S. Ivan

Personnel: T. Shenk, G. Merrill, E. Newkirk

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

ABSTRACT

In an effort to restore a viable population of federally threatened Canada lynx (*Lynx canadensis*) to the southern portion of their former range, 218 individuals were reintroduced into Colorado from 1999–2006 (Devineau et al. 2010). In 2010, the Colorado Division of Wildlife (now Colorado Parks and Wildlife [CPW]) determined that the reintroduction effort met all benchmarks of success, and that a viable, self-sustaining population of Canada lynx had been established. The purpose of this project was to develop a scientifically rigorous statewide plan to monitor this newly established population. Occupancy estimation, the use of presence/absence data to estimate the proportion of sample units used by a species within a study area, is appropriate for such a program. To evaluate this approach and provide initial estimates of occupancy and detection probability for planning purposes, we conducted a pilot occupancy estimation project in the core reintroduction area in the San Juan Mountains of southwestern Colorado. Lynx habitat in the study area was divided into 75–km^2 sample units (8.66 km x 8.66 km cells), and we stratified the units into those accessible for snow tracking and "inaccessible" units which were sampled via remote cameras. We randomly sampled 30 units from each stratum. Sampling consisted of making multiple visits to each selected unit. We covered 2,178 km during our snow tracking effort (min= 1.4, max = 81.7 per visit) and detected lynx on 12 of the 30 sample units. Estimates of occupancy and detection probability from the top model were 0.62 and 0.37-0.43, respectively. Of the 120 cameras we deployed in late fall to survey the 30 inaccessible units, 113 were still operational when retrieved in early summer; 6 had memory cards that reached capacity in either May or June; 1 was stolen. We obtained 151,191 photos (min = 90, max = 6,948 per camera) from this effort. Work to assign species for each photo is ongoing. These pilot data will be used to conduct simulations and power analyses to determine how many sample units will be required to detect a statewide decline in Canada lynx, assuming that a decline in the actual population will be tied to a decline in the proportion of sample units used by lynx.

WILDLIFE RESEARCH REPORT

MONITORING CANADA LYNX IN COLORADO USING OCCUPANCY ESTIMATION: INITIAL IMPLEMENTATION IN THE CORE LYNX RESEARCH AREA

JACOB S. IVAN

P. N. OBJECTIVE

Assess the use of occupancy estimation as a means of monitoring Canada lynx in Colorado using the Core Research Area in the San Juan Mountains as a test site.

1. Obtain initial estimates of occupancy and detection probability based on pilot work.
2. Conduct power analyses using initial estimates to determine the number of sample units, number of visits, and periodicity of sampling required to detect declines of interest in the statewide lynx population.
3. Develop a standardized, statistically rigorous monitoring protocol for estimating the distribution, stability and persistence of Canada lynx in Colorado.

SEGMENT OBJECTIVES

1. Assess and suggest modifications to survey protocols.
2. Construct database to store and query survey information.
3. Obtain initial estimates of occupancy and detection probability based on pilot work.
4. Determine covariates and covariate structures that will be most useful for modeling occupancy and detection probability in the future.
5. Determine the efficacy of collecting lynx scat during occupancy surveys and whether such collections can be helpful in identification of putative lynx tracks and/or individuals.

INTRODUCTION

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

In order to track the distribution, stability, and persistence of this new lynx population, a minimally-invasive, long-term, statewide monitoring program is required. Abundance estimation is not feasible logistically and presents statistical difficulties even when field logistics can be managed. However, occupancy estimation, which uses detection/non-detection survey data to estimate the proportion of area occupied in a study area, is appropriate and feasible. In short, such a monitoring scheme requires multiple visits to a sample of survey units, and on each visit observers record whether a lynx was detected or not. Such information can be used to compute the probability of detecting a lynx given that it is present on a unit, which can in turn be used to estimate the proportion (ψ) of all survey units that are occupied. This metric can be tracked through time and is assumed to be closely tied to the size and extent of the lynx population. That is, if the proportion of survey units occupied by lynx declines through time, we assume this is due to a decline in the lynx population itself. Additionally, occupancy surveys can provide information relative to the distribution of lynx in the state.

CPW initiated work to evaluate detection methods for occupancy estimation in 2009-2010 (Shenk 2009). Three methods of detecting lynx were tested in sample units where lynx were known to occur: snow tracking surveys, remote camera surveillance, and hair snags. The best method for detecting lynx was snow-tracking (daily detection probability = 0.70). Camera surveillance was far less efficient (daily detection probability = 0.085), and hair snares were ineffective (daily detection probability = 0.0; Ivan and Shenk 2010). Snow tracking, however, requires safe and extensive access to a survey unit via truck and/or snowmobile. Therefore, it cannot be used in roadless or wilderness areas, which may provide important lynx habitat. Here we build on this work to test occupancy estimation on a large scale using snow tracking where accessibility permitted it, and remote cameras in areas that were not accessible.

METHODS

Study Area

The study area consisted of the 20,684 km^2 "Lynx Core Research Area" in southwest Colorado. The Core Research Area is defined as areas >2591 m (>8500 ft) in elevation within the area bounded by New Mexico to the south, Taylor Mesa to the west, and Monarch Pass on the north and east (Figure 1). Topography in this area is characterized by wide plateaus, river valleys, and rugged mountains that reach elevations over 4200 m. Engelmann spruce (*Picea engelmanii*) – subalpine fir (*Abies lasiocarpa*) is the most widely distributed coniferous forest type at elevations most typically used by lynx (2591-3353 m, 8500-11,000 ft).

Sampling

The study area was divided into 75 km^2 (8.66 km × 8.66 km) sample units, which reflects the mean annual home range size of reproducing lynx in Colorado (Shenk 2007) and Montana (Squires and Laurion 1999). Sample units that did not meet the following criteria were discarded as they did not represent potential lynx habitat that could be surveyed.

1. ≥ 50 % of the cell contained conifer or montane/alpine habitat, as identified by the SWReGAP LandCover Dataset (http://earth.gis.usu.edu/swgap/swregap_landcover_report.pdf) and
2. ≥ 50 % of the cell was located on public land (tribal, NGO and city and county lands are considered private) as determined by COMaP (Theobald, D.M., G. Wilcox, S.E. Linn, N. Peterson, and M. Lineal. 2008. Colorado Ownership, Management, and Protection v7 database. Human Dimensions of Natural Resources and Natural Resource Ecology Lab, Colorado State University, Fort Collins, CO, www.nrel.colostate.edu/projects/comap).

Each of the remaining sample units was assigned a random number resulting from a spatially balanced sampling scheme (RRQRR; Theobald et al. 2007) and units were stratified by accessibility for snow tracking or camera surveys. The cells with the lowest 30 random numbers for each stratum were selected for sampling during the pilot work. A few cells in both strata were discarded once field work began due to access issues and these were replaced with cells 31, 32, etc.

Snow tracking Surveys

Teams of 2 observers generally searched for lynx tracks within a sample unit using snowmobiles, although portions of some units were surveyed via truck or snowshoe. An effort was made to survey all portions of each unit as access allowed. Each of the 30 units selected for sampling was visited 3 times – roughly once per month from January through March. Occasionally a "visit" actually took place over consecutive days as some units could not be covered completely from a single access point. Once tracks were detected in a unit, that visit was considered complete and no further surveying occurred until the next visit. However, observers forward and back-tracked to find a scat sample. For each visit, observers recorded number of kilometers surveyed, tracking conditions (poor, fair, good, excellent), other species detected, location of lynx tracks, and time/distance to scat discovery.

Camera Surveys

Four remote camera sets (RECONYX RapidFire™ Professional PC85) were placed within each selected "inaccessible" sample unit during September and October. Placement of camera sets was not random within the unit; they were placed strategically on the landscape to maximize coverage of the sample unit and exploit microsites most likely to be used by lynx. Camera sets consisted of 1) a remote camera mounted to a tree using a Master Lock ™ Python™ cable lock, 2) a target tree at which the camera was pointed, generally about 5-10m away, 3) a compact disc strung from a nearby branch to visually attract lynx from a distance, 4) 2 feathers strung up in such a manner as to entice lynx to walk between the camera and the target tree, and 5) wool soaked in commercial scent lure that was packed into the bark of the target tree to hold lynx in front of the camera (Figure 2). Cameras were placed higher than usual, about head-height, and pointed slightly downward at the target tree so photos could be obtained during both snow-free periods and during periods of accumulating snow. Cameras were collected during June and July at which time the number of photos, percent of memory card used, percent battery life remaining, and condition of visual/scent lures was recorded.

Analysis

Assumptions inherent in occupancy estimation are 1) surveyed sites are either occupied or not occupied by the species of interest throughout the duration of the study; no sites change status during the survey period (i.e., the system is closed), 2) the probability of occupancy is constant across sites or can be modeled using covariates, 3) the probability of detection is constant across sites or can be modeled using site-specific covariates, and 4) species detection at a site is assumed to be independent of species detection at other sites (MacKenzie et al. 2006). Sampling mobile carnivores such as lynx presents a clear violation of the first assumption as individuals undoubtedly move into and out of sample units routinely. Fortunately, estimation can proceed, but the quantities estimated are different from traditional occupancy estimation. Rather than estimating the probability that a unit is *occupied* by lynx, we now estimate the probability that a sample unit is *used* by lynx. Also, the estimated detection parameter is not the probability of detection given a site is occupied, it is the product of a) the probability of detection given the species is available for detection, and b) the probability that the species was available. These subtleties aside, the procedure still gives a metric (use) that can be monitored through time to detect trends.

We used the "Occupancy Estimation" data type in Program MARK to produce initial estimates of occupancy (i.e., use, ψ) and detection probability (p) for the snow tracking stratum. We hypothesized that some metric of the number of kilometers surveyed, or number that could be surveyed, would be important in explaining variation in detection probability as it should be an indicator of the amount of access to a unit. Surveys on units with more access should stand a better chance of detecting lynx if they are present. We further hypothesized that tracking conditions during a given visit should have an effect on detection probability. Finally, we did not expect differences among survey teams as both teams were experienced, but we wanted to test that assumption. Therefore, we considered 5 covariates that may explain variation in *p*: 1) total road length available for surveying in each sampled unit, 2) Kilometers surveyed during each visit, 3) maximum number of kilometers surveyed during any visit to a given unit, 4) tracking conditions during each visit, and 5) observer effect. We hypothesized that the proportion of spruce/fir cover in each unit may affect the probability of use, as might proportion of willow (*Salix* spp.), and subalpine/alpine meadow. Thus, we considered those 3 covariates as potentially important for explaining variability in ψ. As this analysis is exploratory, we held ψ constant and built an additive model for each detection covariate (one at a time) to determine the best structure for *p*. Similarly, we held *p* constant and fit additive models using the 3 covariates for ψ. We combined the best structure as determined by AICc (Burnham and Anderson 2002) for each parameter and used results from that single model to produce initial estimates of *p* and ψ. We also ran a model where both *p* and ψ were held constant as a baseline for comparison.

Occupancy estimation for the camera stratum will proceed in a similar fashion as above, but data from the photos is incomplete at this time. Photos will be grouped by month (November to March) for each sample unit such that encounter histories will have 5 "visits" rather than 3. Due to this grouping, there are no meaningful covariates for *p*. Individual cameras recorded moon phase and temperature for each photo, but aggregated over a month, these data are not helpful. Some camera sets used different scent lures than others, but aggregating by unit negates the utility of this information as well. We will consider the same covariates on ψ as listed above.

RESULTS

On average, we covered 24.71 km per visit to each accessible sample unit (min = 1.40 km, max = 81.67 km) for a total of 2,184 km surveyed. We detected 20 lynx tracks in 12 of the 30 units sampled (i.e., tracks were detected on multiple visits to some units; Figure 1). We were able to collect scat from 13 of the 20 tracks, and mean forward/backtracking distance to scat discovery was 0.65 km (min = 0.05, max = 1.60).

According to AICc, the best structures for *p* and ψ were "kilometers surveyed per visit" and "proportion spruce-fir," respectively (Table 1). No other structure for either parameter resulted in improvement over constant *p* and ψ with the exception of modeling ψ as a function of "proportion willow." In fact, this was the AICc top structure, but the parameters could not be estimated so it was dropped from the model set. Estimates (SE) from the model that combined the best structures were ψ = 0.62 (0.25), p_1= 0.37 (0.10), p_2= 0.37 (0.10), and p_3 = 0.43 (0.10) where p_i is the detection probability for visit *I* (i.e., p_1 is the estimated detection probability for January, p_2 = February, p_3 = March) .

As expected, the slope of the spruce-fir effect was highly positive. Probability of use was 0.5 when proportion spruce-fir approached 0.35, and probability of use went to 1.0 when proportion spruce-fir approached 0.6 (Figure 3). The relationships between "proportion meadow" and ψ and "proportion willow" and ψ were also positive, but the relationships were weaker as confidence intervals for these slopes covered zero.

The relationship between *p* and kilometers surveyed was negative. Similarly, the relationship between *p* and visit condition was opposite of our hypothesis (as visit conditions improved, detection probability declined). There was no relationship between "total road length" or "maximum kilometers surveyed" and detection probability. We did not detect differences between teams of observers.

Genetic analysis of scat samples is ongoing. By December 2010, we should be able to assess whether scats were of high enough quality to confirm species and/or individual identification.

Of the 120 cameras deployed during Fall 2010, 113 were still operational when retrieved in Summer 2011 after 234-309 days of deployment. Six had memory cards that reached capacity in either May or June, and one camera was stolen. On average, we obtained 1,260 photos per camera (min = 90, max = 6,948) for a total of 151,191 photos. At the time of retrieval, compact discs were still operational for 46% of camera sets, feathers were operational at 64% of sets, and remnants of scent lure were detected at 55% of sets.

DISCUSSION

Initial results indicate that occupancy (use) can be adequately modeled using data collected via snow tracking. Precision on estimates of ψ and p was relatively poor, but this can be addressed by sampling more units and/or making more visits. Modeling p as a function of the "kilometers surveyed per visit" was a better fit for the data than modeling it as a function of either "total road length within a unit" or "visit conditions." However, we recommend continuing to record "total road length" and "visit conditions" in future surveys as it seems reasonable that these covariates should impact detection probability, and their effects may show through as sample size increases. Similarly, we recommend retaining all covariates on ψ to assess their performance with a larger dataset.

The relationship between p and "kilometers surveyed per visit" was negative, which is likely an artifact of how the units were sampled – when lynx were detected, surveying stopped, so detection probability was higher for visits with few kilometers surveyed. The relationship between p and "visit condition" was opposite of our hypothesis (as visit conditions improved, detection probability declined). Our condition criteria were based largely on the freshness of the snow and degree of melting/crusting where fresh snow was assigned the best condition, and older, crusted snow was assigned the worst. Functionally, this index is an inverse of "time-since-snowfall." Therefore, it is sensible that "poor" condition indices resulted in higher detection probabilities. While the immediate conditions were poor for tracking, significant time had passed in which lynx could move around and leave tracks to be discovered.

We estimated that lynx used approximately 62% of the sample units available in the Core Research Area. However, for this pilot study, lynx habitat was coarsely defined as units with >50% spruce/fir and >50% public land. In several cases, sampled units met these criteria, but field crews that actually made visits indicated these units did not appear to include much lynx habitat. CPW is currently finishing an analysis to produce a map of predicted lynx habitat throughout the state. In the future, we expect to use this map to frame the population of units to sample for lynx monitoring. This more refined population of sample units should reduce time wasted surveying units that do not include good lynx habitat, and will result in an increased estimate of probability of use.

Photos from cameras deployed to sample the inaccessible stratum have not been fully processed, therefore we cannot determine whether that portion of the study worked well enough to be included in any future monitoring effort. Roughly half of the visual attractants we used did not operate through the entirety of the study. These attractants are important for drawing lynx to the set from a distance and their failure diminishes the utility of the cameras for detecting lynx. If cameras are to be used in the future, design changes will be necessary to ensure that most of these visual attractants operate throughout the sampling season.

ACKNOWLEDGMENTS

We thank Britta Schielke, Cate Brown, Wendy Lanier, Joan Meiners, Shane McKenzie, Nick Burgmeier, Doug Clark, Bob Peterson, Tim Hanks, Kei Yasuda, Ashley Bies, Tyler Kelly, Alyssa Winkler, and Carolyn Shores for their efforts in the field. Dale Gomez and Rhandy Ghormley (USFS) graciously coordinated housing for seasonal crews. We thank various personnel from both the Rio Grande and San Juan National Forests for logistical help in the field. Funding was provided by a U.S. Fish and Wildlife Service Section 6 Grant.

LITERATURE CITED

Burnham, K. P., and D. R. Anderson. 2002. Model Selection and Multimodel Inference: A practical information-theoretic approach. Springer, New York, New York, USA.

Devineau, O., T. M. Shenk, G. C. White, P. F. Doherty Jr., P. M. Lukacs, and R. H. Kahn. 2010. Evaluating the Canada lynx reintroduction programme in Colorado: patterns in mortality. Journal of Applied Ecology 47:524-531.

Ivan, J. S., and T. M. Shenk. 2010. Estimating the Extent, Stability and Potential Distribution of Canada Lynx (*Lynx canadensis*) in Colorado: initial implementation in the core lynx research area. Wildlife Research Report, Colorado Division of Wildlife, Fort Collins, Colorado.

MacKenzie, D. I., J. D. Nichols, J. A. Royle, K. H. Pollock, L. L. Bailey, and J. E. Hines. 2006. Occupancy Estimation and Modeling: Inferring Patterns and Dynamics of Species Occurrence. Elsevier Academic Press, Oxford, UK.

McKelvey, K. S., J. von Kienast; K.B. Aubry; G. M. Koehler; B. T. Maletzke; J. R. Squires; E. L. Lindquist; S. Loch; M. K. Schwartz. 2006. DNA analysis of hair and scat collected along snow tracks to document the presence of Canada lynx. Wildlife Society Bulletin 34: 451-455.

Meaney C. 2002. A review of Canada lynx (*Lynx canadensis*) abundance records from Colorado in the first quarter of the 20Th century. Colorado Department of Transportation Report.

Shenk, T. M. 2005. Post-release monitoring of lynx reintroduced to Colorado. Job Progress Report, Colorado Division of Wildlife, Fort Collins, Colorado.

__________. 2007. Post-release monitoring of lynx reintroduced to Colorado. Wildlife Research Report, Colorado Division of Wildlife, Fort Collins, Colorado.

__________. 2009. Post-release monitoring of lynx reintroduced to Colorado. Wildlife Research Report, Colorado Division of Wildlife, Fort Collins, Colorado.

Shenk, T.M., and R. H. Kahn. 2003. Post-release monitoring of lynx reintroduced to Colorado. Wildlife Research Report, Colorado Division of Wildlife, Fort Collins, Colorado.

__________. 2010. The Colorado lynx reintroduction program. Report to the Colorado Division of Wildlife, Fort Collins, Colorado.

Squires, J. R. and T. Laurion. 1999. Lynx home range and movements in Montana and Wyoming: preliminary results. Pages 337-349 in L. F. Ruggiero, K. B. Aubry, S. W. Buskirk, G. M. Koehler, C. J. Krebs, K. S McKelvey, and J. R. Squires, editors. Ecology and Conservation of Lynx in the United States. General Technical Report for U. S. D. A. Rocky Mountain Research Station. University Press of Colorado, Boulder, Colorado.

Theobald, D.M., D.L. Stevens, Jr., D. White, N.S. Urquhart, A.R. Olsen, and J.B. Norman. 2007. Using GIS to generate spatially balanced random survey designs for natural resource applications. *Environmental Management* 40(1): 134-146.

U. S. Fish and Wildlife Service. 2000. Endangered and threatened wildlife and plants: final rule to list the contiguous United States distinct population segment of the Canada lynx as a threatened species. Federal Register 65, Number 58.

Prepared by ____

Jake S. Ivan, Wildlife Researcher

Table 1. Model selection results for estimating occupancy of sample units by Canada Lynx (*Lynx canadensis*) in the Core Research Area, San Juan Mountains, Colorado, Winter 2010-2011.

Model	AICc	ΔAICc	AICc Wt	Num Par
p(KmSurveyPerVisit) *ψ*(SprFir)	81.25	0.00	0.78	4
p(.) *ψ*(SprFir)	84.23	2.98	0.17	3
p(KmSurveyPerVisit) *ψ*(.)	88.60	7.35	0.02	3
p(.) *ψ*(.)	89.95	8.70	0.01	2
p(TtlRoadLen) *ψ*(.)	90.29	9.04	0.01	3
p(.) *ψ*(Meadow)	91.25	9.99	0.01	3
p(Observer) *ψ*(.)	92.10	10.85	0.00	3
p(MaxKmSurv) *ψ*(.)	92.42	11.17	0.00	3
p(VisitCond) *ψ*(.)	97.77	16.52	0.00	5

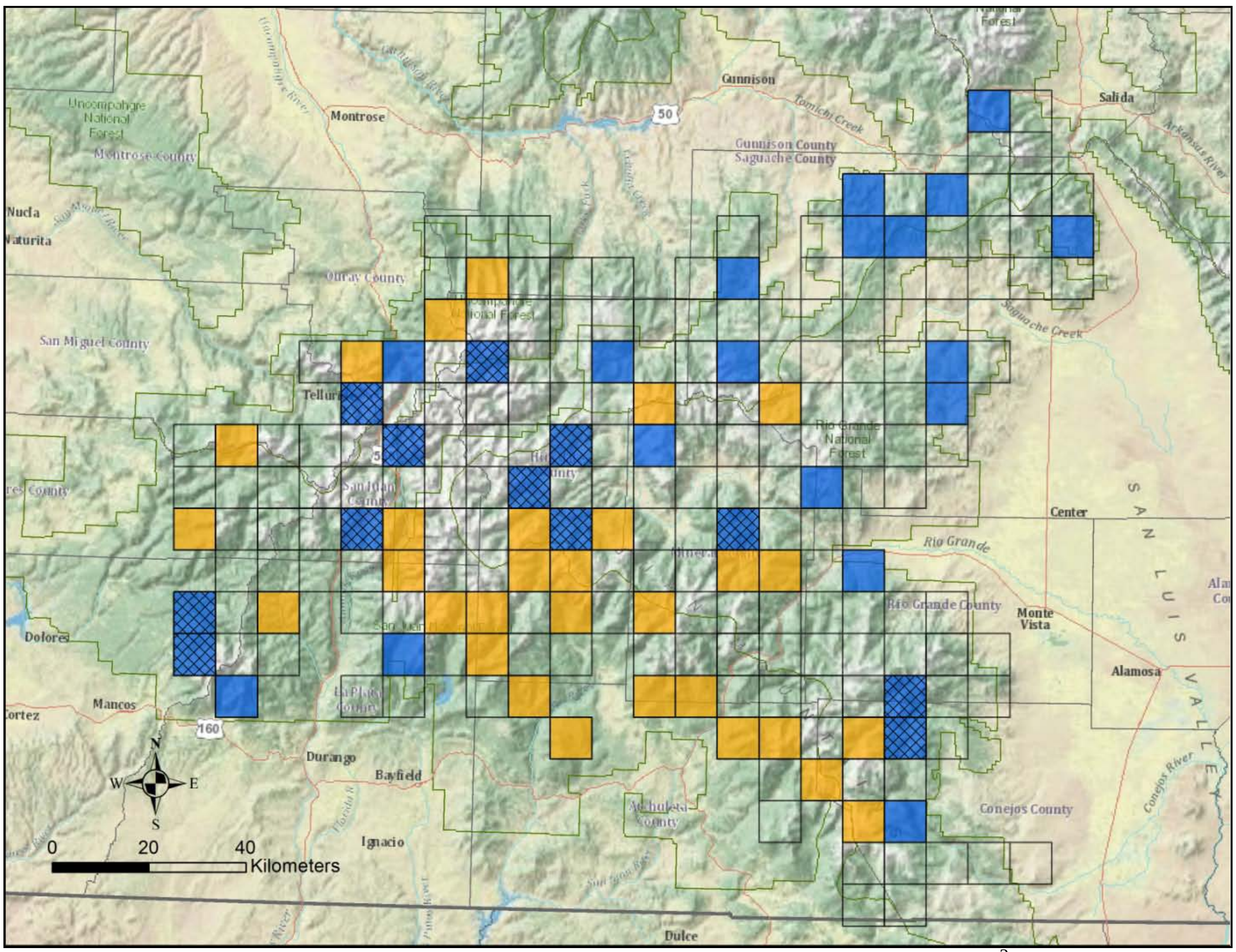


Figure 1. Canada lynx Core Research Area in southwest Colorado. Squares are 75km^2 sample units available for occupancy surveys. Blue represents the sample of 30 “accessible” units selected for snow tracking surveys. Orange are “inaccessible” units selected for surveys using remote cameras. Cross-hatching indicates accessible units where lynx were detected. The data from inaccessible units has not been fully processed and units where lynx were detected are not shown.

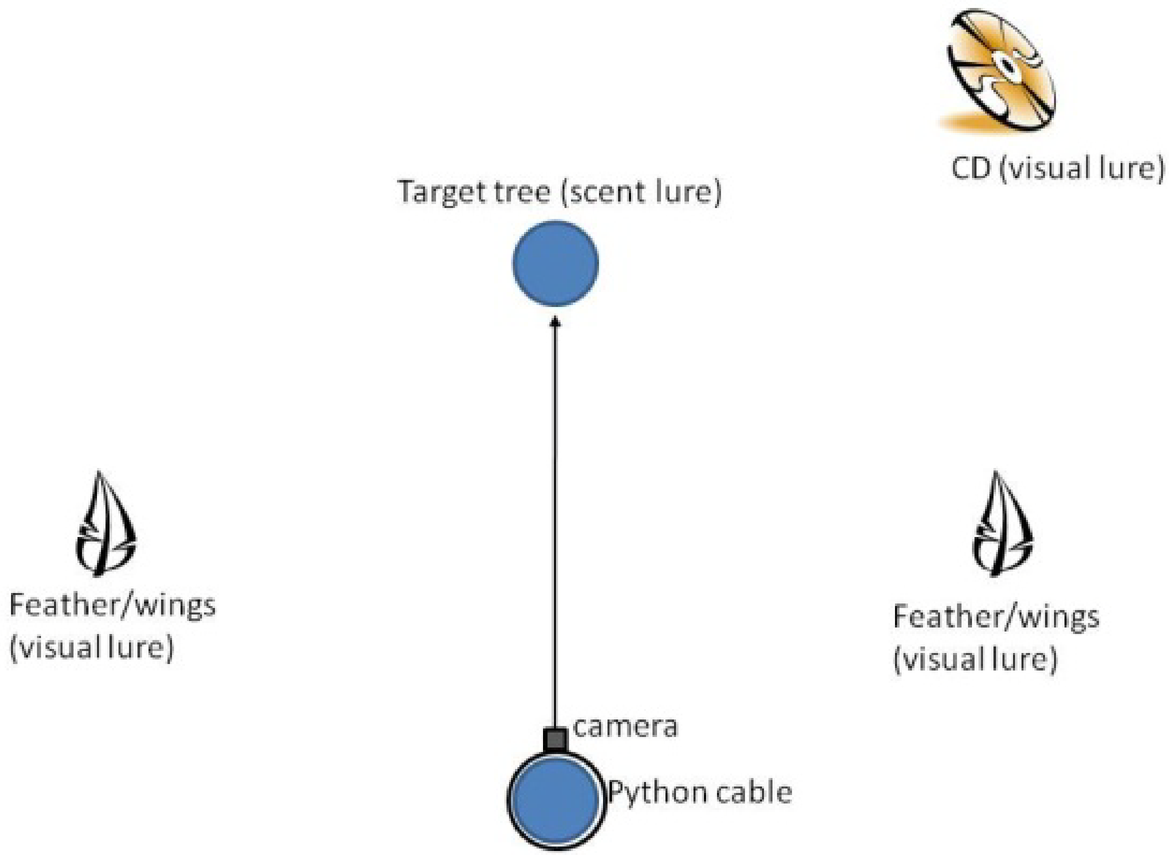


Figure 2. General configuration of remote camera sets for detecting Canada lynx. Four such sets were deployed in each of 30 inaccessible sample units from Fall 2010 to Summer 2011.

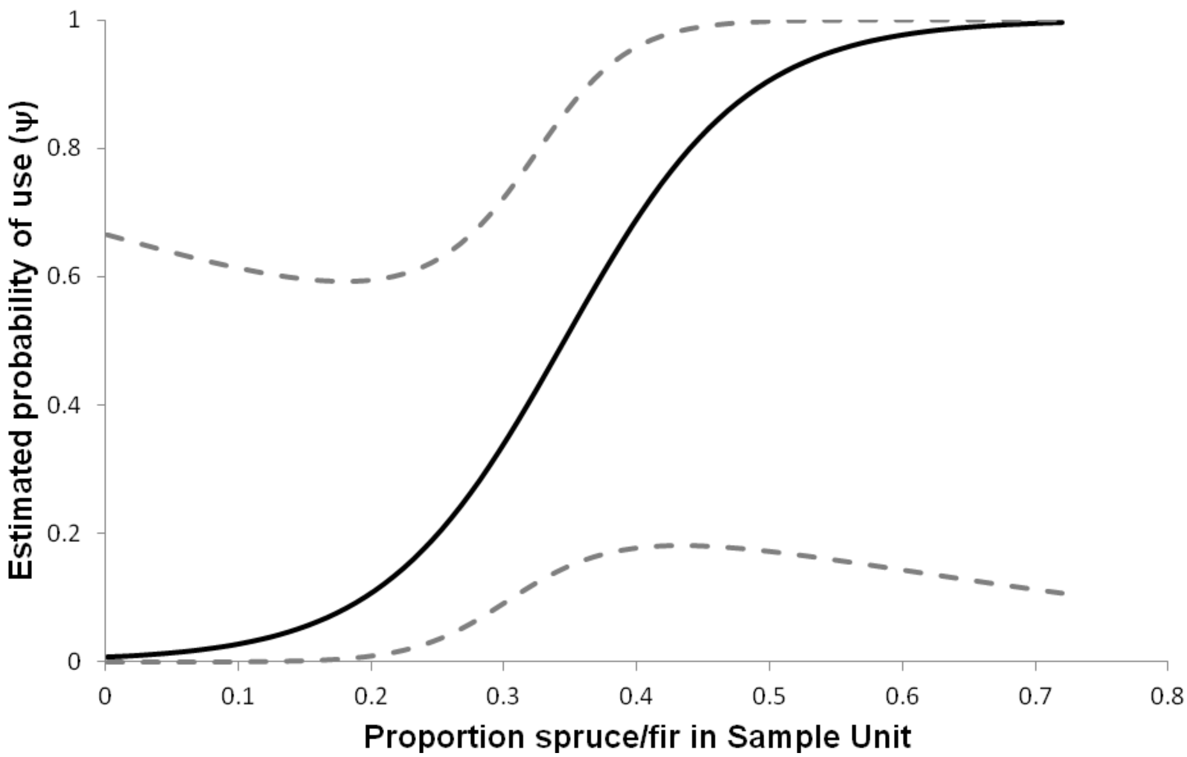


Figure 3. Estimated probability of use (*ψ*) and 95% confidence intervals plotted against proportion spruce/fir in a sample unit. Relationship is based on snow tracking occupancy surveys completed in southwest Colorado, Winter 2010-2011.

Colorado Division of Parks and Wildlife
July 2010–June 2011

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of Parks and Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	0670	:	Lynx Conservation
Task No.:	N/A	:	Predicted lynx habitat in Colorado
Federal Aid Project No.	N/A		

Period Covered: July 1, 2010 – June 30, 2011

Author: J. S. Ivan

Personnel: M. Rice, P. Lukacs, T. Shenk (National Park Service), D. Theobald (Colorado State University), E. Odell

ABSTRACT

In an effort to restore a viable population of federally threatened Canada lynx (*Lynx canadensis*) to the southern portion of their former range, 218 individuals were reintroduced into Colorado from 1999–2006 (Devineau et al. 2010). In 2010, the Colorado Division of Wildlife (now Colorado Parks and Wildlife [CPW]) determined that the reintroduction effort met all benchmarks of success, and that a viable, self-sustaining population of Canada lynx had been established (Shenk and Kahn 2010). The purpose of this project was to develop a statewide predictive map of relative lynx use based upon location data collected during the reintroduction period. To build the map, we divided the state into 1.5 km × 1.5 km cells and tallied the number of locations in each cell. We then fit models to these count data using vegetation, elevation, slope, wetness, and degree of human development in each cell as predictor variables. We produced models for both summer and winter habitat use. We found that regardless of season, lynx were positively associated with spruce/fir (*Picea engelmannii*/*Abies lasiocarpa*), mixed spruce/fir, aspen (*Populus tremuloides*), elevation and slope; they were negatively associated with distance to large forest patches. During summer, lynx use of lodgepole pine (*Pinus contorta*) stands was predicted to increase. Lynx were predicted to avoid montane forest (Douglas-fir [*Pseudotsuga menziesii*], Ponderosa pine [*Pinus ponderosa*]), and areas near high traffic volume road segments, especially during summer. These maps of predicted lynx use should aid land managers in prioritizing areas for conservation, development, and resource extraction with respect to potential impacts to lynx and lynx habitat.

WILDLIFE RESEARCH REPORT

PREDICTED LYNX HABITAT IN COLORADO

JACOB S. IVAN

P. N. OBJECTIVE

Use location data collected during Canada lynx (*Lynx canadensis*) reintroduction to build a model of relative use, then apply this model statewide to produce a predictive map of relative lynx use for Colorado.

SEGMENT OBJECTIVES

1. Compile and filter raw location data to isolate highest quality lynx locations.
2. Compile spatial data for use as covariates for the model (e.g. vegetation type, elevation, etc).
3. Build a series of candidate models to explain variation on locations across the landscape using covariate data layers.
4. Model-average predictions from all candidate models to produce a maps of predicted relative use for Colorado.

INTRODUCTION

In an effort to restore a viable population of federally threatened Canada lynx (*Lynx canadensis*) to the southern portion of their former range, 218 individuals were reintroduced into Colorado from 1999–2006 by the Colorado Division of Wildlife (now Colorado Parks and Wildlife [CPW], Devineau et al. 2010). In 2010, CPW determined that the reintroduction effort met all benchmarks of success, and that a viable, self-sustaining population of Canada lynx had been established (Shenk and Kahn 2010). Attainment of this goal is a conservation success, but it has also created a series of issues for land management agencies to consider as they plan changes to the landscape. These issues require knowledge of the types of landscapes and forest stands important for reproduction, movement, dispersal, and general home range use by lynx.

As a first step toward providing this information, Theobald and Shenk (2011) conducted an analysis to describe the types of areas that were known to be used by re-introduced lynx. Specifically, they used LoCoH (Getz and Wilmers 2004, Getz et al. 2007) methods to create a population-level utilization distribution (UD, a probability surface of lynx occurrence) for lynx in Colorado. They then summarized landscape attributes within the 90% isopleth (i.e., polygon(s) containing 90% of the probability surface) of this UD. This work provides valuable information regarding the types of areas that were *known* to be used by lynx from 1999 to 2010. By nature of the data collection and research focus, most of this "use" information was derived from core areas in the San Juan Mountains of southwest Colorado and Sawatch Range in the central part of the state.

The purpose of the current project is to extend the work of Theobald and Shenk (2011) by producing a map of *predicted* lynx use on a *statewide* scale. Such an exercise will identify areas within Colorado that should contain high quality lynx habitat, regardless of whether or not it was used by the sample of radio-telemetered individuals tracked during reintroduction research. Both works have strengths and weaknesses, but together they provide tools for prioritizing areas for conservation, development, and resource extraction with respect to potential impacts to lynx.

METHODS

Location Data

Location data were collected from reintroduced lynx using 2 types of telemetry devices. All lynx released into Colorado, and those subsequently captured or re-captured, were fitted with a traditional VHF transmitter. VHF data were collected via telemetry from fixed-wing aircraft at approximately weekly intervals when research was ongoing during winter (approximately December – March) and reproductive seasons (May – June), but less often otherwise. Beginning in April 2000, released and captured lynx were outfitted with dual VHF-Argos satellite collars. In addition to sampling via fixed-wing aircraft, the satellite portion of these collars transmitted repeatedly for 12 hours, 1 day per week, year-round. Nearly 40,000 combined locations were collected between VHF and satellite sampling. These data were originally intended for assessing the success of the reintroduction and served CDOW well in estimating survival, productivity, and dispersal. They were not intended for use in constructing a predictive map of habitat use. We used only the best subset of these data following the filters applied by Theobald and Shenk (2011). Specifically, locations obtained during the first 6 months post-release were removed in order to exclude atypical movements made by animals that had not yet settled into home ranges. Next, poor precision satellite data (e.g., Argos location codes A, B, Z, 0 which do not have associated error estimates) were filtered out because they were too unreliable to be informative of lynx habitat use. We minimized dependence among locations (satellite collars transmitted several times per day, and a VHF location could have been obtained during the same day as well) by retaining only the most precise location for each lynx on a given day. When ties occurred, a single location was randomly selected from among the most precise locations. Finally, we discarded all data from lynx that were located fewer than 30 times over the course of the study.

Predictor variables

After filtering the location data, we assembled raw covariate data. We obtained housing density (HDENS, units per 1000 ha), road density (RDENS, km/km^2 – all roads), slope (SLOPE), elevation (ELEV), topographic wetness (TW), distance to high-volume road segments (D10K, annual average daily traffic volume > 10,000 vehicles), and distance to mesic forest patches >50 ha (D50HA) from Theobald and Shenk (2011). We also downloaded vegetation data from the Colorado Vegetation Classification Project (CVCP, Colorado Division of Wildlife, U.S. Department of Interior Bureau of Land Management, U.S. Forest Service. http://ndis.nrel.colostate.edu/coveg/). CVCP is geographically limited to Colorado, but it accurately depicts many vegetation types that may be important to lynx including riparian zones and willow. Other vegetation data sources (i.e., LANDFIRE) have the advantage of a larger spatial extent, but classification of these non-forest vegetation types is not as detailed. We reclassified the 114 vegetation types in CVCP into 17 classes to simplify the number of covariates available for analysis (Appendix 1). Next, we divided the western portion of Colorado into 1.5 km × 1.5 km cells, which corresponds to 1 SD of the error distribution for the most imprecise (satellite) locations retained for analysis, as well as the smallest 90% UD observed for an individual lynx (Theobald and Shenk 2011). We computed the proportion of different vegetation types in each cell as well as mean SLOPE, ELEV, TW, HDENS, RDENS, D10K, and D50HA. We excluded cells with mean elevations <2,438m (8000 ft), assuming such cells do not provide habitat for lynx. This cutoff is consistent with previous literature (McKelvey et al. 2000, Ruediger et al. 2000), and over 99% of locations from our dataset were above 2,438m. We then standardized each covariate using all cells we intended to make predictions for. To maximize precision of parameter estimates and guard against erroneous predictions later on, we computed a correlation matrix between the potential explanatory variables but none were highly correlated (correlation coefficients were all <0.52 for covariates listed here).

Analysis

The response variable of interest for our models was the number of locations per individual in each cell, which we sought to predict using landscape attributes of the cells. We only used cells with ≥1 location for the purpose of constructing models. Excluding cells with no locations (zero counts) results in models that reflect relative use by lynx rather than resource selection. Thus in the generation of the model, we avoided delineation of what was available and suitable to lynx but never used (i.e., we avoided decisions regarding how many zero-count cells to include in the dataset and where they should come from on the landscape), which is a criticism of resource selection approaches. Furthermore, given ~10 years of work including weekly locations on hundreds of animals, we argue that nearly all cells in the Core Study Area that were suitable and available included ≥1 lynx location. This approach does, however, warrant the use of zero-truncated probability models to avoid possibly introducing bias in parameter estimates (Zuur et al. 2009, p. 269). In addition, we expected the data to be over-dispersed (variance of the counts was expected to be larger than the mean), we knew the number of locations collected per animal varied considerably, and we anticipated spatial autocorrelation in the residuals. To evaluate these assertions and determine the best model structure for our data, we successively compared the fits of a basic Poisson generalized linear model (GLM), negative binomial GLM, zero-truncated negative binomial (ZTNB), and ZTNB with an offset. We compared the fit of these alternate structures using Akaike's Information Criterion (AIC, Burnham and Anderson 2002) and found that fitting a basic negative binomial GLM was an improvement over a Poisson (ΔAIC = 700.4), ZTNB was an improvement over the negative binomial (ΔAIC = 6463.0), and ZTNB with an offset provided the best fit (ΔAIC = 53.7). Thus, we used a ZTNB with an offset as the base model structure. We fit all models using the VGAM package (Yee 2010, 2011) in R (R Core Development Team 2011). To assess spatial autocorrelation we computed a variogram using the gstat package (Pebesma 2004) and standardized residuals from a highly parameterized model (including all covariates below; Figure 1). We found minimal autocorrelation, so we proceeded to build ZTNB models absent spatial structure in the error term. Within the general ZTNB model structure, we specified the candidate model set by including combinations of covariates for modeling the mean count for each cell as follows:

1) Lynx are associated with conifer forests and deep snow, and they rely heavily on snowshoe hares. In the Southern Rockies, lynx occur largely in conifer stands within the sub-alpine zone (Aubry et al. 2000). Therefore, we included proportion spruce/fir (SF, *Picea engelmannii*/*Abies lasiocarpa*,), mixed spruce/fir (MIXSF, spruce/fir mixed with Douglas-fir [*Pseudotsuga menziesii*], aspen [*Populus tremuloides*], and/or lodgepole pine [*Pinus contorta*], distance to forest patch >50ha (D50HA), ELEV, and SLOPE in every model. We expected positive associations with each of these covariates except D50HA, which we expected to be negative.

2) Research conducted during the reintroduction of lynx into Colorado focused primarily in the southern portion of the state. Lodgepole pine (LODGE) occurs only in the northern portion of the state, so we know relatively little regarding the importance of this vegetation type with respect to habitat use by lynx. Therefore, we included a LODGE effect in some models, but when LODGE entered as a covariate, we also included a LODGE × latitude (NORTH) interaction to attempt to account for the distribution of this forest type in Colorado. Thus, lodgepole pine was allowed to be an important predictor of lynx use (or not) depending on latitude.

3) Vegetation types other than spruce/fir occur in or adjacent to the subalpine zone. We know relatively little about how lynx use these types but they may be important intermittently and/or as travel corridors. Therefore, we also built models that included combinations of montane forest (MONFOR: Douglas-fir, Ponderosa pine [*Pinus ponderosa*], and mixed Doug-fir/ponderosa pine), aspen (ASPEN), willow (WILLOW), and montane shrub (MONSHB: Gambel oak

[*Quercus gambelii*], serviceberry [Amelanchier utahensis], and snowberry [*Symphoricarpos* sp.]).

4) Though lynx are considered a high elevation species, we opted to exclude "alpine" in any model because lynx are forest-dwelling, and there are few opportunities to manage structure of alpine areas, which included both alpine tundra and rock/snow/ice.

5) Lynx are often considered reclusive. Thus, covariates representing human development might be important predictors of habitats used (or not used) by lynx, and we initially considered HDENS, RDENS, and D10K as potential covariates to include in the model set. However, initial model-fitting resulted in HDENS and RDENS having slightly positive effects on lynx locations (but confidence intervals on these slopes were largely centered on zero indicating the effect was negligible), which is probably an artifact of the trapping/collaring effort that often occurred near roads due to logistical considerations. Many cells outside of those used to construct the models had HDENS and RDENS scores that were orders of magnitude above those used to construct the models. Thus, when projected to the entire set of cells covering western Colorado, these models predicted the best lynx habitat in highly developed, urban areas with high road density. Given this implausible result, we excluded HDENS and RDENS from the analysis. We retained D10K because high volume road segments occurred throughout broad areas used by lynx (nearly every state highway has high volume segments) and it did not result in completely implausible results. We expected counts of lynx locations to be positively associated with distance to high traffic volume road segments.

6) TW was excluded from all models after initial model-fitting produced a result similar to HDENS and RDENS. TW was positively associated with lynx locations, which seems reasonable, but when projected to the expanse of western Colorado, the best lynx habitat was predicted in heavily irrigated agricultural areas, residential lawns, and lakes. These features had TW values that were orders of magnitude larger than any forest-dominated cell. Note that this phenomenon, predicting beyond the range of data used to build the model, can be risky, and it may have operated similarly on other variables but went undetected.

7) Lynx often make long-distance movements outside of the winter season, and these movements may include use of many types of vegetation. Therefore, we fit the model set to summer locations (April through October) and then to winter locations (November through March). Seasonal definitions were based on mean daily movement patterns of telemetered lynx (Theobald and Shenk unpublished data). We expected that the association between lynx locations and vegetation types other than SF and MIXSF would vary with season, with more use of these perceived secondary types during summer.

In summary, our model set included all combinations of 5 vegetation types (LODGE, MONFOR, ASPEN, WILLOW, MONSHB) and D10K. Each combination was always paired with the base covariates (SF, MIXSF, ELEV, SLOPE, D50HA) listed in 1) above. This resulted in $2^6 = 64$ models. We used Akaike's Information Criterion (AIC, Burnham and Anderson 2002) to determine which model structures best explained variation in lynx locations, to assess the importance of each covariate, and to model-average predictions of lynx use for each cell across all models. Predictions were defined as the probability of observing at least 10 locations in a cell over a hypothetical 10-year sampling period, which corresponds to an average of 1 location per year over the time frame of the actual data generating process. We color-coded predictions into 10 quantiles for display such that each color represents 10% of the total (i.e., the darkest red represents the predicted best 10% of cells, dark red plus deep orange represent the predicted best 20% of cells, etc.)

RESULTS

The final winter dataset consisted of 3,915 locations from 68 individuals (min = 30 locations/lynx, max = 113, mean = 57.6). Winter cell counts ranged from 1 to 29 (mean = 2.3). Summer data consisted of 5,464 locations from 74 individuals (min = 30, max = 178, mean = 73.8). Summer cell counts ranged from 1 to 36 total lynx locations (mean = 2.8).

Predicted Winter Use

As expected, relative predicted use by lynx during winter months was negatively associated with D50HA and positively associated with SF, MIXSF, ELEV, and SLOPE (Table 1). Of these associations, SF was strongest (largest magnitude and 95% confidence interval [±2×SE] was well away from zero), followed by ELEV, MIXSF, and D50HA, respectively. The parameter estimate for SLOPE was small and its 95% CI substantially overlapped zero in all models. Thus it was not important in explaining variation in predicted habitat use. Of the covariates that were not included in every model, ASPEN was strongly, positively associated with use and was the only effect in this group that was clearly different from zero. MONSHB was negatively associated with predicted lynx use, but evidence for this effect was weak. WILLOW, MONFOR, and D10K were somewhat positively associated with lynx use, but evidence for these effects was relatively weak as well. LODGE and NORTH did not appear in any of the top models (cumulative AIC weights = 0.12).

The winter predictive map reflects the strong effect of SF. Arbitrarily defining the top 20% of predictions as high quality lynx habitat, there are 1,869,975 ha of such habitat in Colorado. Most of this is predicted to occur in the southern part of the state in the San Juan, Culebra, and Wet Mountain Ranges (Figure 2). In the central portion of the state, high predicted use is expected in the northern Sawatch and West Elk Ranges, along with Grand Mesa. The Park Range and Flat Tops comprise the best predicted winter lynx habitat farther north (Figure 2).

Predicted Summer Use

Associations between relative predicted summer use and SF, MIXSF, ELEV, SLOPE, and D50HA were similar to those observed during winter (Table 2). However, the association with SLOPE was much stronger (larger effect and 95% CI indicated clear separation from zero) during summer, possibly due to den site selection and attendance during this time of year. The association with D50HA was slighter stronger as well. Of the covariates not included in every model, MONFOR and MONSHB were negatively associated with lynx locations; LODGE, NORTH, ASPEN, WILLOW, and D10K were positively associated. The effects of MONFOR, ASPEN, and D10K were substantially different from zero based on 95% CIs. Effects of other covariates were not clearly different from zero.

The summer predictive map reflects more dispersed predicted use by lynx with LODGE, NORTH, and the LODGE × NORTH interaction playing a larger role (Figure 3). The central and southern Sawatch Range in central Colorado is predicted to have more use than during winter, whereas use on Grand Mesa is predicted to decline. In the northern part of the state, lynx use is predicted to shift more toward the Medicine Bow and Front Ranges. Using the same definition as before, we predict 1,791,675 ha of high quality summer habitat in Colorado. The overlap between high quality summer and winter cells (as arbitrarily defined above) is ~95%.

DISCUSSION

The data analyzed here were not collected for the purpose of constructing a predictive map and suffer from at least two shortcomings. First, the locations were not precise. We attempted to account for this imprecision by modeling at a 1.5 km scale, but matching covariates, response variables, and predictions at this scale reduces the clarity of relationships and weakens the modeling process. Second, the bulk of the reintroduction research effort, from which these data originated, was conducted in the southern and central portions of Colorado. Lodgepole pine only occurs in the northern 2/3 of the state, and is dominant there. Thus, predicting lynx habitat use in northern Colorado is difficult because the landscape is very different, yet we have little data available to help model lynx response to that landscape. That is, we are extrapolating beyond the range of covariates used to fit the models, which is tenuous. Caution should be exercised in interpreting results north of I-70.

In addition to issues regarding the location data, we also lack important vegetation data that could be crucial in making accurate predictions. Snowshoe hares (*Lepus americanus*) are tied to forests with dense understory cover throughout their range (Hodges 2000a;b), including Colorado (Dolbeer and Clark 1975, Zahratka and Shenk 2008, Ivan 2011). Given the close tie between hares and lynx, habitat use of the latter should be strongly tied to understory cover as well. However, we have no covariate data for understory. Our models treat all spruce/fir, mixed spruce/fir, and lodgepole forests equally, but the quality of these forests likely varies considerably. Additionally, pine beetle (*Dendroctonus ponderosae*) and spruce beetle (*Dendroctonus rufipennis*) epidemics throughout the state are drastically changing the structure and composition of current and future forests. Our predictions are based on forest composition prior to these outbreaks.

Despite these weaknesses, the predictive maps constructed here also have a distinct strength in that they were constructed objectively from rigorous mathematical models based on empirical data collected from wild lynx. They are the first such maps for Colorado. Results from this effort confirm relationships that were already known (e.g., lynx are strongly associated with high elevation spruce/fir and mixed spruce/fir forests but avoid lower elevation montane forests and montane shrublands), and highlight others that may be of interest. For instance, we found clear evidence that lynx use was positively associated with ASPEN during both summer and winter. It is unclear what the ecological relationship between the two might be and we have no causal evidence for ASPEN driving lynx use. However, this pattern is not a simple artifact of ASPEN occurring near SF or MIXSF – our preliminary vetting of potential covariates indicated that the correlation between ASPEN and SF or MIXSF was small and negative (-0.15 and -0.14, respectively). We also found evidence that lynx use of lodgepole forests may increase during summer, and that they tend to avoid areas near high traffic volume road segments, especially in summer.

The strengths of this analysis and resulting maps merit their inclusion as a tool for making land management decisions. However, inherent weaknesses of the data require the reader to exercise caution when interpreting results. These maps should be viewed as a compliment to expert opinion and existing maps produced by other means. When assessing habitat quality for lynx at a given project site, it is imperative that managers consider current stand characteristics (especially understory) in formulating land use plans or specific management recommendations relative to lynx.

LITERATURE CITED

Aubry, K. B., G. M. Koehler, and J. R. Squires. 2000. Ecology of Canada lynx in southern boreal forests. Pages 373-396 *in* L. F. Ruggiero, K. B. Aubry, S. W. Buskirk, G. M. Koehler, C. J. Krebs, K. S. McKelvey, andJ. R. Squires, editors. Ecology and conservation of lynx in the United States. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado, USA.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. 2nd edition. Springer, New York.

Devineau, O., T. M. Shenk, G. C. White, P. F. Doherty, P. M. Lukacs, and R. H. Kahn. 2010. Evaluating the Canada lynx reintroduction programme in Colorado: patterns in mortality. Journal of Applied Ecology 47:524-531.

Dolbeer, R. A., and W. R. Clark. 1975. Population ecology of snowshoe hares in the central Rocky Mountains. Journal of Wildlife Management 39:535-549.

Getz, W. M., S. Fortmann-Roe, P. C. Cross, A. J. Lyons, S. J. Ryan, and C. C. Wilmers. 2007. LoCoH: Nonparameteric Kernel Methods for Constructing Home Ranges and Utilization Distributions. Plos One 2.

Getz, W. M., and C. C. Wilmers. 2004. A local nearest-neighbor convex-hull construction of home ranges and utilization distributions. Ecography 27:489-505.

Hodges, K. E. 2000a. The ecology of snowshoe hares in northern boreal forests. Pages 117-161 *in* L. F. Ruggiero, K. B. Aubry, S. W. Buskirk, G. M. Koehler, C. J. Krebs, K. S. McKelvey, andJ. R. Squires, editors. Ecology and conservation of lynx in the United States. University Press of Colorado, Boulder, Colorado, USA.

_____. 2000b. Ecology of snowshoe hares in southern boreal and montane forests. Pages 163-206 *in* L. F. Ruggiero, K. B. Aubry, S. W. Buskirk, G. M. Koehler, C. J. Krebs, K. S. McKelvey, andJ. R. Squires, editors. Ecology and conservation of lynx in the United States. University Press of Colorado, Boulder, Colorado, USA.

Ivan, J. S. 2011. Density, demography, and seasonal Movement of snowshoe hares in central Colorado. Dissertation, Colorado State University, Fort Collins, Colorado, USA.

McKelvey, K. S., K. B. Aubry, and Y. K. Ortega. 2000. History and distribution of lynx in the contiguous United States. Pages 207-264 *in* L. F. Ruggiero, K. B. Aubry, S. W. Buskirk, G. M. Koehler, C. J. Krebs, K. S. McKelvey, andJ. R. Squires, editors. Ecology and conservation of lynx in the United States. University Press of Colorado, Boulder, Colorado, USA.

Pebesma, E. J. 2004. Multivariable geostatistics in S: the gstat package. Computers & Geosciences 30:683-691.

R Core Development Team. 2011. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Ruediger, B., J. Claar, S. Gniadek, B. Holt, L. Lyle, S. Mighton, B. Naney, G. Patton, T. Rinaldi, J. Trick, A. Vendehey, F. Wahl, N. Warren, D. Wenger, and A. Williamson. 2000. Canada lynx conservation assessment and strategy. 2nd edition. R1-00-53, U.S. Department of Agriculture, Forest Service, U.S. Department of Interior, Fish and Wildlife Service, Bureau of Land Management, National Park Service, Missoula, Montana, USA.

Shenk, T. M., and R. H. Kahn. 2010. The Colorado lynx reintroduction program. Colorado Division of Wildlife.

Theobald, D. M., and T. M. Shenk. 2011. Areas of high habitat use from 1999-2010 for radio-collared Canada lynx reintroduced to Colorado. Colorado State University.

Yee, T. W. 2010. The VGAM package for categorical data analysis. Journal of Statistical Software 32:1-34.

_____. 2011. VGAM: Vector Generalized Linear and Additive Models. R package version 0.8-3. URL http://CRAN.R-project.org/package=VGAM.

Zahratka, J. L., and T. M. Shenk. 2008. Population estimates of snowshoe hares in the southern Rocky Mountains. Journal of Wildlife Management 72:906-912.

Zuur, A. F., E. N. Ieno, N. J. Walker, A. A. Saveliev, and G. M. Smith. 2009. Mixed Effects Models and Extensions in Ecology with R. Springer, New York, New York, USA.

Prepared by _______________________________________

Jake S. Ivan, Wildlife Researcher

Table 1. Model selection results (top 10 of 64) and parameter estimates (SE) for zero-truncated negative binomial models fit to cell counts of Canada lynx locations collected during winter (November – March) 1999-2010, southwest and central Colorado, USA.

SF	MIXSF	D50HA	ELEV	SLOPE	LODGE	NORTH	LODGE: NORTH	MONFOR	ASPEN	WILLOW	MONSHB	D10K	AIC	ΔAIC	AIC Wt.	*K*
0.53 (0.07)	0.15 (0.08)	-1.1 (0.69)	0.24 (0.11)	0.07 (0.06)					0.28 (0.08)	0.06 (0.04)			4672.1	0.0	0.15	9
0.48 (0.06)	0.13 (0.07)	-1.09 (0.69)	0.29 (0.11)	0.04 (0.05)					0.26 (0.08)				4672.9	0.8	0.10	8
0.52 (0.07)	0.14 (0.08)	-1.09 (0.69)	0.21 (0.11)	0.07 (0.06)					0.28 (0.08)	0.07 (0.04)	-0.33 (0.38)		4673.2	1.1	0.09	10
0.53 (0.07)	0.17 (0.08)	-1.12 (0.69)	0.25 (0.11)	0.07 (0.06)					0.27 (0.08)	0.06 (0.04)		0.08 (0.09)	4673.2	1.1	0.09	10
0.48 (0.06)	0.15 (0.08)	-1.12 (0.69)	0.3 (0.11)	0.04 (0.05)					0.25 (0.08)			0.09 (0.09)	4673.8	1.7	0.06	9
0.54 (0.07)	0.16 (0.08)	-1.1 (0.69)	0.27 (0.13)	0.07 (0.06)				0.08 (0.22)	0.29 (0.08)	0.06 (0.04)			4673.9	1.9	0.06	10
0.47 (0.07)	0.12 (0.07)	-1.09 (0.69)	0.27 (0.11)	0.04 (0.05)					0.26 (0.08)		-0.29 (0.37)		4674.1	2.1	0.05	9
0.52 (0.07)	0.16 (0.08)	-1.12 (0.69)	0.22 (0.11)	0.07 (0.06)					0.28 (0.08)	0.06 (0.04)	-0.32 (0.38)	0.08 (0.09)	4674.3	2.2	0.05	11
0.49 (0.07)	0.14 (0.08)	-1.1 (0.69)	0.31 (0.13)	0.04 (0.05)				0.05 (0.22)	0.26 (0.08)				4674.8	2.8	0.04	9
0.54 (0.08)	0.18 (0.08)	-1.13 (0.69)	0.27 (0.13)	0.07 (0.06)				0.08 (0.22)	0.28 (0.08)	0.06 (0.04)		0.08 (0.09)	4675.0	3.0	0.03	11

Table 2. Model selection results (top 10 of 64) and parameter estimates (SE) for zero-truncated negative binomial models fit to cell counts of Canada lynx locations collected during summer (April – October) 1999-2010, southwest and central Colorado, USA.

SF	MIXSF	D50HA	ELEV	SLOPE	LODGE	NORTH	LODGE: NORTH	MONFOR	ASPEN	WILLOW	MONSHB	D10K	AIC	ΔAIC	AIC Wt.	*K*
0.47 (0.07)	0.11 (0.07)	-2.74 (0.7)	0.38 (0.12)	0.27 (0.05)	0.13 (0.11)	0.08 (0.1)	0.25 (0.12)	-1.65 (0.39)	0.2 (0.08)			0.2 (0.08)	6684.3	0.0	0.13	13
0.45 (0.07)	0.11 (0.07)	-2.75 (0.7)	0.34 (0.13)	0.26 (0.05)	0.11 (0.11)	0.08 (0.1)	0.24 (0.12)	-1.65 (0.4)	0.2 (0.08)		-0.66 (0.5)	0.2 (0.08)	6684.4	0.1	0.13	14
0.39 (0.06)	0.11 (0.06)	-2.76 (0.67)	0.19 (0.11)	0.24 (0.05)				-1.81 (0.39)	0.14 (0.08)		-0.87 (0.51)	0.15 (0.07)	6684.6	0.3	0.11	11
0.41 (0.06)	0.13 (0.06)	-2.77 (0.67)	0.23 (0.11)	0.25 (0.05)				-1.82 (0.39)	0.13 (0.08)			0.15 (0.07)	6685.9	1.6	0.06	10
0.34 (0.05)	0.07 (0.06)	-2.95 (0.67)	0.09 (0.1)	0.25 (0.05)				-1.84 (0.39)			-0.76 (0.49)	0.16 (0.07)	6686.0	1.7	0.06	10
0.4 (0.06)	0.08 (0.06)	-2.75 (0.67)	0.21 (0.11)	0.25 (0.05)				-1.78 (0.39)	0.15 (0.08)		-0.85 (0.5)		6686.2	1.9	0.05	10
0.47 (0.07)	0.12 (0.07)	-2.74 (0.7)	0.37 (0.12)	0.27 (0.05)	0.13 (0.11)	0.08 (0.1)	0.25 (0.12)	-1.65 (0.39)	0.2 (0.08)	0.01 (0.04)		0.2 (0.08)	6686.3	2.0	0.05	14
0.46 (0.07)	0.11 (0.07)	-2.74 (0.7)	0.33 (0.13)	0.27 (0.05)	0.11 (0.11)	0.07 (0.1)	0.24 (0.12)	-1.65 (0.4)	0.2 (0.08)	0.01 (0.04)	-0.67 (0.5)	0.19 (0.08)	6686.3	2.0	0.05	15
0.39 (0.06)	0.11 (0.06)	-2.77 (0.67)	0.2 (0.11)	0.24 (0.05)				-1.81 (0.39)	0.14 (0.08)	0 (0.04)	-0.86 (0.51)	0.15 (0.07)	6686.6	2.3	0.04	12
0.36 (0.05)	0.09 (0.06)	-2.94 (0.67)	0.13 (0.09)	0.25 (0.05)				-1.86 (0.38)				0.16 (0.07)	6686.8	2.4	0.04	9

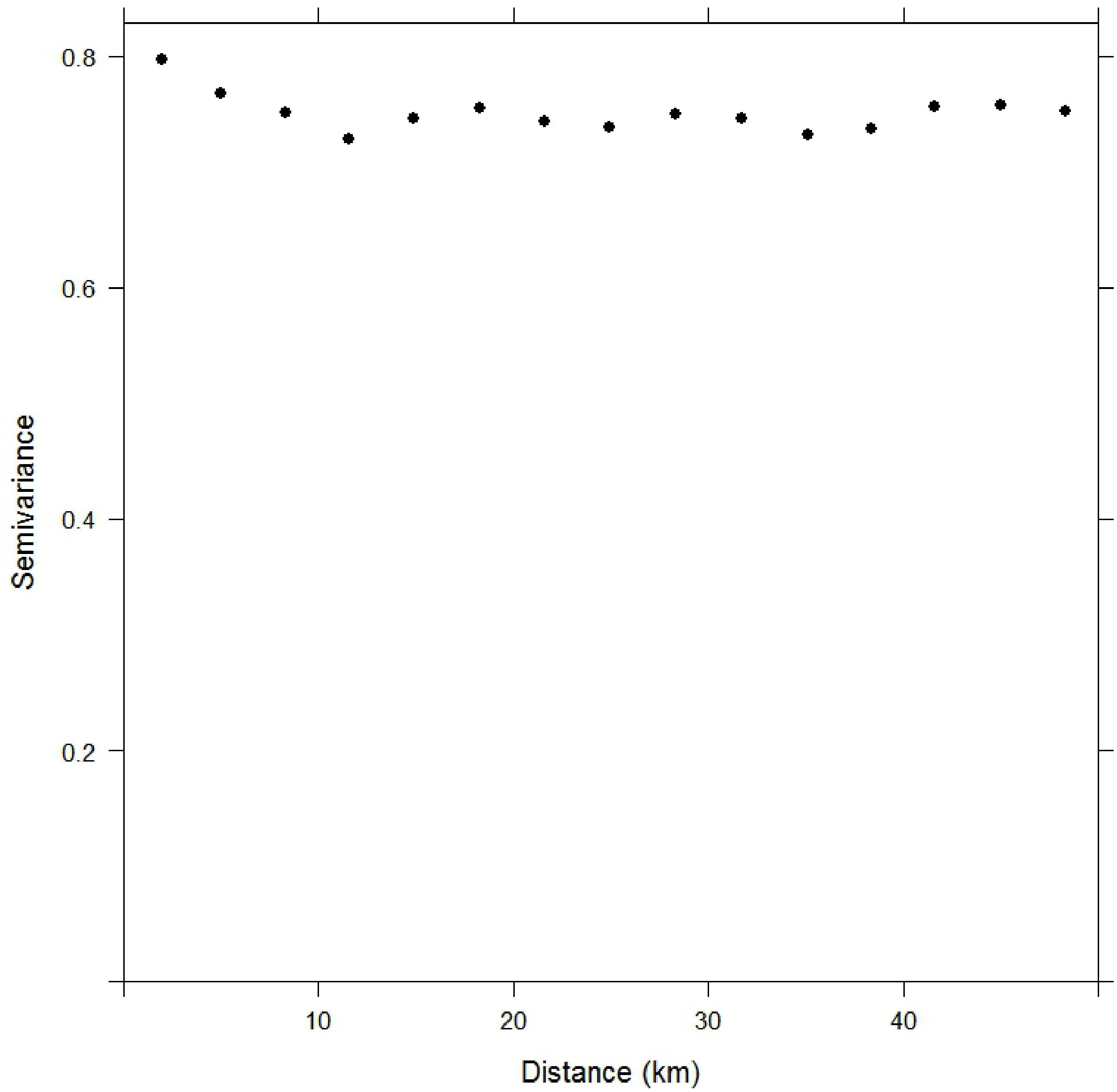


Figure 1. Variogram contructured using standardizied residuals from a highly parameterized model fit to count data of lynx locations within 1.5km × 1.5km cells, 1999-2011, southwestern and central Colorado. Variance among pairs of points is similar regardless of the distance separating them, indicative of a lack of residual spatial autocorrelation after fitting important covariate effects. Strong evidence of spatial autocorrelation in residuals would result in a graph with small variance between pairs points that are near to each other, and larger variance at greater distances (i.e., a monotonically increasing pattern).

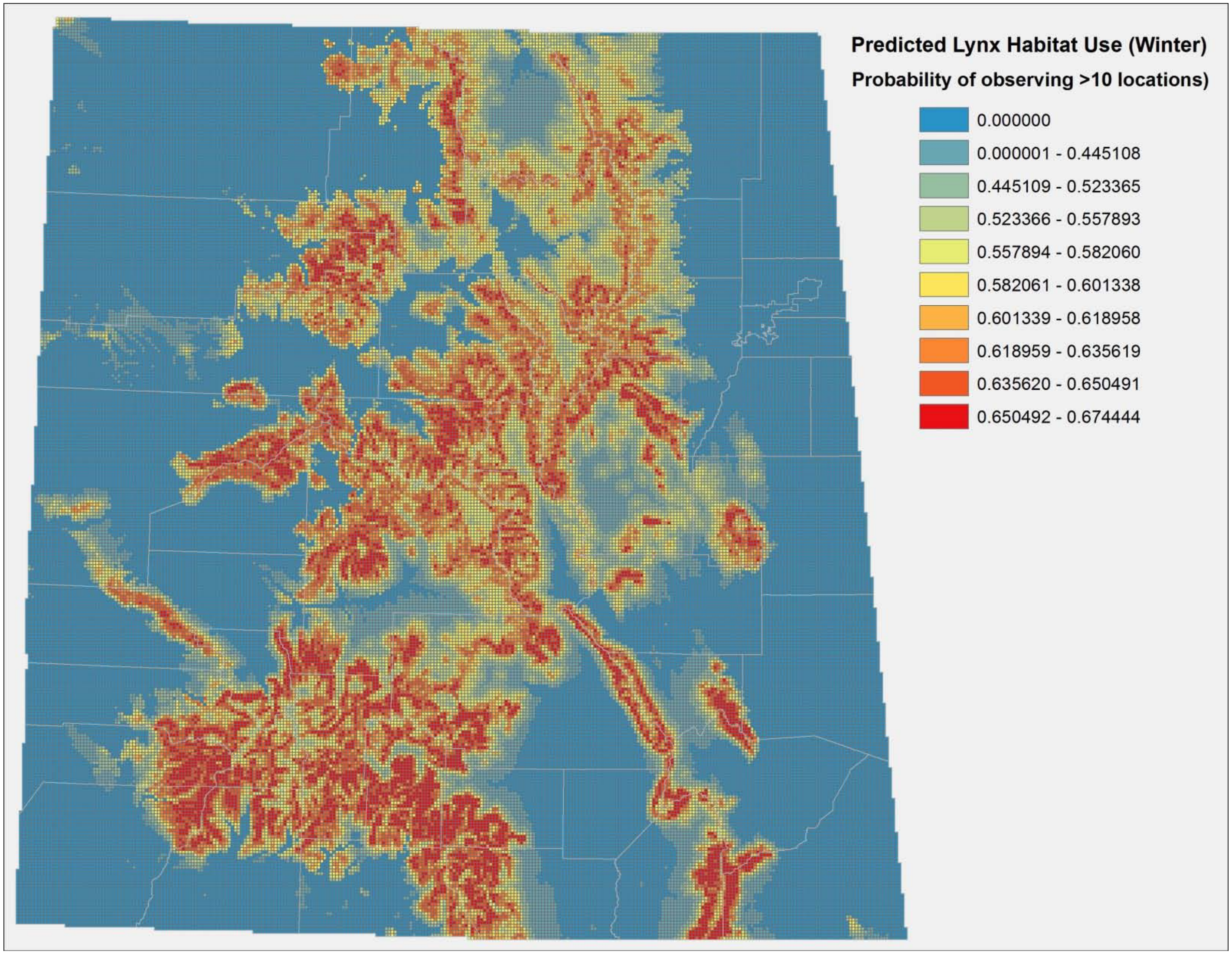


Figure 2. Predicted winter habitat use by Canada lynx in western Colorado. Predictions are probabilities of observing at least 10 locations within a 1.5 × 1.5km cell over a hypothetical 10-year sampling period. Predictions were averaged across 64 models constructed using all combinations of covariates of interest.

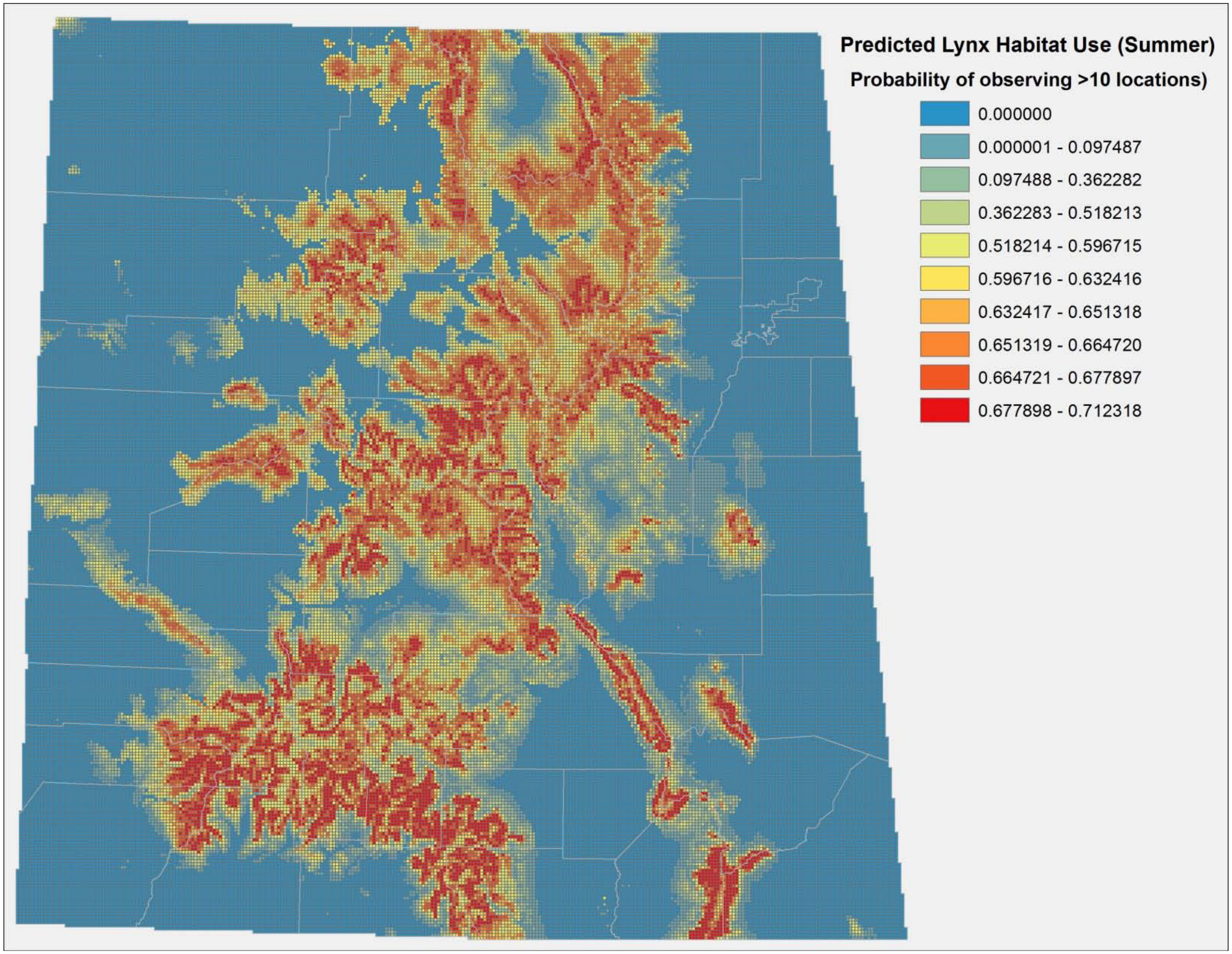


Figure 3. Predicted summer habitat use by Canada lynx in western Colorado. Predictions are probabilities of observing at least 10 locations within a 1.5 × 1.5km cell over a hypothetical 10-year sampling period. Predictions were averaged across 64 models constructed using all combinations of covariates of interest.

Appendix I. Raster reclassification of CVCP dataset for use in lynx predictive map analysis.

Lynx Reclass	CVCP Value	Description
Null	0	Unclassified
2	1	Urban/Built Up
2	2	Residential
2	3	Commercial
1	4	Agriculture Land
1	5	Dryland Ag
1	6	Irrigated Ag
1	7	Orchard
4	8	Rangeland
4	9	Grass/Forb Rangeland
8.2	10	Snakeweed/Shrub Mix
4	11	Grass Dominated
4	12	Forb Dominated
4	13	Grass/Forb Mix
4	15	Mid-grass Prairie
4	16	Short-grass Prairie
14	17	Sand Dune Complex
4	18	Foothill and Mountain Grasses
4	19	Disturbed Rangeland
4	20	Sparse Grass (Blowouts)
8.2	21	Shrub/Brush Rangeland
8.2	22	Sagebrush Community
8.2	23	Saltbush Community
8.2	24	Greasewood
8.2	25	Sagebrush/Gambel Oak Mix
8.2	26	Snakeweed
8.1	27	Snowberry
8.1	28	Snowberry/Shrub Mix
8.2	29	Bitterbrush Community
8.2	30	Salt Desert Shrub Community
8.2	31	Sagebrush/Greasewood
8.2	32	Shrub/Grass/Forb Mix
8.2	33	Sagebrush/Grass Mix
4	34	Rabbitbrush/Grass Mix
8.2	35	Sagebrush/Mesic Mtn Shrub Mix
4	36	Grass/Misc. Cactus Mix
4	37	Winterfat/Grass Mix
4	38	Bitterbrush/Grass Mix
4	39	Grass/Yucca Mix
8.2	40	Sagebrush/Rabbitbrush Mix
10	43	Pinon-Juniper
10	44	Juniper
8.1	46	Gambel Oak
8.2	47	Xeric Mountain Shrub Mix
8.1	48	Mesic Mountain Shrub Mix
8.1	49	Serviceberry/Shrub Mix
3.1	50	Upland Willow/Shrub Mix
8.2	51	Manzanita
10	53	PJ-Oak Mix
10	54	PJ-Sagebrush Mix
10	55	PJ-Mtn Shrub Mix

Lynx Reclass	CVCP Value	Description
10	56	Sparse PJ/Shrub/Rock Mix
10	57	Sparse Juniper/Shrub/Rock Mix
10	58	Juniper/Sagebrush Mix
10	59	Juniper/Mtn Shrub Mix
11	62	Aspen
8.1	63	Aspen/Mesic Mountain Shrub Mix
13	65	Ponderosa Pine
9.1	66	Englemann Spruce/Fir Mix
13	67	Douglas Fir
12	68	Lodgepole Pine
9.1	69	Sub-Alpine Fir
9.1	70	Spruce/Fir Regeneration
9.2	71	Spruce/Lodgepole Pine Mix
13	72	Bristlecone Pine
13	73	Ponderosa Pine/Douglas Fir Mix
13	75	Limber Pine
9.2	77	Lodgepole/Spruce/Fir Mix
9.2	78	Fir/Lodgepole Pine Mix
9.2	79	Douglas Fir/Englemann Spruce Mix
13	80	Mixed Forest Land
9.1	81	Spruce/Fir/Aspen Mix
13	82	P. Pine/Gambel Oak Mix
13	83	Ponderosa Pine/Aspen Mix
13	84	Douglas Fir/Aspen Mix
13	85	P. Pine/Aspen/Gamble Oak Mix
12	86	Lodgepole Pine/Aspen Mix
9.2	87	Spruce/Fir/Lodgepole/Aspen Mix
13	88	Ponderosa Pine/Mesic Mtn. Shrub
13	89	Ponderosa Pine/Aspen/Mesic Mtn.
14	90	Barren Land
6	91	Rock
6	92	Talus Slopes & Rock Outcrops
1	93	Soil
2	94	Disturbed Soil
7	96	Alpine Meadow
7	97	Alpine Forb Dominated
7	98	Alpine Grass Dominated
7	99	Alpine Grass/Forb Mix
7	100	SubAlpine Shrub Community
6	101	Snow
7	102	Subalpine Meadow
7	103	Subalpine Grass/Forb Mix
3.2	104	Riparian
3.2	105	Forested Riparian
3.2	106	Cottonwood
3.1	108	Conifer Riparian
3.2	109	Shrub Riparian
3.1	110	Willow
3.2	111	Exotic Riparian Shrubs
3.2	112	Herbaceous Riparian
3.2	113	Sedge
5	114	Water

Colorado Division of Parks and Wildlife
July 1, 2010 – June 30, 2011

PROGRAM FINAL REPORT
DEER CONSERVATION RESEARCH
FOR 5-YEAR FEDERAL AID GRANT W-185-R
JULY 2006 – JUNE 2011

State of Colorado : Division of Parks and Wildlife
Cost Center 3430 : Mammals Research
Work Package 3001 : Deer Conservation Research
Federal Aid Project W-185-R :

Period Covered: July 1, 2006 – June 30, 2011

Authors: Chad J. Bishop, Charles R. Anderson, Jr., and Eric J. Bergman

Principal Investigators: M. W. Alldredge, C. R. Anderson, E. J. Bergman, C. J. Bishop, D. J. Freddy, P. M. Lukacs, D. P. Walsh, and B. E. Watkins. Colorado Division of Wildlife; P. F. Doherty 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 (now Colorado Parks and Wildlife [CPW]) with the funding support of Federal Aid Grant W-185-R during the 5-year grant segment, July 2006-June 2011. Two major multi-year research projects addressing mule deer population limiting factors and habitat enhancements were completed and reported upon during this segment. Two other major multi-year research projects were designed and implemented during this period. One project is comprehensively addressing approaches to mitigate the impacts of natural gas development on mule deer. The other project is evaluating survival rates and harvest management of adult male mule deer. Several other smaller research projects were designed and implemented, addressing mule deer-elk-cougar interactions and development of techniques for marking and monitoring mule deer. Additionally, funding provided scientific and technical expertise for mule deer population monitoring and analysis.

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 that mechanical habitat treatments in senescent pinyon-juniper winter ranges were an effective strategy for increasing deer survival by increasing the amount of higher-quality forage. These research results provided wildlife managers support and direction for managing pinyon-juniper habitat across western Colorado. These research results also framed the experimental design for evaluating approaches to mitigate impacts of natural gas development on deer. Specifically, a large field experiment was initiated in northwest Colorado to evaluate effectiveness of habitat treatments in late-seral pinyon juniper and mountain shrub habitats that are experiencing high-intensity and low-intensity energy development.

From activities supported by this Grant during this segment, principal investigators published 13 peer-reviewed scientific articles for prominent wildlife research journals, provided 21 annual CPW Wildlife Research Reports summarizing yearly progress of projects, provided 34 presentations at professional meetings or workshops, and initiated 2 graduate student projects. The cumulative impact of

this programmatic effort provides Colorado the basis to progress and proactively sustain the mule deer resource in an increasingly complex landscape. 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, staffing, and common goals.

PROGRAM FINAL REPORT
DEER CONSERVATION RESEARCH
FOR 5-YEAR FEDERAL AID GRANT W-185-R
JULY 2006 – JUNE 2011

CHAD J. BISHOP, CHARLES R. ANDERSON, JR., AND ERIC J. BERGMAN

PROGRAM NEED

During the late 1990s, CPW was challenged by sportsmen and other stakeholders to investigate potential causes of declining numbers of mule deer in Colorado. The concerns of stakeholders gained the attention of the Colorado Legislature which directed CPW 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. At the same time, the Colorado Wildlife Commission approved statewide limitations on hunting licenses for mule deer, which significantly reduced the number of deer harvested annually in Colorado. Several years later, a sudden and significant increase in natural gas development in the Piceance Basin of northwest Colorado prompted mule deer researchers and managers to initiate a comprehensive effort to mitigate development impacts on deer. The research projects conducted during this 5-year grant period directly or indirectly addressed these various management issues and concerns. This report highlights the accomplishments of research efforts conducted by CPW from July 1, 2006 through June 30, 2011 that were wholly or partially supported by Federal Aid Grant funds.

PROGRAM NARRATIVE OBJECTIVES

The primary Program Narrative research objectives were divided into two broad categories: 1) managing factors limiting mule deer populations, and 2) monitoring mule deer populations. The specific project objectives were:

Managing Factors Limiting Mule Deer Populations

Project 1 Objective. Evaluate the impacts of prescribed landscape habitat manipulations in senescent pinyon-juniper habitats on behavior and demographics (survival, reproduction, densities) of mule deer populations.

Project 2 Objective. Evaluate approaches to mitigate the impacts of natural gas resource extraction and other related human-caused developments on mule deer habitats and population demographics.

Project 3 Objective. Investigate behavioral and spatial relationships between mule deer and elk, and among mule deer, elk, and cougar as these species simultaneously utilize prescribed landscape habitat manipulations.

Monitoring Mule Deer Populations

Project 4 Objective. Evaluate the technical quality and applications of statewide mule deer research and management systems.

Project 5 Objective. Evaluate new approaches to monitoring mule deer population demographics and habitat conditions.

Project 6 Objective. Evaluate hunting systems that could maintain a balance between hunter opportunity and the quality of hunting experience.

RESULTS

Objective 1. Evaluate the impacts of prescribed landscape habitat manipulations in senescent pinyon-juniper habitats on behavior and demographics (survival, reproduction, densities) of mule deer populations.

Project Objective 1 was formulated in response to field research conducted during the previous 5-year grant cycle, which indicated that habitat quality was ultimately limiting mule deer population growth in western Colorado. Final data analyses and preparation of publications from this research was completed during 2006-2008, and therefore, are reported here as part of this project objective. We evaluated the effect of enhanced nutrition of deer during winter and spring on fecundity and survival rates of free-ranging mule deer on the Uncompahgre Plateau in southwest Colorado. The treatment represented an instantaneous increase in nutritional carrying capacity of a pinyon (*Pinus edulis*)–Utah juniper (*Juniperus osteosperma*) winter range and was intended to simulate optimum habitat quality. Prior studies on the Uncompahgre Plateau indicated predation and disease were the most common proximate causes of deer mortality. By manipulating nutrition and leaving natural predation unaltered, we determined whether habitat quality was ultimately a critical factor limiting the deer population. We measured annual survival and fecundity of adult females and survival of fawns, then estimated population rate of change as a function of enhanced nutrition. Our estimate of the population rate of change was 1.165 (SE = 0.036) for deer receiving the nutrition treatment and 1.033 (SE = 0.038) for control deer. We documented food limitation in the Uncompahgre deer population because survival of fawns and adult females increased considerably in response to enhanced nutrition. We found strong evidence that enhanced nutrition of deer reduced coyote (*Canis latrans*) and mountain lion (*Puma concolor*) predation rates of ≥6-month-old fawns and adult females. We concluded that winter-range habitat quality was a limiting factor of the Uncompahgre Plateau mule deer population. We, therefore, recommended evaluating habitat treatments for deer that were designed to set-back succession and increase productivity of late-seral pinyon-juniper habitats that presently dominate the winter range.

Pinyon-juniper habitats across western Colorado have been exposed to minimal natural disturbance during recent decades. In particular, the natural role of fire in these systems has been significantly altered through aggressive efforts to extinguish fires ignited by lightning strikes. Fire suppression has become necessary because human dwellings are scattered across pinyon-juniper habitat throughout much of western Colorado. This has caused many mule deer winter ranges to become dominated by late-seral pinyon-juniper, which is unproductive for mule deer. Collaborative management efforts among state and federal agencies, NGOs, and private citizens have been initiated to incorporate disturbance into pinyon-juniper systems through the use of prescribed fire and mechanical treatments that remove or mulch pinyon and juniper trees. We evaluated the effectiveness of these types of habitat treatments on mule deer body condition, survival, and density.

<u>Peer-Reviewed Publications:</u>

Watkins, B. E., C. J. Bishop, E. J. Bergman, A. Bronson, B. Hale, B. F. Wakeling, L. H. Carpenter, and D. W. Lutz. 2007. Habitat guidelines for mule deer: Colorado Plateau shrubland and forest ecoregion. Mule Deer Working Group, Western Association of Fish and Wildlife Agencies.

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

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

Bishop, C. J., B. E. Watkins, L. L. Wolfe, D. J. Freddy, and G. C. White. 2009. Evaluating mule deer body condition using serum thyroid hormone concentrations. Journal of Wildlife Management 73:462–467.

Bishop, C. J., G. C. White, D. J. Freddy, B. E. Watkins, and T. R. Stephenson. 2009. Effect of enhanced nutrition on mule deer population rate of change. Wildlife Monographs 172:1–28.

Annual Wildlife Research Reports:

Bishop, C. J., G. C. White, D. J. Freddy, and B. E. Watkins. 2007. Effect of nutrition and habitat enhancements on mule deer recruitment and survival rates. Colorado Division of Wildlife, Wildlife Research Report July: 59-71.

Bergman, E. J., C. J. Bishop, D. J. Freddy, and G. C. White. 2007. Evaluation of winter range habitat treatments on over-winter survival and body condition of mule deer. Colorado Division of Wildlife, Wildlife Research Report July: 73-96.

Bishop, C. J., G. C. White, D. J. Freddy, and B. E. Watkins. 2008. Effect of nutrition and habitat enhancements on mule deer recruitment and survival rates. Colorado Division of Wildlife, Wildlife Research Report July: 39-51.

Bergman, E. J., C. J. Bishop, D. J. Freddy, and G. C. White. 2008. Evaluation of winter range habitat treatments on over-winter survival and body condition of mule deer. Colorado Division of Wildlife, Wildlife Research Report July: 53-62.

Bergman, E. J., C. J. Bishop, D. J. Freddy, and G. C. White. 2009. Evaluation of winter range habitat treatments on over-winter survival and body condition of mule deer. Colorado Division of Wildlife, Wildlife Research Report July: 101-110.

Bergman, E. J., C. J. Bishop, D. J. Freddy, G. C. White, and P. F. Doherty. 2010. Evaluation of winter range habitat treatments on over-winter survival and body condition of mule deer. Colorado Division of Wildlife, Wildlife Research Report July: 81-91.

Bergman, E. J., C. J. Bishop, D. J. Freddy, and G. C. White. 2011. Evaluation of winter range habitat treatments on over-winter survival and body condition of mule deer. Colorado Division of Parks and Wildlife, Wildlife Research Report July: in press.

Presentations at Professional Meetings/Workshops/Symposia:

Bishop, C. J., G. C. White, D. J. Freddy, and B. E. Watkins. 2006. Effect of enhanced nutrition of free-ranging mule deer on population performance. The Wildlife Society 13th Annual Conference, September 23–27, Anchorage, Alaska, USA.

Bishop, C. J., G. C. White, D. J. Freddy, and B. E. Watkins. 2007. Effect of enhanced nutrition of free-ranging mule deer on population performance and effectiveness of vaginal implant transmitters. Colorado State University Student Chapter of The Wildlife Society, February 26, Fort Collins, Colorado, USA.

Bishop, C. J. 2007. Capture techniques and radio-telemetry used in wildlife research and management, and an example of technique application using the Uncompahgre deer research study. Colorado State University's Wildlife Management Short Course, March 26–30, Fort Collins, CO, USA.

Bishop, C. J., and E. J. Bergman. 2007. Status of big game habitats and implications for wildlife within the Colorado Plateau. Plant Community Restoration Workshop, September 5–7, Grand Junction, Colorado, USA.

Bishop, C. J., G. C. White, and P. M. Lukacs. 2007. Evaluating dependence among mule deer siblings in fetal and neonatal survival analyses. The Wildlife Society 14th Annual Conference, September 22–26, Tucson, Arizona, USA.

Bishop, C. J., G. C. White, and P. M. Lukacs. 2008. Evaluating dependence among mule deer siblings in fetal and neonatal survival analyses. Colorado Chapter of The Wildlife Society Annual Meeting, January 23–25, Denver, Colorado, USA.

Bishop, C. J. 2008. Capture techniques and radio-telemetry used in wildlife research and management, and an example of technique application using the Uncompahgre deer research study. Colorado State University's Wildlife Management Short Course, April 1, Fort Collins, CO, USA.

Bergman, E. J., C. J. Bishop, D. J. Freddy, and G. C. White. 2008. Evaluation of winter range habitat treatments on over-winter survival and body condition of mule deer. Colorado Division of Wildlife Research Review, August 20-21, Denver, CO, USA.

Bergman, E. J. 2009. Monitoring habitat for deer. Joint Meeting of Colorado's Habitat Partnership Program and the Colorado Chapter of The Wildlife Society, February 5, Grand Junction, CO, USA.

Bishop, C. J. 2009. Capture techniques and radio-telemetry used in wildlife research and management, ungulate ecology, and a case study using the Uncompahgre deer research study. Colorado State University's Wildlife Management Short Course, March 31, Fort Collins, CO, USA.

Bergman, E. J., C. J. Bishop, D. J. Freddy, G. C. White, and P. F. Doherty. 2009. Evaluation of winter range habitat treatments on over-winter survival and body condition of mule deer. Colorado State University Student Chapter of The Wildlife Society, April, Fort Collins, CO, USA.

Bergman, E. J., C. J. Bishop, D. J. Freddy, G. C. White, and P. F. Doherty. 2009. Evaluation of winter range habitat treatments on over-winter survival and body condition of mule deer. 2009 Western States and Provinces Deer and Elk Workshop, May, Spokane, Washington, USA.

Bishop, C. J. 2010. Capture techniques and radio-telemetry used in wildlife research and management, ungulate ecology, and a case study using the Uncompahgre deer research study. Colorado State University's Wildlife Management Short Course, March 30, Fort Collins, CO, USA.

Bergman, E. J., C. J. Bishop, D. J. Freddy, G. C. White, and P. F. Doherty. 2010. Evaluation of winter range habitat treatments on over-winter survival and body condition of mule deer. Joint Meeting of Colorado's Habitat Partnership Program and the Colorado Section of the Society of Range Management, December 1, Grand Junction, CO, USA.

Bergman, E. J., C. J. Bishop, D. J. Freddy, G. C. White, and P. F. Doherty. 2011. Evaluation of winter range habitat treatments on overwinter survival of mule deer. Northwest Region Biology Days, January 19, Glenwood Springs, CO, USA.

Bishop, C. J. 2011. Capture techniques and radio-telemetry used in wildlife research and management, ungulate ecology, and a case study using the Uncompahgre deer research study. Colorado State University's Wildlife Management Short Course, March 29, Fort Collins, CO, USA.

Bishop, C. J., G. C. White, D. J. Freddy, B. E. Watkins, and T. R. Stephenson. 2011. Effect of enhanced nutrition of free-ranging mule deer on population performance. 2011 Western States and Provinces Deer and Elk Workshop, May 17, Santa Ana Pueblo, New Mexico, USA.

Bergman, E. J., C. J. Bishop, D. J. Freddy, G. C. White, and P. F. Doherty. 2011. Evaluation of winter range habitat treatments on over-winter survival and body condition of mule deer. 2011 Western States and Provinces Deer and Elk Workshop, May 17, Santa Ana Pueblo, New Mexico, USA.

Objective 2. Evaluate approaches to mitigate the impacts of natural gas resource extraction and other related human-caused developments on mule deer habitats and population demographics.

We designed and implemented a project to experimentally evaluate habitat treatments and human-activity management alternatives (i.e., best management practices; BMPs) that may benefit mule deer exposed to extensive energy development. The Piceance Basin of northwestern Colorado was selected as the project area due to ongoing natural gas development in one of the most extensive and important mule deer winter and transition range areas within the state. This project was initiated in 2007 and is expected to go to 2016 at a minimum and ideally to 2019. The project timeline was recently extended by 1 year due to a delay in implementing habitat mitigation treatments.

The Piceance Basin in northwest Colorado supports one of the largest migratory mule deer populations in North America and also exhibits one of the highest natural gas reserves in North America.

Public stakeholders and CPW are concerned that the cumulative impacts of natural gas extraction will negatively affect mule deer and other wildlife resources in the region. Concern is particularly high for mule deer due to their recreational and economic importance as a principal game species and their ecological importance as one of the primary herbivores of the Colorado Plateau Ecoregion. Extraction of natural gas is directly affecting the potential suitability of the landscape for mule deer by converting native habitat vegetation to drill pads, roads, and noxious weeds, by fragmenting habitat because of drill pads and roads, by increasing noise levels via compressor stations and vehicle traffic, and by increasing the year-round presence of human activities. Extraction is indirectly affecting deer by increasing the human work-force population of the region and the subsequent need for developing additional landscape for human housing, supporting businesses, and upgraded road/transportation infrastructure. Additionally, increased traffic on rural roads is raising the potential for direct mortality from vehicle-animal collisions. Thus, research documenting these impacts and evaluating the most effective strategies for minimizing and mitigating these activities will greatly enhance future management efforts to sustain mule deer populations for future recreational and ecological values.

Impacts of natural gas development may be most effectively mitigated for mule deer by restoring or enhancing habitat conditions on or adjacent to disturbed sites and by modifying development practices. However, we presently lack information to appropriately guide the expenditure of mitigation dollars to offset or lessen impacts. The purpose of this project is to address these mitigation questions so that dollars are spent wisely. For example, it remains unknown whether we can effectively mitigate impacts of natural gas development by treating habitat within a developing area. Results from this study will indicate whether mitigation dollars would be better spent enhancing/restoring habitat on-site or enhancing habitat in adjacent, undeveloped areas. Although not hypothesized, there is also the possibility that efforts to enhance habitat within heavily developed areas have a negative impact on deer and other species by causing further disturbance. Thus, this project will scientifically assess approaches for mitigating effects of natural gas development on mule deer to guide future management decisions.

From December 2007 to present, we gathered baseline demographic and habitat utilization data from radio-collared deer across the Piceance Basin to allow assessment of mitigation approaches that are presently being implemented. We selected 5 winter range study areas representing varying levels of development to serve as treatment and control sites and recorded habitat use and movement patterns using GPS collars. We also estimated winter fawn survival and annual adult female survival, late winter body condition of adult females using ultrasonography, and deer abundance using helicopter mark-resight surveys. We started with 5 study sites to allow flexibility to respond to changing energy development plans, which can directly affect experimental design. In 2009, we refined our study design using our baseline deer data and current energy development plans of the major companies operating in Piceance Basin. We also eliminated a study site to reduce the annual project budget to the minimum necessary to meet the original research objectives.

During December 2010-January 2011, we implemented 100 acres of habitat treatments as a pilot effort to evaluate logistics and effectiveness of habitat treatment strategies. We will implement an additional 1,100 acres of habitat treatments across two of our study sites as a mitigation strategy during 2011-13. ExxonMobil Corporation is directly funding all habitat treatments in this research as part of an agreed-upon mitigation plan with CPW. One study site receiving habitat treatments has undergone extensive energy development whereas the other site receiving treatments is experiencing modest development. We will continue to collect the various population and habitat use data across all study sites in order to evaluate the effectiveness of the habitat treatments. This approach will allow us to determine whether it is possible to effectively mitigate development impacts in highly developed areas, or whether it is better to allocate mitigation dollars toward less-impacted areas. We may also find that habitat mitigation efforts are not effective in developed areas at all, suggesting that habitat enhancement efforts may be only effective in areas that are not impacted by development. In 2010, we initiated a PhD project in collaboration with Colorado State University and ExxonMobil to evaluate deer behavioral responses to varying levels of development activity and habitat mitigation treatments. ExxonMobil is funding this project via a cooperative funding agreement with Colorado State University and CPW. This will allow us to assess the effectiveness of certain BMPs and habitat manipulations for reducing disturbance to deer. We also initiated a Masters project in collaboration with CSU and funded by ExxonMobil to evaluate vegetation responses to the habitat treatments described above. Danielle Johnston in the Avian Research Section is taking the lead on this project, working in collaboration with Chuck Anderson. Last, we plan to initiate a PhD project in collaboration with CSU during FY 11-12 to measure neonatal deer survival, also funded by ExxonMobil. Through combined funding from Federal Aid and energy companies, we are comprehensively evaluating effects of natural gas development on deer and associated mitigation strategies.

<u>Annual Wildlife Research Reports:</u>

Anderson, C. R., and D. J. Freddy. 2007. Population performance of Piceance Basin mule deer in response to natural gas resource extraction and mitigation efforts to address human activity and habitat degradation. Colorado Division of Wildlife, Wildlife Research Report July: 103-110.

Anderson, C. R., and D. J. Freddy. 2008. Population performance of Piceance Basin mule deer in response to natural gas resource extraction and mitigation efforts to address human activity and habitat degradation. Stage I, Objective 5: patterns of mule deer distribution and movements. Colorado Division of Wildlife, Wildlife Research Report July: 63-86.

Anderson, C. R. 2009. Population performance of Piceance Basin mule deer in response to natural gas resource extraction and mitigation efforts to address human activity and habitat degradation. Colorado Division of Wildlife, Wildlife Research Report July: 111-124.

Anderson, C. R., and C. J. Bishop. 2010. Population performance of Piceance Basin mule deer in response to natural gas resource extraction and mitigation efforts to address human activity and habitat degradation. Colorado Division of Wildlife, Wildlife Research Report July: 47-62.

Anderson, C. R., and C. J. Bishop. 2011. Population performance of Piceance Basin mule deer in response to natural gas resource extraction and mitigation efforts to address human activity and habitat degradation. Colorado Division of Parks and Wildlife, Wildlife Research Report July: in press.

<u>Presentations at Professional Meetings/Workshops/Symposia:</u>

Anderson, C. R., and D. J. Freddy. 2008. Population performance of Piceance Basin mule deer in relation to natural gas development and mitigation measures to address habitat degradation and human activity management alternatives. Tri-state energy meeting addressing wildlife management in relation to energy development activities, Parachute, CO, USA.

Anderson, C. R. 2008. Population performance of Piceance Basin mule deer in response to natural gas resource extraction and mitigation efforts to address human activity and habitat degradation. Energy Company Cooperators Meeting, October, Grand Junction, CO, USA.

Anderson, C. R. 2009. Population performance of Piceance Basin mule deer in relation to natural gas development and mitigation measures to address habitat degradation and human activity management alternatives. Graduate-Faculty Seminar Series, Colorado State University, September 18, Fort Collins, CO, USA.

Anderson, C. R. 2009. Population performance of Piceance Basin mule deer in response to natural gas resource extraction and mitigation efforts to address human activity and habitat degradation. Energy Company Cooperators Meeting, October, Grand Junction, CO, USA.

Anderson, C. R. 2010. Population performance of Piceance Basin mule deer in relation to natural gas development and mitigation measures to address habitat degradation and human activity management alternatives. Faculty-Student Seminar, Western State College, Gunnison, CO, USA.

Anderson, C. R., and C. J. Bishop. 2010. Population performance of Piceance Basin mule deer in response to natural gas resource extraction and mitigation efforts to address human activity and habitat degradation. Energy Company Cooperators Meeting, October, Grand Junction, CO, USA.
Anderson, C. R. 2010. Piceance Basin mule deer and energy development: improving winter range habitat as mitigation. Joint Meeting of Colorado's Habitat Partnership Program and Colorado Section of the Society for Range Management, December 1, Grand Junction, CO, USA.
Anderson, C. R. 2011. Piceance Basin mule deer and energy development: improving winter range habitat as mitigation. Northwest Region Biology Training, January 19, Glenwood Springs, CO, USA.
Anderson, C. R., and C. J. Bishop. 2011. Current understanding of mule deer-energy development interactions in the western United States. Northwest Region Biology Training, January 19, Glenwood Springs, CO, USA.
Northrup, J., G. Wittemyer, and C. R. Anderson. 2011. Behavioral response of mule deer to energy development activities in the Piceance Basin, Colorado. Colorado Chapter of The Wildlife Society Annual Meeting, February 25, Fort Collins, CO, USA.

Objective 3. Investigate behavioral and spatial relationships between mule deer and elk, and among mule deer, elk, and cougar as these species simultaneously utilize prescribed landscape habitat manipulations.

We capitalized on an opportunity to simultaneously monitor spatial movements and predator-prey dynamics of radio-collared mule deer, elk, and cougars on the Uncompahgre Plateau. Mule deer were marked as part of ongoing research described above under Objective 1. Elk were marked as part of a pilot study to monitor spatial movements of deer and elk on the Uncompahgre Plateau, and cougars were marked with GPS collars as part of a long-term research study (not funded by Federal Aid) evaluating the effects of harvest on cougar populations and the assumptions used by CPW to manage cougar populations. Our primary goal was to improve understanding of cougar-prey dynamics. We investigated GPS location clusters for cougars and assessed if a predation event occurred and what species of prey was involved. Locations of predation events were assessed in relation to vegetation treatments applied to the landscape to benefit mule deer and elk. As predicted, cougar kill sites were associated with deer and elk distribution. The greatest density of kill sites occurred across mid-upper elevation deer winter range where overlap of wintering elk and deer was greatest. We investigated 462 clusters during this pilot study. Kill probability increased as cluster size increased. Kill probability exceeded 0.9 with ≥ 10 locations/cluster and approached 1 with ≥ 15 locations/cluster. The probability of a kill was high if a cougar spent >2 days in the same general area, and a kill was essentially certain if a cougar spent >3 days in the same general area. There was some probability of a kill at clusters that comprised only 1 location, indicating that isolated cougar locations may periodically be associated with kills and should not be ruled out when using GPS location data to address cougar prey utilization. Our estimates of kill probability are conservative because the estimates assume prey detection probability was 1, which is unlikely. Cougars killed adult deer, fawn deer, adult elk, and calf elk in roughly equal proportions. Each prey class comprised 0.22–0.24 of the total kill. Kill composition varied as a function of percent vegetative cover and elevation. In FY 09-10, for logistical and study design reasons, we transitioned all research on this objective to a non-Federal Aid cougar project along the Front Range of Colorado.

Annual Wildlife Research Reports:
Alldredge, M. W., E. J. Bergman, C. J. Bishop, K. A. Logan, and D. J. Freddy. 2008. Pilot evaluation of predator-prey dynamics on the Uncompahgre Plateau. Colorado Division of Wildlife, Wildlife Research Report July: 87-104.

Objective 4. Evaluate the technical quality and applications of statewide mule deer research and management systems.

Considerable progress has been made during recent decades in developing and implementing quality mule deer research and management programs within CPW by enlisting the biostatistical support of faculty at Colorado State University (CSU). This objective has been attained for many years via annual contract for professional services with individual faculty at CSU. Federal Aid grant funding has routinely been used to help fund this contract to support mule deer management and research. Other funds (non-Federal Aid) have also supported this contract, which permits biostatistical support of other research and management functions in CPW as well. During 2006-07, Gary White (CSU faculty) provided support to CPW biologists on designing and implementing harvest surveys, terrestrial inventory systems, and population modeling procedures. Ongoing support was also provided for CPW's DEAMAN software package, which was used by staff for the storage, summary, and analysis of mule deer and other big game population and harvest data. In July 2007, CPW terminated the annual contract with faculty at CSU after hiring a permanent biometrician within CPW to provide these same services in-house.

Peer-Reviewed Publications:

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 11:231-248.

Martin, D. J., G. C. White, and F. M. Pusateri. 2007. Occupancy rates by swift foxes (Vulpes velox) in eastern Colorado. Southwestern Naturalist 52:541-551.

White, G. C. 2008. Closed population estimation models and their extensions in Program MARK. Environmental and Ecological Statistics 15:89-99.

Odell, E. A., F. M. Pusateri, and G. C. White. 2008. Estimation of occupied and unoccupied black-tailed prairie dog colony acreage in Colorado. Journal of Wildlife Management 72:1311-1317.

Conn, P. B., D. R. Diefenbach, J. L. Laake, M. A. Ternent, and G. C. White. 2008. Bayesian analysis of wildlife age-at-harvest data. Biometrics 64:1170-1177.

Annual Wildlife Research Reports:

White, G. C. 2007. Multispecies investigations consulting services for mark-recapture analysis. Colorado Division of Wildlife, Wildlife Research Report July: 97-101.

Objective 5. Evaluate new approaches to monitoring mule deer population demographics and habitat conditions.

We conducted two separate research projects focused on the development and evaluation of new approaches to enhance monitoring of mule deer populations for research and management: 1) modification and evaluation of vaginal implant transmitters in deer, and 2) development of an automated collaring device for mule deer.

Redesigned Vaginal Implant Transmitters

Our understanding of factors that limit mule deer populations may be improved by evaluating neonatal survival as a function of dam characteristics under free-ranging conditions, which generally requires that both neonates and dams are radiocollared. The only viable technique facilitating capture of neonates from radiocollared adult females is use of vaginal implant transmitters (VITs). To date, VITs have allowed research opportunities that were not possible previously; however, VITs are often expelled from adult females prepartum, which limits their utility. During the previous 5-year Federal Aid Grant Segment, we evaluated effectiveness of VITs in mule deer. Based on this research, during the current grant segment, we redesigned an existing vaginal implant transmitter (VIT) manufactured by Advanced

Telemetry Systems (ATS) by lengthening and widening wings used to retain the VIT in an adult female. Our objective was to increase VIT retention rates to increase likelihood of locating birth sites and newborn fawns. We placed the newly designed VITs in 59 adult female mule deer and evaluated the probability of retention to parturition and the probability of detecting newborn fawns. The probability of a VIT being retained until parturition was 0.766 (SE = 0.0605) and the probability of a VIT being retained to within 3 days of parturition was 0.894 (SE = 0.0441). In our earlier study using the original VIT wings, the probability of a VIT being retained until parturition was 0.447 (SE = 0.0468) and the probability of retention to within 3 days of parturition was 0.623 (SE = 0.0456). Thus, our design modification increased VIT retention to parturition by 0.319 (SE = 0.0765) and VIT retention to within 3 days of parturition by 0.271 (SE = 0.0634). Considering dams that retained VITs to within 3 days of parturition, the probability of detecting at least 1 neonate was 0.952 (SE = 0.0334) and the probability of detecting both fawns from twin litters was 0.588 (SE = 0.0827). Our study expands opportunities for conducting research that links adult female attributes to productivity and offspring survival in mule deer.

Automated Collaring Device for Deer

We designed and produced a trap-like device for mule deer that would automatically attach a radio collar to a ≥6-month-old fawn and record the fawn's weight and sex, without requiring physical restraint or handling of the animal. Our passive collaring device is designed to allow biologists and researchers to radio-collar, weigh, and identify sex of ≥6-month-old mule deer fawns with minimal expense and labor when compared to traditional mule deer capture techniques. This technique significantly reduces stress that is typically associated with capture and handling and should eliminate capture-related mortality. We collaborated with students and faculty in the Mechanical Engineering Department at Colorado State University to produce a conceptual model and early prototype. We then worked with professional engineers at Dynamic Group Circuit Design in Fort Collins, Colorado, to produce a fully-functional prototype of the device. We conducted an extensive field evaluation of the device with free-ranging mule deer during winter 2010-11. We successfully collared, weighed, and identified sex of 6 different mule deer fawns across 4 winter range locations along Colorado's northern Front Range. Collars were purposefully made to shed from deer within several weeks or months of being captured. Two fawns were successfully re-collared after they shed the first collars they received. Thus, we observed 8 successful collaring events involving 6 different fawns. Most fawns demonstrated minimal response to collaring events, either remaining in the device or calmly exiting. Certain components of the collaring device failed to function optimally when temperatures dropped below approximately −15° C, while other components did not adequately withstand mule deer use under field conditions. Also, certain behaviors of mule deer when approaching and using the device created circumstances where it was possible to collar the same animal twice, which happened on one occasion. We identified a series of device modifications that would be necessary to address these various issues. We will modify the device accordingly and conduct a follow-up field evaluation during 2011-12.

Peer-Reviewed Publications:

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

Bishop, C. J., C. R. Anderson, Jr., D. P. Walsh, E. J. Bergman, P. Kuechle, and J. Roth. 2011. Effectiveness of a redesigned vaginal implant transmitter in mule deer. Journal of Wildlife Management 75:1797–1806.

Annual Wildlife Research Reports:

Bishop, C. J., D. P. Walsh, M. W. Alldredge, E. J. Bergman, and C. R. Anderson. 2009. Development of an automated device for collaring and weighing mule deer fawns. Colorado Division of Wildlife, Wildlife Research Report July: 55-67.

Bishop, C. J., C. R. Anderson, D. P. Walsh, P. Kuechle, J. Roth, and E. J. Bergman. 2009. Effectiveness of a redesigned vaginal implant transmitter in mule deer. Colorado Division of Wildlife, Wildlife Research Report July: 69-99.

Bishop, C. J., C. R. Anderson, D. P. Walsh, E. J. Bergman, P. Kuechle, and J. Roth. 2010. Effectiveness of a redesigned vaginal implant transmitter in mule deer. Colorado Division of Wildlife, Wildlife Research Report July: 63-80.

Bishop, C. J., D. P. Walsh, M. W. Alldredge, E. J. Bergman, and C. R. Anderson. 2010. Development of an automated device for collaring and weighing mule deer fawns. Colorado Division of Wildlife, Wildlife Research Report July: 93-100.

Bishop, C. J., C. R. Anderson, D. P. Walsh, E. J. Bergman, P. Kuechle, and J. Roth. 2011. Effectiveness of a redesigned vaginal implant transmitter in mule deer. Colorado Division of Parks and Wildlife, Wildlife Research Report July: in press.

Bishop, C. J., M. W. Alldredge, D. P. Walsh, E. J. Bergman, and C. R. Anderson. 2011. Development of an automated device for collaring and weighing mule deer fawns. Colorado Division of Parks and Wildlife, Wildlife Research Report July: in press.

Presentations at Professional Meetings/Workshops/Symposia:

Bishop, C. J., D. J. Freddy, G. C. White, B. E. Watkins, T. R. Stephenson, and L. L. Wolfe. 2007. Using vaginal implant transmitters to aid in capture of mule deer neonates. Colorado Chapter of The Wildlife Society Annual Meeting, January 17−19, Glenwood Springs, Colorado, USA.

Bishop, C. J., D. J. Freddy, G. C. White, B. E. Watkins, T. R. Stephenson, and L. L. Wolfe. 2007. Using vaginal implant transmitters to aid in capture of mule deer neonates. 7th Western States and Provinces Deer and Elk Workshop, May 13–16, Estes Park, Colorado, USA.

Bishop, C. J., M. W. Alldredge, D. P. Walsh, E. J. Bergman, and D. Kilpatrick. 2011. Automated collaring device for mule deer. Colorado Chapter of The Wildlife Society Annual Meeting, February 25, Fort Collins, CO, USA.

Objective 6. Evaluate hunting systems that could maintain a balance between hunter opportunity and the quality of hunting experience.

Historically, management of big game species has focused on the performance of the female and young of the year components of the population. In the case of mule deer, this has been further refined to the aspects of annual (for adult females) and overwinter (for young of the year) survival. The performance of the male component of populations was deemed less important, primarily due to the fact that it takes relatively few males to provide adequate breeding potential for the population. Additionally, harvest management objectives were to provide maximal hunting opportunity for hunters. Thus, as long as there were adequate numbers of males to breed females there was no need to restrict hunting opportunity. However, during the past 10-15 years, the management of big game populations, and mule deer populations in particular, has started to shift away from the objective of providing maximal opportunity towards providing fewer but higher quality opportunities. High quality opportunities are typically defined by hunters as a combination of the opportunity to see a greater number of male deer during the hunt, the potential to harvest an older age class animal (i.e., an animal with more developed antler morphometry), but also reduced interaction and competition with other hunters. In response to this shift in hunter desires and concerns over declining mule deer numbers, in 1999 CPW implemented a statewide limitation in deer hunting. This statewide limitation gave the CPW the ability to greatly reduce total hunter numbers but also the ability to control the distribution of hunters throughout the state. Since 1999, a few marked changes in Colorado's deer herd have occurred. First, due to reduced harvest an overall increase in deer numbers has been observed. Second, because the reduction in harvest was primarily focused on adult males, a subsequent increase in the ratio of adult males to adult females has occurred. Stemming from this shift in harvest management and the subsequent changes in herd size and structure, a gap in biological information has been identified. Specifically, Colorado's deer herds have become composed of a greater number of males, yet little biological data on them exist. Also stemming from the change in harvest management was a new responsibility for Colorado's terrestrial biologists and wildlife managers. Prior to 1999, licenses were sold over-the-counter and were not limited in number (i.e., any hunter who wished to purchase one was able to do so). The decision of how many licenses to make available did not need to be considered. Since 1999, the CPW has the added responsibility of deciding how many licenses should be allocated in each Data Analysis Unit (DAU). This decision must further reflect a balance between meeting DAU population performance objectives, but also provide as much hunter opportunity as possible.

Big game populations in Colorado are currently modeled using multiple sources of biological data (White and Lubow 2002). Model inputs include harvest, young recruitment to December, and measured rates of survival of adult females and fawns. Also, the ratio of adult males to adult females is estimated and used to align models by minimizing the difference between observed and modeled values. Very rarely have the survival rates of adult males been measured. This gap in knowledge has historically been viewed as trivial and rates have been assumed to not be different from the rates of females. Similarly, it has been assumed that natural survival rates (i.e., post hunt survival) of males do not geographically vary. However, model performance under these assumptions has been poor and the need to measure adult male survival as a parameter has increased. Presently, a number of population models in Colorado suggest that natural adult male survival may be lower than adult female survival, yet empirical data is lacking to verify these suppositions.

A different, but not unrelated need in Colorado pertains to the harvest management of adult male mule deer. As discussed above, a large shift in mule deer herd size and structure occurred as a result of the change in harvest management that occurred between 1998 and 1999. Overall, this shift has been viewed as positive by both the CPW as well as the public. However, the CPW still maintains the responsibility of optimally managing the deer of Colorado and providing the maximal amount of hunting opportunity under this new set of constraints. To date, the CPW has had limited biological information and data to guide harvest management decisions. In particular for this issue, as DAUs reach and surpass their adult male: adult female ratio objectives, the CPW typically responds by increasing the number of available hunting licenses. In situations where herds are continually lower than DAU objectives, available hunting licenses are reduced. What remains unknown about survival of adult male deer is at what level natural survival is reduced due to intraspecific competition. If, or when deer herds exceed the adult male: adult female objectives for DAUs, it is often assumed that the surplus of male deer will remain in the population into perpetuity. However, this assumption is based on the premise that compensatory mortality does not occur. Similarly, it assumes that annual variation in survival is negligible. However, this is biologically not realistic. It is very likely that herds with large post-hunt populations of adult males experience higher levels of mortality. Under this scenario, harvest has not been optimized and more hunters could have been afforded the opportunity to hunt with no effect on post hunting season ratios of adult males to adult females. The simplest way to learn about the mortality process is via manipulative experimentation.

Our study objective is two-fold. First, we wish to assess annual survival of adult male mule deer. We wish to establish baseline survival estimates, and related estimates of variance, for different age classes of deer. Second, we wish to manipulate hunting license allocation within the Game Management Units (GMUs) of a single DAU such that adult male: adult female ratios become measurably different between two halves of the DAU. Accordingly, we wish to measure and correlate changes in natural survival of adult male deer with this management action. Similarly, as part of this second objective, we will determine if changes in the age structure of harvested animals occur as the sex ratio and age structure of the hunted population changes. We designed the study and wrote a study plan during 2009-10 and initiated field work during 2010-11.

Peer-Reviewed Publications:

Bergman, E. J., B. E. Watkins, C. J. Bishop, P. M. Lukacs, and M. Lloyd. 2011. Biological and socio-economic effects of statewide limitation of deer licenses in Colorado. Journal of Wildlife Management 75:1443–1452.

Annual Wildlife Research Reports:

Bergman, E. J., C. J. Bishop, K. Oldham, and L. Sidener. 2011. Assessment of survival and optimal harvest strategies of adult male mule deer in Middle Park, Colorado. Colorado Division of Parks and Wildlife, Wildlife Research Report July: in press.

Presentations at Professional Meetings/Workshops/Symposia:

Bergman, E. J., B. E. Watkins, C. J. Bishop, P. M. Lukacs, and M. Lloyd. 2007. Biological, social, and economic effects of totally limited deer licenses in Colorado. 7th Western States and Provinces Deer and Elk Workshop, May 13–16, Estes Park, Colorado, USA.

Bergman, E. J., B. E. Watkins, C. J. Bishop, P. M. Lukacs, and M. Lloyd. 2008. Biological, social, and economic effects of totally limited deer licenses in Colorado. Colorado Chapter of The Wildlife Society Annual Meeting, January 25, Denver, Colorado, USA.

Bergman, E. J., C. J. Bishop, L. Sidener, and K. Oldham. 2011. Survival and optimal harvest management of mule deer bucks in Middle Park, CO. Presentation to the Colorado Wildlife Commission, April 7, Meeker, CO, USA.

SUMMARY

We conducted work on seven research projects addressing mule deer limiting factors, habitat enhancement, mitigation of natural gas development impacts, predator-prey dynamics, buck harvest management, and technique developments. Additionally, funding provided biostatistical support for implementing or maintaining statewide deer harvest surveys, population databases, aerial surveys, population modeling, and research projects. From activities supported by this Grant during this segment, principal investigators published 13 peer-reviewed scientific articles for prominent wildlife research journals, provided 21 annual CPW Wildlife Research Reports summarizing yearly progress of projects, provided 34 presentations at professional meetings, workshops, or symposia, and initiated 2 graduate student projects. The cumulative impact of this programmatic effort provides Colorado the basis to progress and proactively sustain the mule deer resource in an increasingly complex landscape. 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, staffing, and common goals.

LITERATURE CITED

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.

White, G.C. and B.C. Lubow. 2002. Fitting population models to multiple sources of observed data. Journal of Wildlife Management 66:300-309.

Prepared by ____
Chad J. Bishop, Mammals Research Leader

Colorado Division of Parks and Wildlife
July 1, 2010 – June 30, 2011

WILDLIFE RESEARCH REPORT

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

Period Covered: July 1, 2010 – June 30, 2011

Authors: C. R. Anderson and C. J. Bishop

Personnel: E. Bergman, J. Broderick, P. Damm, B. deVergie, D. Finley, L. Gepfert, M. Grode, C. Harty, K. Kaal, T. Knowles, J. Lewis, P. Lukacs, T. Parks, B. Petch, M. Peterson, R. Velarde, L. Wolfe, CPW; E. Hollowed, L. Belmonte, BLM; S. Monsen, Western Ecological Consulting, Inc.; D. Freddy, Hoch Berg Enterprises; T. Graham, Ranch Advisory Partners; M. Wille, T & M Contractors.; H. Sawyer, Western Ecosystems Technology; P. Lendrum, T Bowyer, Idaho State University; P. Doherty, J. Northrup, G. Wittemyer, K. Wilson, G. White, Colorado State University; M. Keech, L. Shelton, M. Shelton, R. Swisher, Quicksilver Air, Inc.; D. Felix, Olathe Spray Service, Inc.; L. Coulter, Coulter Aviation. Project support received from Federal Aid in Wildlife Restoration, Colorado Mule Deer Association, Colorado Mule Deer Foundation, Colorado State Severance Tax Fund, EnCana Corp., ExxonMobil Production Co., Marathon Oil Corp., Shell Petroleum, and Williams Production LMT Co.

ABSTRACT

We propose to experimentally evaluate winter range habitat treatments and human-activity management alternatives intended to enhance mule deer (*Odocoileus hemionus*) populations exposed to energy development activities. The Piceance Basin of northwestern Colorado was selected as the project area due to ongoing natural gas development in one of the most extensive and important mule deer winter and transition range areas within the state. The data presented here represent the first 3 pretreatment years of a long-term study addressing habitat modifications and improved energy development practices intended to improve mule deer fitness in areas exposed to extensive energy development. We monitored 4 winter range study areas representing varying levels of development to serve as treatment (Ryan Gulch, North Magnolia, South Magnolia) and control (North Ridge) sites and recorded habitat use and movement patterns using GPS collars (5 location attempts/day), estimated overwinter fawn and annual adult female survival, estimated early and late winter body condition of adult females using ultrasonography, and estimated abundance using helicopter mark-resight surveys. We targeted 250 fawns (50—80/study area) and 100 does (20—40/study area) in early December 2010 for VHF and GPS radiocollar attachment,

respectively, and 80 does in March 2011(20/study area) for late winter body condition assessment and to increase our GPS radiocollar sample in 3 of the 4 areas (10 of 20/area excluding Ryan Gulch). Based on the data collected since January 2008, deer from all areas appear to be in reasonably good condition and exhibited high survival rates the first 2 years, with lower winter fawn survival through mid-June this past winter in 3 of 4 study areas (excluding North Ridge), and winter range deer densities appear to be stable or increasing. Mild winter conditions the first 2 years followed by more severe winter conditions this year likely contributed to the observed survival rates and population trends. Observed differences in winter concentration areas thus far may indicate behavioral modifications to areas of high development activity, but resource selection analyses will be necessary to confirm this supposition. Pilot habitat treatments (126 acres total) were completed January 2011 and moist spring weather conditions have resulted in excellent vegetation response thus far. We will continue to collect the various population and habitat use data across all study sites to evaluate the effectiveness of additional habitat treatments (North and South Magnolia) scheduled for fall/winter 2012—2013 (1,200 acres total). This evaluation will allow us to determine whether it is possible to effectively mitigate development impacts in highly developed areas, or whether it is better to allocate mitigation dollars toward less or non-impacted areas. In collaboration with Colorado State University, we are also evaluating deer behavioral responses to varying levels of development activity in the Ryan Gulch study area. This will allow us to assess the effectiveness of certain Best Management Practices (BMPs) for reducing disturbance to deer. The study is slated to run through at least 2017, and preferably 2019, to adequately measure mule deer population responses to landscape level manipulations.

WILDLIFE RESEARCH REPORT

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

CHARLES R. ANDERSON, JR and CHAD J. BISHOP

PROJECT NARRITIVE OBJECTIVES

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

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

SEGMENT OBJECTIVES

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

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

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

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

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

INTRODUCTION

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

The Piceance Basin in northwest Colorado contains one of the largest migratory mule deer populations in North America and also exhibits some of the largest natural gas reserves in North America. Projected energy development throughout northwest Colorado within the next 20 years is expected to reach about 15,000 wells, many of which will occur in the Piceance Basin, which currently supports over 250 active gas well pads (http://cogcc.state.co.us). Anderson and Freddy (2008*a*) in their long-term research proposal identified 6 primary study objectives to assess measures to offset impacts of energy extraction on mule deer population performance. During the past 4 years, we have gathered baseline habitat utilization data from GPS-collared deer across the Piceance Basin to allow assessment of mitigation approaches that will be implemented over the next 1-2 years and evaluated for another 4-6 years. We are currently monitoring 1 control area without development (North Ridge), 2 areas with relatively high development activity (0.6—0.8 well pads & facilities/km^2; Ryan Gulch, South Magnolia), and another area with relatively minor development activity (0.1 well pads & facilities/km^2; North Magnolia). In comparison to the un-manipulated control area (North Ridge), the North and South Magnolia areas will receive similar levels of mechanical habitat treatments to evaluate this mitigation technique in relation to differing development intensities, and deer behavior patterns relative to differing development activities in the Ryan Gulch area will be monitored to identify effective Best Management Practices (BMPs) for future application. This progress report describes the previous 3.5 years (Jan 2008—June 2011) of addressing mule deer population performance during the pretreatment phase on 4 winter range herd segments, which includes monitoring habitat selection and behavior patterns of adult female mule deer, overwinter fawn and adult female survival, estimates of adult female body condition during early and late winter, and abundance estimates.

STUDY AREAS

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

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

METHODS

Tasks addressed this period included mule deer capture and collaring efforts, monitoring overwinter fawn and annual adult female survival, estimating adult female body condition during early and late winter using ultrasonography, estimating mule deer abundance applying helicopter mark-resight surveys, and initiating winter range habitat treatments to benefit mule deer in areas experiencing disturbance from energy development activities. We employed helicopter net-gunning techniques (Barrett et al. 1982, van Reenen 1982) to capture 50—80 fawns and 20—40 adult females during early December 2010 and 20 adult females during early March 2011 in each of the 4 study areas. Once netted, all deer were hobbled and blind folded. Fawns were weighed, radio-collared and released on site, and adult females were transported to localized handling sites for collection of body measurements and were fitted with GPS collars (20—40/area during December 2010, 0—10/area during March 2011; 5 or 24 fixes/day; G2110B, Advanced Telemetry Systems, Isanti, MN, USA) and released. To provide direct measures of decline in overwinter body condition, 20 does were recaptured in Ryan Gulch and 10 from the other 3 study areas that were captured the previous December; 10 uncollared does were also captured in North Ridge, North Magnolia, and South Magnolia to increase sample sizes in those areas. Fawn collars were spliced and fitted with rubber surgical tubing to facilitate collar drop during mid-summer—early autumn and GPS collars were supplied with timed drop-off mechanisms scheduled to release early April of the year following deployment. All radio-collars were equipped with mortality sensing options (i.e., increased pulse rate following 4—8 hrs of inactivity).

Mule Deer Habitat Use and Movements

We downloaded and summarized data from GPS collars deployed March 2010 following collar drop and retrieval in early April 2011. GPS collars deployed early December 2010 maintained the same fix schedule of attempting fixes every 5 hours except in Ryan Gulch where fix rates were increased to 1/hour to increase resolution of GPS data for evaluation of deer behavior patterns in relation to differing development activities. We plotted deer locations and recorded timing and distance of spring and fall 2010 migrations for each study area. Mule deer winter concentration areas were created using composite GPS data (winter locations March 2010—April 2011 from all deer; 5 location attempts/day) from each study area and mapped in ArcGIS (ver. 9.3) using Spatial Analyst (kernel probability density functions separated by quantiles). Mule deer resource selection analyses are pending completion of high resolution habitat data layers currently being developed by BLM.

Mule Deer Survival

Mule deer mortality monitoring consisted of daily ground telemetry tracking and aerial monitoring approximately every 2 weeks from fixed-wing aircraft on winter range and bi-weekly aerial monitoring on summer range. Once a mortality signal was detected, deer were located and necropsied to assess cause of death. We estimated weekly survival using the staggered entry Kaplan-Meier procedure (Kaplan and Meier 1958, Pollock et al. 1989). Capture-related mortalities (any mortalities occurring within 10 days of capture) and collar failures were censored from survival rate estimates. We estimated survival rates 1 July 2010—30 June 2011 for adult females and early December 2010—mid June 2011 for fawns.

Adult Female Body Measurements

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

Abundance Estimates

We conducted 4 (North Ridge) or 5 (the remaining study areas) helicopter mark-resight surveys (2 observers and the pilot) during late March, 2011 to estimate deer abundance in each of the 4 study areas. We delineated each study area from GPS locations collected during winter from previous years (since Jan 2008) and aerial telemetry locations of radio-collared deer within 1 week of the first mark-resight survey. Two aerial fixed-wing telemetry surveys/study area were conducted during helicopter mark-resight surveys to determine which marked deer were within each survey area. We delineated flight paths in ArcGIS 9.3 prior to surveys following topographic contours (e.g., drainages, ridges) and approximating 500 m spacing throughout each study area; flight paths during surveys were followed using GPS navigation in the helicopter. Two approximately 12 x 12 cm pieces of Ritchey livestock banding material (Ritchey Livestock ID, Brighton, CO USA) were uniquely marked using color, number, and symbol combinations and attached to each radio-collar to enhance mark-resight estimates. Each deer observed during surveys was recorded as mark ID#, unmarked, or unidentified mark.

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

RESULTS AND DISCUSSION

Deer Captures and Survival

The helicopter crew captured 264 fawns and 107 does in December 2010 and 81 does during March 2011. Nine fawn mortalities (ultimate cause = 6 capture myopathy and 3 predation) occurred within the 10 day myopathy period following the December capture and 1 doe mortality each followed the December and March captures (ultimate cause = 1capture myopathy and 1 predation).

Fawn survival from early-December 2010—mid June 2011 was similar (*P* > 0.05) among 3 of 4 study areas ranging from 0.48 to 0.51, with North Ridge fawns exhibiting marginally higher over-winter survival (0.70; *P* < 0.10, Table 1). In comparison to previous years, North Ridge fawn survival has been consistent since winter 2008/09, but survival in the other 3 areas was lower than last year and lower than the previous 2 years in Ryan Gulch (Fig. 2). Annual adult female survival was similar among study areas (*P* > 0.05) ranging from 0.77 (North Ridge) to 0.89 (Ryan Gulch; Table 1) and was comparable to previous years (*P* > 0.05; Anderson 2009, Anderson and Bishop 2010). The relatively lower fawn survival observed this winter (3 of 4 study areas) was likely due to increased winter severity present through mid February, and doe survival was consistent with other mule deer populations experiencing normal winter conditions in the western US (Unsworth et al. 1999).

Seasonal Movement Patterns

Migration patterns differed among areas with North Ridge and North Magnolia deer generally migrating east-west and South Magnolia and Ryan Gulch deer migrating south-north (Fig. 3). Median straight-line migration distances were similar ranging from 32.6 km (Ryan Gulch) to 41.3 km (North Magnolia). Similar to seasonal ranges, most deer monitored exhibited strong fidelity to spring and fall migration routes (Fig. 3). Timing of spring migration during 2010 was similar among study areas with median spring migration dates occurring between 8 and 16 May and median fall migration dates occurring between 15 and 23 October. Median migration duration was relatively short among areas ranging from 3 to 8 days in the spring and 2 to 6 days in the fall; these observations were comparable to previous years. More detailed analyses of these migration data investigating the influence of human activity are currently being conducted by Patrick Lendrum and Terry Bowyer of Idaho State University. A final report is scheduled to be completed by spring 2012.

Winter concentration areas identified from March 2010—April 2011 (Fig. 4) reasonably followed study area boundaries delineated from previous GPS locations of adult female mule deer (Anderson and Bishop 2010). Winter concentration areas outside study area boundaries primarily resulted from atypical distribution shifts of some North Ridge deer. Within study areas, we noted more continuous distributions from North Magnolia and North Ridge deer, with Ryan Gulch and South Magnolia deer exhibiting more fragmented and concentrated distributions, which may be related to relative development densities and longevity within each study area. Future resource selection analyses will address these differences relative to habitat attributes within each area.

Mule Deer Body Condition

Body condition measurements of adult female mule deer December 2010 were comparable to last year (Anderson and Bishop 2010) with higher values evident from North and South Magnolia deer, intermediate from Ryan Gulch deer, and lower values from North Ridge deer (Table 2), but differences were only marginal (*P* < 0.01) between North Ridge and the 2 Magnolia populations (mm rump fat: *P* = 0.05—0.07). Unlike last year, deer coming into winter range with higher body condition did not maintain improved condition by late winter and all herd segments were similarly low when assessed in March 2011. The similarly low body condition among areas we observed during late winter can likely be attributed to increased winter severity this winter relative to last winter. Overwinter decline in mean % body fat ranged from 3.8% in Ryan Gulch to 4.7% in South Magnolia (Table 2). Pregnancy rates were expectedly high ranging from 95% to 100%/study area (*n* = 20/area).

Similar to subtle trends in adult female body condition the past 3 years (Table 2), December fawn weights were slightly higher in 2009 than during 2008 and 2010 (Fig. 5). In 2009, male fawns from North and South Magnolia were heavier ($P < 0.05$) than during 2008 as were Ryan Gulch males when compared to 2010. Similarly, 2009 females were heavier from North Magnolia compared to 2008 and from North Magnolia and Ryan Gulch than during 2010 (Fig. 5). In comparing fawn weights from December 2010, Ryan Gulch fawns were marginally ($P = 0.055$; South Magnolia females) or significantly lighter ($P < 0.05$; both sexes from the other 3 study areas and males from South Magnolia) than other fawns.

Mule Deer Population Estimates

Mark-resight models that best predicted abundance estimates (lowest AICc; Burnham and Anderson 2002) exhibited homogenous individual sightability ($\sigma^2 = 0$) and constant sightability across surveys (*P.*) for South Magnolia and Ryan Gulch, homogenous individual sightability and variable sightability with survey period for North Ridge, and heterogeneous individual sightability with variable sightability across surveys for North Magnolia. North Ridge exhibited the highest deer density (22.9/km^2), followed by North Magnolia (11.2/km^2), with comparably lower deer densities in South Magnolia and Ryan Gulch (7.6 and 8.7/km^2; Table 3, Fig. 6). Abundance estimates were similar ($P >$ 0.05) to last year except in North Magnolia where deer numbers increased from 595 to 884. Over the 3 year survey period so far the population trend in North Ridge appears to be increasing with a recent increase in North Magnolia and stability in the other 2 areas (Fig. 6). Abundance estimates from 2011 were similarly precise from all 4 study areas with the mean Confidence Interval Coefficient of Variation (CICV) ranging from 0.14—0.18.

SUMMARY AND FUTURE PLANS

The goal of this study is to investigate habitat treatments and energy development practices that enhance mule deer populations exposed to extensive energy development activity. The information presented here provide data describing mule deer population parameters from the first 3.5 years of the pre-treatment period of a long-term study intended to address how mule deer react to landscape scale habitat and human activity modifications. The pretreatment period is intended to continue 1 to 2 more winters to provide baseline data to compare against intended improvements in habitat conditions and evaluation of concentration/reduction in human development activities, which will be maintained for 4—6 years to provide sufficient time to measure how deer respond to these changes. Based on the data collected thus far, deer from all areas appear to be in reasonably good condition and are exhibiting expected survival rates relative to changes in winter severity. Mild winter conditions the first 2 years and more severe winter conditions during the current year likely contributed to the observed mule deer population parameters. Observed differences in winter concentration areas (Fig. 4) may indicate behavioral modifications to areas of prolonged high development activity, but resource selection analyses will be necessary to confirm this supposition. We will continue to collect the various population and habitat use data across all study sites to evaluate the effectiveness of habitat improvements on winter range. This approach will allow us to determine whether it is possible to effectively mitigate development impacts in highly developed areas, or whether it is better to allocate mitigation dollars toward less or non-impacted areas. In a recent project conducted on the Uncomphahgre Plateau, Bergman et al. (2009) found that habitat treatments implemented in pinyon-juniper habitat in undeveloped areas were effective for deer. We are also evaluating deer behavioral responses to varying levels of development activity. This will allow us to assess the effectiveness of certain BMPs for reducing disturbance to wintering mule deer.

We recently implemented a habitat improvement plan and completed our pilot habitat treatments January 2011 (126 acres total) and plan to complete the remaining treatments (~1,080 acres) in the

Magnolia study areas by fall/winter 2012—2013; vegetation response thus far in the pilot treatment sites have been promising, likely due to the moist spring conditions this year. In addition, hay field improvements have been implemented in the North Magnolia area from a collaborative agreement with Williams Production LMT Co. Additional collaboration with Williams Production LMT Co. have produced a clustered development plan to be implemented in the Ryan Gulch study area and new technologies will be implemented to reduce human activity through remote monitoring of well pads and fluid collection systems. Recent collaboration agreements with ExxonMobil Development Co. and Colorado State University have provided graduate research opportunities to enhance data collection and inference about mule deer/energy development interactions. We are continuing to work with Dr. Terry Bowyer and Patrick Lendrum (MS candidate) of Idaho State University to address mule deer migration and potential influences of human activity along migration routes. Additional funding and cooperative agreements will be necessary to sustain this project through completion (through at least 2017 and preferably through 2019). We optimistically anticipate the opportunity to work cooperatively toward developing solutions for allowing the nation's energy reserves to be developed in a manner that benefits wildlife and the people who value both the wildlife and energy resources of Colorado.

LITERATURE CITED

Anderson, C. R., Jr. 2009. Population performance of Piceance Basin mule deer in response to natural gas resource extraction and mitigation efforts to address human activity and habitat degradation. Job Progress Report, Colorado Division of Wildlife, Ft. Collins, CO, USA.

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

Anderson, C. R., Jr., and D. J. Freddy. 2008*b*. Population performance of Piceance Basin mule deer in response to natural gas resource extraction and mitigation efforts to address human activity and habitat degradation—Stage I, Objective 5: Patterns of mule deer distribution & movements. Pilot Study, Colorado Division of Wildlife, Ft. Collins, CO, USA.

Anderson, C. R., Jr., and C. J. Bishop. 2010. Population performance of Piceance Basin mule deer in response to natural gas resource extraction and mitigation efforts to address human activity and habitat degradation. Job Progress Report, Colorado Division of Wildlife, Ft. Collins, CO, USA.

Bartmann, R. M. 1975. Piceance deer study—population density and structure. Job Progress Report, Colorado Divison of Wildlife, Fort Collins, Colorado, USA.

Bartmann, R. B., and S. F. Steinert. 1981. Distribution and movements of mule deer in the White River Drainage, Colorado. Special Report No. 51, Colorado Division of Wildlife, Fort Collins, Colorado, USA.

Bartmann, R. M., G. C. White, and L. H. Carpenter. 1992. Compensatory mortality in a Colorado mule deer population. Wildlife Monograph No. 121.

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

Bergman, E. J., C. J. Bishop, D. J. Freddy, and G. C. White. 2009. Evaluation of winter range habitat treatments on over-winter survival and body condition of mule deer. Job Progress Report, Colorado Division of Wildlife, Ft. Collins, USA.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multi-model inference: a practical information-theoretic approach. Second edition. Springer-Verlag, New York, New York, USA.

Cook, R. C., J. G. Cook, D. L. Murray, P. Zager, B. K. Johnson, and M. W. Gratson. 2001. Development of predictive models of nutritional condition for rocky mountain elk. Journal of Wildlife Management 65:973-987.

Cook, R. C., T. R. Stephenson, W. L. Meyers, J. G. Cook, and L. A. Shipley. 2007. Validating predictive models of nutritional condition for mule deer. Journal of Wildlife Management 71:1934-1943.

Gibbs, H. D. 1978. Nutritional quality of mule deer foods, Piceance Basin, Colorado. Thesis, Colorado State University, Fort Collins, Colorado, USA.
Kaplan, E. L., and P. Meier. 1958. Nonparametric estimation from incomplete observations. Journal of the American Statistical Association 52:457-481.
McClintock, B. T., G. C. White, K. P. Burnham, and M. A. Pride. 2008. A generalized mixed effects model of abundance for mark—resight data when sampling is without replacement. Pages 271-289 *in* D. L. Thompson, E. G. Cooch, and M. J. Conroy, editors, Modeling demographic processes is marked populations. Springer, New York, New York, USA.
Pollock, K. H., S. R. Winterstein, C. M. Bunck, and P. C. Curtis. 1989. Survival analysis in telemetry studies: the staggered entry design. Journal of Wildlife Management 53:7-15.
Stephenson, T. R., V. C. Bleich, B. M. Pierce, and G. P. Mulcahy. 2002. Validation of mule deer body composition using in vivo and post-mortem indices of nutritional condition. Wildlife Society Bulletin 30:557-564.
Stephenson, T. R., K. J. Hundertmark, C. C. Swartz, and V. Van Ballenberghe. 1998. Predicting body fat and mass in moose with untrasonography. Canadian Journal of Zoology 76:717-722.
Unsworth, J. W., D. F. Pack, G. C. White, and R. M. Bartmann. 1999. Mule deer survival in Colorado, Idaho, and Montana. Journal of Wildlife Management 63:315-326.
Van Reenen, G. 1982. Field experience in the capture of red deer by helicopter in New Zealand with reference to post-capture sequela and management. Pages 408-421 *in* L. Nielsen, J. C. Haigh, and M. E. Fowler, editors. Chemical immobilization of North American wildlife. Wisconsin Humane Society, Milwaukee, USA.
White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked individuals. Bird Study 46:120-139.
White, C. C., and B. C. Lubow. 2002. Fitting population models to multiple sources of observed data. Journal of Wildlife Management 66:300-309.

Prepared by ____
Chuck R. Anderson, Wildlife Researcher

Table 1. Survival rate estimates ($\hat{S}$) of fawn (1 Dec. 2010—18 June 2011) and adult female (1 July 2010—30 June 2011) mule deer from 4 winter range study areas of the Piceance Basin in northwest Colorado.

Cohort Study area	Initial sample size (*n*)	March doe sample[a] (*n*)	$\hat{S}$ (95% CI)
Fawns			
Ryan Gulch	50		0.480 (0.342—0.618)
South Magnolia	55		0.508 (0.375—0.640)
North Magnolia	60		0.481 (0.351—0.610)
North Ridge	77		0.697 (0.594—0.080)
Adult females			
Ryan Gulch	31	51	0.892 (0.800—0.983)
South Magnolia	28	53	0.832 (0.708—0.955)
North Magnolia	32	54	0.783 (0.654—0.912)
North Ridge	33	44	0.765 (0.622—0.908)

[a]Adult female sample size following capture and radio-collaring efforts March, 2011.

Table 2. Mean rump fat (mm), Body Condition Score (BCS[a]), and % body fat (% fat) of adult female mule deer from 4 study areas in the Piceance Basin of northwest Colorado, March and December, 2009—2011. Values in parentheses = SD.

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

Table 2. Continued.

	December 2010			March 2011		
Study Area	Rump fat	BCS	% fat	Rump fat	BCS	% fat
Ryan Gulch	7.75 (6.15)	3.34 (0.98)	10.82 (4.32)	1.55 (0.60)	2.53 (0.42)	7.05 (1.20)
South Magnolia	9.85 (6.78)	3.30 (0.61)	11.21 (3.32)	1.65 (0.75)	2.35 (0.50)	6.56 (1.49)
North Magnolia	9.55 (6.49)	2.56 (0.68)	11.65 (4.86)	1.65 (0.67)	2.53 (0.49)	7.06 (1.35)
North Ridge	6.14 (5.29)	3.32 (0.82)	10.32 (3.39)	1.45 (0.76)	2.24 (0.49)	6.24 (1.45)

[a]Body condition score taken from palpations of the rump following Cook et al. (2001).

Table 3. Mark-resight abundance (*N*) and density estimates of mule deer from 4 winter range herd segments in the Piceance Basin, northwest Colorado, 29 March—4 April 2011. Data represent 4 resight surveys from North Ridge and 5 resight surveys from the other 3 study areas.

Study area	Mean No. sighted	Mean No. marked	*N* (95% CI)	Density (deer/km^2)
Ryan Gulch	327	22	1,219 (1,040—1,431)	8.7
South Magnolia	156	21	630 (542—735)	7.6
North Magnolia	239	22	884 (739—1,060)	11.2
North Ridge	409	30	1,221 (1,067—1,399)	22.9

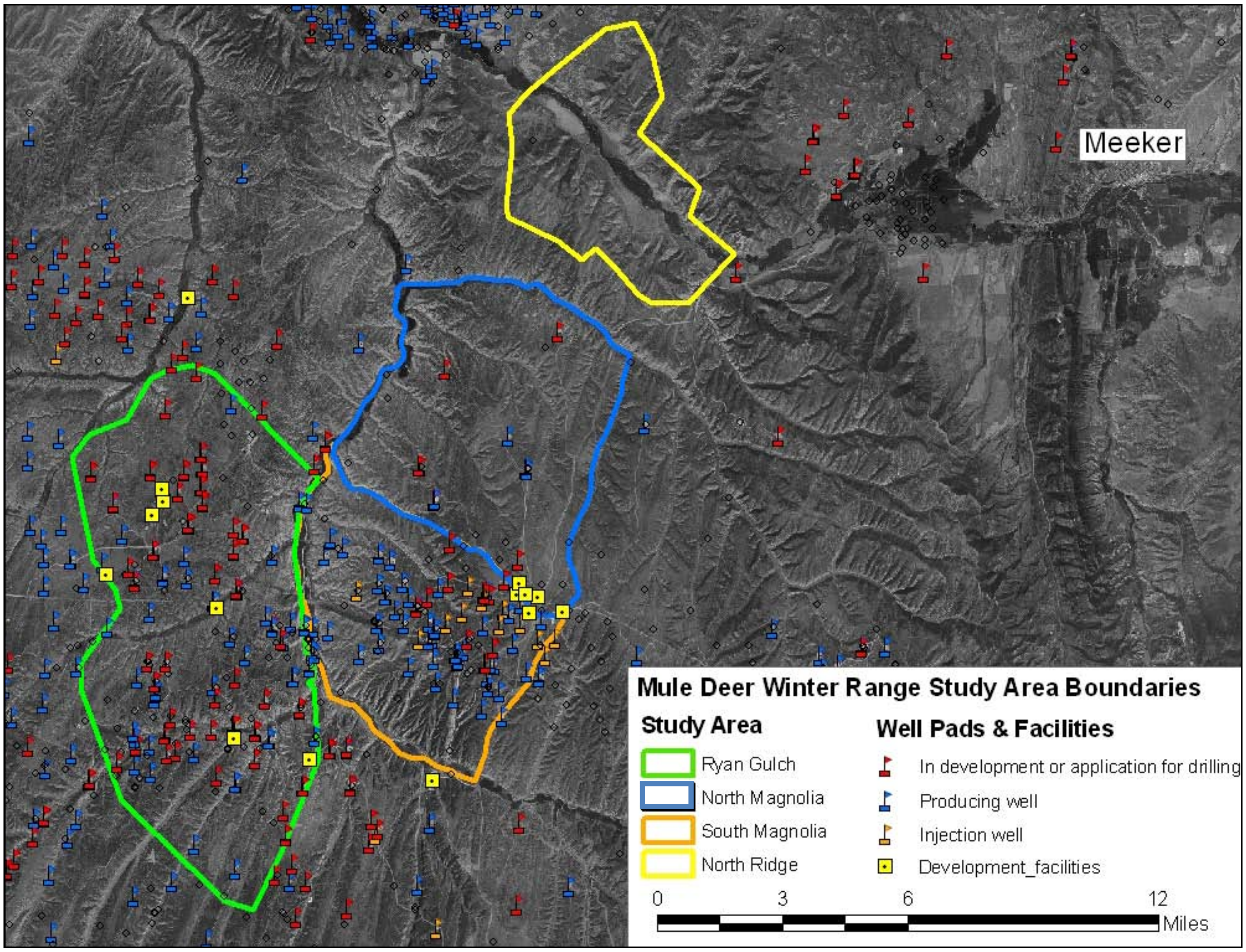


Figure 1. Mule deer winter range study areas relative to active natural gas well pads and energy development facilities in the Piceance Basin of northwest Colorado, summer 2011(Accessed http://cogcc.state.co.us/ Aug. 8, 2011).

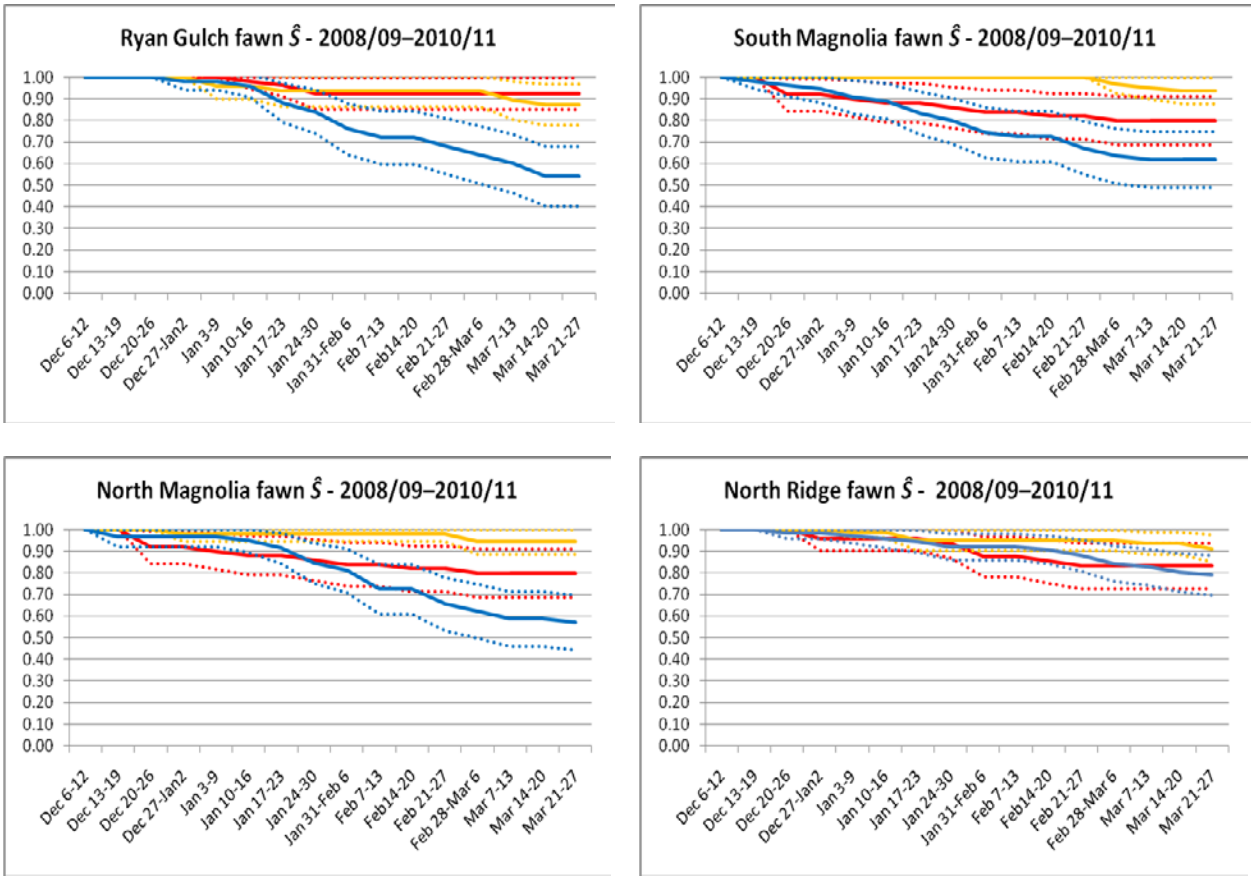


Figure 2. Over-winter (Dec—Mar) mule deer fawn survival ($\hat{S}$) from 4 study areas in the Piceance Basin, northwest Colorado, 2008/09 (red lines), 2009/10 (orange lines) and 20010/11 (blue lines). Solid lines = $\hat{S}$ and dashed lines = 95% CI. Comparable data among years December—March due to premature collar drop during 2008 and 2009.

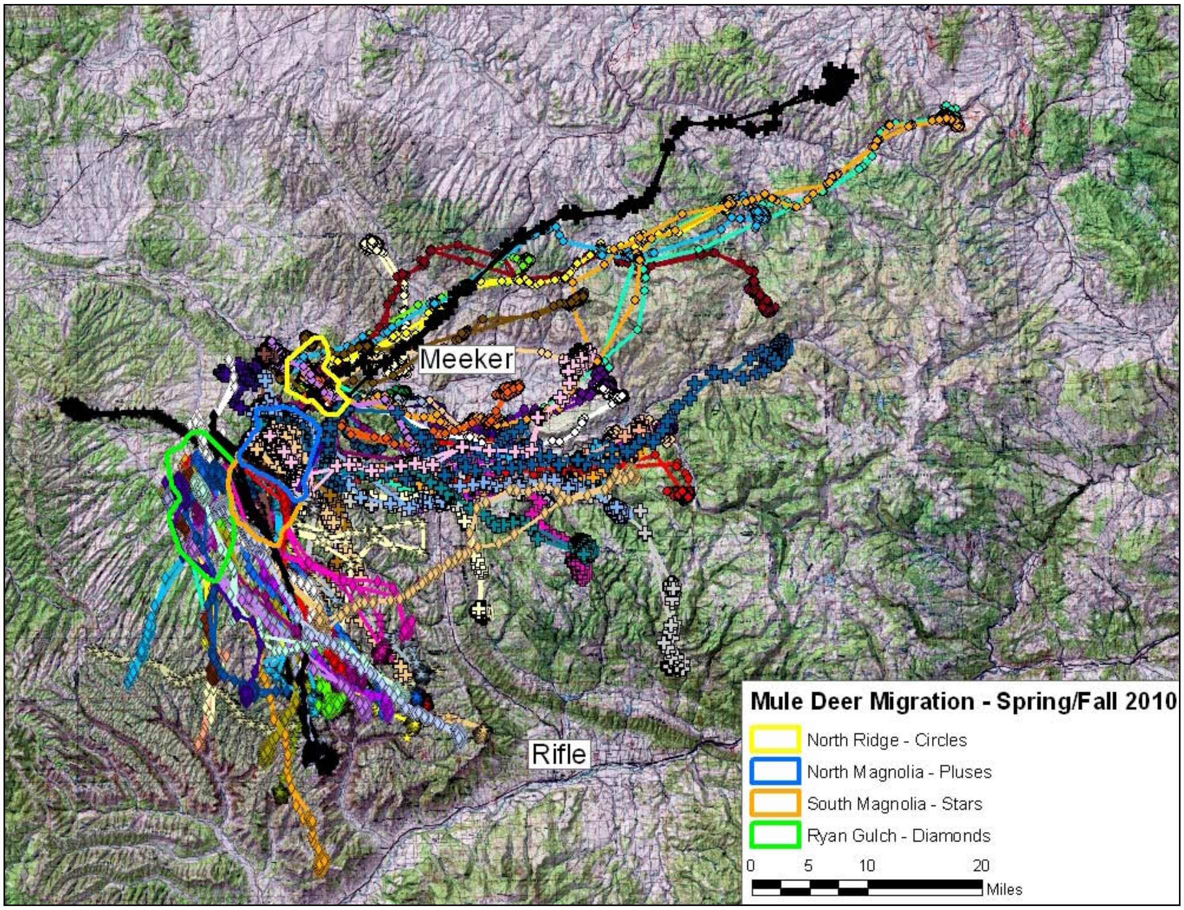


Figure 3. Mule deer migration routes from 4 winter range study areas in the Piceance Basin of northwest Colorado, spring and fall 2010.

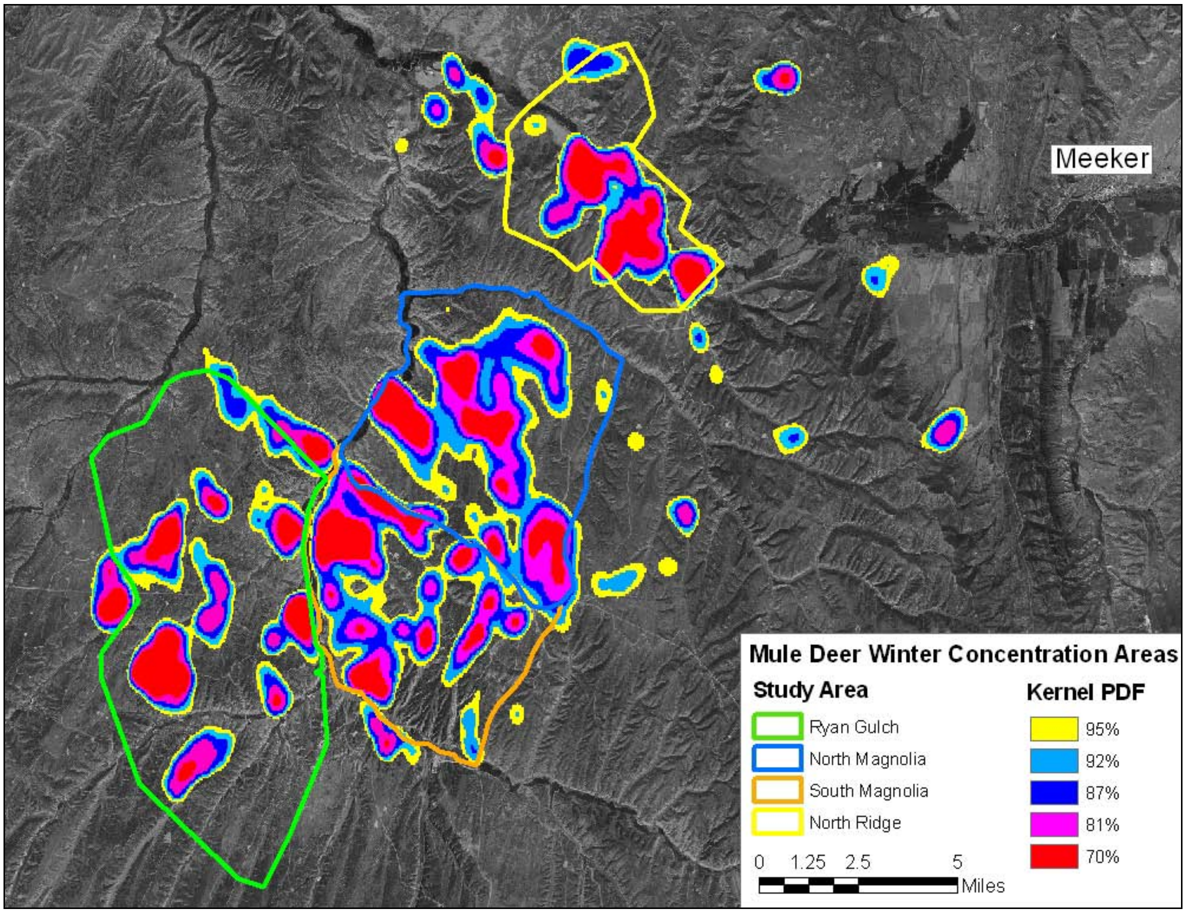
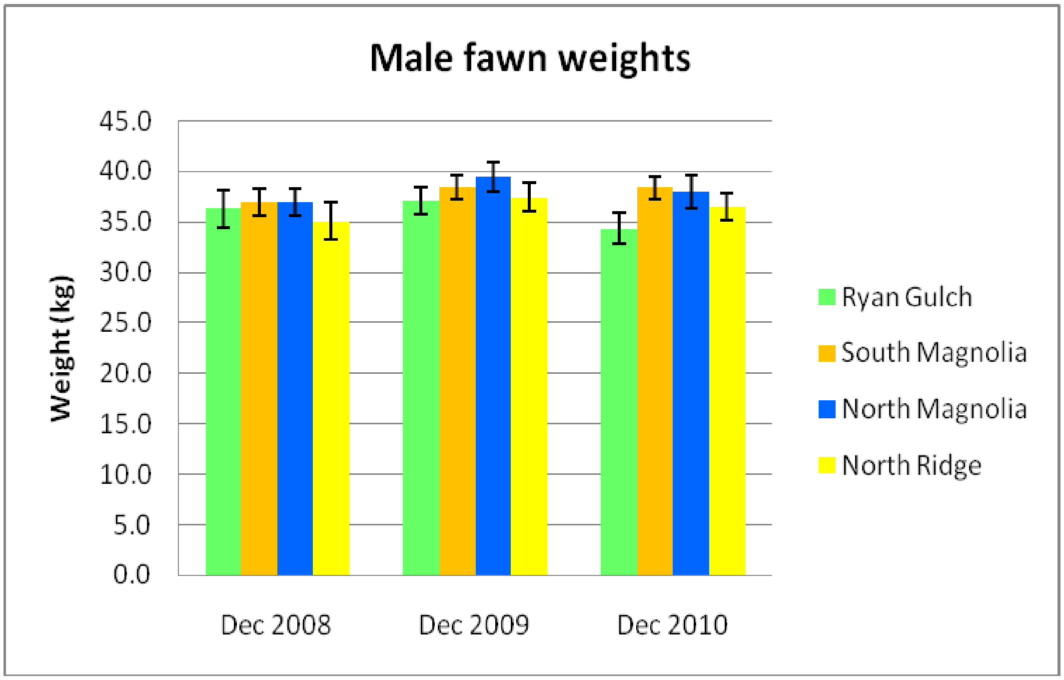


Figure 4. Mule deer winter concentration areas (composite kernel Probability Density Functions; PDF) from 4 study areas in the Piceance Basin of northwest Colorado, March 2010—April 2011. Data from composite GPS locations (5 GPS location attempts/day) of adult female mule deer by study area.



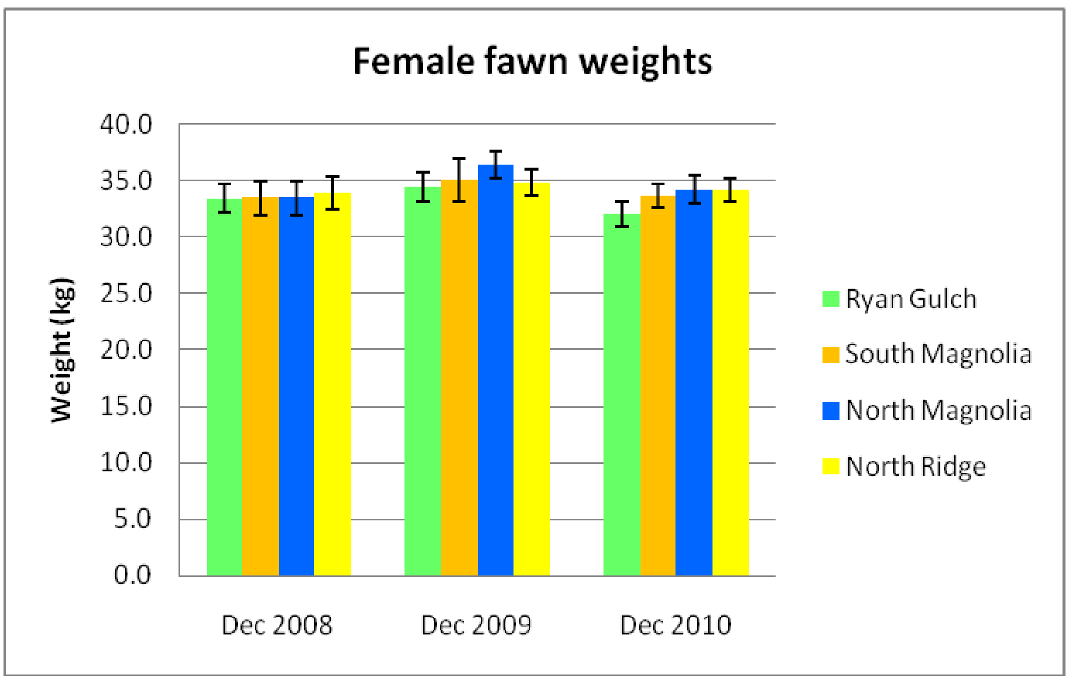


Figure 5. Mean male and female fawn weights and 95% CI (error bars) from 4 mule deer study areas in the Piceance Basin, northwest Colorado, December 2008—2010.

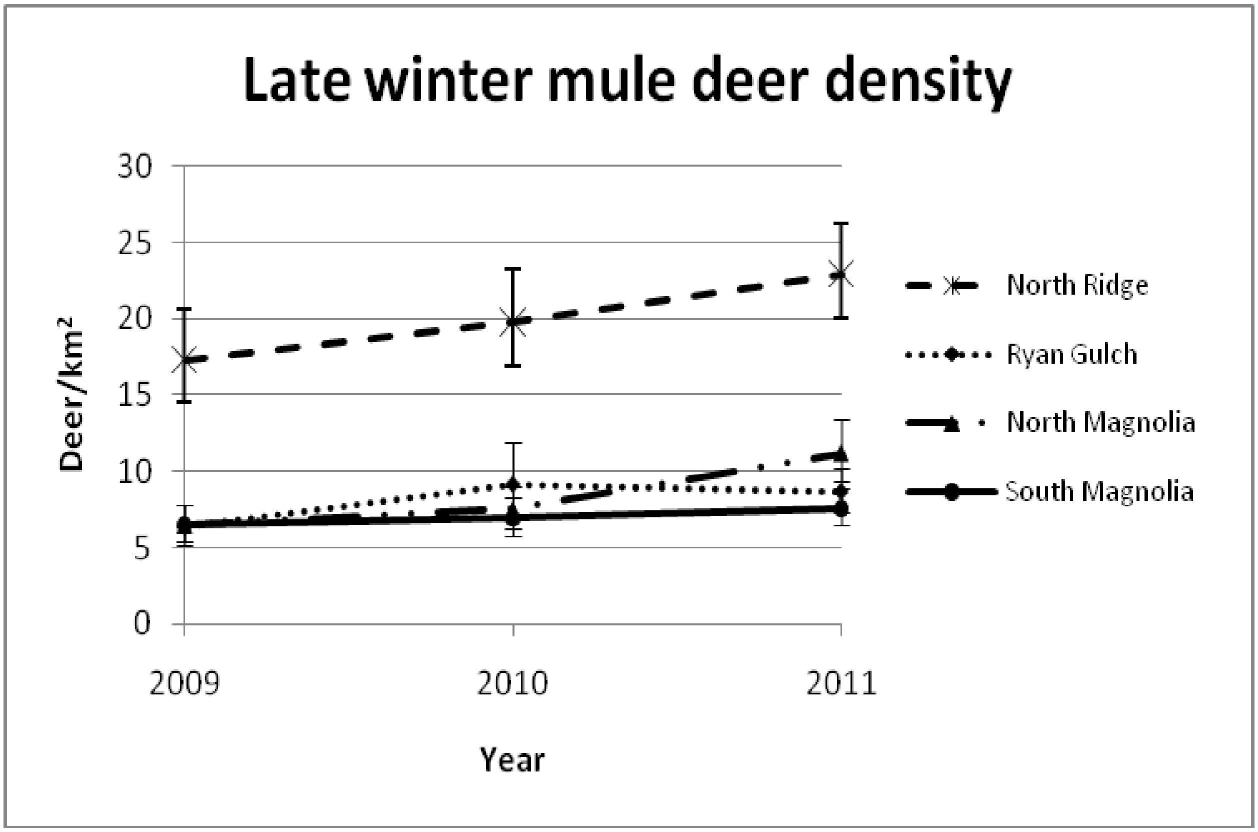


Figure 6. Mule deer density estimates and 95% CI (error bars) from 4 winter range herd segments in the Piceance Basin, northwest Colorado, late winter 2009—2011.

Colorado Division of Parks and Wildlife
July 2010 – June 2011

WILDLIFE RESEARCH REPORT

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

Period Covered: July 1, 2010 – June 30, 2011

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

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 completed all field work on this project and prepared draft manuscripts for publication prior to FY 10-11. As explained in our Segment Narrative for FY 10-11, our final objective for this project was to publish results of the study in Journal of Wildlife Management (JWM). Our manuscript was accepted for publication in JWM on March 23, 2011. The manuscript will be published in the November 2011 issue of JWM.

WILDLIFE RESEARCH REPORT

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

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

P. N. OBJECTIVE

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

SEGMENT OBJECTIVES

6. Publish findings in Journal of Wildlife Management.

INTRODUCTION

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

The most promising technique employed to capture neonates from marked adult females is use of vaginal implant transmitters (VITs), which are placed in the vagina of adult females during early to mid gestation. In theory, adult females retain VITs until parturition, at which point VITs are expelled at birth sites along with newborn fawns. Assuming VITs are routinely monitored, researchers can promptly radio-locate shed VITs and capture the newborn fawns. Recent applications of VITs in white-tailed deer (*O. virginianus*; Carstensen et al. 2003, Haskell et al. 2007, Saalfeld and Ditchkoff 2007), black-tailed deer (*O. hemionus columbianus*; Pamplin 2003), mule deer (Bishop et al. 2007, Haskell et al. 2007), and elk (*Cervus elaphus*; Johnson et al. 2006, Barbknecht et al. 2009) have been moderately successful. Vaginal implant transmitters also permit measurement of fetal survival in free-ranging populations, which has important implications in populations where stillborn mortality occurs (Bishop et al. 2007, 2008, 2009). An additional advantage of using VITs to capture neonates may be a reduction in sampling bias when compared to capture techniques that rely on opportunistic fawn capture (White et al. 1972, Ballard et al. 1998, Pojar and Bowden 2004). Opportunistic techniques are susceptible to bias because of unequal capture success among vegetation types, distances to roads, fawn ages, and stages of fawning. For example, if roads are used to conduct opportunistic searches, fawn capture probability will decline with increasing distance from a road and neonates will be disproportionately sampled in areas with high road densities. When using VITs, the distribution of radio-marked adult females carrying VITs determines where neonates are sampled. Inferences will be less biased with VITs than with opportunistic capture techniques if all VITs are monitored with equal intensity during fawning and the sample of radio-marked adult females was captured with minimal bias. Thus, VITs could have broad applicability regardless of whether study objectives require that fawns be captured from previously marked adult females.

The most significant problem associated with VITs has been premature expulsion and subsequent failure to locate birth sites or newborn fawns, especially in mule deer (Johnstone-Yellin et al. 2006, Bishop et al. 2007, Haskell et al. 2007). The VIT has flexible, plastic wings coated with a soft silicone that induce pressure against the vaginal wall to retain the transmitter. The VIT design facilitates a quick, non-surgical insertion process and is safe for the animal (Johnson et al. 2006), but the current wing design is inadequate with respect to retention. Bishop et al. (2007) found that 43% (SE = 4.7) of VITs in mule deer shed prepartum, although the probability of capturing ≥1 fawn was relatively high (0.792, SE = 0.0847) when VITs shed only 1–3 days prepartum. They noted that 25% (SE = 4.1) of VITs shed >3 days prepartum and that retention probability declined as deer body size increased, indicating the retention wings were too small to be effective in larger deer. Based on these results, considerable oversampling of adult females would be required in the design of future projects to achieve a target sample size of fawns. That is, extra adult females would need to be sampled to offset those adult females that shed VITs prematurely. Oversampling, in this instance, is undesirable from an animal care and use perspective and unnecessarily expensive. Thus, our objective was to redesign the plastic-silicone retention wings of VITs to allow maximum retention in larger deer species.

Prior to our study, the wings used to retain VITs had been purchased from a company in New Zealand (Carter Holt Harvey Plastic Products, Hamilton, New Zealand) that originally produced them for an application in the livestock industry (Bowman and Jacobson 1998). The company manufactured 1 large wing and 1 small wing; the former has been used in production of VITs for bison (*Bison bison*) and elk (*Cervus elaphus*) whereas the latter has been used in production of VITs for deer (Advanced Telemetry Systems, Isanti, MN). Advanced Telemetry Systems (ATS), in cooperation with wildlife researchers, made an initial effort in 2004 to lengthen the retention wings by adding resin to the wing tips. Using these VITs with antennas cut to the appropriate length, Haskell et al. (2007) reported that 81% of VITs (n = 21) in deer were retained until parturition. Retention improved but the aftermarket wing-modification was problematic because the wing tips were hard and thus not ideal for placement in the vaginal canal. That study provided justification to pursue further wing development. We therefore redesigned retention wings of VITs used in deer and similar-sized ungulates, fabricated a new production mold, and evaluated retention rates of VITs in free-ranging mule deer.

STUDY AREA

We conducted our research in Piceance Basin and on the Roan Plateau in northwest Colorado (Fig. 1). Our winter range study area comprised 4 study units distributed across much of the Piceance Basin. The 4 units ranged in size from 70 to 130 km^2 and are referenced as South Magnolia, Story-Sprague, Ryan Gulch, and Yellow Creek (Fig. 1).

METHODS

We prepared and submitted a draft manuscript to Journal of Wildlife Management (JWM). Initial reviews were favorable, and thus, we were invited to submit a revised manuscript for further consideration. We prepared a revised manuscript based on comments submitted by peer reviewers and the associate editor.

RESULTS AND DISCUSSION

Our revised manuscript was accepted for publication on March 23, 2011. The manuscript will be published in the November 2011 issue of JWM. The abstract from this publication follows:

Our understanding of factors that limit mule deer (*Odocoileus hemionus*) populations may be improved by evaluating neonatal survival as a function of dam characteristics under free-ranging conditions, which generally requires that both neonates and dams are radiocollared. The most viable technique facilitating capture of neonates from radiocollared adult females is use of vaginal implant

transmitters (VITs). To date, VITs have allowed research opportunities that were not previously possible; however, VITs are often expelled from adult females prepartum, which limits their effectiveness. We redesigned an existing VIT manufactured by Advanced Telemetry Systems (ATS; Isanti, MN) by lengthening and widening wings used to retain the VIT in an adult female. Our objective was to increase VIT retention rates and thereby increase the likelihood of locating birth sites and newborn fawns. We placed the newly designed VITs in 59 adult female mule deer and evaluated the probability of retention to parturition and the probability of detecting newborn fawns. We also developed an equation for determining VIT sample size necessary to achieve a specified sample size of neonates. The probability of a VIT being retained until parturition was 0.766 (SE = 0.0605) and the probability of a VIT being retained to within 3 days of parturition was 0.894 (SE = 0.0441). In a similar study using the original VIT wings (Bishop et al. 2007), the probability of a VIT being retained until parturition was 0.447 (SE = 0.0468) and the probability of retention to within 3 days of parturition was 0.623 (SE = 0.0456). Thus, our design modification increased VIT retention to parturition by 0.319 (SE = 0.0765) and VIT retention to within 3 days of parturition by 0.271 (SE = 0.0634). Considering dams that retained VITs to within 3 days of parturition, the probability of detecting at least 1 neonate was 0.952 (SE = 0.0334) and the probability of detecting both fawns from twin litters was 0.588 (SE = 0.0827). We expended approximately 12 person-hours per detected neonate. As a guide for researchers planning future studies, we found that VIT sample size should approximately equal the targeted neonate sample size. Our study expands opportunities for conducting research that links adult female attributes to productivity and offspring survival in mule deer.

The full text publication can be obtained electronically or in hard copy through JWM and Wiley-Blackwell Publishers.

SUMMARY

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

The question remains as to whether premature expulsion of VITs can be eliminated in mule deer. We observed modest evidence that deer expelling VITs >3 days prepartum were older and larger than deer that retained or nearly-retained VITs. We therefore recommend manufacturing slightly larger wings for large, older mule deer (e.g., >65 kg and >5 yrs old) as a possible strategy to further investigate VIT retention.

An article documenting our research findings will be published in the November 2011 issue of JWM.

LITERATURE CITED

Ballard, W. B., H. A. Whitlaw, D. L. Sabine, R. A. Jenkins, S. J. Young, and G. J. Forbes. 1998. White-tailed deer, *Odocoileus virginianus*, capture techniques in yarding and non-yarding populations in New Brunswick. Canadian Field-Naturalist 112:254–261.

Barbknecht, A. E., W. S. Fairbanks, J. D. Rogerson, E. J. Maichak, and L. L. Meadows. 2009. Effectiveness of vaginal-implant transmitters for locating elk parturition sites. Journal of Wildlife Management 73:144–148.

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

Bishop, C. J., G. C. White, D. J. Freddy, B. E. Watkins, and T. R. Stephenson. 2009. Effect of enhanced nutrition on mule deer population rate of change. Wildlife Monographs 172:1–28.

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

Bowman, J. L., and H. A. Jacobson. 1998. An improved vaginal-implant transmitter for locating white-tailed deer birth sites and fawns. Wildlife Society Bulletin 26:295–298.

Carstensen, M., G. D. DelGiudice, and B. A. Sampson. 2003. Using doe behavior and vaginal-implant transmitters to capture neonate white-tailed deer in north-central Minnesota. Wildlife Society Bulletin 31:634–641.

Haskell, S. P., W. B. Ballard, D. A. Butler, N. M. Tatman, M. C. Wallace, C. O. Kochanny, and O. J. Alcumbrac. 2007. Observations on capturing and aging deer fawns. Journal of Mammalogy 88:1482–1487.

Johnson, B. K., T. McCoy, C. O. Kochanny, and R. C. Cook. 2006. Evaluation of vaginal implant transmitters in elk (*Cervus elaphus nelsoni*). Journal of Zoo and Wildlife Medicine 37:301–305.

Johnstone-Yellin, T. L., L. A. Shipley, and W. L. Myers. 2006. Evaluating the effectiveness of vaginal implant transmitters for locating neonatal mule deer fawns. Wildlife Society Bulletin 34:338–344.

Pamplin, N. P. 2003. Ecology of Columbian black-tailed deer fawns in western Oregon. Thesis, Oregon State University, Corvallis, 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.

Saalfeld, S. T., and S. S. Ditchkoff. 2007. Survival of neonatal white-tailed deer in an exurban population. Journal of Wildlife Management 71:940–944.

White, M., F. F. Knowlton, and W. C. Glazener. 1972. Effects of dam-newborn fawn behavior on capture and mortality. Journal of Wildlife Management 36:897–906.

Prepared by ________________________

Chad J. Bishop, Mammals Research Leader

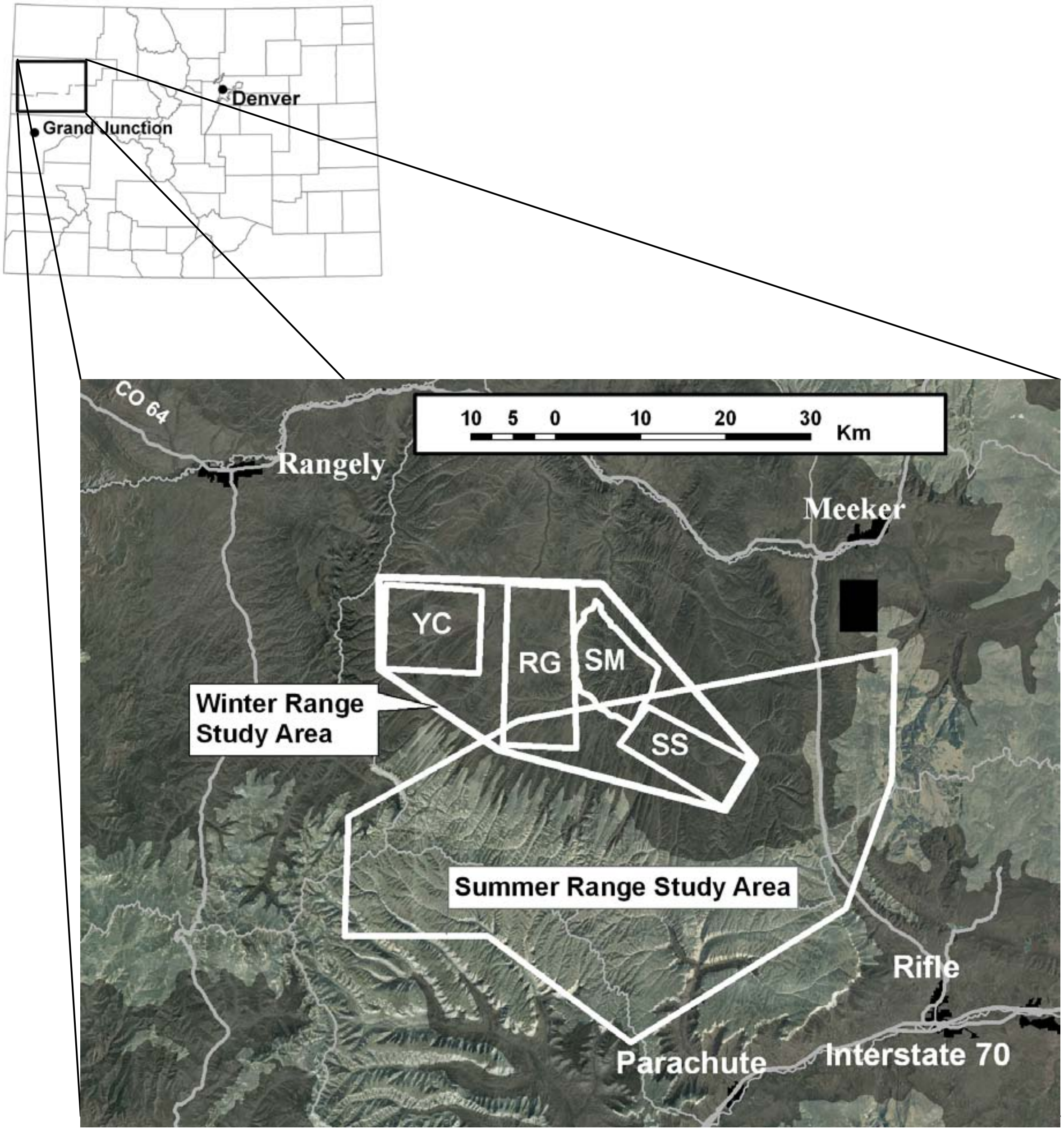


Figure 1. Location of winter and summer range study areas in Piceance Basin and Roan Plateau, northwest Colorado. Winter range study units where we captured and radio-marked mule deer are noted as: YC = Yellow Creek, RG = Ryan Gulch, SM = South Magnolia, and SS = Story-Sprague.

Colorado Division of Parks and Wildlife
July 2010 – June 2011

WILDLIFE RESEARCH REPORT

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

Period Covered: July 1, 2010 - June 30, 2011

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

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

ABSTRACT

Between November 2004 and June 2009 we conducted a five year, multi-area study to assess the impacts of landscape level winter range habitat improvement efforts on mule deer population performance. This study took place on the Uncompahgre Plateau and in adjacent valleys in southwestern Colorado. We measured over-winter fawn survival and deer abundance annually on 5 study areas. Four study areas were permanently located, whereas location of the fifth area varied each year to accommodate the variability in habitat treatments over the southern half of the Uncompahgre Plateau. Additionally, on 2 of the study areas we estimated late winter body condition of adult female deer. Compared to results from other research throughout the West, as well as on the Uncompahgre Plateau, survival estimates for 6-month old mule deer fawns were highly variable between areas, and tended to be near published long term averages. Estimated survival rates from this study ranged between 0.359 (SE = 0.0950) and 0.933 (SE = 0.0648). Evidence suggests that areas that have received habitat treatments have higher fawn survival. Based on estimates of total body fat for adult female deer, there was a slight distinction between treatment and reference study areas. Deer abundance on the study areas varied between winters, but in general abundance estimates did not show increasing or decreasing trends. Major fluctuations within abundance estimates are likely attributable to animal movements and winter severity. Final publications will be completed during the fall of 2011 and spring of 2012 and submitted for peer-reviewed publication upon completion.

WILDLIFE RESEARCH REPORT

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

ERIC J. BERGMAN

P.N. OBJECTIVES

To determine whether mechanical/chemical treatments of native habitat vegetation increases over-winter mule deer fawn survival, adult doe body condition, and localized deer densities on the Uncompahgre Plateau in southwest Colorado and to conduct a simulation based optimization study to determine optimal management strategies of deer under variable environmental, habitat and harvest conditions.

SEGMENT OBJECTIVES

1. Complete all portions of academic/coursework requirements of PhD through Colorado State University.
2. Complete final analyses for survival and density components of the study.
3. Initiate preliminary body condition analyses and narrative for mule deer management strategies.

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 19^{th} century (Connolly 1981, Gill 2001, Hurley and Zager 2004). However, only one period of increase, a general trend during the 1940's and 1950's, has been noted. The most recent and pressing decline took place during the 1990's (Unsworth et al. 1999). Colorado has not escaped these tendencies, with certain parts of the state experiencing population declines by as much as 50% between the 1960's and present time (Gill 2001, B. Watkins personal communication). Primarily due to the value of mule deer as a big game hunting species, wildlife managers' challenges are two-fold: understanding the underlying causes of mule deer population change and managing populations to dampen the effects of these fluctuations.

In Colorado, the role of habitat as the limiting factor for mule deer populations was recently tested. Specifically, the role of forage quality and quantity on over-winter fawn survival was tested using a treatment/reference cross-over design with *ad libitum* pelleted food supplements as a substitute for instantaneous high quality habitat improvements (Bishop et al. 2009). The primary hypothesis behind this research concerned the interaction between predation and nutrition. If supplemental forage treatments improved over-winter fawn survival (i.e. if predation did not prevent an increase), then it could be concluded that over-winter nutrition was the primary limiting factor on populations. As such, nutrition enhancement treatments increased fawn survival rate by 0.22 (Bishop et al. 2009). This research effectively identified some of the underlying processes in mule deer population regulation, but did not test the effectiveness of acceptable habitat management techniques. Due to the undesirable effects of feeding wildlife (e.g. artificially elevating density, increased potential for disease transmission and cost), a more appropriate technique for achieving a high quality nutrition enhancement needs to be assessed.

We completed a multi-year, multi-area study to assess the impacts of landscape level winter range treatments on mule deer population performance. We conducted the study on the Uncompahgre Plateau and adjacent valleys in southwestern Colorado because this area had an active history of habitat treatments that were implemented in part to enhance deer populations. To assess the impacts of habitat treatments on mule deer in these areas, we measured over-winter fawn survival, mule deer density and late winter body condition.

STUDY AREA

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

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

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

The high density treatment area was located on the Billy Creek tract of Billy Creek State Wildlife Area (approximately 20km south of Montrose, CO). The high density reference area was 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 were located in GMU 65 (DAU D-40). The low density treatment area was located on Peach Orchard Point, on/near Escalante State Wildlife Area (approximately 25km southwest of Delta, CO). The low density reference area was 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 were located in GMU 62 (DAU D-19). All of the other study areas, mentioned above, were also located in GMU 62 (DAU D-19) to the west of Montrose, CO.

METHODS

Twenty-five mule deer fawns were captured and radio-collared in each of the 5 study areas. Fawns were captured via baited drop-nets (Ramsey 1968, Schmidt et al. 1978, Bartmann et al. 1992) and helicopter net-gunning (Barrett et al. 1982, van Reenen 1982) between mid-November and late-

December. To make fawn collars temporary, one end of the collar was cut in half and reattached using rubber surgical tubing; fawns shed the collars after approximately 6 months.

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

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

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

Survival analyses were conducted on all years of data. In addition to including individual covariates (fawn sex and mass), we tested the role of habitat treatment history on survival. Estimating survival for study areas took place in several different forms. The simplest form was constant survival where all study areas were pooled and survival was estimated using a single parameter. The second simplest form was to estimate survival for each unique study area (i.e., 8 survival estimates were generated, hereafter "Area"). The remaining model structures allowed study areas to be partitioned according to treatment history. Derivations of these models that included year as either an additive or multiplicative effect were then built.

All survival models were evaluated in program MARK using the known-fate model type with logit link function (White and Burnham 1999). All models were compared using Akaike's Information Criterion corrected for small sample size (Burnham and Anderson 2003). All abundance and density estimates were also computed using program MARK (White and Burnham 1999). Abundance models varied via the process used to estimate the detection probability of deer, but abundance estimates across areas and years were not pooled.

RESULTS AND DISCUSSION

Survival models indicate that landscape treatments tend to benefit deer. Model structures that incorporate the landscape treatment history of an area tend to outperform those that do not accommodate treatment history (Table 1). Additionally, the top performing model allowed year to vary as an additive effect and incorporated fawn mass. Fawn sex did not add much additional strength to any given model. Of particular interest to this study is that models incorporating study area treatment level consistently improved the performance of simpler models that had identical structure, save this one aspect. Not surprisingly, allowing survival rates to vary by year was fundamental for a model to receive any model weight.

Density estimates were collected during March for all study areas, during the last four years of the study. Abundance estimation was done in program MARK (White and Burnham 1999). Abundance estimates tended to fluctuate by year in each area, but no discernable trends were observed (Table 2). Fluctuations were likely due to localized winter conditions and the concentrating or diluting of deer on our study areas. Overall, no major changes in abundance, in any of the study areas, are believed to have occurred.

Late winter body condition estimates for adult females were consistent during all years of this study, but they tended to be higher than those estimates during previous research on the Uncompahgre Plateau (Bishop et al. 2009 and C.J. Bishop, personal communication). The lowest single total percent body fat estimate for this study was recorded during the final winter, despite the fact that observations of winter severity indicated that body fat estimates likely should have been higher. For the two study areas where body condition estimates were measured, they did have a tendency to reflect the same trends that were observed in survival estimates. However, there was no apparent statistical distinction in total percent body fat between our study areas. This lack of distinction was also observed in the levels of the T3 hormone, whereas T4 hormone (nmol/l) was higher in Billy Creek (mean = 85.72, SD = 10.07) than in Beaton Creek (Mean = 63.01, SD = 13.06) (Table 3). Pregnancy rates were surprisingly variable during this study, with rates ranging between 80% and 97% (Table 3).

Progress towards completion of the requirements for a PhD was also made during the 2010-11 year. As of summer 2011, all coursework needed to meet scholastic requirements has been completed.

SUMMARY

Survival rates for mule deer fawns across our study areas and across years ranged between 36% and 93%. Throughout the course of the study, overall body condition parameter estimates for late-winter adult female deer mirrored estimates collected during different studies (Bishop et al. 2009). Estimates of total deer density across our study areas continued to reflect historical estimates, but annual variation was observed. Overall, a consistent trend of higher survival of fawns was observed in treated study areas, indicating winter range treatments likely have a positive effect on survival.

LITERATURE CITED

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

Bartmann, R.M., L.H. Carpenter, R.A. Garrott, and D.C. Bowden. 1986. Accuracy of helicopter counts of mule deer in pinyon-juniper woodland. Wildlife Society Bulletin 14:356-363.

——————, G.C. White, and L.H. Carpenter. 1992. Compensatory mortality in a Colorado mule deer population. Wildlife Monographs 121:5-39.

Bergman, E.J., C.J. Bishop, D.J. Freddy, G.C. White. 2005. Pilot evaluation of winter range habitat treatments of mule deer fawn over-winter survival. Wildlife Research Report July: 23-35. Colorado Division of Wildlife, Fort Collins, USA.

Bishop, C.J., G.C. White, D.J. Freddy, B.E. Watkins and T.R. Stephenson. 2009. Effect of enhanced nutrition on mule deer population rate of change. Wildlife Monographs 172.

Burnham, K.P. and D.R. Anderson. 2003. Model selection and multi-model inference. Springer, New York, USA.

Clutton-Brock, T., and J. Pemberton, editors. 2004. Soay sheep: dynamics and selection in an island population. Cambridge University Press, UK.

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.

Cook, R. C. 2000. Studies of body condition and reproductive physiology in Rocky Mountain Elk. Thesis, University of Idaho, Moscow, USA.

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.

Gill, R.B. 1969. A quadrat count system for estimating game populations. Colorado Division of Game, Fish and Parks, Game Information Leaflet 76. Fort Collins, USA.

—————— 2001. Declining mule deer populations in Colorado: reasons and responses. Colorado Division of Wildlife Special Report Number 77.

Hurley, M., and P. Zager. 2004. Southeast mule deer ecology - Study I: Influence of predators on mule deer populations. Progress Report, Idaho Department of Fish and Game, Boise, USA.

Jedrzejewska, B., and W. Jedrzejewski. 1998. Predation in Vertebrate Communities: the Białowieża Primeval Forest as a case study. Springer-Verlag, Berlin, Germany.

Krebs, C.J., S. Boutin, and R. Boonstra, editors. 2001. Ecosystem dynamics of the boreal forest: the Kluane project. Oxford University Press, New York, New York, USA.

Kufeld, R.C., J.H. Olterman, and D.C. Bowden. 1980. A helicopter quadrat census for mule deer on Uncompahgre Plateau, Colorado. Journal of Wildlife Management 44:632-639.

Ramsey, C.W. 1968. A drop-net deer trap. Journal of Wildlife Management 32:187-190.

Schmidt, R.L., W.H. Rutherford, and F.M. Bodenham. 1978. Colorado bighorn sheep-trapping techniques. Wildlife Society Bulletin 6:159-163.

Stephenson, T.R., V.C. Bleich, B.M. Pierce, and G.P. Mulcahy. 2002. Validation of mule deer body composition using *in vivo* and post-mortem indices of nutritional condition. Wildlife Society Bulletin 30:557-564.

—————— , T. R., K. J. Hundertmark, C. C. Schwartz, and V. Van Ballenberghe. 1998. Predicting body fat and body mass in moose with ultrasonography. Canadian Journal of Zoology 76:717-722.

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.

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

White, G.C., and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46 Supplement:120-138.

Prepared by______________________________

Eric J. Bergman, Wildlife Researcher

Table 1. Survival model results for radio collared fawns on the Uncompahgre Plateau.

Model	**AICc**	**Delta AICc**	**AICc Weights**	***k***
3Trt Levels + Year + Mass	1418.08	0.00	0.4163	7
Year + Mass	1419.05	0.97	0.25626	5
3Trt Levels + Year + Sex + Mass	1419.45	1.37	0.20989	8
Year + Sex + Mass	1420.61	2.53	0.11735	6
3Trt Levels + Year	1436.06	17.98	0.00005	6
Area + Mass	1436.89	18.81	0.00003	9
3Trt Levels + Year + Sex	1437.10	19.02	0.00003	7
Year	1437.59	19.52	0.00002	4
Area + Sex + Mass	1438.19	20.11	0.00002	10
Year + Sex	1438.43	20.36	0.00002	5
Area + Year	1438.59	20.51	0.00001	11
Area * Year	1441.89	23.81	0	20
3Trt Levels * Year	1443.92	25.85	0	12
3Trt Levels	1453.32	35.25	0	3
Area	1456.25	38.17	0	8
Area + Sex	1457.35	39.27	0	9
Area * Year * Week	2033.12	615.04	0	480

Table 2. Abundance estimates with 95% confidence intervals for the 8 study areas, collected during the last 4 years of the study.

Study Area	Year	Abundance	95% C.I. on Abundance
Buckhorn	2006	1324	794 - 2217
Buckhorn	2007	780	695 - 875
Buckhorn	2008	1675	1460 - 1922
Buckhorn	2009	721	548 - 951
Billy Creek SWA	2006	691	483 - 992
Billy Creek SWA	2007	536	479 - 601
Billy Creek SWA	2008	507	458 - 562
Billy Creek SWA	2009	552	449 - 681
Peach Orchard Point	2006	429	307 - 603
Peach Orchard Point	2007	470	340 - 655
Peach Orchard Point	2008	462	340 - 633
Peach Orchard Point	2009	361	215 - 615
Sowbelly/Tatum	2006	402	294 - 554
Sowbelly/Tatum	2007	663	534 - 826
Sowbelly/Tatum	2008	461	356 - 599
Sowbelly/Tatum	2009	444	296 - 674
Shavano Valley	2006	819	586 - 1148
Colona	2007	528	482 - 577
McKenzie Butte	2008	691	441 - 1089
Transfer Road	2009	352	164 - 784

Table 3. Late-winter body condition estimates for female adult mule deer on the Uncompahgre Plateau. Sample sizes were 30 does in each area. Mean T3 and T4 samples are reported in nmol/l. Parameters marked with an asterisk designate a significant difference between areas at the 0.05 level.

Year	Parameter	Billy Creek	Buckhorn	Sowbelly
2005-2006	% Body Fat	8.80% (2.02)	N.A.	9.81% (2.88)
	T3*	1.12 (0.28)	N.A.	1.41 (0.51)
	T4	70.69 (20.94)	N.A.	79.97 (15.80)
2006-2007	% Body Fat	7.61% (1.94)	7.03% (1.80)	N.A.
	T3	1.55 (0.53)	1.42 (0.31)	N.A.
	T4	88.23 (19.53)	78.07 (22.34)	N.A.
2007-2008	% Body Fat	8.09% (1.10)	7.20% (1.69)	N.A.
	T3	1.17 (0.28)	1.17 (0.56)	N.A.
	T4*	94.30 (20.7)	56.20 (23.30)	N.A.
2008-2009	% Body Fat	7.20% (1.85)	6.25% (1.63)	N.A.
	T3	1.22 (0.32)	1.26 (0.35)	N.A.
	T4*	74.63 (14.61)	54.77 (19.34)	N.A.

Colorado Division of Parks and Wildlife
July 2010 – June 2011

WILDLIFE RESEARCH REPORT

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

Period Covered: July 1, 2010 – June 30, 2011

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

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 designed and produced a trap-like device for mule deer that would automatically attach a radio collar to a ≥6-month-old fawn and record the fawn's weight and sex, without requiring physical restraint or handling of the animal. Our passive collaring device is designed to allow biologists and researchers to radio-collar, weigh, and identify sex of ≥6-month-old mule deer fawns with minimal expense and labor when compared to traditional mule deer capture techniques. This technique should significantly reduce stress that is typically associated with capture and handling and eliminate capture-related mortality. We collaborated with students and faculty in the Mechanical Engineering Department at Colorado State University to produce a conceptual model and early prototype. We then worked with professional engineers at Dynamic Group Circuit Design in Fort Collins, Colorado, to produce a fully-functional prototype of the device. We conducted an extensive field evaluation of the device with free-ranging mule deer during winter 2010-11. We successfully collared, weighed, and identified sex of 6 different mule deer fawns across 4 winter range locations along Colorado's northern Front Range. Collars were purposefully made to shed from deer within several weeks or months of being collared. Two fawns were successfully re-collared after they shed the first collars they received. Thus, we observed 8 successful collaring events involving 6 different fawns. Most fawns demonstrated minimal response to collaring events, either remaining in the device or calmly exiting. Certain components of the collaring device failed to function optimally when temperatures dropped below approximately –15° C, while other components did not adequately withstand mule deer use under field conditions. Also, certain behaviors of mule deer when approaching and using the device created circumstances where it was possible to collar the same animal twice, which happened on one occasion. We identified a series of device modifications that would be necessary to address these various issues. During 2011-12, we will modify the device accordingly and conduct a follow-up field evaluation.

WILDLIFE RESEARCH REPORT

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

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

P. N. OBJECTIVE

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

SEGMENT OBJECTIVES

7. Evaluate effectiveness and functionality of an automated collaring device for collaring, weighing, and identifying sex of mule deer fawns during winter under free-ranging conditions.

INTRODUCTION

Colorado Parks and Wildlife (CPW) captures and radio-marks 6-month-old mule deer (*Odocoileus hemionus*) fawns each year to support research and management of mule deer. Approximately 240–300 deer fawns are captured annually to monitor survival among 4–5 populations distributed across western Colorado and an additional 100–350 deer fawns are captured as part of ongoing research studies. Other state agencies in the western United States capture large numbers of mule deer fawns annually also. Most capture is accomplished with net-guns fired from helicopters (Barrett et al. 1982, van Reenen 1982, Webb et al. 2008), which is becoming increasingly expensive (i.e., >$500 per captured deer). Also, net gunning is inherently dangerous with a small market, which at times limits availability of contractors. Drop nets (Ramsey 1968, Schmidt et al. 1978), clover traps (Clover 1956), drive nets (Beasom et al. 1980), and darting (Wolfe et al. 2004) are used occasionally in the western United States to capture deer, but these techniques can be time consuming and labor intensive. Many biologists lack time and resources given other job requirements to conduct such capture operations for any length of time. The increasing cost of helicopter net-gun capture coupled with increasing demand for capturing and radio-collaring 6-month-old fawns has created a need for another capture alternative. Specifically, there is need for a capture technique that is relatively inexpensive to employ considering both operating and personnel costs.

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

A passive marking device would minimize animal stress associated with capture and should have virtually no potential to cause capture-related mortality. The large-mammal capture techniques described above place considerable, temporary stress on animals as part of netting and handling. Roughly 2-3% of animals typically die from capture-related injuries or stresses under routine capture conditions. Thus, successful development of a passive marking system would reduce CPW's operating expenses and improve animal welfare. Therefore, we designed, produced, and evaluated an automated device for collaring, weighing, and identifying sex of mule deer fawns during winter under free-ranging conditions.

STUDY AREA

We conducted all evaluations with captive deer at the Foothills Wildlife Research Facility (FWRF) in Fort Collins, Colorado. We conducted field evaluations with free-ranging deer at 5 sites along Colorado's northern Front Range: 1) Horsetooth Reservoir, west of Fort Collins, private land 2) Masonville, southwest of Fort Collins, private land, 3) Red Feather, northwest of Fort Collins, private land, 4) Hall Ranch, west of Lyons, Boulder County Parks and Open Space, and 5) Heil Valley Ranch, southwest of Lyons, Boulder County Parks and Open Space. We plan to conduct additional field evaluations with free-ranging deer in northwest Colorado during 2011-12.

METHODS

We identified detailed specifications to guide the design and development of an automated collaring device and sought assistance from Colorado State University's Mechanical Engineering Department. The collaring device became a senior design project for 6 CSU engineering students during the 2008-09 school year. We met with the students weekly and provided them a materials budget of $10,000 to produce a prototype device. We conducted staged evaluations of device components during the year by working with captive deer at FWRF. We also conducted limited evaluations with free-ranging deer during spring 2009. Field evaluations focused primarily on how deer utilized and interacted with the device to guide subsequent design and development decisions. We documented utilization and interactions using direct observation and motion-sensor digital cameras. We relied exclusively on digital cameras when we were not on-site during an evaluation. Automation of the collaring device was disabled any time we were not present to prevent any potential harm to deer.

Following preliminary field evaluations, we refined our design specifications and developed a contract with Dynamic Group Circuit Design (DGCD), located in Fort Collins, Colorado, to produce a fully-functional prototype device. We routinely met with electrical engineers from DGCD, and a mechanical engineer subcontracted by DGCD, during 2009-10. These meetings ensured that our device specifications were being satisfactorily met from both engineering and deer biology perspectives. Working with DGCD, we produced a fully-functional prototype device in 2010 that met our design specifications as set forth in the contract.

The prototype device comprises an aluminum cage attached to a bait compartment (Fig. 1). Deer enter the device through an adjustable opening at the front of the cage. The adjustable opening can be used to deter entry of larger animals by adjusting both width and height. The sides of the cage comprise one-way gates that prevent entry into the device but allow an animal to exit the device at any point. The bait compartment is accessed through an opening positioned at the rear of the cage. An expandable radio collar is placed in this opening by extending it around four rectangular, aluminum plates that hold the collar in the fully-expanded position (Fig. 2). Radio collars are made expandable by attaching springs to each end of the transmitter; that is, springs are used in place of belting on standard radio collars. Clear plexiglass separates the cage from the bait compartment to maximize visibility. A deer is able to extend its head and neck through the expanded radio collar positioned in the rear opening to access the bait in the bait compartment, which is the only access point to the bait (i.e., it cannot be reached by an animal outside of the device). The floor of the cage is a scale that continuously records weight and informs device operation. Only animals in a specified weight range can be collared, which allows the user to target fawns and avoid collaring adult deer. Specifically, the mechanism that releases the collar around a deer's neck will not trigger when an animal is too heavy or too light. Also, an actuator moves a plexiglass plate into the space between the rear cage opening and the bait pan, preventing animals outside of the weight range from accessing the bait. Shortly after a non-target animal exits the device, the collar release mechanism is once again able to be released (when triggered) and the actuator lowers the plexiglass plate so that the bait is accessible. To prevent an animal from being collared twice, a loop antenna is placed around the entrance to the cage and connected to a radio frequency identification (RFID) reader. All collars used with the device include a small RFID transponder sewn into the collar material. If a previously-collared fawn enters the cage, the RFID transponder is detected, which in turn prevents the collar from being released and activates the actuator to block access to the bait.

If a deer enters the cage that is in the specified weight range and has not been previously collared, the collar will release around the deer's neck once it accesses the bait. The collar release is triggered when a deer's head breaks an infrared beam positioned immediately above the bait pan. The collar is released by activating a solenoid, which in turn releases a lever that causes the upper 2 aluminum plates holding the expanded collar in place to collapse (Figs. 3 and 4). The collar is then situated around the deer's neck. When the collar is released, 2 different cameras are immediately activated to take a series of 3 photographs each. One camera is positioned in the back of the bait compartment and set to take a close-up photo of the top of the deer's head. The second camera is positioned in the floor of the cage and set to take a photo of the deer's abdomen and groin. These cameras are activated only when a collar is released and facilitate determination of deer sex. Last, when a collar is released, the device records and stores the weight of the deer.

An external computer can be hooked up to the device to change program settings, remotely operate the device, and upload weight data. The device is powered by a 12 volt battery that must be recharged every 2-3 days assuming continuous operation. DGCD prepared a user's manual that explains device operation and detailed schematics to allow future production.

We evaluated effectiveness of the device in the field during winter 2010-11. Initially, we only set the device with a collar in place when we were present and able to directly observe deer interactions with the device. After collaring several animals in this manner and troubleshooting problems with the device, we set the device to operate remotely without an observer on-site, which is how it was intended to be used.

RESULTS AND DISCUSSION

We began baiting sites at Horsetooth Reservoir and Masonville on October 21, 2010, to attract deer for evaluating the device. We baited sites with alfalfa hay, apple pulp, dried fruit, and cereal. We baited several other sites briefly but discontinued baiting due to lack of deer use. Deer immediately responded to bait at Horsetooth Reservoir and began accessing the bait daily. On October 26, we placed the collaring device on site and began encouraging deer to walk into the device by placing bait on the scale inside the cage. On October 29, we documented a deer accessing the bait pan within the bait compartment for the first time. In the following weeks, we continued to periodically document deer entering the device and accessing the bait pan, although malfunctioning of the device prevented deer from being collared. One malfunction occurred because an electrical signal emitted from a camera placed at the entry of the device interfered with the RFID reader, which ultimately prevented fawns from being collared. It took roughly a week to diagnose the problem, which was corrected by simply removing the camera from the entry of the device. This particular camera was not wired into the device and was not critical to device functioning. We deemed that this camera was unnecessary and would be more useful if placed approximately 5 meters away from the trap to better document deer use and behavior. A second malfunction occurred because the scale did not have adequate support underneath and touched the ground, thereby giving inaccurate weight readings, which also prevented deer from being collared. We corrected this particular problem by welding an aluminum frame to better support the scale. Once these problems were corrected and other adjustments were made, we remotely collared our first fawn (female) on November 17, 2010. The fawn showed little reaction to the collaring event, calmly exiting the trap shortly after receiving the collar. The fawn's weight and sex were successfully recorded. Sex was positively confirmed based on a photograph of the fawn's head taken by the camera positioned in the bait compartment.

We continued to monitor the device at Horsetooth Reservoir because there were adequate numbers of uncollared fawns in the area. However, we continued to encounter various problems with the device that affected functionality. Most notably, the collar release mechanism began failing to release the collar when a fawn was in position. We quickly determined that device controls were working properly and that an electrical signal was successfully being sent to the solenoid when an uncollared fawn was in the proper position accessing the bait. The source of the problem was a mechanical failing associated with the release mechanism itself. When an expanded collar was in place (i.e., in a fully-expanded state), the tension of the collar sometimes prevented the release lever from moving enough to release the aluminum plates holding the collar in position. Once aware of the problem, we began making adjustments to the release mechanism to improve its functionality. Another problem we identified was that fawns were placing their front hooves on a piece of metal trim at the front of the cage when accessing the bait, which led to inaccurate weight readings and missed opportunities to collar fawns. We corrected this problem by placing a plastic shield above the metal trim so that deer could no longer place hooves on the metal trim. Following this modification, the entire floor surface of the cage comprised only the scale. We also noted that small fawns accessing the bait sometimes failed to break the infrared beam extending across the center of the bait pan, thereby failing to be collared. Thus, we adjusted the positioning of the bait pan to make sure that fawns successfully broke the infrared beam when accessing the bait, regardless of size. Once these changes were made, we successfully collared two more fawns (1 male and 1 female) on successive days, December 13 and 14, 2010. Also, the female fawn that was collared on November 17 shed its collar on December 13 and was successfully recollared on December 20.

On December 21, the actuator that opens and closes the bait door short-circuited in response to cold, snowy weather and damaged the circuit board that controls operation of the device. The actuator was positioned such that moisture could enter it. The moisture, in combination with cold temperatures, caused the failure. It became evident at this point that future device modifications would likely require a heavier-duty actuator. However, until a new actuator could be researched, tested, and installed, DGCD used the same actuator and positioned it differently so that it was less likely to take on moisture. DGCD also replaced the circuit board to restore functionality of the collaring device. Several weeks were required to make these modifications, causing the device to be inoperable from December 21, 2010, through January 15, 2011. On January 20, we recollared the female fawn that was initially collared on December 14 (it shed the first collar on January 13). We then moved the device to the Masonville bait site on January 21, after documenting 5 successful collaring events at Horsetooth Reservoir.

The Masonville bait site was regularly visited by 4 bucks, 3 does, and 2 fawns. The fawns were aggressively chased by the 4 bucks once we put the collaring device in place and restricted the amount of bait available outside of the collaring device. We solved this problem by creating a separate bait site for the bucks a short distance away. It took one week before the fawns at Masonville became comfortable entering the collaring device and accessing the bait in the bait pan. We did not put a collar in place initially because we speculated that the fawns would be more likely to access the bait pan for the first time if they were not required to extend their head through the collar. Once one of the fawns became acclimated and we put a collar in the device, the bait door/actuator began malfunctioning again, preventing the fawn from being collared. The malfunctioning was apparently related to cold temperatures. The bait door/actuator began functioning correctly again several days later and we collared a male fawn on February 4, 2011. The only other fawn on site showed no interest in accessing the bait in the bait pan during the ensuing week. Thus, we stopped baiting the site on February 12 and moved the device to the Red Feather site on February 14.

Several of the gate arms that prevent deer entry into the sides of the device had been damaged by deer over the course of the winter. During February 14–20, as deer became accustomed to the collaring device, we replaced all gate arms with a new, more durable hinge system. We then resumed normal operations and collared our 7^{th} fawn (female) on February 27, 2011. Unfortunately, the RFID reader failed to detect this collared fawn the following day, allowing the fawn to receive a second collar on February 28. We suspended collaring efforts for several days evaluating the RFID failure. It became evident that if a collared fawn entered the device quickly, it could go undetected by the RFID reader. This issue was already understood as a potential problem, but this was the first time a fawn was actually double-collared. We documented no ill effects of the second collar on the fawn. Realizing the odds of a double-collaring event were low, we resumed collaring efforts on approximately March 6. Incidentally, the odds of the double-collared fawn receiving a third collar were essentially zero because the fawn now had two RFID transponders. We made note that the RFID problem would need to be resolved with a device modification during the following year. The other couple of fawns routinely visiting the site were reluctant to access the bait pan. On March 17, we moved the collaring device to the Heil Valley Ranch site on Boulder County Parks and Open Space land.

Deer regularly visiting the Heil site included 4 bucks, 2 does, and 1 fawn. We were unable to keep the bucks from being aggressive toward the does and fawn around the collaring device, which prevented the fawn from entering the device. In response, we moved the device to the Hall Ranch bait site on March 24, 2011, where 3-4 bucks, 2-3 does, and 1-3 fawns were using the site. Deer acclimated quickly to the collaring device and we collared our 8^{th} fawn on March 28^{th}, immediately after placing the collar in the device. A few days later we concluded the field evaluation because weather was turning warm, green forage was abundant, and bears were coming out of hibernation.

During our field evaluation, we documented a number of issues with the collaring device that need resolved in subsequent design modifications:

- The solenoid release mechanism occasionally failed to release the collar even when the solenoid was triggered. We plan to evaluate an alternative release mechanism that uses an archery caliper release instead of the existing metal, latch system.
- We documented several scenarios that could allow a fawn to receive a second collar. First, if a collared fawn extends its head through the entry to the device and is detected by the RFID reader but fails to move forward onto the scale for ≥30 seconds, the bait door will move back into the open position. Second, if a collared fawn is on the scale for >15 minutes (i.e., beds down on the scale), the scale will rezero and the door will move back into the open position. At this point another fawn could step into the device, which would indicate a correct weight range, and the collared fawn could receive a second collar if it then accessed the bait. Third, as we directly witnessed, if a collared fawn enters the device quickly, it is possible the RFID reader could fail to detect the RFID transponder in the fawn's collar. These scenarios, albeit unlikely, can be corrected by changing the device programming and increasing sensitivity of the RFID reader/antenna.
- The actuator that controls the bait door commonly malfunctioned in cold temperatures (i.e., ≤ –12 °C). We intend for the device to be fully functional at –32 °C. We plan to research other actuators and evaluate them under controlled temperature settings. A number of actuators are available on the market that meet our temperature specifications, but they range in cost from <$100 to >$1000. The actuator we evaluated was the cheapest available and did not meet its

stated specifications. Our intent is to find the cheapest actuator that will hold up under field conditions.

- The camera mounted on the floor of the device commonly failed to provide useful images for identifying sex. We therefore plan to remove the floor-mounted camera. In contrast, the camera in the bait compartment positioned to take pictures of a fawn's head provided conclusive evidence of sex. The only needed adjustment is to more securely attach the "head camera" to the bait compartment.

Working with DGCD, we will research and implement the necessary device modifications to address these issues. We plan to incorporate the design modifications during summer-fall 2011 and conduct a follow-up field evaluation during winter 2011-12.

SUMMARY

We developed a fully-functional prototype of an automated collaring device for mule deer in collaboration with professional engineers. The automated collaring device is designed to allow biologists and researchers to radio-collar portions of their deer samples with minimal time and expense because no animal handling is required and deer can be collared at any time. Primary time commitments include baiting sites, moving device(s) among sites, and adding collars to the devices. The collaring device should also have distinct benefits for studies in urban environments by providing a non-invasive technique for collaring deer. We successfully collared 6 different fawns during Nov–Mar, 2011–12, along Colorado's northern Front Range. We recollared 2 of these fawns after they shed their initial collars, resulting in 8 successful collaring events. Fawns generally showed minimal reaction to being collared. It was evident that fawns did not experience the type of stress that is associated with typical capture and handling techniques. We documented a number of functional issues with the collaring device, which we plan to resolve through design modifications during summer-fall 2011. We then plan to conduct a follow-up field evaluation during winter 2011-12.

LITERATURE CITED

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

Beasom, S. L., W. Evans, and L. Temple. 1980. The drive net for capturing western big game. Journal of Wildlife Management 44:478–480.

Clover, M. R. 1956. Single-gate deer trap. California Fish and Game 42:199–201.

Ramsey, C. W. 1968. A drop-net deer trap. Journal of Wildlife Management 32:187–190.

Schmidt, R. L., W. H. Rutherford, and F. M. Bodenham. 1978. Colorado bighorn sheep-trapping techniques. Wildlife Society Bulletin 6:159–163.

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

Webb, S. L., J. S. Lewis, D. G. Hewitt, M. W. Hellickson, and F. C. Bryant. 2008. Assessing the helicopter and net gun as a capture technique for white-tailed deer. Journal of Wildlife Management 72:310–314.

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

Prepared by ________________________

Chad J. Bishop, Mammals Research Leader

Figure 1. Automated collaring device for mule deer, comprising an aluminum cage and a bait compartment. Deer become collared by entering the cage and extending their head through an expanded radio collar when accessing bait.

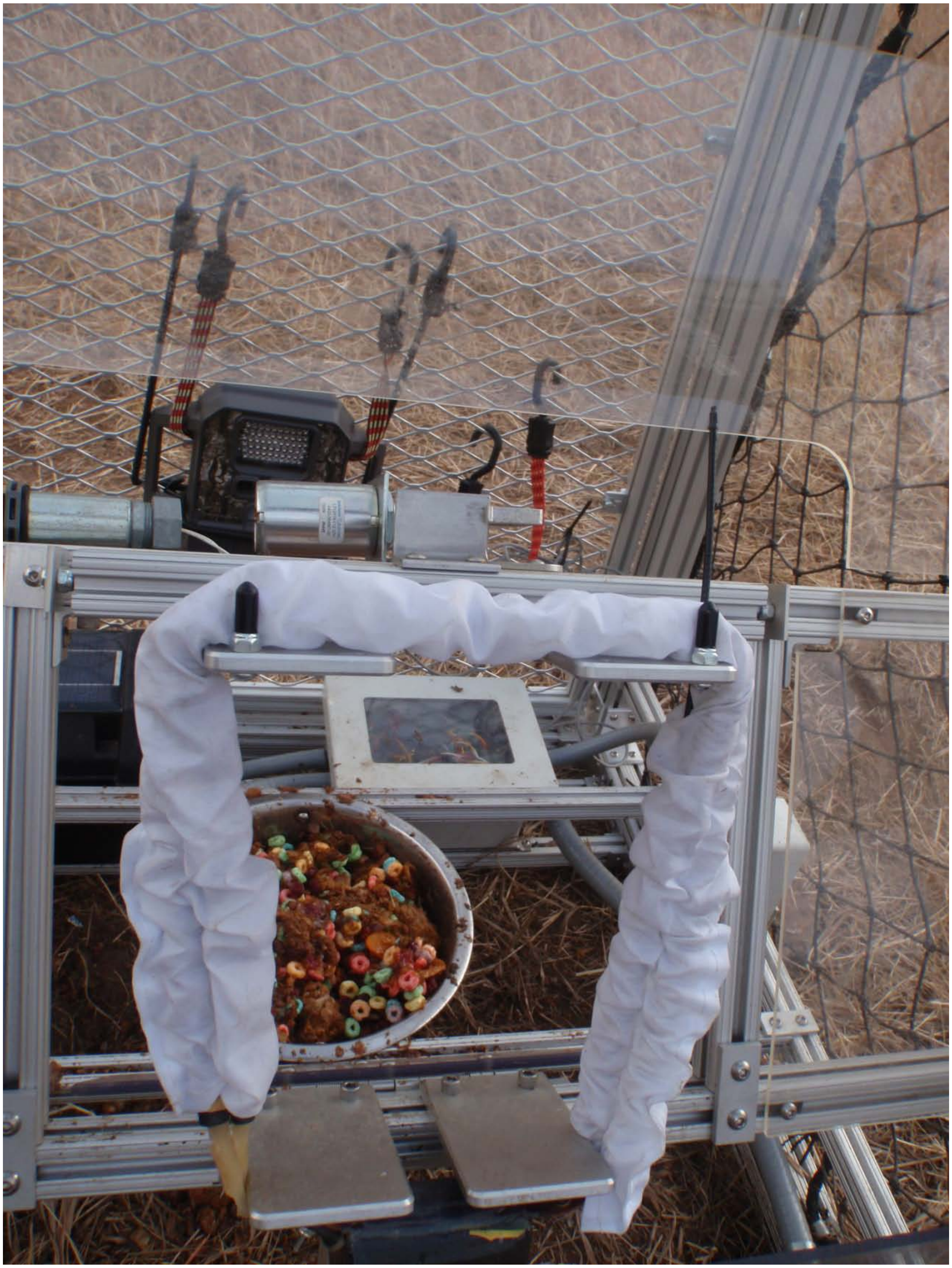


Figure 2. View of the radio collar and bait compartment of an automated collaring device for mule deer. To reach bait, deer must extend their head and neck through the expanded radio collar.

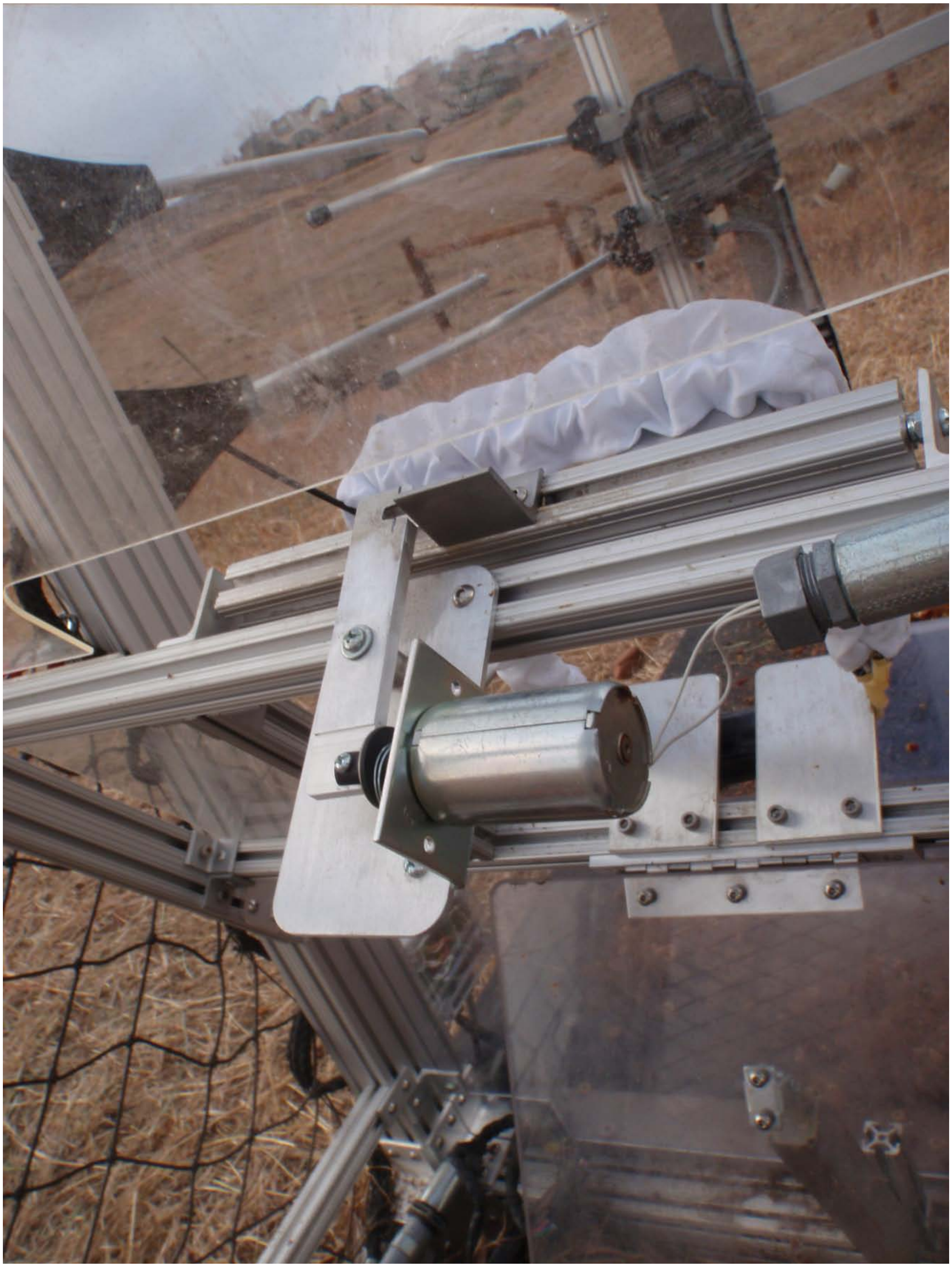


Figure 3. View of the collar release mechanism in an automated collaring device for mule deer.

Figure 4. Female mule deer fawn accessing bait by extending her head through an expanded radiocollar.

Colorado Division of Parks and Wildlife
July 2010 – June 2011

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of Parks and Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	3001	:	Deer Conservation
Task No.:		:	Assessment of survival and optimal harvest Strategies of adult male mule deer in Middle Park, Colorado
Federal Aid Project No.	W-185-R		

Period Covered: July 1, 2010 - June 30, 2011

Author: E.J. Bergman; Project Cooperators; C.J. Bishop, K. Oldham, and L. Sidener

Personnel: G. Abram, G. Birch, J. Broderick, M. Crosby, B. Davies, T. Elm, D. Gillham, K. Holinka, A. Holland P. Lukacs, B. Manly, S. Murdoch, S. Schwab, S. Shepherd
Colorado Division Parks and Wildlife

R. Swisher, S. Swisher, T. McKendrick
Quicksilver Air

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

ABSTRACT

We developed a study plan and initiated field work on a study designed to assess the survival and optimal harvest strategies of adult male mule deer in Middle Park, Colorado. Three years of baseline survival data for adult (≥ 1 yr. old) male deer will be collected before implementing a harvest management action that will redistribute hunters within DAU-9. One hundred adult (1.5 years old and older) male deer were captured and radio collared. The survival rate for these deer was estimated at 0.879 (SE = 0.0326) for the first survival period (January through July).

WILDLIFE RESEARCH REPORT

ASSESSMENT OF SURVIVAL AND OPTIMAL HARVEST STRATEGIES OF ADULT MALE MULE DEER IN MIDDLE PARK, COLORADO

ERIC J. BERGMAN

P.N. OBJECTIVES

SEGMENT OBJECTIVES

1. Develop a project study plan to address the lack of knowledge regarding survival and harvest strategies of adult mule deer.
2. Initiate field work in the form of capturing and radio collaring animals.
3. Collect survival data on radio collared deer and provide preliminary survival estimates for adult male mule deer.

INTRODUCTION

Historically, management of big game species has focused on the performance of adult females and the young of the year segments of the population. In the case of mule deer, this has been further refined to the aspects of annual (for adult females) and overwinter (for young of the year) survival. The performance of the male component of populations was deemed less important because it takes few males to provide adequate breeding coverage for the population, and historic harvest management objectives were set to maximize hunting opportunities. As long as sufficient numbers of males were available to breed females there was no desire to restrict hunting opportunity. However, during the past 10-15 years, the management of big game populations, and mule deer populations in particular, has shifted from the objective of providing maximal opportunity towards providing higher quality opportunities (Bishop et al. 2005b, Bergman et al. 2010). High quality opportunities are typically defined by hunters as a combination of the chance to see a greater number of male deer during the hunt, increased potential to harvest an older age class animal (i.e., an animal with more developed antler morphometry), but also reduced interaction and competition with other hunters. In response to this shift in hunter desires and concerns over declining mule deer numbers, the Colorado Division of Wildlife (now Colorado Parks and Wildlife [CPW]) implemented a statewide limitation in deer hunting in 1999. This statewide limitation gave CPW the ability to reduce total hunter numbers but also the ability to control the distribution of hunters throughout the state. Since 1999 Colorado’s deer herds have become composed of a greater number of males, yet little biological data on them exist. Also stemming from this change in harvest management was a new responsibility for Colorado’s terrestrial biologists and wildlife managers. Prior to 1999, licenses were sold over-the-counter and were not limited in number (i.e., any hunter who wished to purchase one was able to do so), and the decision of how many licenses to make available did not need to be considered. Since 1999, CPW has the added responsibility of deciding how many licenses should be allocated in each Data Analysis Unit (DAU). This decision must reflect a balance between meeting DAU population performance objectives, but also provide as much hunter opportunity as possible.

Big game populations in Colorado are currently modeled using multiple sources of biological data (White and Lubow 2002). Model inputs include harvest estimates, young recruitment to December, and measured rates of survival of adult females and fawns. Also, the ratio of adult males to adult females is estimated and used to align models by minimizing the difference between observed and modeled values. Only rarely have the survival rates of adult males been measured. This gap in knowledge has historically been viewed as trivial and adult male survival rates have been assumed to be similar to the rates of females. Similarly, it has been assumed that natural survival rates (i.e., post hunt survival) of males do not geographically vary. However, model performance under these assumptions has been poor and the need to measure adult male survival as a parameter has increased. Presently, a number of population models in Colorado suggest that natural adult male survival may be lower than adult female survival, yet empirical data is lacking to verify these suppositions.

Despite this apparent lack of information, survival of adult male mule deer and adult male black-tail deer are not completely novel parameters of interest (Pac and White 2007, Bender et al. 2004b, Bleich et al. 2006, Bishop et al. 2005a, McCorquodale 1999). These studies also suggest that adult male mule deer survival tends to be lower than adult female survival when differences occur, further emphasizing the need to rigorously evaluate adult male survival rates. Bishop et al. (2005a) observed lower natural survival rates of adult males than adult females in southwest Idaho: differences were most apparent during winter in 2 of 3 study areas. Pac and White (2007) found that natural survival rates of yearling males in Montana were lower than the average adult female survival rate documented by Unsworth et al. (1999). Finally, Miller et al. (2008) found that adult male survival rates were lower than adult female survival rates in Colorado in response to chronic wasting disease (CWD). In particular to the population modeling interests of Colorado outside the CWD endemic area, the work conducted by Pac and White (2007) has had the greatest utility. This work focused on the survival of males under differing management scenarios and showed a shift in cause-specific mortality of males in areas where harvest was more restricted. It is currently unknown if survival rates would be similar between Montana and Colorado. Similarly, the likelihood of observing shifts in mortality sources is unknown. It has been demonstrated that adult female deer herds in Colorado tend to be habitat limited (Bishop et al. 2009, Bartmann et al. 1992), but the trade-off between harvest, habitat and survival in adult male mule deer has not been explored.

An additional need in Colorado pertains to the harvest management of adult male mule deer. As discussed above, a large shift in mule deer herd size and structure occurred as a result of changes in harvest management. Overall, this shift has been viewed as positive by both CPW as well as the public. However, CPW maintains the responsibility of optimally managing the deer of Colorado and maximizing hunting opportunity under this new set of constraints. To date, CPW has had limited biological information and data to guide harvest management decisions. In particular for this issue, as Data Analysis Units (DAUs) reach and surpass their adult male: adult female ratio objectives, CPW typically responds by increasing the number of available hunting licenses. In situations where herds are continually lower than DAU objectives, available hunting licenses are reduced. What remains unknown about survival of adult male deer is at what level natural survival is reduced due to intraspecific competition (i.e., increased density of adult male deer). If, or when deer herds exceed the adult male: adult female objectives for DAUs, it is often assumed that the surplus of male deer remain in the population into perpetuity. However, this assumption is based on the premise that compensatory mortality does not occur. Similarly, it assumes that annual variation in survival is negligible. However, these assumptions are not biologically realistic. It is possible that herds with large post-hunt populations of adult males experience higher levels of non-harvest mortality. Under this scenario, harvest has not been optimized and more hunters could have been afforded the opportunity to hunt with no effect on post hunting season ratios of adult males to adult females. The most effective way to learn about the mortality process is via manipulative experimentation, but to date this topic has not been deemed a high enough priority to pursue.

STUDY AREA

This study is taking place in Middle Park, Colorado (see Appendix I for discussion of criteria for study area selection). Under the current management structure, Middle Park falls within DAU D-9. Within D-9 are 6 Game Management Units (27,181, 18, 37, 371, and 28; Fig. 1). Due to the geologic and topographical landscape in Middle Park, this area is conducive to splitting the DAU into experimental units (see Appendix I for experimental design). Additionally, from a management perspective, D-9 is currently managed for 35 adult males per 100 adult females. This ratio objective represents an average "quality" management objective in Colorado (i.e., DAUs with higher or lower objectives exist, thus data from D-9 will be the most universally applicable). Finally, the topography and landscape of Middle Park also makes it prone to periodic, harsh winters. This variability is fundamental to attaining reasonable estimates of process variation in adult male survival.

METHODS

Capture of adult male deer was initiated in January of 2011. Capture was conducted via helicopter net-gunning (Webb et al. 2008, Potvin and Breton 1988, White and Bartmann 1994, Barrett et al. 1982). All captures occurred after the completion of the 4th rifle hunting season, eliminating conflicts between capture efforts and hunting. Due to the need to generate survival estimates linked to animals of known age, all animals were handled by CPW personnel for aging purposes. Field aging of animals was done by visual inspection of tooth wear patterns (Severinghaus 1949, Robinette et al. 1957, Hamlin et al. 2000). Colorado Parks and Wildlife researchers/biologists were ferried to the general area in which capture was occurring and subsequently ferried the short distance to each capture location after individual animals were captured. Prior to release, all animals had their antlers removed via handsaw to minimize the potential risk of injury as the animal was released. All captures occurred after annual mule deer classification flights had been conducted, alleviating the potential for misclassification of antlerless males as females.

All deer were fitted with expandable radio collars (see Appendix I for discussion of radio collar development). All radio collars were equipped with mortality sensors that doubled in pulse rate after remaining motionless for 4 hours. Between the time of capture and mid-June, we used ground based monitoring to determine the live/dead status of deer 3-4 times per week. Additionally, every 5-10 days we conducted a telemetry flight to hear any animals that hadn't been heard from the ground during the preceding week. A general location was collected for each radio marked deer in early-March to determine if it had departed the GMU in which it had originally been captured. From mid-June through remainder of the summer, deer were monitored from the ground weekly and from the air once per month. When detected, all mortalities were investigated as quickly as possible to determine cause of death and to get an accurate estimate of the date of death.

To help evaluate the effects of a changing sex ratio on hunter harvest, we are currently preparing to sample successful hunters to acquire an age of animals harvested in D-9. Ages will be estimated via the cementum aging process of incisors (Hamlin et al. 2000). When possible, a lower incisor was also collected from each radio collared deer that died in order to validate animal ages of captured animals. To acquire teeth for aging purposes, all hunters who have licenses to hunt in any GMU in D-9 will be contacted via mail. Each hunter will be provided with a sampling kit, a pre-posted return envelope and detailed directions on how to extract teeth for aging purposes. These data will help inform terrestrial biologists and wildlife managers if changes in the age of animals harvested occur as populations shift up or down in age structure as sex ratios are increased or decreased.

RESULTS AND DISCUSSION

In January, 100 deer were captured, aged, weighed, radio collared and released during a 3½ day period. On one occasion, the skull plate of an animal was fractured immediately anterior to the animal's antler pedestals while being captured. This animal was immediately euthanized via gunshot to the head. No other capture related injuries or mortalities occurred.

With the exception of animals falling in the 2 youngest age classes (1½ years old (yearlings) and 2½ years old), the age distribution of captured animals followed the expected age distribution of the population (Fig. 2). In the case of the 2 youngest age classes, we captured more 2½ year old animals than yearlings. We believe this result was primarily due to misidentification of yearlings as part of the capture process. Small yearlings and particularly those with small antler morphometry had a greater probability of being skipped by the capture crew as they flew over groups of deer. In future years we will make a more concerted effort to increase the number of yearlings in the sample. The mass of adult male deer ranged between 52.3 kg and 106.8 kg, with the average mass being 82.2 kg (Fig. 3). Observationally, the largest animals appeared to be captured in areas in close proximity to irrigated agricultural fields.

Survival of adult male deer between the time of capture and the end of July was high. Combined survival for the northern and southern halves of D-9 was 0.879 (SE = 0.0326). When separated, the survival rates for the northern and southern halves of D-9, for the same time period, were 0.858 (SE = 0.0495) and 0.900 (SE = 0.0495). Of the 12 mortalities that occurred, a suite of causes were observed. Six mortalities were attributed to predation (4 coyote, 2 mountain lion), 1 was attributed to starvation, 1 to disease (conjunctivitis that blinded the animal), and 2 were attributed to vehicular collisions (1 automobile and 1 train). The cause of mortality could not be determined for 2 deer. Survival patterns during the winter months during the first year did not demonstrate dramatic swings or mortality pulses during which several animals died. Rather, mortalities tended to occur at a relatively constant interval of approximately 2-3 mortalities per month. However, with the exception of the animal killed by a train, mortalities during the summer months (June and July) were not observed.

SUMMARY

Project efforts were successful during the first year of the study. Capture and handling of animals was efficient, cost effective and mortality/injury rates were low. The survival rate of adult male mule deer was high. Baseline data collection will continue for 2 additional winters before implementation of the harvest management experiment.

LITERATURE CITED

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

Bartmann, R.M., G.C. White, and L.H. Carpenter. 1992. Compensatory mortality in a Colorado mule deer population. Wildlife Monographs 121:1-39.

Bender, L.C., J.C. Lewis and D.P. Anderson. 2004a. Population ecology of Columbian black-tailed deer in Urban Vancouver, Washington. Northwestern Naturalist 85:53-59.

Bender,L.C., G.A. Schirato, R.D. Spencer, K.R. McAllister, and B.L. Murphie. 2004b. Survival, cause-specific mortality, and harvesting of male black-tailed deer in Washington. Journal of Wildlife Management 68:870-878.

Bergman, E.J., B.E. Watkins, C.J. Bishop, P.M. Lukacs, and M. Lloyd. 2010. Biological and socio-economic effects of statewide limitation of deer licenses in Colorado. Journal of Wildlife Management. *In Review.*

Bishop, C.J., J.W. Unsworth and E.O. Garton. 2005a. Mule deer survival among adjacent populations in southwest Idaho. Journal of Wildlife Management 69:311-321.

Bishop, C.J., G.C. White, D.J. Freddy and B.E. Watkins. 2005b. Effect of limited antlered harvest on mule deer sex and age ratios. Wildlife Society Bulletin 33:662-668.

Bishop, C.J., G.C. White, D.J. Freddy, B.E. Watkins, and T.R. Stephenson. 2009. Effect of enhanced nutrition on mule deer population rate of change. Wildlife Monographs 172:1-28.

Bleich, V.C., B.M. Pierce, J.L. Jones and R.T. Bowyer. 2006. Variance in survival of young mule deer in the Sierra Nevada, California. California Fish and Game. 92:24-38.

Hamlin, K.L., D.F. Pac, C.A. Sime, R.M. DeSimone, and G.L. Dusek. 2000. Evaluating the accuracy of ages obtained by two methods for Montana ungulates. Journal of Wildlife Management. 64:441-449.

Miller, M.W., H.M. Swanson, L.L. Wolfe, F.G. Quatarone, S.L. Huwer, C.H. Southwick and P.M. Lukacs. 2008. Lions and prions and deer demise. Plos One 3:1-7.

McCorquodale, S.M. 1999. Movements, survival, and mortality of black-tailed deer in the Klickitat Basin of Washington. Journal of Wildlife Management 63:861-871.

Pac, D.F., and G.C. White. 2007. Survival and cause-specific mortality of male mule deer under different hunting regulations in the Bridger Mountains, Montana. Journal of Wildlife Management 71:816-827.

Potvin, F., and L. Breton. 1988. Use of a net gun for capturing white-tailed deer, Odocoileus-virginianus, on Anticosti Island, Quebec. Canadian Field Naturalist 102:697-700.

Robinette, W.L., J.S. Gashwiler, D.A. Jones, and H.S. Crane. 1957. Notes on tooth development and wear for Rocky Mountain mule deer. Journal of Wildlife Management 21:134-153.

Severinghaus, C.W. 1949. Tooth development and wear as criteria of age in white-tailed deer. Journal of Wildlife Management 13:195-216.

Underwood, A.J. 1994. On beyond BACI-sampling designs that might reliably detect environmental disturbances. Ecological Applications. 4:3-15.

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.

Webb, S.L., J.S. Lewis, D.G. Wewitt, M.W. Hellickson, and F.C. Bryant. 2008. Assessing the helicopter and net gun as a capture technique for white-tailed deer. Journal of Wildlife Management 72:310-314.

White, G.C. and R.M. Bartmann. 1994. Drop nets versus helicopter net guns for capturing mule deer fawns. Wildlife Society Bulletin 22:248-252.

White, G.C. and B.C. Lubow. 2002. Fitting population models to multiple sources of observed data. Journal of Wildlife Management 66:300-309.

Prepared by________________________________

Eric J. Bergman, Wildlife Researcher

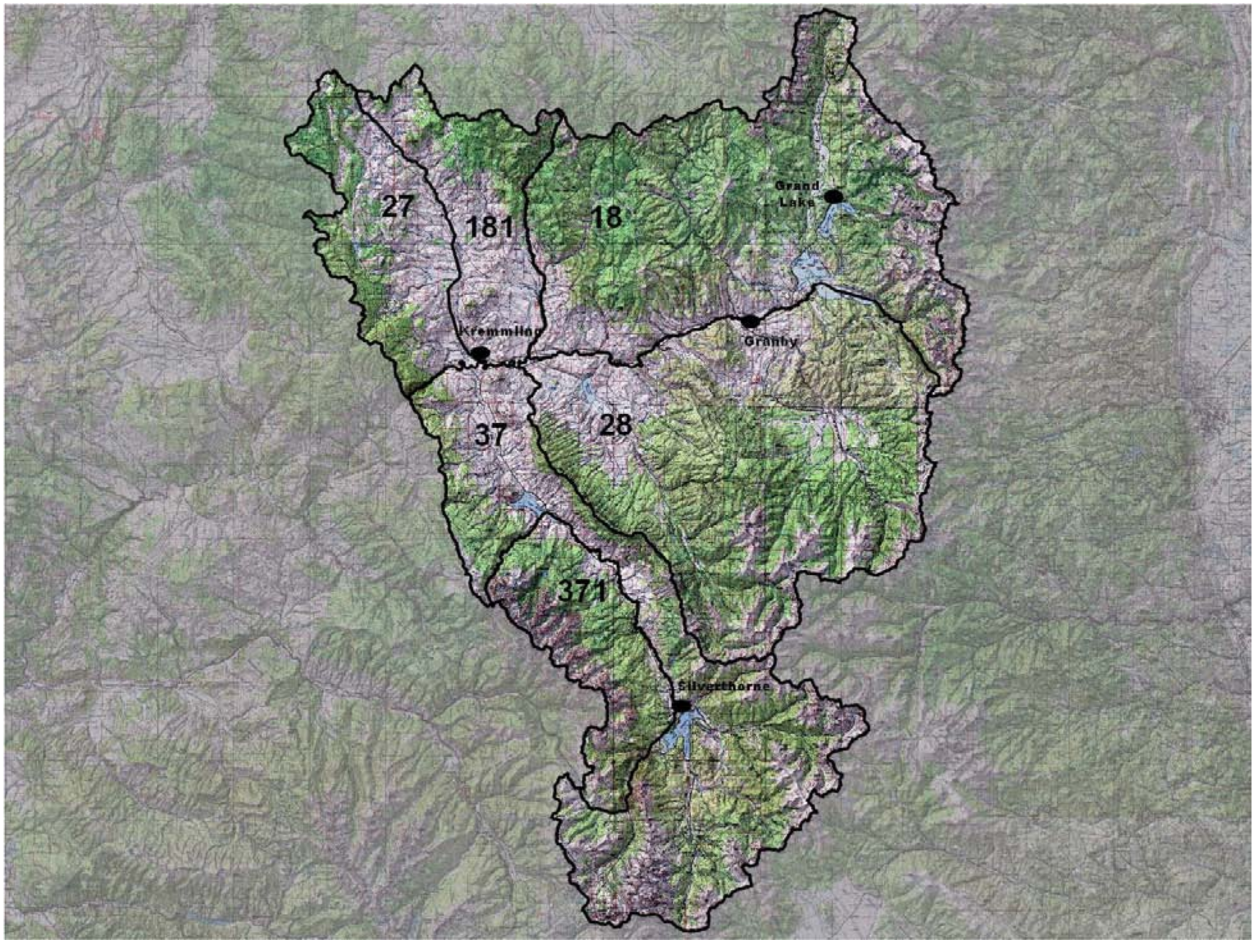


Figure 1. Data Analysis Unit 9 (D-9) encompasses the Middle Park area of central Colorado. D-9 includes 6 Game Management Units (27, 181 and 18 on the northern half and 37, 371 and 28 on the southern). Current management sex ratio management objectives for D-9 are consistent across GMUs with an overall post hunt objective of 35 adult males per 100 adult females.

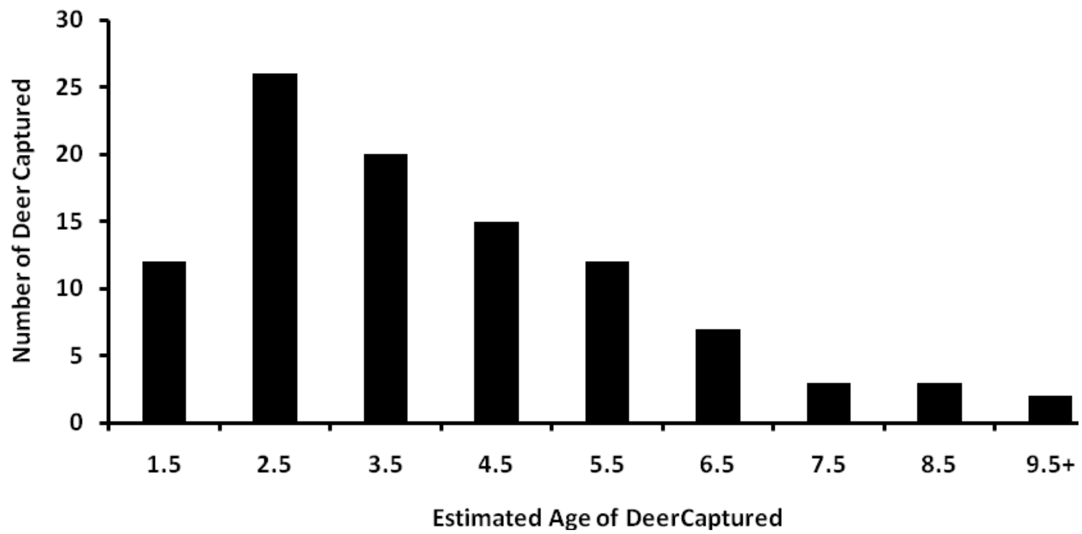


Figure 2. Frequency of ages of 100 adult male mule deer captured in January (2011) in Middle Park, Colorado. Future capture efforts will be made to increase the frequency of 1½ year old males to accommodate for an expected underrepresentation in the current sample as well as for aging of radio collared animals throughout the study.

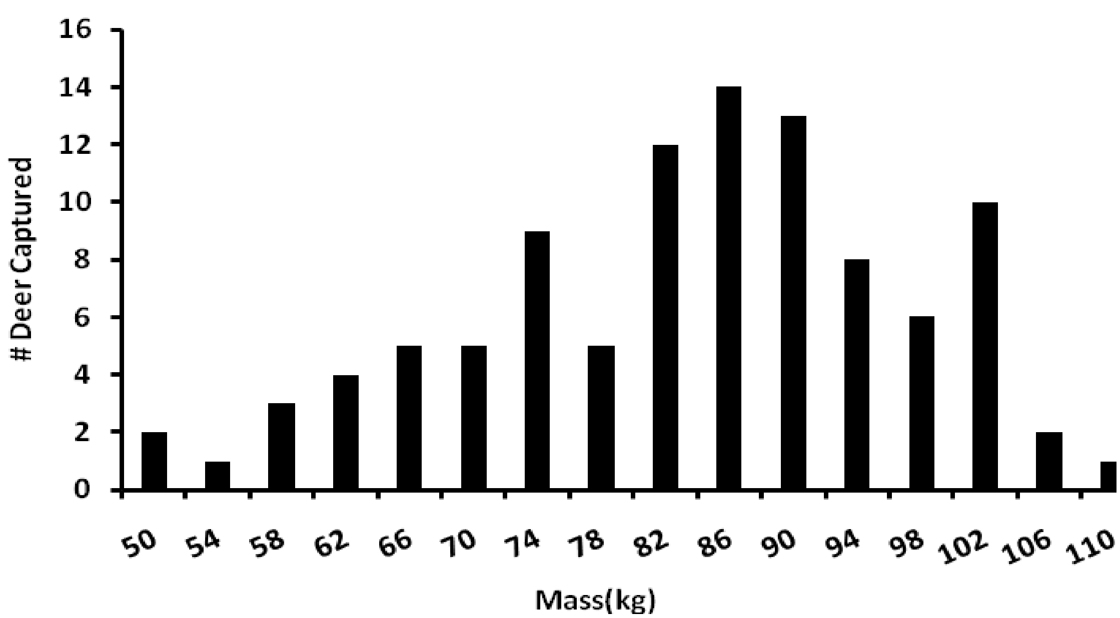


Figure 3. Frequency of masses of 100 adult male mule deer captured in January (2011) in Middle Park, Colorado. Ages of deer captured ranged between 1½ years old and in excess of 9½ years old.

APPENDIX I

PROGRAM NARRATIVE STUDY PLAN
FOR MAMMALS RESEARCH
FY 2010-11 – FY 2015-16

State of:	Colorado	:	Division of Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	3001	:	Deer Conservation
Task No.		:	Assessment of Survival and Optimal Harvest
		:	Strategies of Adult Male Mule Deer in Middle
			Park, Colorado.
Federal Aid Project No.	W-185-R		

Assessment of Survival and Optimal Harvest Strategies of Adult Male Mule Deer in Middle Park, Colorado

Principal Investigators
Eric J. Bergman, Mammals Researcher, Colorado Parks and Wildlife
Chad J. Bishop, Mammals Researcher Leader, Colorado Parks and Wildlife
Kirk Oldham, Terrestrial Biologist, Colorado Parks and Wildlife
Lyle Sidener, Area Wildlife Manager, Colorado Parks and Wildlife

Cooperators
Andy Holland, Big Game Coordinator, Colorado Parks and Wildlife
John Broderick, Terrestrial Management Leader, Colorado Parks and Wildlife
Area 9 Personnel, Colorado Parks and Wildlife

STUDY PLAN APPROVAL

Prepared by:	Eric J. Bergman	Date:	Nov. 2010
Submitted by:	Eric J. Bergman	Date:	Nov. 2010
Reviewed by:	Chuck Anderson	Date:	Nov. 2010
	Mike Phillips	Date:	
Biometrician:	Paul Lukacs	Date:	Nov. 2010
Approved by:	Chad Bishop Mammals Research Leader	Date:	Nov. 2010

PROGRAM NARRATIVE STUDY PLAN
FOR MAMMALS RESEARCH

ASSESSMENT OF SURVIVAL AND OPTIMAL HARVEST STRATEGIES OF ADULT MALE MULE DEER IN MIDDLE PARK, COLORADO

A Study Plan Proposal Submitted by:
Eric J. Bergman, Mammals Researcher, Colorado Parks and Wildlife
Chad J. Bishop, Mammals Research Leader, Colorado Parks and Wildlife
Kirk Oldham, Terrestrial Biologist, Colorado Parks and Wildlife
Lyle Sidener, Area Wildlife Manager, Colorado Parks and Wildlife
Andy Holland, Big Game Coordinator, Colorado Parks and Wildlife
John Broderick, Terrestrial Management Leader, Colorado Parks and Wildlife

A. Need

Historically, management of big game species has focused on the performance of the female and the young of the year components of the population. In the case of mule deer, this has been further refined to the aspects of annual (for adult females) and overwinter (for young of the year) survival. The performance of the male component of populations was deemed less important, primarily due to the fact that it takes relatively few males to provide adequate breeding potential for the population. Additionally, historic harvest management objectives were set to maximize hunting opportunities. Thus, as long as sufficient numbers of males were available to breed females there was no desire to restrict hunting opportunity. However, during the past 10-15 years, the management of big game populations, and mule deer populations in particular, has started to shift away from the objective of providing maximal opportunity towards providing fewer but higher quality opportunities (Bishop et al. 2005b, Bergman et al. 2010). High quality opportunities are typically defined by hunters as a combination of the chance to see a greater number of male deer during the hunt, and the potential to harvest an older age class animal (i.e., an animal with more developed antler morphometry), but also reduced interaction and competition with other hunters. In response to this shift in hunter desires and concerns over declining mule deer numbers, the Colorado Division of Wildlife (now Colorado Parks and Wildlife [CPW]) implemented a statewide limitation in deer hunting in 1999. This statewide limitation gave CPW the ability to greatly reduce total hunter numbers but also the ability to control the distribution of hunters throughout the state. Since 1999, a few marked changes in Colorado's deer herd have occurred. First, due to reduced harvest an overall increase in deer numbers has been observed (Fig. 1). Second, because the reduction in harvest was primarily focused on adult males, a subsequent increase in the ratio of adult males to adult females has resulted (Fig. 2) (Bergman et al. 2010). Stemming from this shift in harvest management and the subsequent changes in herd size and structure, a gap in biological information has been identified. Specifically, Colorado's deer herds have become composed of a greater number of males, yet little biological data on them exist. Also stemming from this change in harvest management was a new responsibility for Colorado's terrestrial biologists and wildlife managers. Prior to 1999, licenses were sold over-the-counter and were not limited in number (i.e., any hunter who wished to purchase one was able to do so), and the decision of how many licenses to make available did not need to be considered. Since 1999, CPW has the added responsibility of deciding how many licenses should be allocated in each Data Analysis Unit (DAU). This decision must further reflect a balance between meeting DAU population performance objectives, but also provide as much hunter opportunity as possible.

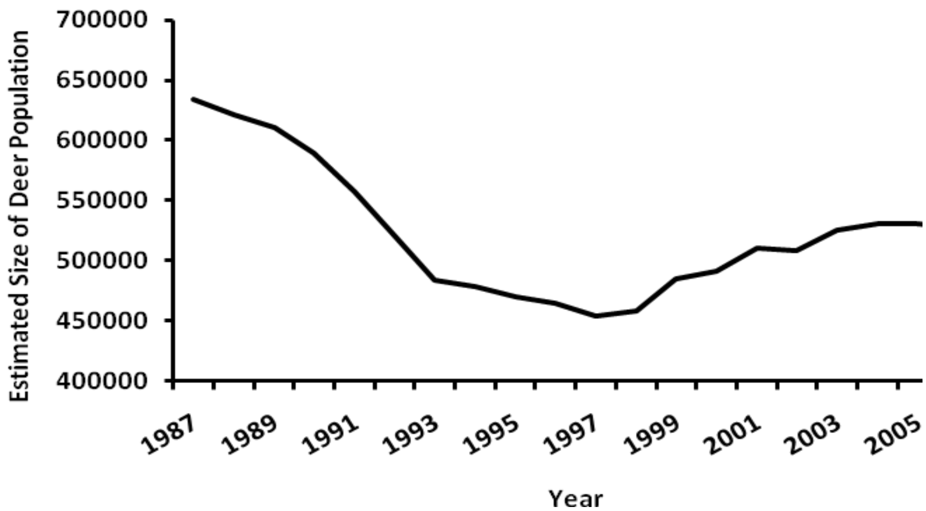


Figure 1. Colorado's statewide deer herd estimate covering the past 2+ decades. Between 1998 and 1999 CPW implemented a statewide limitation process on the number of deer licenses sold. Since that time, a marked reversal in population trajectory has occurred, largely due to the increase in survival of adult males from reduced hunting license allocation.

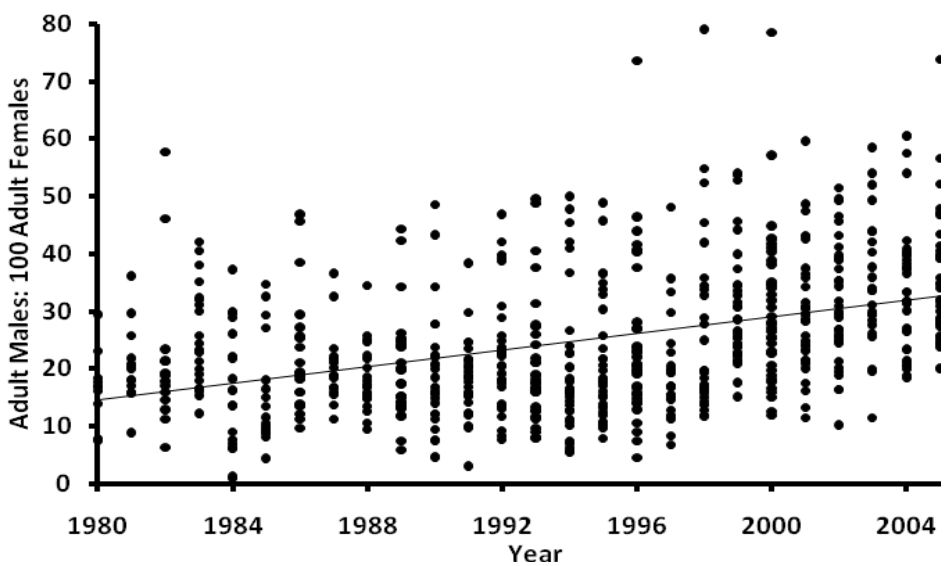


Figure 2. Estimates of adult male: adult female ratios, collected via aerial survey, in the DAUs in western Colorado during the past three decades. Of note, between 1998 and 1999, CPW implemented a statewide limitation on the number of deer hunting licenses sold. The harvest management action brought about a marked increase in estimates of the ratio of adult males to adult females.

Big game populations in Colorado are currently modeled using multiple sources of biological data (White and Lubow 2002). Model inputs include harvest, young recruitment to December, and measured rates of survival of adult females and fawns. Also, the ratio of adult males to adult females is estimated and used to align models by minimizing the difference between observed and modeled values. Very rarely have the survival rates of adult males been measured. This gap in knowledge has historically been viewed as trivial and rates have been assumed to be similar to the rates of females. Similarly, it has been assumed that natural survival rates (i.e., post hunt survival) of males do not geographically vary. However, model performance under these assumptions has been poor and the need to measure adult male survival as a parameter has increased. Presently, a number of population models in Colorado suggest that natural adult male survival may be lower than adult female survival, yet empirical data is lacking to verify these suppositions.

Despite this apparent lack of information, survival of adult male mule deer and adult male black-tail deer are not completely novel parameters of interest (Pac and White 2007, Bender et al. 2004b, Bleich et al. 2006, Bishop et al. 2005a, McCorquodale 1999). However, rates of adult male survival reported in the literature are often linked to unique management situations such as variation in harvest structure (Pac and White 2007, Bender et al. 2004b), urban settings (Miller et al. 2008, Bender et al. 2004a) or disease management scenarios (Conner and Miller 2004, Miller et al. 2008). Similarly, most of these studies have been constrained by relatively small sample sizes and were of short duration, making the estimation of the process variation of adult male survival unreliable. However, available data suggest that adult male mule deer survival tends to be lower than adult female survival when differences occur, further emphasizing the need to rigorously evaluate adult male survival rates. Bishop et al. (2005a) observed lower natural survival rates of adult males than adult females in southwest Idaho: differences were most apparent during winter in 2 of 3 study areas. Pac and White (2007) found that natural survival rates of yearling males in Montana were lower than the average adult female survival rate documented by Unsworth et al. (1999). Finally, Miller et al. (2008) found that adult male survival rates were lower than adult female survival rates in Colorado in response to chronic wasting disease (CWD). In particular to the population modeling interests of Colorado outside the CWD endemic area, the work conducted by Pac and White (2007) has had the greatest utility. This work focused on the survival of males under differing management objectives and showed a shift in cause-specific mortality of males in areas where harvest was more restricted. It is currently unknown if survival rates would be similar between Montana and Colorado. Similarly, the likelihood of observing shifts in mortality sources is unknown. It has been demonstrated that adult female deer herds in Colorado tend to be habitat limited (Bishop et al. 2009, Bartmann et al. 1992), but the trade-off between harvest, habitat and survival in adult male mule deer has not been explored.

A different, but not unrelated need in Colorado pertains to the harvest management of adult male mule deer. As discussed above, a large shift in mule deer herd size and structure occurred as a result of the change in harvest management. Overall, this shift has been viewed as positive by both CPW as well as the public. However, CPW still maintains the responsibility of optimally managing the deer of Colorado and maximizing hunting opportunity under this new set of constraints. To date, CPW has had limited biological information and data to guide harvest management decisions. In particular for this issue, as DAUs reach and surpass their adult male: adult female ratio objectives, CPW typically responds by increasing the number of available hunting licenses. In situations where herds are continually lower than DAU objectives, available hunting licenses are reduced. What remains unknown about survival of adult male deer is at what level natural survival is reduced due to intraspecific competition (i.e., increased density of adult male deer). If, or when deer herds exceed the adult male: adult female objectives for DAUs, it is often assumed that the surplus of male deer will remain in the population into perpetuity. However, this assumption is based on the premise that compensatory mortality does not occur. Similarly, it assumes that annual variation in survival is negligible. However, this is biologically not realistic. It is very likely that herds with large post-hunt populations of adult males experience higher levels of mortality. Under this scenario, harvest has not been optimized and more hunters could have been afforded the opportunity to hunt with no effect on post hunting season ratios of adult males to adult females. The most effective way to learn about the mortality process is via manipulative experimentation, but to date this topic has not been deemed a high enough priority to pursue.

B. Objectives

Our study objective is two-fold. First, we wish to assess annual survival of adult male mule deer. We wish to establish baseline survival and variance estimates for different age classes of deer. Second, we wish to manipulate hunting license allocation within the Game Management Units (GMUs) of D-9 such that adult male: adult female ratios become measurably different between the northern and southern halves of the DAU. Accordingly, we wish to measure and correlate changes in natural survival of adult male deer with this management action. Similarly, as part of this second objective, we will determine if changes in the age structure of harvested animals occur as the sex ratio and age structure of the hunted population changes. While not a direct objective of the study, we will also be able to learn if increasing adult male: adult female ratios causes an increase in the emigration rate of animals from populations composed of a greater proportion of adult male deer.

C. Expected Results or Benefits

Data and information generated from this study will have immediate use to terrestrial biologists and wildlife managers across the state of Colorado. Survival estimates of adult male deer will be immediately incorporated in the annual population modeling process. As measurements are repeated over years, estimates of process variation will be generated, allowing a refinement of how adult male survival is incorporated into the modeling process. From a general ecology perspective, we will measure the direct and indirect effects of a concerted management action on the male component of the deer population. We expect to detect differences in the harvest rates of radio-collared deer under different hunter/license allocation strategies. We also expect to detect differences in the harvest rate of radio collared deer based on age and antler morphometry. Similarly, we expect to detect a difference in natural survival/mortality rates of deer under differing levels of harvest. Ultimately this will provide information about the additive/compensatory relationship of adult male deer, adult female deer and mule deer fawn survival in Colorado. This information will allow us to directly inform tradeoff decisions between hunting opportunity and hunter desires for various quality standards. Additionally, these data will allow us to identify thresholds where further license restrictions would fail to result in more adult males in the population and fail to increase the mean age or antler structure of males harvested.

D. Approach

1. *Radio Collar Development*

Radio collars deployed as part of this project will be permanent (i.e., they will not be fitted with any sort of release mechanism). However, utilizing traditional radio collars with a fixed diameter is not ideal due to the seasonal variation in the size of adult male mule deer necks; as adult male deer enter the breeding period, neck swelling occurs. Researchers have historically addressed this issue with several different approaches. The use of loosely-fitted, fixed diameter radio collars has occurred on several hundred white-tailed deer in Texas with no known incidence of mortality or injury (K. VerCauteren – personal communication). It is unknown if a similar result could be expected for mule deer in Colorado. Researchers in Montana used an expandable radio collar that was made of tubular aircraft grade bungee material to measure survival of 136 adult male mule deer (Pac and White 2007, D. Pac – personal communication). When this research was conducted, expandable radio collars were not commercially available, so the expansion design was developed and installed on a traditional VHF collar that was produced by Telonics, Inc (Mesa, AZ, USA). This radio collar design alleviated concerns over neck constriction during the breeding period and it sufficiently contracted as neck swelling reduced after the breeding period. However, in a few instances (1%-2% of radio collared population) it was documented that deer were able to get a front hoof/leg between the collar and neck (D. Pac – personal communication). On these occasions, deer were either recaptured or euthanized if recapture was not possible. Researchers in Idaho as well as Colorado used a different expandable collar design, fitted with an expansion device that was made of flat elastic encased in Cordura™ to measure survival of 70 (Idaho) and ~100 (Colorado) adult male mule deer, respectively (Bishop et al. 2005a, Conner and Miller 2004). This collar was also made by Telonics, Inc. This design also alleviated constriction around the neck as deer entered the breeding period, but the contraction properties of the elastic were such that as neck diameter reduced as deer exited the breeding period the collar did not adequately contract to the pre-breeding period diameter. This was not ideal as loosely fitting collars had a propensity to slide on the necks of animals and to cause hair loss. Additionally, researchers had concerns over the potential for deer to get hooves caught between the collars and their necks. This event occurred on one occasion with a fawn during the Idaho study (subsequently resulting in the animal's mortality) and on two occasions in Colorado (both animals were recaptured and collars were removed during the Colorado study). To address the issue of expansion collars failing to contract back to pre-breeding period diameters, a third generation expansion collar was developed by CPW (M. Sirochman – personal communication). This new design incorporated nylon sleeved springs as the expansion device. As was the case in Montana, the spring based expansion collar adequately expanded and contracted through the initial breeding periods. However, on a few occasions the springs in these collars did eventually expand beyond their critical limit and ultimately failed to contract after having been deployed. On these occasions, it appeared that springs had snagged on external features, thereby reducing the integrity of the spring itself. Outside of these external factors, resilience of the spring appeared to be sound. The occurrence of deer getting their hooves caught between the collars and their necks was also documented in this study, but due to the tractability of animals, all were recaptured and radio collars were safely removed (M. Sirochman – personal communication). One additional downfall of the spring based expansion collar was that irritation caused by the pressure of the springs on the dorsal portion of the neck was documented in a few cases. While the irritation did not appear to jeopardize the health of the animal, it was undesirable.

For our study, what can be considered a fourth generation expandable radio collar has been designed in collaboration with Advanced Telemetry Systems, Inc. (Isanti, MN, USA) (Figs. 3a and 3b). This newly designed collar closely resembles the earlier generation collars that incorporated flat elastic material. The elastic based expansion collar had fairly high success because only on a single occasion was it documented that a deer had its hoof caught between the collar and its neck. The primary weakness of this design was that the contraction properties of the elastic expansion material were inadequate. This new design incorporates a more robust, high quality, flat bungee material that is sheathed between traditional nylon belting material on the outside and nylon webbing on the inside (Fig. 3b). Due to the sheathing design, only a small portion of the bungee material is exposed, reflecting the desired qualities of the elastic based expansion collar and retaining the reduced potential for deer to get hooves caught in the collar. The higher quality bungee is expected to maintain contraction properties far longer than elastic and thus the potential for loose fitting collars during the later years of the study is reduced, minimizing the opportunity for hair breakage. This new collar design was scrutinized by the researchers who represent the bulk of knowledge on the subject of radio collaring adult male mule deer (D. Pac - retired, MT Fish, Wildlife and Parks; C. Bishop, M. Miller, M. Sirochman and L. Wolfe, CPW). The only additional concern pertained to the orientation and potential wear/irritation of the collar on the dorsal portion of deer necks during the breeding period. However, due to the width of the bungee material, it is expected to be less than that of the spring based expansion design. Concern over the orientation of the collar will be addressed by testing the collar design on a captive animal at CPW wildlife health research facility.

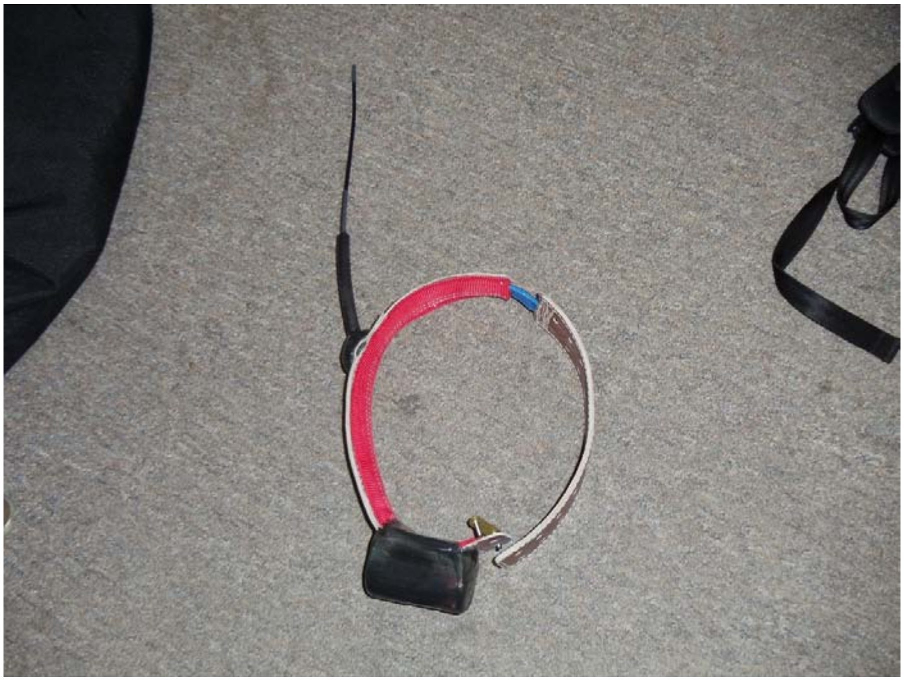


Figure 3a.

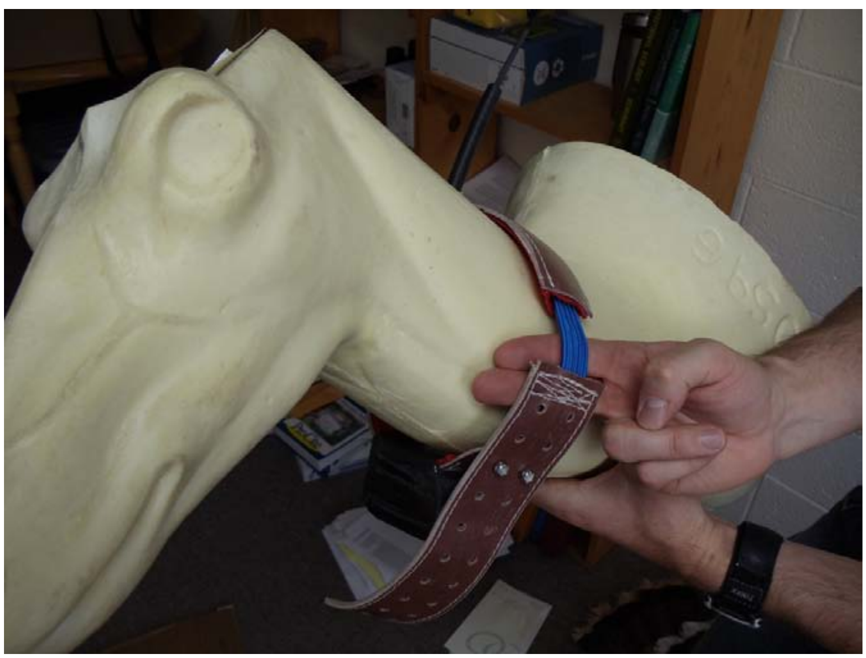


Figure 3b.

Figures 3a and 3b. The newly designed, expandable, VHF radio-collar that will be utilized on adult male mule deer during this study. Collars were designed to meet CPW specifications by Advanced Telemetry Systems, INC. (Isanti, MN, USA). The blue banding material seen in figures 3a and 3b is nylon coated bungee that will allow expansion and contraction, as needed, during the breeding period. To allow maximal expansion, but to help prevent the opportunity for deer to get hooves and legs caught between the neck and collar, the bungee material is sleeved in nylon webbing (red material visible in figure 3a).

2. *Capture*

Capture of adult male deer for this project will be conducted via helicopter net-gunning (Webb et al. 2008, Potvin and Breton 1988, White and Bartmann 1994, Barrett et al. 1982). All captures will occur after the completion of the 4th rifle hunting season, eliminating potential conflicts between capture efforts and hunting. Typically capture will occur between mid-December and mid-January. Exact timing of capture each year will be dependent on availability of the helicopter net-gunning crew. Due to the need to have survival estimates linked to animals of known age, all animals will be handled by CPW personnel for aging purposes. Depending on situation, captured animals will be handled in one of two ways. When feasible, captured deer will be ferried to a processing area staffed by CPW researchers/biologists who are qualified to age animals according to tooth wear (Severinghaus 1949, Robinette et al. 1957, Hamlin et al. 2000). Deer will subsequently be returned to the capture site for release. In situations when capture locations are too far from processing areas to efficiently ferry animals, CPW researchers/biologists will be ferried to the general area in which capture is occurring and subsequently be ferried the short distance to each capture location to process animals at that site. Regardless of situation, it is possible that a single person will be responsible for collaring, aging and releasing animals. As such, prior to release, all animals will have their antlers removed via handsaw to minimize the potential risk of injury as the animal is released. The removal of antlers from animals at this time of year should have no negative impact on survival as all captures will occur post-rut. Similarly, all legal harvest of animals will have occurred and negative response of hunters should not occur. The only exception to the antler removal process will be if post-hunt sex/age class survey flights have not yet occurred and if the captured animal is located near a survey quadrat. If a deer is captured near a survey quadrat, prior to deer classification flights having been conducted and it is still deemed necessary to remove antlers, these deer will be temporarily marked with livestock marking paint on the back and neck. Marking deer in such a manner will allow biologists to accurately classify those individual deer as adult males, thereby removing any potential bias that may stem from capturing deer prior to classification flights. Whenever possible, capture will be conducted after classification flights to alleviate this problem.

All deer will be fitted with expandable radio collars (discussed above). All radio collars will be equipped with mortality sensors which will double in pulse rate after remaining motionless for 4 hours. The desired sample size for each year of this study will be a total of 220 adult ($\geq$ 1.5 years old) male deer. One hundred deer will be captured and radio collared during the first year of the study as a pilot assessment of the radio collar design and to test underlying assumptions about deer movement (discussed below). During the second year of the study, 120 additional deer, as well replacements for any deer that die during the first year will be captured and radio collared. Thus, not until the second winter of the study will the full sample size be achieved. For every year thereafter, only enough deer to maintain the 220 animal sample size will be captured. The 220 deer sample will be distributed such that 110 of the radio collared deer are located in the northern half and 110 are located in the southern half of the DAU.

3. *Survival/Location Monitoring*

The primary objective of this study is to generate annual natural survival estimates and harvest rates for adult male deer. While most mortality is expected to occur via rifle harvest between October and November, the bulk of natural mortality is expected to occur between December and May of each year. In order to minimize bias of survival estimates during these periods, we will attempt to monitor the live/dead status of each animal 3-4 times per week. Each year, prior to the start of the archery hunting season, all deer will be located to asses in which half (northern versus southern) of the DAU each animal is located. A similar set of locations will be collected after the 4th rifle hunting season. Between each hunting season, a live/dead flight will be conducted to determine if any animals have disappeared, and subsequently assumed to have been harvested, without having been reported to CPW. Once all hunting seasons have been completed, we will revert to a weekly flight schedule to assess live/dead status of all animals. A field technician will check live/dead status 2-3 times for each animal between flights. All animals will be located 1 additional time during the winter to confirm that animals have not left the DAU and to determine if any animals have switched between the northern and southern halves of the DAU. Based on historical location data for adult female and fawn mule deer, approximately 10% of deer are expected to cross between northern and southern halves of the DAU (K. Oldham – unpublished data). Any animals switching between halves of the DAU will be censored from the optimal harvest management portion of the analysis.

During periods when survival is expected to be higher and less dynamic (June through September), the level of effort of to determine live/dead status will be reduced. Flights to determine live/dead status will occur approximately every 14 days and efforts to hear animals from the ground will occur as time allows. A single location will be collected for each animal after it has arrived on summer range (between late-June and late-July). While not ideal, weekly survival estimates for summer months can be computed from bi-monthly estimates via the delta method (Powell 2007). This approach to survival monitoring will allow us to minimize bias but also minimize costs associated with aircraft and temporary personnel.

4. *Harvest Management Experiment*

We will implement a management experiment to evaluate adult male survival rates under different harvest management strategies. Hunting management in Colorado is partitioned into DAUs. The boundaries of DAUs are intended to reflect the biological boundaries of deer such that deer movement between DAUs is non-existent or infrequent enough to be biologically insignificant. Within DAUs are GMUs. GMU boundaries tend to be highly permeable to deer, but serve to partition DAUs for human oriented management purposes such as survey work and hunter distribution. Typically all GMUs within a DAU have the same management objective. However, this study will deviate from this trend by establishing two different harvest objectives within a single DAU. This approach will help ensure that all deer in the study will experience similar environmental conditions and limiting factors except for different harvest objectives. Thus, any survival differences we observe are likely to be a result of differential harvest as opposed to some other factor.

This study will take place in Middle Park, Colorado (see below for rationale). Under the current management structure, Middle Park falls within DAU D-9. Within D-9 are 6 GMUs (27,181, 18, 37, 371, and 28; Fig. 4). D-9 is managed for an adult male: adult female ratio of 35 adult males per 100 adult females. As part of this study, the management of D-9 will be temporarily altered such that it will be viewed as two separate populations (one population will be composed of the northern 3 GMUs (27, 181 and 18) and the other population will be the southern 3 GMUs (37, 371 and 28)). During the 4th-7th years of this study we will redistribute hunters within the DAU via hunting license allocation. During the 1st-3rd years of the study we will monitor survival across the DAU to provide baseline data (Fig. 5). The objective behind the redistribution of hunters will be to increase adult male: adult female ratios in one half of D-9 and to decrease adult male: adult female ratios in the other half of D-9. The current DAU objective of 35 adult males: 100 adult females will not change, but one half of the DAU will be managed for 25 adult males: 100 adult females and the other half will be managed for 45 adult males: 100 adult females. The determination of which half of D-9 will experience higher harvest and which half will experience lower harvest has not yet been made. This decision will ultimately be made by Area 9 and Northwest Region personnel. In the event that there are no overwhelming management concerns about this selection process, the selection will be random.

5. *Age at Harvest*

To help evaluate the effects of a changing sex ratio on hunter harvest, we will attempt to acquire an age for animals harvested in D-9 for years 2-7 of the study. Ages will be estimated via the cementum aging process of incisors (Hamlin et al. 2000). To acquire teeth for aging purposes, all hunters who have licenses to hunt in any GMU in D-9 will be contacted prior to the archery season via mail. Each hunter will be provided with a sampling kit, a pre-posted return envelope and detailed directions on how to extract teeth for aging purposes. These data will help inform terrestrial biologists and wildlife managers if changes in the age of animals harvested occur as populations shift up or down in age structure as sex ratios are increased or decreased.

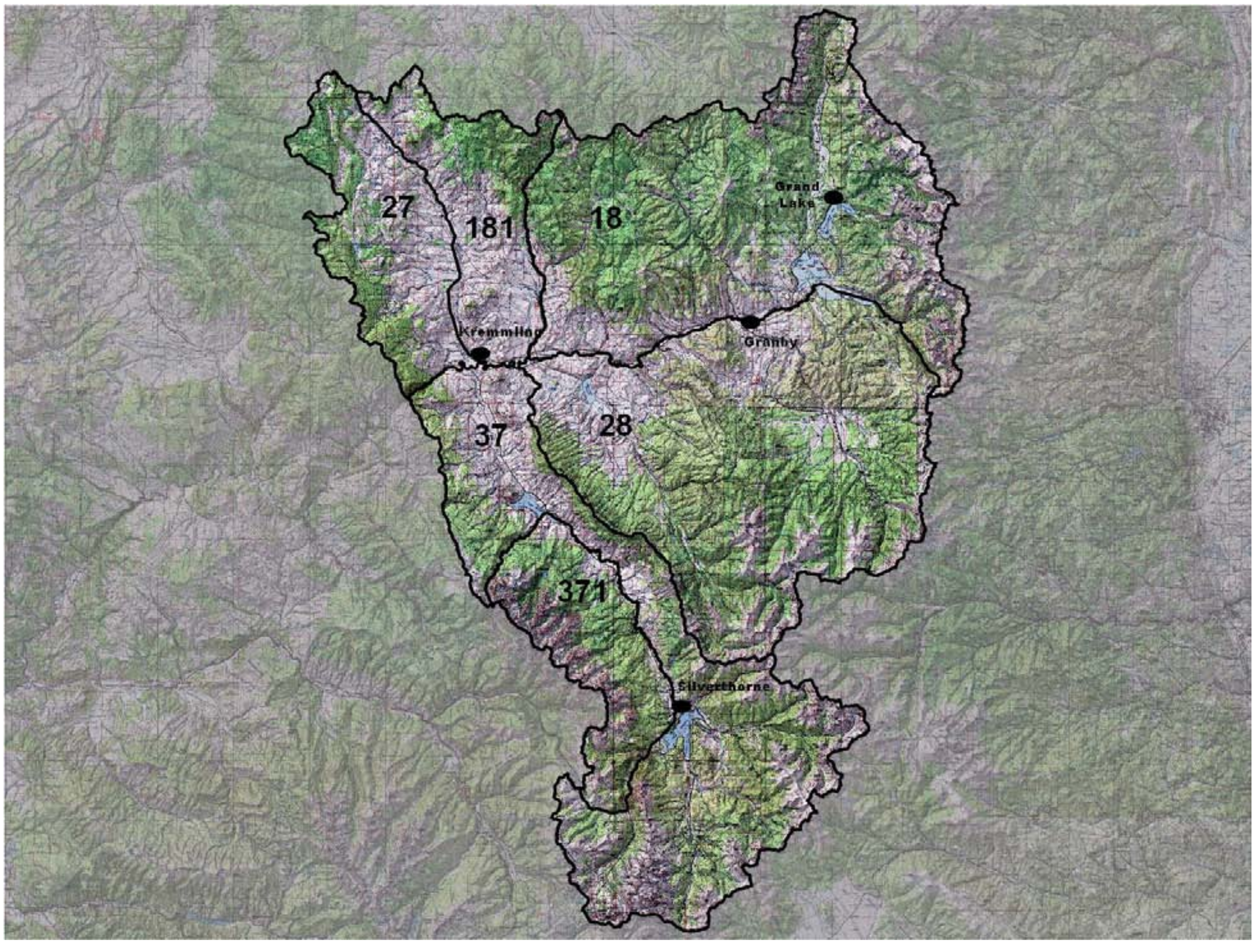


Figure 4. Data Analysis Unit 9 (D-9) encompasses the Middle Park area of central Colorado. D-9 includes 6 Game Management Units (27, 181 and 18 on the northern half and 37, 371 and 28 on the southern). Current management sex ratio management objectives for D-9 are consistent across GMUs with an overall post hunt objective of 35 adult males per 100 adult females.

6. *Data Analysis*

This study can be structured as a multi-state study (Fig. 6). We are primarily interested in deer that exist in three different states: 1) deer that survive, 2) deer that are harvested, and 3) deer that die due to non-harvest causes. While most multi-state studies include survival, detection and transition probabilities for different states, this study is purely focused on the transition probability of deer that transition from the living state to either one of the two non-living states, or back into the living state. Due to the relatively safe assumptions that deer will not leave study area, that use of radio-telemetry is essentially always detectable and the fates of deer can be readily identified, detection probabilities can be fixed at 1.0 and survival can be artificially set at 1.0. Thus, the transition probabilities between states becomes a surrogate for survival, thereby allowing us to distinguish and easily measure differences between causes of mortality.

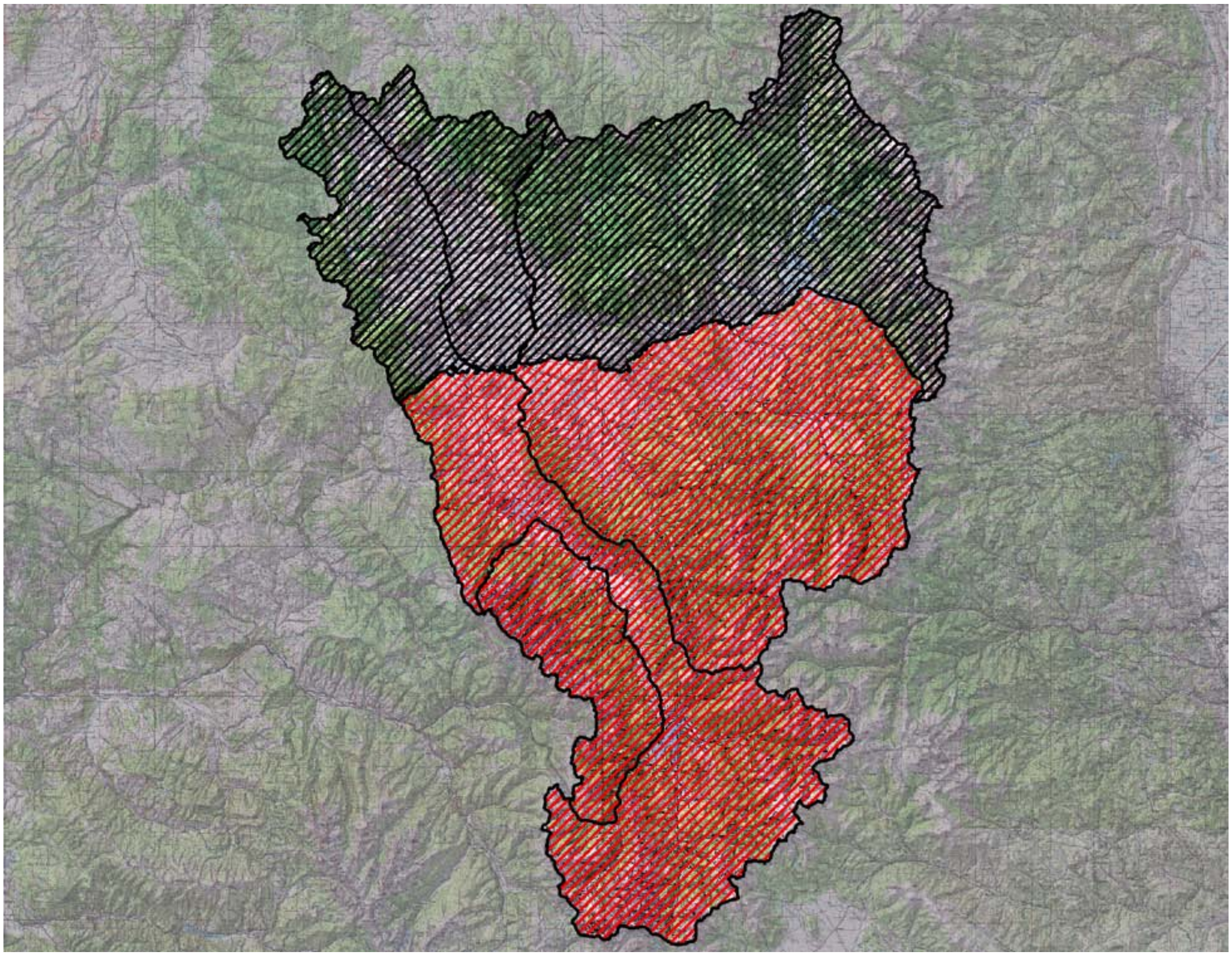


Figure 5. For this study, the northern and southern halves of D-9 will managed under different harvest management objectives during years 3-7. One half will be managed under less restrictive objectives, with a post hunt sex ratio objective of 25 adult males per 100 adult females. The other half of the DAU will be managed under more restrictive conditions with a post hunt sex ratio objective of 45 adult males per 100 adult females.

For this study, we will have numerous response variables of interest. The basic analysis of this study will follow a before-after-control-impact (BACI) design (Green 1979, Hurlbert 1984, Underwood 1994 and Conner et al. 2007) (Fig. 7). Overall, survival of adult male deer will be analyzed using known-fate models in program MARK (White and Burnham 1999). Survival will be modeled using age of deer, GMU/DAU, year and trophy score. For the purposes of this study, we are primarily interested in weekly survival rates throughout the year. Cause specific mortality will be analyzed under a multi-state modeling framework in which detection probabilities will be fixed to 1.0 based on the known-fate properties of the data for the BACI analysis. We will use mixed models to assess the impact of manipulating harvest management. For the mixed model analyses, we will use adult male: adult female ratio as the response variable for one analysis and hunter success as the response variable in a second analysis.

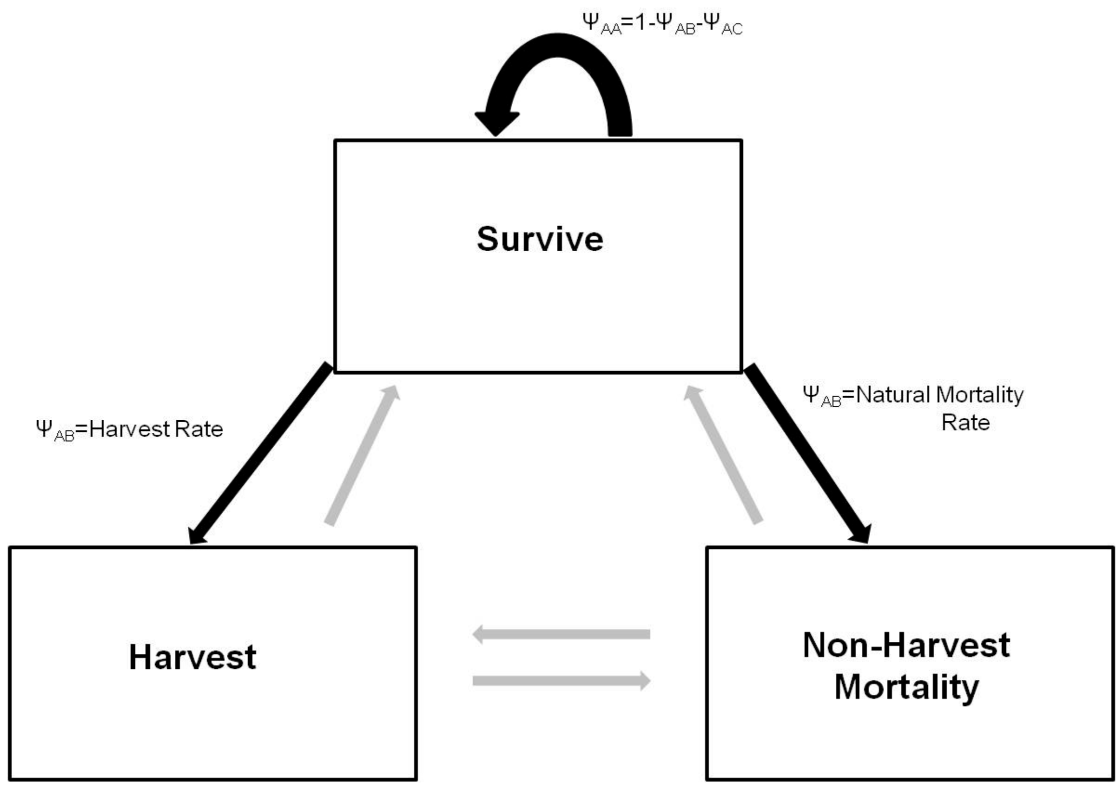


Figure 6. Assessment of survival and mortality causes can be conceptualized as a multi-state analysis with transition rates from the surviving state to the harvest state or the non-harvest related mortality state being the parameters of interest. In this case, transitions represented by black arrows can be estimated via radio collared deer. Transitions represented by gray arrows are not biologically feasible. Deer that are harvested cannot return to the survival state, nor can they enter the non-harvest related mortality. Similarly, deer dying to non-harvest related causes cannot simultaneously survive or be harvested. Under this multi-state framework, all other parameters of interest will be fixed at 1.0.

7. *Sample Size*

Sample size estimates for this study are based on the desire to detect a difference in the non-harvest mortality rates of deer under different harvest management regimes. Best estimates of harvest mortality rates, natural survival rates and the associated variance of each were based on the work published by Pac and White (2007). For our power calculations, baseline/ control harvest rates were set at 0.21 and the associated natural survival was 0.72. For high harvest areas, we set harvest at 0.37 and the associated natural survival at 0.77. For low harvest areas, we set harvest at 0.06 and subsequent natural survival at 0.67. Thus, our power calculation was set up to detect a 10% difference in natural survival under different harvest management regimes. For sample size estimation we chose to fix the number of radio collared deer entering the study each winter at ~200 (~100 animals per area) and then used simulation models to determine the number of releases (i.e., number of winters in the study) that would be needed to detect our desired effect size. Simulations were set up to test the differences in natural survival by comparing survival rates as beta offsets from the expected survival rates under normal conditions (Fig. 8).

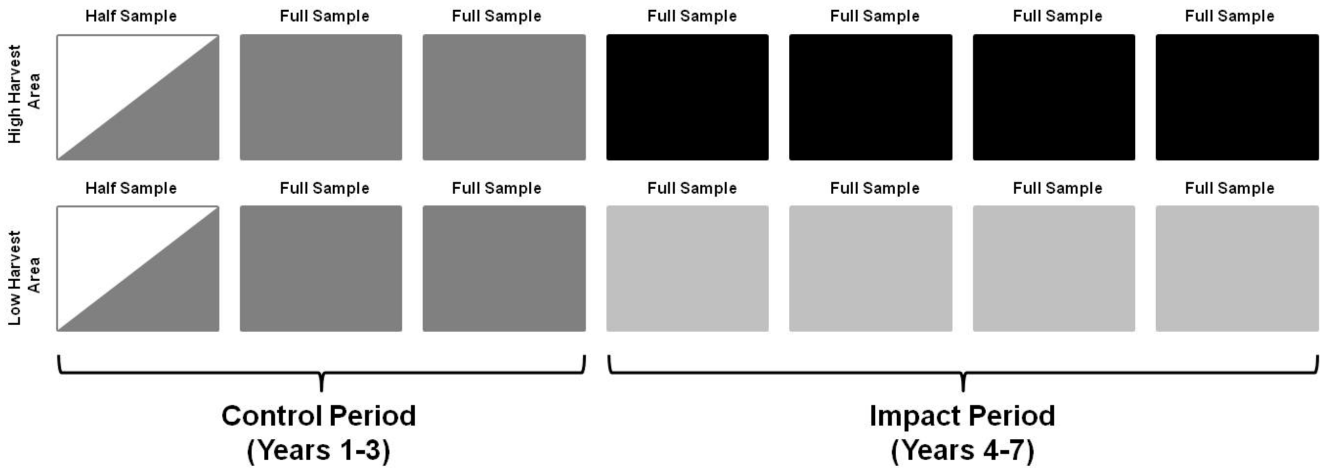


Figure 7. The Before-After-Control-Impact design for this study is based on 6 years of a full sample of deer, with an initial build up year to help offset logistic and financial constraints associated with capturing 220 deer for the full sample (110/area). The control period will experience no change to harvest management, whereas the impact period with experience a concerted effort to redistribute hunters across the DAU to impact post hunt sex ratios.

Based on these initial conditions, it appears that 6 winters with a full sample of deer will be needed to reliable detect a 10% difference in natural survival rates. Due to the estimated censoring of 10% of the radio-collared deer, due to movement between the northern and southern halves of the study area, we will inflate the total sample size from 100 animals per area to 110 animals for years 2-7 of the study. Duration of the study was determined by comparison of 95% confidence intervals surrounding the expected difference in natural survival (Fig. 9). Confidence intervals that included 0 were indicative of not enough statistical power to detect a difference. While 5 years may adequately meet the needs of the study, our results indicate that 6 years with a full sample of deer will be substantially more robust.

E. Location

This work will be conducted in Middle Park, Colorado. Middle Park was selected for this work based on several criteria. First, Middle Park is one of CPW's mule deer winter survival monitoring areas and has ongoing monitoring of the survival of adult females and fawns. Adding estimates of adult male survival in this area will allow us to compute correlation and covariance between the different sexes through time. Similarly, in the event that changing adult male: adult female ratios affects survival of adult females or fawns, we will have all relevant sex and age classes marked and should be able to detect any changes. Additionally, geological and topographical structure of Middle Park is conducive to splitting the DAU into halves such that few deer migrate from one half to the other during the annual movement cycle. Existing data indicate that 10%-15% of deer cross between halves. As such, the number of deer needing to be censored from the management experiment portion of this study should be minimized.

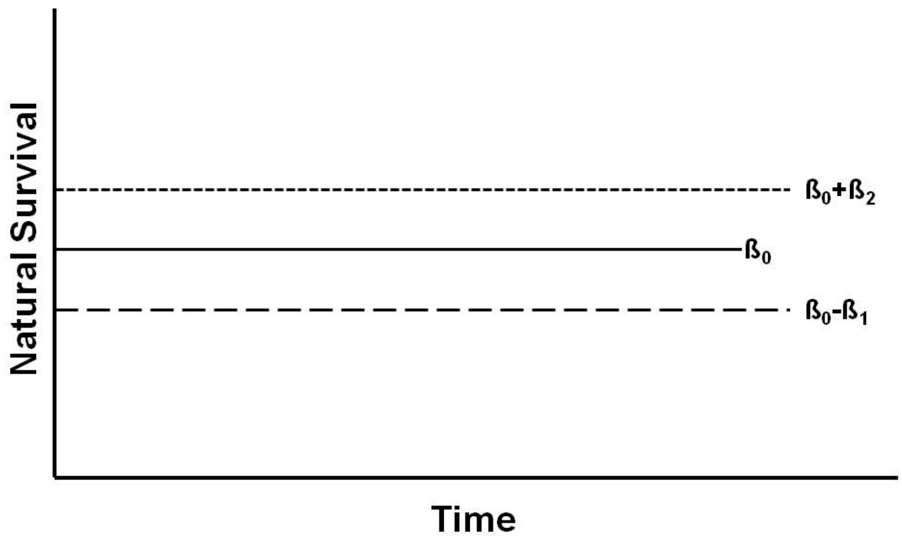


Figure 8. Non-harvest survival will be analyzed using the log scale comparison of beta estimates. The control period will be the baseline survival estimate ($ß_0$) to which natural survival under differing harvest management efforts will be compared (solid black line). Non-harvest related survival in restrictive harvest units ($ß_1$) is expected to be lower than estimates for both the control phase and more liberal harvest units (long dashed line). Non-harvest related survival in liberal harvest units ($ß_2$) is expected to be higher than estimates for both the control phase and more conservative harvest units (short dashed line).

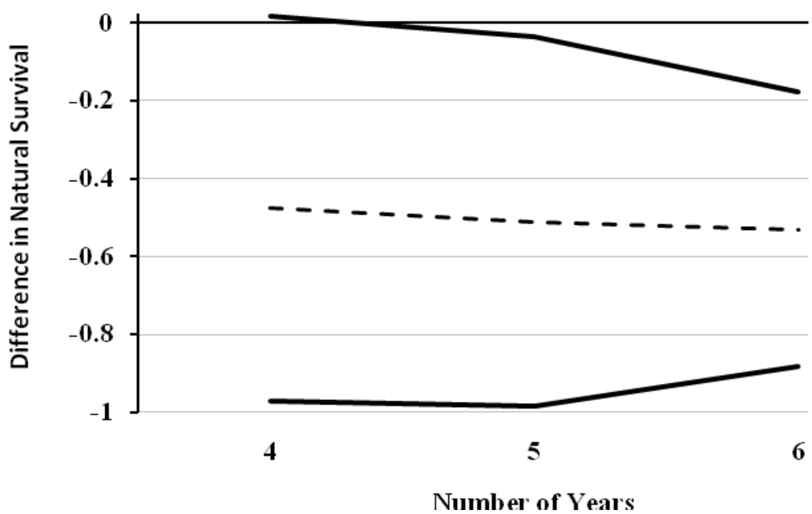


Figure 9. Power calculation set up to determine the number of years necessary to detect a 10% difference in non-harvest related moratality rates under differing harvest management regimes. Solid lines depict 95% confidence intervals. Adequate power is achieved once 95% confidence interval estimates do not include 0. While statistical power may be adequate after 5 years, addition of a 6^{th} year will make the study more robust to violations or deviations from the underlying parameter estimates used to structure the analysis.

From a management perspective, D-9 is currently managed for 35 adult males per 100 adult females. The management experiment portion of this study will allow the DAU to be split with half of the DAU being managed for 25 adult males per 100 females and the other half being managed for 45 adult males per 100 females. These ratios are largely representative of objectives throughout the state (i.e., management is not purely trophy or opportunity driven) and should allow adequate inference to be drawn. By not altering the overall DAU population objectives, implementing this research will not require that the D-9 management plan be rewritten. Additionally, Middle Park has historically been prone to periodic, harsh winters which are fundamental to getting reasonable estimates of process variation. Lastly, Middle Park has also been the site of numerous deer research and concerted management efforts over the past several decades. Knowledge and information from these past efforts have greatly facilitated the design of this study and historical data are readily available should refinement of study design or objectives become necessary.

F. Schedule Of Work

Activity	Date
Design and Purchase Expandable Radio Collars	June 2010–Nov 2010
Purchase Field Supplies	June 2010–Nov 2010
Capture ½ of initial sample of deer	Dec 2010-Jan 2011
Monitor Survival and Movement of Deer	Dec 2010–June 2017
Capture remaining sample of deer	Dec 2011–Jan 2012
Capture deer to bring sample back to full size	Dec 2012–Jan 2013
Implement change in hunter distribution within DAU	Feb 2013-Feb 2016
Capture deer to bring sample back to full size	Dec 2013–Jan 2014
Capture deer to bring sample back to full size	Dec 2014–Jan 2015
Capture deer to bring sample back to full size	Dec 2015–Jan 2016

G. Estimated Costs

Category	Item or Position	FY 10-11
Personnel	Eric Bergman	0.25 PFTE
	Chad Bishop	0.25 PFTE
	Kirk Oldham	0.05 PFTE
	Lyle Sidener	0.00 PFTE
Operating	Field Equipment and Capture	$100,000

H. Related Federal Projects

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

I. Literature Cited

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

Bartmann, R.M., G.C. White, and L.H. Carpenter. 1992. Compensatory mortality in a Colorado mule deer population. Wildlife Monographs 121:1-39.

Bender, L.C., J.C. Lewis and D.P. Anderson. 2004a. Population ecology of Columbian black-tailed deer in Urban Vancouver, Washington. Northwestern Naturalist 85:53-59.

Bender,L.C., G.A. Schirato, R.D. Spencer, K.R. McAllister, and B.L. Murphie. 2004b. Survival, cause-specific mortality, and harvesting of male black-tailed deer in Washington. Journal of Wildlife Management 68:870-878.

Bergman, E.J., B.E. Watkins, C.J. Bishop, P.M. Lukacs, and M. Lloyd. 2010. Biological and socio-economic effects of statewide limitation of deer licenses in Colorado. Journal of Wildlife Management. *In Review.*

Bishop, C.J., J.W. Unsworth and E.O. Garton. 2005a. Mule deer survival among adjacent populations in southwest Idaho. Journal of Wildlife Management 69:311-321.

Bishop, C.J., G.C. White, D.J. Freddy and B.E. Watkins. 2005b. Effect of limited antlered harvest on mule deer sex and age ratios. Wildlife Society Bulletin 33:662-668.

Bishop, C.J., G.C. White, D.J. Freddy, B.E. Watkins, and T.R. Stephenson. 2009. Effect of enhanced nutrition on mule deer population rate of change. Wildlife Monographs 172:1-28.

Bleich, V.C., B.M. Pierce, J.L. Jones and R.T. Bowyer. 2006. Variance in survival of young mule deer in the Sierra Nevada, California. California Fish and Game. 92:24-38.

Conner, M.M., and M.W. Miller. 2004. Movement patterns and spatial epidemiology of a prion disease in mule deer population units. Ecological Applications 14:1870-1881.

Conner, M.M., M.W. Miller, M.R. Ebinger and K.P. Burnham. 2007. A meta-BACI approach for evaluating management intervention on chronic wasting disease in mule deer. Ecological Applications 17:140-153.

Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. Wiley Interscience, Chichester, England.

Hamlin, K.L., D.F. Pac, C.A. Sime, R.M. DeSimone, and G.L. Dusek. 2000. Evaluating the accuracy of ages obtained by two methods for Montana ungulates. Journal of Wildlife Management. 64:441-449.

Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs 54:187-211.

Miller, M.W., H.M. Swanson, L.L. Wolfe, F.G. Quatarone, S.L. Huwer, C.H. Southwick and P.M. Lukacs. 2008. Lions and prions and deer demise. Plos One 3:1-7.

McCorquodale, S.M. 1999. Movements, survival, and mortality of black-tailed deer in the Klickitat Basin of Washington. Journal of Wildlife Management 63:861-871.

Pac, D.F., and G.C. White. 2007. Survival and cause-specific mortality of male mule deer under different hunting regulations in the Bridger Mountains, Montana. Journal of Wildlife Management 71:816-827.

Potvin, F., and L. Breton. 1988. Use of a net gun for capturing white-tailed deer, Odocoileus-virginianus, on Anticosti Island, Quebec. Canadian Field Naturalist 102:697-700.

Powell, L.A. 2007. Approximating variance of demographic parameters using the delta method: a reference for avian biologists. Condor 109:949-954.

Robinette, W.L., J.S. Gashwiler, D.A. Jones, and H.S. Crane. 1957. Notes on tooth development and wear for Rocky Mountain mule deer. Journal of Wildlife Management 21:134-153.

Severinghaus, C.W. 1949. Tooth development and wear as criteria of age in white-tailed deer. Journal of Wildlife Management 13:195-216.

Underwood, A.J. 1994. On beyond BACI-sampling designs that might reliably detect environmental disturbances. Ecological Applications. 4:3-15.

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.

Webb, S.L., J.S. Lewis, D.G. Wewitt, M.W. Hellickson, and F.C. Bryant. 2008. Assessing the helicopter and net gun as a capture technique for white-tailed deer. Journal of Wildlife Management 72:310-314.

White, G.C. and R.M. Bartmann. 1994. Drop nets versus helicopter net guns for capturing mule deer fawns. Wildlife Society Bulletin 22:248-252.

White, G.C. and K.P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46:120-139.

White, G.C. and B.C. Lubow. 2002. Fitting population models to multiple sources of observed data. Journal of Wildlife Management 66:300-309.

Colorado Division of Parks and Wildlife
July 2010 – June 2011

WILDLIFE RESEARCH REPORT

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

Period Covered: July 1, 2010 – June 30, 2011

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

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

Elk and mule deer provide important recreational, ecological, and economic benefits, but they can also cause substantial damage to agricultural resources in rural environments. This situation has generated significant challenges for wildlife agencies that are responsible for maintaining viable ungulate populations while also minimizing crop damage. One of the most severe areas of ungulate damage in Colorado has been the sunflower fields around Dove Creek. In this region, roughly a quarter of million dollars were annually paid to farmers between 2007 and 2009, and kill permits, distribution hunts and private-land-only doe hunts have been routinely distributed to farmers. Pressure from local growers over damage, and frustration from the general public over kill permits, have generated the need for the Colorado Division of Wildlife (now Colorado Parks and Wildlife [CPW]) to evaluate other management options for reducing elk and deer crop depredation. As a result, CPW partnered with wildlife damage researchers from the National Wildlife Research Center to find science-based solutions for reducing crop damage. Collaboratively, our goals are to 1) examine elk and mule deer distribution patterns to design public hunting opportunities to reduce depredation, 2) experimentally test a suite of non-lethal fencing techniques to minimize crop damage, and 3) map and model landscape characteristics associated with damage to specify more effective site-specific management practices. During FY10-11 we developed a research proposal for internal review, generated project funding, and initiated the construction of experimental fence plots. Other project activities (i.e., monitoring the effectiveness of the different fence types for minimizing elk and deer damage, deploying telemetry collars, and mapping and modeling ungulate damage) will be initiated between FY11-12 and FY13-14.

WILDLIFE RESEARCH REPORT

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

HEATHER E. JOHNSON

P.N. OBJECTIVES

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

SEGMENT OBJECTIVES

1. Work with staff from CPW and the National Wildlife Research Center to develop a research proposal for internal CPW peer review and funding solicitation.

2. Implement the construction of experimental fence plots on sunflower fields south of Dove Creek, Colorado, including electric fences, temporary winged fences, and chemical repellent fences.

INTRODUCTION

Elk and deer provide important recreational, ecological, and economic benefits, but they can also cause substantial damage to agricultural resources in rural areas (Austin et al. 1998, Wisdom and Cook 2000). In Colorado, elk and deer damage of crops accounts for a majority of the wildlife damage claims in the state. CPW is obligated to pay eligible wildlife damage claims on agricultural resources, and in recent years, the agency has spent approximately $500,000 on an annual basis to compensate growers.

One of the most significant hotspots of elk and mule deer damage has been in the vicinity of Dove Creek, in conjunction with a recent switch in the agricultural crops that are locally grown. Farmers traditionally grew crops such as dry beans, spring and winter wheat, oats, alfalfa and grass hay which had minimal damage by wild ungulates. In recent years, however, local growers have planted sunflowers, a high-value seed oil crop used to produce biofuels, and highly desirable by wild ungulates. The main management tool available to CPW to reduce ungulate sunflower damage has been to increase harvest through the use of kill permits, distribution hunts, and private land only doe hunts, however tolerance for these permits has been low among local sportsman and the general public.

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

STUDY AREA

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

METHODS

During winter and spring of FY10-11 project collaborators developed a research proposal for internal CPW review and for funding solicitation (Appendix I). We successfully obtained project funds from the Rocky Mountain Elk Foundation, Colorado Statewide Habitat Partnership Program (HPP), Montelores HPP, National Wildlife Research Center and CPW Auction/Raffle Grants. Project grants and in-kind contributions totaled ~$279,000 which was sufficient to fully finance the project.

Once project funding was solidified we initiated field logistics: the acquisition of field materials (fencing materials, elk and deer GPS collars, etc), contracting a fence installation company to construct experimental fence plots, hiring a temporary employee to monitor elk and deer damage on experimental fence plots, and scheduling a helicopter capture to deploy elk and deer collars. During FY10-11 we constructed the experimental fence plots based on a randomized block design. We identified 5 replicate fields that have repeatedly suffered high ungulate crop damage. Within each field we specified 4 10-acre plots, one for each experimental fence treatment type (polyrope fence, temporary winged fence, chemical repellent fence) and a control (see Appendix I for detailed descriptions of the fence types and study design). The 4 plots were randomly assigned within each field, such that each field (block) contained one replicate of all treatments (Gotelli and Ellison 2004).

Other scheduled project activities will be initiated during FY11-12 such as monitoring the effectiveness of the different fence types for minimizing elk and deer damage, deploying telemetry collars, and mapping and modeling ungulate damage.

SUMMARY AND FUTURE PLANS

During FY10-11 we successfully developed a research proposal, generated project funding, and constructed the experimental fence plots for the first year of fieldwork. Starting in FY11-12 we will monitor the efficiency of the experimental fence plots in reducing elk and deer damage (July – Oct 2011) and deploy 40 GPS collars; 20 collars on adult female elk and 20 on adult female deer (Oct 2011). Experimental fence plots will also be monitored for elk and deer damage during FY12-13 (July-Oct). Elk and deer collars will collect data for 2 years and then detach in Sept 2013. Once collars are retrieved we will analyze and model elk and deer location data relative to agricultural and wildland habitat (FY13-14)

LITERATURE CITED

Austin, D.D., P.J. Urness, and D. Duersch. 1998. Alfalfa hay crop loss due to mule deer depredation. Journal of Range Management 51:29-31.

Gotelli, N.J., and A.M. Ellison. 2004. A primer of ecological statistics. Sinauer Associates, Sunderland, Massachusetts.

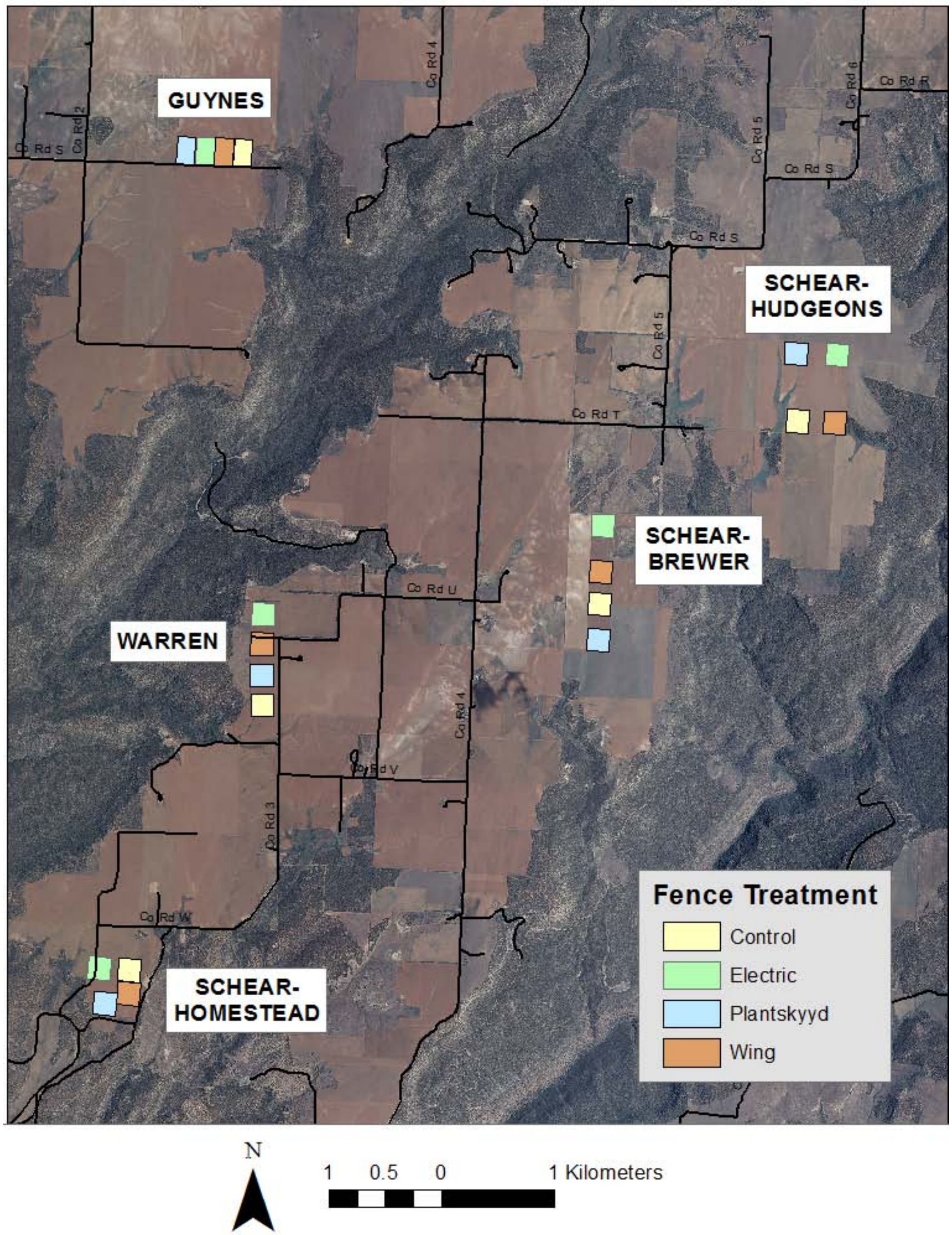
Johnson, H.E., P.Dorsey, M. Hammond, C. Bishop, K. VerCauteren, D. Walter, and C. Anderson. 2011. Evaluating solutions to reduce elk and mule deer damage on agricultural resources. Study Proposal, Colorado Division of Parks and Wildlife, Fort Collins, USA.

Wisdom, M.J., and J.G. Cook. 2000. North American Elk. Pages 694-735 *in* S. Demarais and P.R. Krausman, editors. Ecology and management of large mammals in North America. Prentice Hall, Upper Saddle River, New Jersey, USA.

Prepared by ____

Heather E. Johnson, Wildlife Researcher

Figure 1. Placement of experimental fence plots within the 5 replicate sunflower fields. Fields are located adjacent to wildland canyons.



APPENDIX I

PROGRAM NARRATIVE STUDY PLAN
FOR MAMMALS RESEARCH
FY 2010-11

Evaluating solutions to reduce elk and mule deer damage on agricultural resources

A Research Proposal Submitted By

Heather Johnson, Mammals Researcher, CPW
Patt Dorsey, Area Wildlife Manager, CPW
Matt Hammond, District Wildlife Manager, CPW
Chad Bishop, Mammals Research Leader, CPW
Kurt VerCauteren, Ungulate Damage and Disease Project Leader, National Wildlife Research Center
David Walter, Post-Doctoral Researcher, National Wildlife Research Center
Charles Anderson, Post-Doctoral Researcher, National Wildlife Research Center

A. Need

Elk and deer provide important recreational, ecological, and economic benefits, but they can also cause substantial damage to agricultural resources in rural environments (Austin et al. 1998, Wisdom and Cook 2000). Because crops are typically more digestible and contain higher levels of crude protein than native grasses and browse species, they are often preferentially selected and consumed by wild ungulates (Mould and Robbins 1981). Agricultural producers have reported more damage by elk and deer than any other wildlife species, and damage by deer alone has been projected to exceed 100 million dollars annually in the U.S. (Conover 2002). This situation has generated significant challenges for management agencies that are responsible for maintaining viable ungulate populations while also minimizing crop damage (Van Tassell et al. 1999, Wagner et al. 1997, Wilson et al. 2009, Hegel et al. 2009, Walter et al. 2010).

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

In Colorado, elk and deer damage of crops accounts for a majority of the wildlife damage claims in the state. The Colorado Division of Wildlife (now Colorado Parks and Wildlife [CPW]) is obligated to pay eligible wildlife damage claims on agricultural resources, and in recent years, the agency has spent approximately $500,000 on an annual basis to compensate growers. One of the most significant hotspots of elk and mule deer damage has been in the vicinity of Dove Creek (Montezuma, San Miguel and Dolores Counties; Fig. 1), where roughly a quarter of million dollars was annually paid to farmers between 2007 and 2009. These extraordinary reimbursements have resulted from a recent switch in the agricultural crops that are locally grown. Farmers around Dove Creek traditionally grew crops such as dry beans, spring and winter wheat, oats, alfalfa and grass hay which had minimal damage by wild ungulates. In recent years, however, local growers have planted sunflowers, a high-value seed oil crop used to produce biofuels. In 2009 growers were paid approximately $.43/lb for organically grown sunflowers and $.28/lb for conventionally grown sunflowers. In that same year, dry land yields averaged 800 lbs/acre in the region. Elk and deer have demonstrated a strong affinity for sunflowers, causing up to 100% crop loss on certain fields, and resulting in high damage claims. Ungulate damage around Dove Creek is exacerbated by the spatial distribution of sunflower fields in relation to the surrounding wildlands (e.g., sagebrush-mixed shrublands and piñon-juniper woodlands). The region is fractured with deep canyons that provide refugia for elk, and fields adjacent to the canyon rims experience the greatest amount of depredation. With the substantial increase in biofuel production in the U.S. (World Resources Institute 2008), the agricultural conversion observed around Dove Creek will likely become common, as high-priced, crops replace more traditionally-grown, lower-cost crops (Walter et al. 2009).

The main management tool available to CPW to reduce ungulate sunflower damage has been to increase harvest through the use of kill permits (for males and females), distribution hunts, and private land only (PLO) doe hunts. In response to damage reports, CPW has been allocating these permits to local growers between June and October, with the intent of harvesting resident animals rather than migratory elk and deer. This management strategy has resulted in exceptionally high private land harvests. For example, in 2008, kill permits or distribution hunts were allocated on as many as 25 different fields, with approximately 300 deer and 30 elk harvested. On a single 140-acre sunflower field, 57 female mule deer were harvested, and still the annual damage claim for the field was approximately $40,000 in that year. The CPW, the Bureau of Land Management, Montelores Habitat Partnership Program (HPP) Committee, U.S. Forest Service and Rocky Mountain Elk Foundation have initiated several habitat enhancement projects in the region to draw elk and deer off of agricultural fields, but the benefits of these projects are expected to take several years to fully materialize.

Although tolerance for elk and mule deer damage on sunflower crops is low among farmers, tolerance for kill permits and distribution hunts is also low among sportsmen, the general public and some farmers. A majority of the damage occurs during July and August when calves and fawns are still dependent on their mothers, reducing the acceptability of female hunts. Additionally, both elk and deer population numbers in the study area (DAUs D24 and E24) are below or near management objectives creating a paradox where CPW ultimately wants to increase ungulate herds, but reduce crop depredation. Finally, this region is popular with hunters, as large bulls and bucks have been harvested in recent years. Hunting is economically important to Dolores, Montezuma and San Miguel Counties, providing approximately 230 jobs and there is a strong desire to have increased public hunting opportunities.

Pressure from local growers over damage, and frustration from the general public over kill permits, have generated the need for CPW to evaluate other management options for reducing elk and mule deer crop depredation. As a result, managers from CPW have partnered with wildlife-damage researchers from the National Wildlife Research Center (NWRC) to find science-based solutions for reducing sunflower damage. Collaboratively, the goals of our study are to design public hunting opportunities to reduce crop damage, test a suite of non-lethal techniques to minimize crop depredation, and map and model landscape characteristics associated with damage behavior to specify more effective management practices. Results from this study should ultimately enable CPW and local growers to reduce ungulate crop depredation, leading to a decrease in compensation payments and kill permits/distribution hunts, and an increase in public hunting opportunities and support from farmers and sportsmen.

B. Objectives

Objective 1: Examine the spatial structure, distribution, and migration patterns of local elk and mule deer around agricultural areas. This will enable CPW to design public hunting opportunities that better address crop damage while decreasing the need for kill permits/distribution hunts on private lands.

Objective 2: Use treatment and control fields to experimentally test novel methods for reducing elk and mule deer damage to crops including a) the repellent "fence" *Plantskydd*, b) an electric polyrope fence, and c) a temporary "winged" fence.

Objective 3: Map and model the spatial juxtaposition of crop fields, ungulate habitats, human infrastructure and topographic features to assess the predictors of elk and mule deer resource-use and damage. This will allow CPW to explicitly account for landscape configuration when working with landowners to identify best management strategies for reducing damage.

C. Expected Results or Benefits

Long-Term Benefits

- Sustain healthy elk and mule deer populations on public and private lands where they do not cause agricultural damage and can provide quality hunting opportunities.
- Reduce elk and deer game damage payments on sunflowers and other crops.
- Allow sportsmen to harvest a greater proportion of elk and deer by strategically allocating the number of licenses, the location of those licenses, and the timing of hunts to target conflict animals, reducing the need for kill permits and distribution hunts.
- The identification of alternative, non-lethal methods to prevent damage and reduce elk and deer use of crop fields.
- The development of a modeling tool that can be used by CPW and growers to select the most appropriate management techniques to minimize damage based on field characteristics, ungulate distribution and landscape configuration.
- The application of sound science to on-the-ground wildlife damage management.

Short-Term Benefits

- Gain knowledge about local elk and deer movements and distribution relative to the location of crop damage.
- Help farmers with on-going damage by providing management tools and assistance.
- Strengthen CPW's relationship with the local community (farmers, sportsmen, and the general public) by reducing elk and deer crop damage and increasing public hunting opportunities.

D. Approach

Examining the spatial distribution of elk and mule deer:

To understand ungulate movement patterns and more effectively address damage problems we will capture and collar 20 adult female elk and 20 adult female mule deer. Females cause a majority of the crop depredation and will provide the greatest insight into herd distributions. We will capture animals using a net-gun fired from a helicopter (Krausman et al. 1985), targeting elk and mule deer in the vicinity of high-damage crops. Captured animals will be fitted with global positioning system (GPS) collars, and locations of elk and mule deer will be remotely downloaded, collected once collars are retrieved, and recorded via ground or aerial telemetry. For both species, GPS collars will be programmed to collect ≥3 locations a day on a revolving schedule for 2 years. Elk and mule deer locations will be tracked year-round so that seasonal resource-use, migration patterns, and distributions can be clearly identified. Due to the elk herd's close proximity to the Utah border, information on elk locations will be shared with Utah Division of Wildlife, as it is suspected that some animals travel across the Utah border during winter and forage on Colorado sunflower crops during summer.

We will use elk and mule deer locations to map seasonal distributions and migration patterns, using kernel density analyses in ArcGIS mapping software (Worton 1989, Worton 1995). This will allow CPW to determine the best timing of special season hunts, kill permits and distribution hunts to avoid the private land harvest of migratory elk at the sportsman's expense. CPW will also be able use distribution data to design public hunts that will target conflict elk and mule deer. For example, the Utah Division of Wildlife Resources is willing to consider special elk hunts south of Hwy 491 if we find that any or all of the resident elk herds (causing damage) spend portions of the year in Utah. Locations will also allow us to determine the amount of use of crop fields by elk and deer, and the proportion of animals using crop fields (whether it is only certain segments of the population, or the population at large).

Testing 3 novel methods to reduce crop damage:

In addition to implementing effective harvest practices to reduce crop damage, there is strong public interest in the application of nonlethal techniques for reducing ungulate depredation, generating a need for rigorous evaluation of such techniques by wildlife agencies. Most nonlethal techniques are designed to physically exclude offending animals or reduce the motivation of animals to access protected resources (Nolte 1999). We will test three exclusionary management tools for reducing elk and mule deer crop damage that can be easily implemented by farmers during the growing season: a repellent "fence", a polyrope electric fence, and a temporary "winged" fence.

To test the effectiveness of these methods we will initially select 5 replicate fields that have repeatedly suffered high ungulate crop damage (~160-200 acres), situated along the canyon rims. Within each of those fields we will identify 4 plots, one for each treatment type (repellent, polyrope fence, winged fence) and a control. The 4 plot types will be randomly assigned within each field, utilizing a randomized block study design where each field (block) contains one replicate of all treatments (Gotelli and Ellison 2004). This will allow us to statistically account for environmental heterogeneity, as we expect that damage will be variable among fields. Within the fields, study plots will be spaced as far apart as possible, to account for plot independence, and each plot will be 10 $acres^2$ in size. All study plots will be placed along the agriculture/wildland boundary, where depredation is expected to be concentrated. Plots will be monitored from June through October during the growing seasons of 2011 and 2012. We will quantify the relative success of each nonlethal method by comparing crop depredation and ungulate incursion among treatment and control plots.

Plantskydd - Repellents are nonlethal substances used to deter ungulates by decreasing a plant's palatability, and have had mixed success in deterring ungulate foraging activity (Andelt et al. 1992; Baker et al. 1999). We will test the effectiveness of a relatively new product, Plantskydd, for reducing sunflower damage around Dove Creek. This product was developed in Sweden to reduce mammalian wildlife damage on commercial forests and works by emitting an odor that animals associate with predator activity, repelling the animal before it forages on crop plants. There is great interest in the success of such a technique as it can be easily applied to vegetation by ground and aerial spraying, used on both organic and conventionally grown sunflower crops, and is cost-effective for growers. That said, the effectiveness of Plantskydd has not been experimentally tested, only anecdotally reported. To test this method, the 5 Plantskydd treatment plots will be ground or aerial sprayed around field borders once germination has been begun. We will then re-apply Plantskydd to the treatment plots once/month throughout the sunflower growing season as the repellent may wash off or decompose over time and will need to be reapplied to new plant material.

Polyrope electric fence – Fences provide an effective long-term, nonlethal tool for minimizing ungulate crop damage, providing both a physical and psychological barrier (Walter et al. 2010). While a permanent 2.4 meter woven-wire fence provides a true physical barrier to elk and deer, such a structure is can cost >$20/meter, prohibiting wide-spread use. We will test a novel design of a less expensive polyrope electric fence (approximately $8/meter), which acts primarily as psychological barrier based on learned behavioral, avoidance conditioning (Fig. 2; McKillop and Sibly 1988). These fences consist of conductive wires which are woven into synthetic electric "ropes" that are more durable, visible, and easy to install than traditional electric fences (Hygnstrom and Craven 1988, VerCauteren et al. 2006). Permanent fence posts are placed, and then the polyrope is strung between the posts to provide seasonal crop protection. Avoidance conditioning occurs when an animal contacts the fence, often with the nose or tongue, and receives a powerful electric shock. Training can be expedited by baiting the fence wire with peanut butter or molasses to create a negative stimuli when making contact with the electric charge (Porter 1983, Hygnstrom and Craven 1988, Jordan and Richmond 1992, USDA National Wildlife Research Center, unpublished data). Polyrope fences have had success in reducing deer damage (Hygnstrom and Craven 1988, Seamans and VerCauteren 2006), but have not been experimentally tested for reducing elk damage. For the 5 randomly selected polyrope treatment plots, we will construct a fence that is approximately 1.8 meter tall with 5 strands to discourage passage under, through, or over the fence. We will treat the polyrope with a sweet attractant, designed to facilitate avoidance learning, using a minimum charge of 3,000 volts (Curtis et al. 1994). The polyrope will be powered by a Speedrite™ 3000 energizer (Tru-Test Incorporated, San Antonio, Texas) which has a maximum pulse output of 3.0 joules and will be powered by a 12-volt deep-cycle battery with a solar-panel recharger.

Temporary winged fence - For seasonal agricultural resources, such as sunflowers, temporary fences may provide reliable ungulate protection. Temporary fences are inexpensive, lightweight, and easy to erect and remove (Rosenberry et al. 2001, VerCauteren et al. 2006). Recently, investigators have been experimenting with a temporary "winged" fence made of polypropylene mesh. The fence is installed completely on one side of the target field, and partially installed on two other sides having 50-100 meter "wings" that extend perpendicular from the full fence line (see Fig. 3). This design was found to reduce deer damage in corn fields (Hildreth et al. In Review) while requiring limited costs for fence materials and installation. The effectiveness of such a fence has not yet been tested on elk or on deer with other crops than corn, but has potential to be an easily implemented management tool that could reduce crop depredation. On those plots randomly selected to be winged-fence treatments, we will install a fence with a similar design to Hildreth et al. (In Review), where the crop/wildland interface receives complete protection. For increased height and visual deterrence, the fence will be made of 2.4 meter tall orange barrier material (e.g., Guardian Orange Warning Barrier, Tenax Corporation, USA, Baltimore, Maryland).

Monitoring the effectiveness of non-lethal treatments: All treatment and control plots will be monitored for 2 response variables: crop damage and elk/deer incursion. To measure damage to sunflower crops, we will monitor fields every 2 weeks between the time of germination and harvest. We will utilize the variable-area-transect (VAT) method for estimation of crop damage, which consists of both low and high intensity area monitoring (Engeman and Sterner 2002, Gilsdorf et al. 2004a, Gilsdorf et al. 2004b). We will randomly place 4 low-intensity sampling areas within each study plot. In each low-intensity sampling area, we will inspect a row of sunflowers, counting the total number of sunflowers including those that are damaged and undamaged. If 5 cervid-damaged sunflowers are tallied in 100 meters, we will record the distance traveled and the total number of sunflowers. If 5 cervid-damaged sunflowers were not tallied in 100 meters, the observer will record the total number of sunflowers and any cervid-damaged sunflowers observed in that distance. We will calculate the percentage of sunflowers damaged per sampling area using the equation ~ damage per area = [number of damaged sunflowers/(number of damaged sunflowers+number of undamaged sunflowers)] x 100 (Gilsdorf et al. 2004a, Gilsdorf et al. 2004b). We will also randomly locate 2 high-intensity sampling areas along every treatment and control plot edge to measure damage in proximity to places of high cervid pressure. Within the high-intensity sampling areas, we will use 5 VATs within each area. This will result in 12 total sampling areas (4 low intensity, 8 high intensity) per plot. Additionally, at the end of the season, we will evaluate game damage and year-end yields between treatment and control plots, the ultimate measure of success for each management technique.

We will also quantify the level of incursion that occurs into treatment and control fields by elk and mule deer. To do this, we will use animal-activated cameras to record the number and frequency of elk and mule deer that pass through repellents or fence designs into sunflower fields. Cameras will be mounted on posts on the corners of treatment and control fields, capturing images of elk and mule deer inside and outside the field boundaries. Cameras will be positioned along field border that is closest to the agriculture/wildland boundary which is most likely to experience depredation. The Camera type is Moultrie® Game Spy Digital I-65 Infrared, 6.0 mega pixel (Moultry Products, LLC, Alabaster, AL, USA). Cameras can capture images up to 50 feet away, are weather-resistant with a built in solar panel and security box, and can wirelessly transmit images to a private web site for download by project personnel. Cameras will be activated for the duration of the growing season, and at the end of the season we will tally the number of elk and mule deer that penetrated each treatment and control plot boundary. Differences in elk and mule deer use of treatment/control fields will then be tested using repeated measures parametric statistics. This will allow us to evaluate the effectiveness of the repellent, polyrope fence, and winged fence in reducing crop depredation, relative to control plots.

Mapping and modeling the spatial juxtaposition of ungulate damage within the landscape:

To more effectively address ungulate damage problems we will use ArcGIS software to map crop fields, surrounding habitat types, human development, and topography. These variables have been important in explaining rates of ungulate depredation as damage tends to increase closer to cover, further from roads, and depending on crop palatability (Grover and Thompson 1986, Nixon et al. 1989, Hegel et al. 2009). Information about the location of a crop field in the context of the overall landscape will allow CPW to work with local growers to identify the most appropriate tools, and the timing of their implementation, to reduce damage. To meet this objective we will use satellite imagery to digitize agricultural fields and attribute those fields by crop type. We will use existing landcover, infrastructure, and digital elevation model (DEM) coverages to identify non-agricultural vegetation types, distance to human development, and topographic features (i.e. elevation, slope, aspect), respectively. We can then use landscape variables in conjunction with elk and mule deer location data (see Objective 1) to model the probability that a field is depredated by ungulates (Manly et al. 2002). This model can provide a powerful tool for CPW managers, as they will be able to predict the likelihood of depredation, depending on field location, the surrounding environment, and the crop type, and therefore help landowners specify crop choice or management actions that will reduce elk and deer damage.

Timeline

The study will take 3 years to complete. Non-lethal management techniques to reduce elk and deer damage will be implemented and monitored during the growing seasons of 2011 and 2012 (June – October), and the results of treatment/control plots will be analyzed thereafter. We will collar elk and deer during August or September 2011, and monitor animals for 2 years (the length of battery life of GPS collars). Once the GPS collars have been retrieved, we will analyze elk and deer location data. We will use that data to conduct damage mapping and modeling over the following ~6 months.

Budget

We obtained grants from the Colorado Statewide Habitat Partnership Program, the Montelores Committee Habitat Partnership Program, the Rocky Mountain Elk Foundation, the National Wildlife Research Center and from Colorado Division of Parks and Wildlife Auction/Raffle funds to conduct this work. Below is an itemized project budget.

Item	Cost
EQUIPMENT	
20 Elk GPS Collars ($1,300 ea)	$26,000
Capture of Elk ($454 ea + per diem)	$9,330
20 Deer GPS Collars ($2,500 ea)	$50,000
Capture of Mule Deer ($429 ea + per diem)	$8,830
Plantskydd Materials & Application	$16,710
Polyrope Materials & Installation	$32,643
Winged Fence Materials & Installation	$19,042
Animal-Activated Cameras (20 @ $750 ea)	$15,000
Camera Activation/Maintenance	$4,180
GIS Mapping	$3,000
Leased Truck (Jun-Oct/2 yrs)	$12,000
Gas for Leased Truck (Jun-Oct 2 yrs)	$5,000
PERSONNEL	
Technician for Monitoring (Jun-Oct/2 yrs)	$25,583
CPW Permanent Employee Salary (2 yrs)	$40,000
NWRC Post-doctoral Salary	$12,000
TOTAL	$279,318

E. Location

The study will be conducted in the vicinity of Dove Creek, Colorado (Montezuma, San Miguel and Dolores Counties), which is comprised of a mixture of agricultural and public lands. The project will focus on the north half of CPW Game Management Unit 72 and the west half of 711 (the portion west of the Dolores River). The area is generally characterized as mountain shrubland interspersed in irrigated and dryland agricultural areas. The mountain shrub habitat type, which occurs on both private and public lands, is composed primarily of serviceberry, antelope bitterbrush, mountain mahogany, squaw apple and black sagebrush. This habitat type is limited to elevations between 6,500 and 8,500 feet.

F. Literature Cited

Andelt, W.F., K.P. Burnham, and J.A. Manning. 1991. Relative effectiveness of repellents for reducing mule deer damage. Journal of Wildlife Management 55:341-347.

Austin, D.D., P.J. Urness, and D. Duersch. 1998. Alfalfa hay crop loss due to mule deer depredation. Journal of Range Management 51:29-31.

Baker, D.L., W.F. Andelt, K.P. Burnham, and W.D. Sheppard. 1999. Effectiveness of hot sauce and Deer Away repellents for deterring elk browsing of aspen sprouts. Journal of Wildlife Management 63:1327-1336.

Blejwas, K.M., B.J. Sacks, M.M. Jaeger, and D.R. McCullough. 2002. The effectiveness of selective removal of breeding coyotes in reducing sheep predation. Journal of Wildlife Management 66:451-462.

Conover, M.R. 2002. Resolving human-wildlife conflicts: the science of wildlife damage management. CRC Press LLC, Boca Raton, Florida, USA.

Curtis, P.D., M.J. Farigone, and M.E. Richmond. 1994. Preventing deer damage with barrier, electrical, and behavioral fencing systems. Proceedings of the Vertebrate Pest Control Conference 16:223-227.
Engeman, R.M., R.T. Sterner. 2002. A comparison of potential labor-saving sampling methods for assessing large mammal damage in corn. Crop Protection 21:101-105.
Gilsdorf, J.M., S.E. Hygnstrom, K.C. VerCauteren, G.M. Clements, E.E. Blankenship, and R.M. Engeman. 2004a. Evaluation of a deer-activated bio-acoustic frightening device for reducing deer damage in cornfields. Wildlife Society Bulletin 32:515-523.
Gilsdorf, J.M., S.E. Hygnstrom, K.C. VerCauteren, G.M. Clements, E.E. Blankenship, and R.M. Engeman. 2004b. Propane exploders and Electronic Guards were ineffective at reducing deer damage in cornfields. Wildlife Society Bulletin 32:524-531.
Gotelli, N.J., and A.M. Ellison. 2004. A primer of ecological statistics. Sinauer Associates, Sunderland, Massachusetts.
Grover, K.E., and M.J. Thompson. 1986. Factors influencing spring feeding site selection by elk in the Elkhorn Mountains, Montana. Journal of Wildlife Management 50:466-470.
Hegel, T.M., C.C. Gates, and D. Eslinger. 2009. The geography of conflict between elk and agricultural values in the Cypress Hills, Canada. Journal of Environmental Management 90:222-235.
Hildreth, A.M., S.E. Hygnstrom, E.E. Blankenship, and K.C. VerCauteren. In Review. Efficacy of a partial poly-mesh fence with wings to reduce deer damage to corn.
Hygnstrom, S.E. and S.R. Craven. 1988. Electric fences and commercial repellents for reducing deer damage in cornfields. Wildlife Society Bulletin 16:291-296.
Jordon, D.M., and M.E. Richmond. 1992. Effectiveness of a vertical 3-wire electric fence modified with attractants or repellents as a deer exclosure. Proceedings of the Eastern Wildlife Damage Control Conference 5:44-47.
Krausman, P. R., J. J. Hervert, and L. L. Ordway. 1985. Capturing deer and mountain sheep with a net-gun. Wildlife Society Bulletin 13:71–73.
McKillop, I.G., and R.M. Sibly. 1988. Animal behaviour at electric fences and implications for management. Mammal Review 18:91-103.
Manly, B.F.J., L.L. McDonald, D.L. Thomas, T.L. McDonald, and W.P. Erickson. 2002. Resource selection by animals; statistical design and analysis for field studies. Second Edition. Kluwer Academic Publishers, Boston, Massachussetts.
Mould, E.D., and C.T. Robbins. 1982. Digestive capabilities in elk compared to white-tailed deer. Journal of Wildlife Management 46:22-29.
Nixon, C.M., L.P. Hansen, P.A. Brewer, J.E. Chelsvig. 1989. Ecology of white-tailed deer in an intensively farmed region of Illinois. Wildlife Monographs 118:1-77.
Nolte, D. 1999. Behavioral approaches for limiting depredation by wild ungulates. Pages 60-69 *in* K.L. Launchbaugh, K.D. Sanders, and J.C. Mosley, editors. Grazing behavior of livestock and wildlife. Idahor Forest, Wildlife & Range Experimental Station Bulletin #70, University of Idaho, Moscow, USA.
Porter, W.F. 1983. A baited electric fence for controlling deer damage to orchard seedlings. Wildlife Society Bulletin 11:325-329.
Rosenberry, C.S., L.I. Muller, and M.C. Conner. 2001. Movable, deer-proof fencing. Wildlife Society Bulletin 29:754-757.
Seamans, T.W., and K.C. VerCauteren. 2006. Evaluation of ElectroBraid™ fencing as a white-tailed deer barrier. Wildlife Society Bulletin 34:8-15.
Van Tassell, L.W., C. Phillips, B. Yang. 1999. Depredation claim settlements in Wyoming. Wildlife Society Bulletin 25:886-894.
Vecellio, G.M., R.H. Yahner, and G.L. Storm. 1994. Crop damage by deer at Gettysburg Park. Wildlife Society Bulletin 22:89-93.
VerCauteren, K.C., M.J. Lavelle, and S. Hygnstrom. 2006. Fences and deer-damage management: a review of designs and efficacy. Wildlife Society Bulletin 34:191-200.

Wagner, K.K., R.H. Schmidt, and M.R. Conover. 1997. Compensation programs for wildlife damage in North America. Wildlife Society Bulletin 25:312-319.

Walter, W.D., M.J. Lavelle, J.W. Fischer, T.L. Johnson, S.E. Hygnstrom, and K.C. VerCauteren. 2010. Management of damage by elk (*Cervus elaphus*) in North America: a review. Wildlife Research 37:630-646.

Walter, W.D., K.C. VerCauteren, J.M. Gilsdorf, and S.E. Hygnstrom. 2009. Crop, native vegetation, and biofuels: response of white-tailed deer to changing management priorities. Journal of Wildlife Management 73:339-344.

World Resources Institute. 2008. WRI EarthTrends monthly update page. http://earthtrends.org/updates/node/180.

Worton, B.J. 1989. Kernal methods for estimating the utilization distribution in home-range studies. Ecology 70:164-168.

Worton, B.J. 1995. Using Monte Carlo simulation to evaluate kernel-based home range estimators. Journal of Wildlife Management 59:794-800.

Yoder, J. 2002. Deer-inflicted crop damage and crop choice in Wisconsin. Human Dimensions of Wildlife 7:179-196.

Figure 1. Pink areas delineate zones of high ungulate-crop depredation around Dove Creek, Colorado (Montezuma, San Miguel and Dolores Counties; figure from a Montelores HPP report).

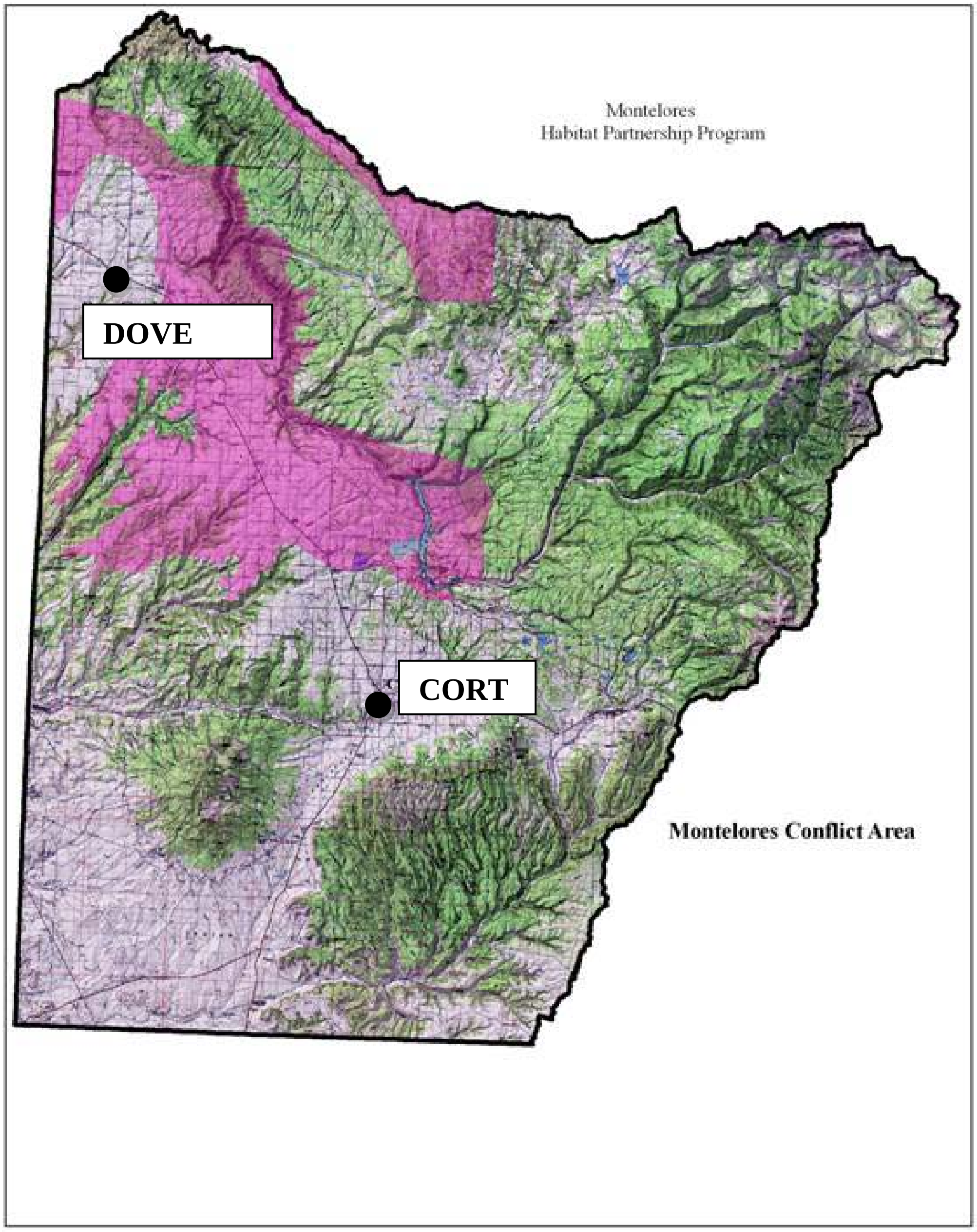


Figure 2. Photo of a polyrope electric fence constructed in a sunflower field south of Dove Creek, CO.

Figure 3. Photo along a wing of a temporary fence constructed in a sunflower field south of Dove Creek, CO.

Colorado Division of Parks and Wildlife
July 2010 – June 2011

WILDLIFE RESEARCH REPORT

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

Period Covered: July 1, 2010 – June 30, 2011

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

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

ABSTRACT

Across the country conflicts among people and black bears are increasing in number, frequency and severity, and have become a high priority wildlife management issue. Whether increases in conflicts reflect recent changes in bear population trends or just bear behavioral shifts to anthropogenic food resources, is largely unknown, with key implications for bear management. This issue has generated a pressing need for bear research in Colorado and has resulted in a unique collaboration that builds on the resources and abilities of personnel from 5 entities: the Colorado Division of Wildlife (now Colorado Parks and Wildlife [CPW]), the National Wildlife Research Center, Colorado State University, Wildlife Conservation Society, and Bear Trust International. Collectively, we are implementing a 5-year study on black bears that 1) tests management strategies for reducing bear-human conflicts, including a large-scale treatment/control urban-food-removal experiment; 2) determines the consequences of bear-use of urban environments on regional bear population dynamics; and 3) develops population and habitat models to support the sustainable monitoring and management of bears in Colorado. We initiated this project in FY10-11 by developing a research proposal, selecting a field site for detailed data collection (Durango, CO), coordinating with numerous entities (non-profit organizations, private citizens, and personnel from city, county, state, and federal government agencies) on field logistics, and commencing several aspects of data collection (trapping and collaring bears, monitoring human-related bear mortalities, implementing DNA hair-snare protocols, monitoring garbage-related bear-human conflicts, and conducting mast surveys). Project collaborators will continue to seek additional funding to implement the remaining activities outlined in the research proposal (i.e., conduct an urban-food-removal experiment, increase the sample size of GPS collared bears, and acquire telemetry collars to test a translocation model). Information from this study will provide solutions for sustainably managing black bears outside urban environments, while reducing bear-human conflicts within urban environments; knowledge that is critical for wildlife managers in Colorado and across the country.

WILDLIFE RESEARCH REPORT

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

HEATHER E. JOHNSON

P.N. OBJECTIVES

To conduct a study on black bears in Colorado that 1) tests management strategies for reducing bear-human conflicts, including a large-scale treatment/control urban-food-removal experiment; 2) determines the consequences of bear-use of urban environments on regional bear population dynamics; and 3) develops population and habitat models to support the sustainable monitoring and management of bears in the state.

SEGMENT OBJECTIVES

1. Develop a research proposal for internal CPW peer review and funding solicitation.
2. Consult with CPW personnel on potential study sites and compile key information about those sites including numbers of reported bear-human conflicts, public land access, urban sanitation practices, harvest data, and urban development statistics.
3. Work with personnel from the City of Durango, La Plata County, the San Juan Public Lands Office (USFS/BLM), the Columbine and Pagosa USFS/BLM Ranger Districts, Bear Smart Durango, CPW Southwest Region, CPW Area 15, and private landowners on logistical field considerations.
4. Initiate black bear capture and GPS collaring efforts to collect data on bear movements, habitat-use patterns, and vital rates.
5. Track human-related bear mortalities and removals around Durango from translocations, vehicle collisions, conflict mortalities and harvest.
6. Deploy bear hair-snares in an “urban” Durango sampling grid and a “wildland” Piedra sampling grid to obtain DNA for genetic mark-recapture analyses. Genotyped hair samples will be used to estimate population densities.
7. Collect data on natural food availability for bears based on the mast abundance of gambel oak, serviceberry, chokecherry, hawthorne, pinyon pine and squaw apple.
8. Monitor the frequency of garbage-related bear-human conflicts within proposed treatment and control areas for an urban-food-removal experiment.

INTRODUCTION

Conflicts among people and black bears (*Ursus americanus*) are increasing nationwide (Hristienko and McDonald 2007), as the human population grows and urban development expands in and around bear habitat. State and federal wildlife agencies are responsible for both minimizing bear-human conflicts and maintaining and monitoring viable bear populations; two mandates that are proving to be incredibly challenging. Conflicts between bears and people can result in human injuries, property damage, and bear mortality (i.e. euthanasia), but despite increasing efforts from wildlife agencies to reduce conflicts, rates have been on the rise (Baruch-Mordo et al. 2008). Meanwhile, bear population parameters have been exceedingly difficult to estimate across large spatial scales (Garshelis and Hristienko 2006), and current population sizes and trends are largely unknown. As a result, management agencies are uncertain whether recent increases in bear-human conflicts reflect increases in the bear population or just bear behavioral shifts to anthropogenic food resources. Without a thorough understanding of the factors that drive nuisance bear behavior, and the relationship between conflict rates and bear dynamics, it has been difficult for wildlife agencies to initiate effective management practices.

This issue has generated a pressing need for comprehensive bear research in Colorado, and resulted in the development of a detailed study proposal by Johnson et al. (2011; Appendix I). The proposal outlines a 5-year project on black bears that 1) tests management strategies for reducing bear-human conflicts, including a large-scale treatment/control urban-food-removal experiment; 2) determines the consequences of bear-use of urban environments on regional bear population dynamics; and 3) develops population and habitat models to support the sustainable monitoring and management of bears in Colorado. Overall, this study should explicitly link bear movement and resource-use to population parameters, while rigorously testing an array of management techniques to reduce conflicts. This information should provide solutions for sustainably managing black bears *outside* urban environments, while reducing bear-human conflicts *within* urban environments; knowledge that is critical for wildlife managers in Colorado and across the west.

During FY10-11 we developed a research proposal, identified a study site, determined the logistics of collecting field data at that site, and initiated data collection. Field efforts focused largely on meeting research objectives 1 and 2, which will yield data that will eventually be used to address objective 3. Specifically, we captured and collared adult female bears, collected data on human-related bear mortalities, deployed and monitored hair-snares to collect DNA for estimating population size, tracked garbage-related bear-human conflicts, and collected data on natural food availability for bears. We report general summary information from recent fieldwork (1 May – 15 Sept 2011) in this progress report; detailed analyses of field data will occur during FY11-12. While we have initiated data collection for several aspects of this project, collaborators will need to generate additional funding to conduct all research activities outlined in the proposal (i.e., conduct the urban-food-removal experiment, increase the sample size of GPS collared bears, and obtain telemetry collars to test a translocation model).

STUDY AREA

To meet study objectives, a combination of detailed, site-specific field data, and statewide data will be required. For the information presented in this progress report, we focus specifically on the selection of a site for detailed data collection on bear resource-use, demography, and the effectiveness of urban bear-proofing. To make this determination we evaluated a suite of factors. We first identified urban areas in Colorado that reported the highest numbers of conflict-related bear mortalities, translocations, and public calls. From those cities, we then considered the quality and history of bear-human conflict reporting, current bear-proofing infrastructure, the feasibility of conducting a large-scale human-food-removal experiment (based on current city waste management practices), the size of the urban-wildland interface, harvest management, and public land accessibility. Based on those factors, project collaborators decided that field efforts should be initiated around the urban center of Durango, Colorado (La Plata County). Durango consistently exhibits some of the highest numbers of bear-human conflicts in the state, conflict reports are regularly monitored by CPW Area 15 and Bear Smart Durango (a local non-profit organization), and unlike other areas experiencing high conflict rates, bear harvest was expected to be maintained at similar levels for the foreseeable future. Durango also had limited bear-proofing infrastructure, was the only city with a coordinated residential waste management system (all residential waste is removed by the city), and is largely surrounded by public land (USFS, BLM, CPW, City of Durango and La Plata County; Fig. 1).

The city of Durango contains ~17,000 people (within city limits) and sits at 1,985 m along the Animas river valley. The town is surrounded by mountainous terrain ranging in elevation from ~1,930 to ~3,600 m, and is generally characterized by mild winters and warm summers that experience monsoon rains. Vegetation in the region is dominated by ponderosa pine, oak, pinyon-juniper, aspen, mountain shrub, and agricultural communities. Key forage species for black bears include gambel oak (*Quercus gambelii*), chokecherry (*Padus virginiana*), serviceberry (*Amelanchier alnifolia*), hawthorne (*Crataegus spp*), squaw apple (*Peraphyllum ramosissimum*), angelica (*Angelica spp*), sweet cicily (*Osmorhiza spp*), cow parsnip (*Heracleum sphondylium*) and waterleaf (*Hydrophyllum spp*). Public land in the region is primarily managed by the San Juan National Forest, the Bureau of Land Management, Colorado Parks and Wildlife, La Plata County and the City of Durango.

METHODS

Logistical Considerations

During fall and early winter FY10-11, we developed a research proposal for internal CPW review and identified a field site for collecting detailed bear habitat-use and demography data. In late winter and spring we worked with various entities around Durango to prepare to conduct fieldwork. We presented our research proposal to personnel from the U.S. Forest Service and BLM (San Juan Public Lands Office, Columbine Ranger District, and Pagosa Ranger District) and worked to develop an operating plan for capturing bears and deploying hair-snares on federal land. We also presented our proposal to staff from the City of Durango and La Plata County, and discussed access to their respective lands for meeting research objectives. Within CPW, we worked with personnel from Area 15 and the Southwest Region to identify initial capture and hair-snare sites, create a bear-human conflict mailbox for recording public calls, and clarify the research objectives relative to local management actions. Additionally, we solicited various entities for financial contributions to the project. Bear trapping and collaring, tracking of human-related bear mortalities, DNA hair-snare surveys, garbage-related conflict monitoring, and mast surveys were all initiated during summer 2011; the study proposal (Appendix I) provides detailed descriptions of these methods so we only briefly describe them below.

Bear Trapping and Collaring

To relate the habitat-use patterns of bears to their demographic trends, we captured and collared adult female bears. We specifically targeted adult females as they represent the reproductive segment of the population and should provide reliable inference to general demographic trends. Additionally, we can obtain information on multiple key vital rates from collaring a single sex-stage class, because, in addition to adult female survival (the vital rate with the greatest elasticity), collared females allow us to track fecundity and cub survival from winter den checks. While our long-term goal is to collar ~50 adult females (Appendix I), in the first year of the study we had the resources available to deploy 25 GPS collars (20 new Vectronics collars, 5 used Lotek collars). We targeted our trapping efforts within ~12 km of the center of Durango to capture a cohort of bears that experience similar natural food availability, have anthropogenic food resources readily available, and encompass a range of habitat-use patterns relative to the urban-wildland interface.

From May through 15 September we used a combination of box traps and leg-hold snares to capture black bears (Jonkel 1993). We built smaller box traps than those previously used for bear research in Colorado (previously built traps are 0.91 x 0.91 x 1.83 m and weigh ~205 kg; newly constructed traps are 0.71 x 0.66 x 1.83 m and weigh ~125 kg), allowing for increased mobility and flexibility in placement (Fig. 2). A detailed description of the capture and handling procedures is available in Appendix II. Traps and snares were baited with fish, fruit, human foods (at urban locations) and manufactured scents; they were set in the evening and checked the following morning. Adult female bears were fitted with a GPS collar, marked with a PIT tag, and had a tooth pulled for age verification. All other bears (except cubs) were uniquely marked with a PIT and ear-tag (a single small black tag). Bears were weighed, measured, and sampled for blood and hair. GPS locations from Vectronics collars were programmed to upload 4 locations/day through a satellite system, while locations from Lotek collars were manually downloaded in the field using a hand-held device from the ground or air (fixed-wing aircraft).

Monitoring Human-Related Bear Mortalities

Between 1 May and 15 September 2011 we recorded all human-related black bear mortalities and removals in the vicinity of Durango. Mortalities and removals occurred from translocations, vehicle collisions, conflict-related euthanasia and harvest. For all bears removed from the study area we collected a hair and tooth sample and recorded the date, mortality/removal cause, location, bear age, sex, weight, and morphological measurements. Tooth samples will be used to age and genotype these bears so they can be incorporated into population density analyses.

Hair-Snare Surveys

To estimate the density of black bears around Durango we used a DNA hair-snare sampling scheme (Woods et al. 1999, Mowat and Strobeck 2000). We centered a 36 cell grid (576 km^2) over Durango where each cell was 4 x 4 km in size and contained one snare. We sampled a total of 31 grid cells, dropping 5 cells along the outer edge of the grid where public or motorized access was prohibited (Fig. 3). Snares consisted of a scented bait hanging high in a tree, surrounded by barbed wire around a cluster of trees encircling the bait; when the bears climbed over or under the wire to investigate the bait, they left a hair sample on the barbed wire. On half of the snares we hung a single strand of barbed wire (50 cm high), and on the other half of the snares we hung two strands (50 and 20 cm high). Our goal with this design was to determine whether the additional strand of wire increased capture probability. Snares were deployed from June 1 to 14, and we conducted 6 weekly sampling occasions thereafter. On each occasion, we re-baited the snare (randomly baited with anise, strawberry, fish, or maple), and collected hair samples off all barbs. Each hair sample was uniquely catalogued according to the site, date, occasion, and barb number. Samples will be sent to the laboratory at Wildlife Genetics International for genotyping during fall 2011 and we will use the pattern of genotypes to estimate density using mark-recapture statistics.

In addition to implementing the Durango hair-snare grid, we also conducted a pilot grid in the Piedra watershed (located between Durango and Pagosa Springs; see Appendix I Figure 7). This site was chosen as high quality "wildland" bear habitat, reflecting representative densities of bears in the region in the absence of urban development and human food resources. Initially, we intended to deploy and monitor ~32 snares in both the Durango and Piedra grids, however, lack of motorized access in the Piedra watershed inhibited field crews from constructing and checking all snares in a timely fashion. As a result, we opted to run a subset of 9 snare sites in the Piedra to determine whether twice/month sampling (as opposed to weekly) would have significant impacts on DNA quality, DNA contamination (hair samples from >1 bear/barb), and recapture rate. These samples will be genotyped this fall. Depending on the results, we will design an appropriate sampling scheme to estimate the wildland bear density in FY11-12.

Mast Surveys

Bear-human conflicts and bear-use of urban environments may increase when natural foods are in short supply (Zack et al. 2003, Baruch-Mordo 2007, Baruch-Mordo et al. 2010). To quantify the role of natural food availability on bear habitat selection, we initiated weekly surveys of the local soft and hard mast. In the Durango region, the key mast species for bears are gambel oak, chokecherry, serviceberry, hawthorne, squaw apple, and pinyon pine (Beck 1991, Tom Beck, personal communication). Although the phenology of these species is variable throughout the late summer/early fall, they generally reach peak fruit or nut maturation between mid-August and mid-September. We randomly selected 12 transects throughout the 576 km^2 hair-snare study area to evaluate bear natural food availability (Fig. 3). Each transect was 1 km in length and ran along an existing public trail or public-accessible stream drainage. Field technicians walked vegetation transects each week between 15 August and 15 September and for each species, recorded the phenological stage and the percentage of plants that exhibited mast in different abundance categories (mast failure, <25% of plants with mast, etc).

Conflict Monitoring

One management strategy proposed for reducing bear-human conflicts is removing access to human foods for bears (Peine 2001, Spencer et al. 2007). Given the high price to operationally "bear-proof" a community, municipalities must have definitive evidence that such an effort would significantly decrease conflict activity before initiating major changes to waste storage and collection practices. As part of this study we plan on implementing the first rigorous scientific evaluation of the efficiency of wide-scale urban bear-proofing for minimizing bear-human conflicts. Although this portion of the project has not yet been funded, we conducted pre-treatment monitoring in proposed treatment and control areas (Fig. 4). During July and August, the months that experience the highest numbers of bear-human conflicts (CPW unpublished data) we patrolled each street within proposed treatment/control areas on the day that waste removal was scheduled to occur (when maximum human food was assumed to be available to bears). Patrols were conducted from 06:00 - 07:00 AM; for all locations where there was evidence that bears had obtained garbage we recorded UTM coordinates and the trash container type.

RESULTS AND DISCUSSION

During the summer 2011 field season we conducted 92 total bear captures; 71 captures were unique individuals and 21 were recaptures (see map of capture locations in Fig. 3). Of the unique individuals captured, there were 30 females, 38 males, and three cubs of unidentified sex (cubs were released without being immobilized and thus, gender was not determined; Table 1). The mean age of captured bears ≥1 year old was 4.9, and the mean weight was 80.9 kg (60.0 kg for females and 97.4 kg for males). In total, we placed traps/snares at 105 different locations and we had 1,253 trap nights. Across all bear captures (new captures and re-captures), 86 bears were captured using box traps (1,119 box trap nights) and 6 with leg-hold snares (134 snare nights). Generally capture success peaked during the first couple weeks of June and again in mid-August; capture success was low during July. We modified our newly constructed, smaller box traps to have a locking mechanism on the door that, once triggered, only allowed the door to close shut and not re-open. This was a critical design element, and allowed us to use the smaller box traps to catch bears ≤ 214 kg. Generally, we found these traps to be convenient to place in the field and successful in safely capturing and holding bears until they were immobilized.

We collared a total of 26 female bears, however two bears slipped out of their collars and were not recaptured leaving us with 24 collared bears at the end of the field season. During the trapping season, Vectronics collars successfully uploaded >5,000 GPS locations through the satellite system, and we downloaded an additional 1,500 locations from Lotek collars (Fig. 5). One Vectronics collar prematurely switched to low-battery mode in August; we are currently attempting to recapture the bear to replace the collar. Although we have not yet conducted any formal movement analyses, one collared female moved

~50 km southwest from Perins Peak State Wildlife Area (adjacent to Durango), eventually moving back after several weeks. The second longest movement by a collared bear was ~16 km.

Between 1 May and 15 September, 23 bears were removed from the greater Durango area due to human-related causes. Of those bears that were removed, three were translocated due to conflicts with people, seven were killed in vehicle collisions, one was killed during research trapping, and 12 were euthanized due to conflicts with people (breaking into house, killing livestock, etc). There were three cubs, two yearling females, five yearling males, six adult females and nine adult males that were removed. Until bears begin hibernating, additional mortalities and removals are expected to occur.

Field crews collected a total of 998 individual bear hair samples, 743 samples from the Durango grid and 255 samples from the pilot Piedra grid. Over the 6 sampling occasions from 31 snares around Durango we collected 224, 167, 138, 77, 68, and 69 hair samples, respectively. Over the three sampling occasions from nine snares in the Piedra we collected 127 samples; 46, 50, and 31 samples/occasion, respectively. We also collected 128 additional samples from snares in the Piedra watershed that were only checked on a single occasion. Samples will be sent to Wildlife Genetics International for genotyping in the fall, and results will allow us to estimate bear density.

Within the proposed treatment and control areas for the urban bear-proofing experiment, we observed 129 incidences of bears accessing human garbage during July and August; incidences peaked during the first week of August. Of those events, 10% were wildlife-resistant garbage containers and 90% were regular containers. Bears accessed human food from wildlife-resistant containers when they were not closed properly or could break the locking mechanism on the lid. In assessing the availability of garbage to bears, we recorded the location and container type of 1,167 garbage cans in the proposed treatment and control areas (Fig. 4). Of those containers, 14% were wildlife resistant and 86% were regular (non-wildlife resistant). This demonstrates the limited residential bear-proofing that currently exists in Durango, and the relevance of conducting an experimental test of wide-scale urban bear-proofing in this community.

Mast surveys are currently ongoing; results will be in the annual report for FY11-12.

SUMMARY AND FUTURE PLANS

During FY10-11 we successfully developed a research proposal addressing bear-human conflict issues in Colorado, selected a field site, coordinated with numerous entities (non-profit organizations, private citizens, and personnel from city, county, state, and federal government agencies) on field logistics, and initiated several aspects of data collection (trapping and collaring bears, tracking human-related bear mortalities, implementing DNA hair-snare protocols, monitoring garbage-related bear-human conflicts, and conducting mast surveys). We will continue these field activities during summers 2012-2015. Additionally, we will begin winter den checks in January 2012 to track fecundity and cub survival, and ensure that collars are fitting appropriately. Project collaborators will continue to seek additional funding to implement the remaining activities outlined in the research proposal. These activities include the implementation of an urban bear-proofing experiment, increasing the number of GPS collared female bears, and purchasing telemetry collars for a translocation study. In addressing the objectives of this project we hope to better understand the influence of urban environments on bear populations, elucidate the relationship between bear-human conflicts and bear population trends, develop tools to promote the sustainable management of bears in Colorado, and ultimately, identify solutions for reducing bear-human conflicts in urban environments.

LITERATURE CITED

Baruch-Mordo, S. 2007. Black-bear human conflicts in Colorado: spatiotemporal patterns and predictors. Thesis, Colorado State University, Fort Collins, Colorado.

Baruch-Mordo, S., S.W. Breck, K.R. Wilson, and D.M. Theobald. 2008. Spatiotemporal distribution of black bear-human conflicts in Colorado, USA. Journal of Wildlife Management 72:1853-1862.

Baruch-Mordo, S., K.R. Wilson, D. Lewis, J. Broderick, J. Mao, and S.W. Breck. 2010. Roaring Fork Valley urban black bear ecology study: progress report to the Colorado Division of Wildlife. Contact Sharon Baruch-Mordo for copy. Email: sharonb_m@yahoo.com

Beck, T.D.I. 1991. Black bears of west-central Colorado. Technical Publication No. 39, Colorado Division of Wildlife, Colorado.

Garshelis, D.L., and H. Hristienko. 2006. State and provincial estimates of American black bear numbers versus agency assessments of population trend. Ursus 17:1-7.

Hristienko, H., and J.E. McDonald Jr. 2007. Going into the 21st century: a perspective on trends and controversies in the management of the American black bear. Ursus 18:72-88.

Johnson, H.E, C.J. Bishop, M.W. Alldredge, J. Brodrick, J. Apker, S. Breck, K. Wilson, and J. Beckmann. 2011. Black bear exploitation of urban environments: finding management solutions and assessing regional population effects. Research Proposal, Colorado Division of Parks and Wildlife, Fort Collins, USA.

Jonkel, J.J. 1993. A manual for handling bears for managers and researchers. Office of Grizzly Bear Recovery, United States Fish and Wildlife Service, Missoula, Montana.

Mowat, G., and C. Strobeck. 2000. Estimating population size of grizzly bears using hair capture, DNA profiling, and mark-recapture analysis. Journal of Wildlife Management 64:183-193.

Peine, J.D. 2001. Nuisance bears in communities: Strategies to reduce conflicts. Human Dimensions of Wildlife 6:223-237.

Spencer, R.D., R.A. Beausoleil, and D.A. Martorello. 2007. How agencies respond to human–bear conflicts: a survey of wildlife species in North America. Ursus 18: 217–229.

Woods, J.G., D. Paetkau, D. Lewis, B.N. McLellan, M. Proctor, and C. Strobeck. 1999. Genetic tagging of free-ranging black and brown bears. Wildlife Society Bulletin 27:616-627.

Zack, C.S., B.T. Milne, and W.C. Dunn. 2003. Southern oscillation index as an indicator of encounters between humans and black bears in New Mexico. Wildlife Society Bulletin 31:517-520.

Prepared by ____

Heather E. Johnson, Wildlife Researcher

Table 1. Capture information for 65 bears ≥1 year old in the vicinity of Durango, CO.

					Capture Location	
Unique ID	**Capture Date**	**Sex**	**Estimated Age**	**Weight (kg)**	**UTM Easting**	**UTM Northing**
B1	5/10/2011	M	1	35	246233	4142768
B2	5/12/2011	M	5	144	271495	4130889
B3	5/13/2011	M	5	130	271495	4130894
B4	5/16/2011	M	3	84	270950	4127914
B5	5/16/2011	M	6	135	270227	4139984
B6	5/17/2011	F	3	63	243210	4128716
B7	5/17/2011	F	6	64	243225	4133053
B8	5/18/2011	F	3	52	271478	4130892
B9	5/26/2011	M	1	35	238803	4126790
B10	5/26/2011	F	4	81	269869	4139040
B11	6/3/2011	M	8	130	252163	4137968
B12	6/2/2011	M	5	103	253216	4137387
B13	6/3/2011	M	3	59	253216	4138868
B14	6/6/2011	F	6	58	252157	4137967
B15	6/6/2011	M	3	58	253216	4138868
B16	6/7/2011	M	7	117	253216	4138868
B17	6/7/2011	F	6	52	256936	4134633
B18	6/8/2011	F	6	62	256918	4134625
B19	6/9/2011	M	9	147	235193	4128894
B20	6/9/2011	M	10	132	243258	4133040
B21	6/10/2011	F	7	69	252298	4136435
B22	6/10/2011	M	8	88	252163	4137968
B23	6/13/2011	M	3	65	246350	4135617
B24	6/14/2011	F	8	65	243252	4133030
B25	6/15/2011	F	4	64	239003	4134158
B26	6/15/2011	M	10	109	252164	4137966
B27	6/16/2011	F	10	75	243252	4133030
B28	6/16/2011	M	6	101	253233	4138873
B29	6/21/2011	M	1	49	239840	4126949
B30	6/22/2011	F	4	60	235911	4128916
B31	6/24/2011	M	4	85	239840	4126949
B32	6/24/2011	F	1	19	243252	4133030
B33	6/28/2011	M	1	35	239294	4133260
B34	6/28/2011	M	3	85	239001	4134154
B35	7/5/2011	F	3	44	246350	4135617
B36	7/6/2011	M	4	67	239840	4126949
B37	7/7/2011	M	1	39	243252	4133030
B38	7/13/2011	M	8	145	243236	4128710
B39	7/13/2011	M	6	150	251222	4133120
B40	7/21/2011	F	5	81	248550	4131645
B41	7/22/2011	M	3	67	237368	4132272
B42	7/26/2011	F	6	70	245945	4141391
B43	8/3/2011	F	8	85	246183	4142791
B44	8/3/2011	M	2	35	756124	4132494
B45	9/3/2011	M	6	176	245965	4139587
B46	9/5/2011	F	3	58	243435	4128720
B47	8/8/2011	F	8	54	251783	4131581

Table 1-Continued					Capture Location	
Unique ID	**Capture Date**	**Sex**	**Estimated Age**	**Weight (kg)**	**UTM Easting**	**UTM Northing**
B48	8/10/2011	F	1	26	245914	4139620
B49	8/11/2011	F	3	55	243435	4128720
B50	8/11/2011	F	7	101	245965	4139587
B51	8/12/2011	F	12	62	249049	4130370
B52	8/12/2011	F	4	65	245965	4139587
B53	8/15/2011	M	7	163	243435	4128720
B54	8/16/2011	M	2	53	251898	4130516
B55	8/18/2011	F	3	49	251464	4134423
B56	8/29/2011	M	10	167	246321	4132993
B57	8/30/2011	F	3	46	243374	4135903
B58	8/31/2011	M	3	48	243374	4135903
B59	9/1/2011	M	15	153	243952	4132935
B60	9/2/2011	F	2	35	242187	4133020
B61	9/3/2011	M	7	214	244602	4130321
B62	9/6/2011	M	1	23	245790	4128530
B63	9/7/2011	M	2	37	248612	4131251
B64	8/6/2011	M	1	30	245850	4141969
B65	9/15/2011	F	5	91	243948	4134848
B66	9/20/2011	F	1	41	240731	4130163
B67	9/21/2011	F	3	54	256930	4134626
B68	9/21/2011	M	8	209	249067	4133006

Figure. 1. Land ownership in the vicinity of Durango, CO.

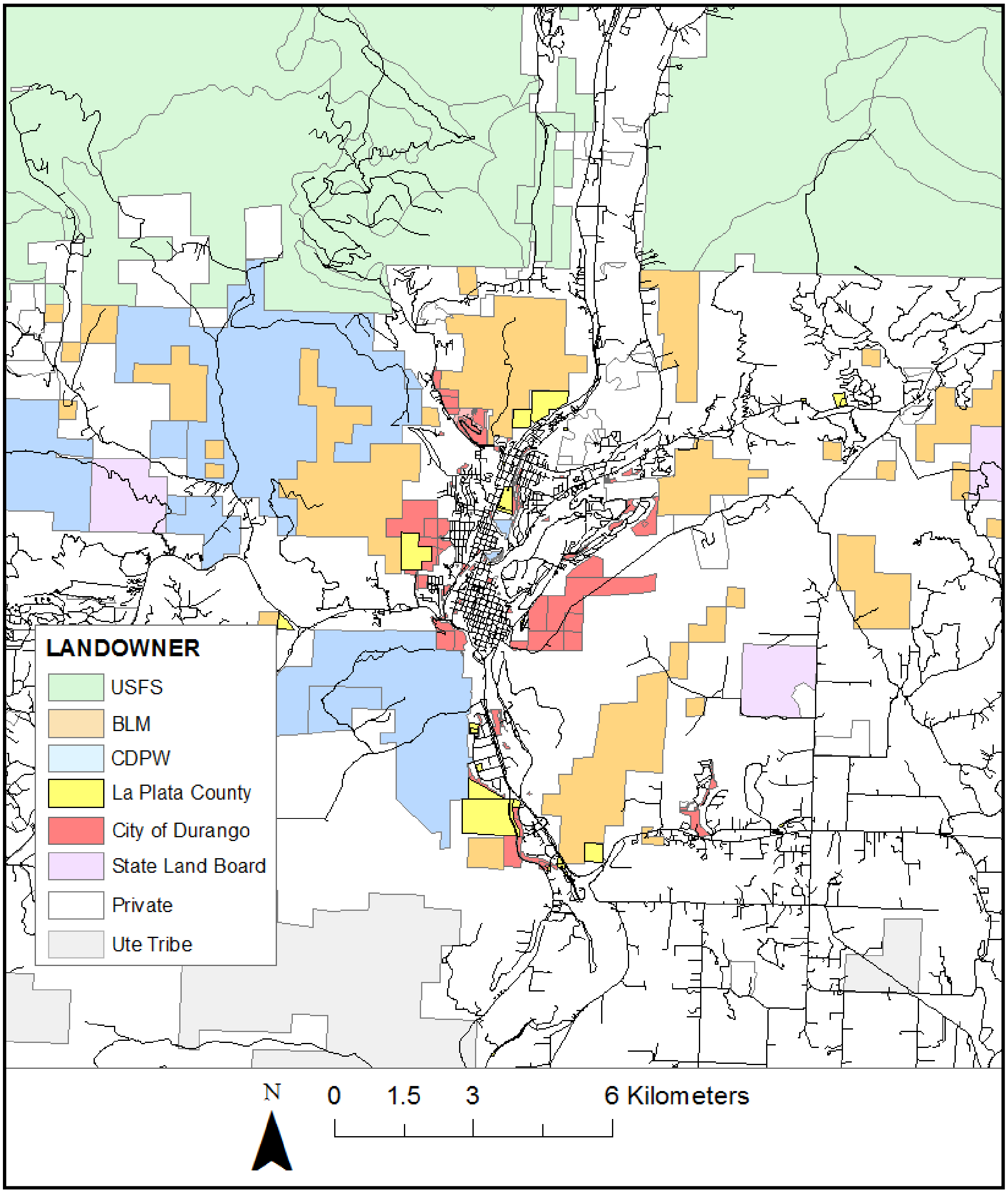


Figure 2. Photos of a newly designed box trap to capture black bears.

Figure 3. Location of bear hair-snare sites, mast survey transects, and capture sites around Durango, CO.

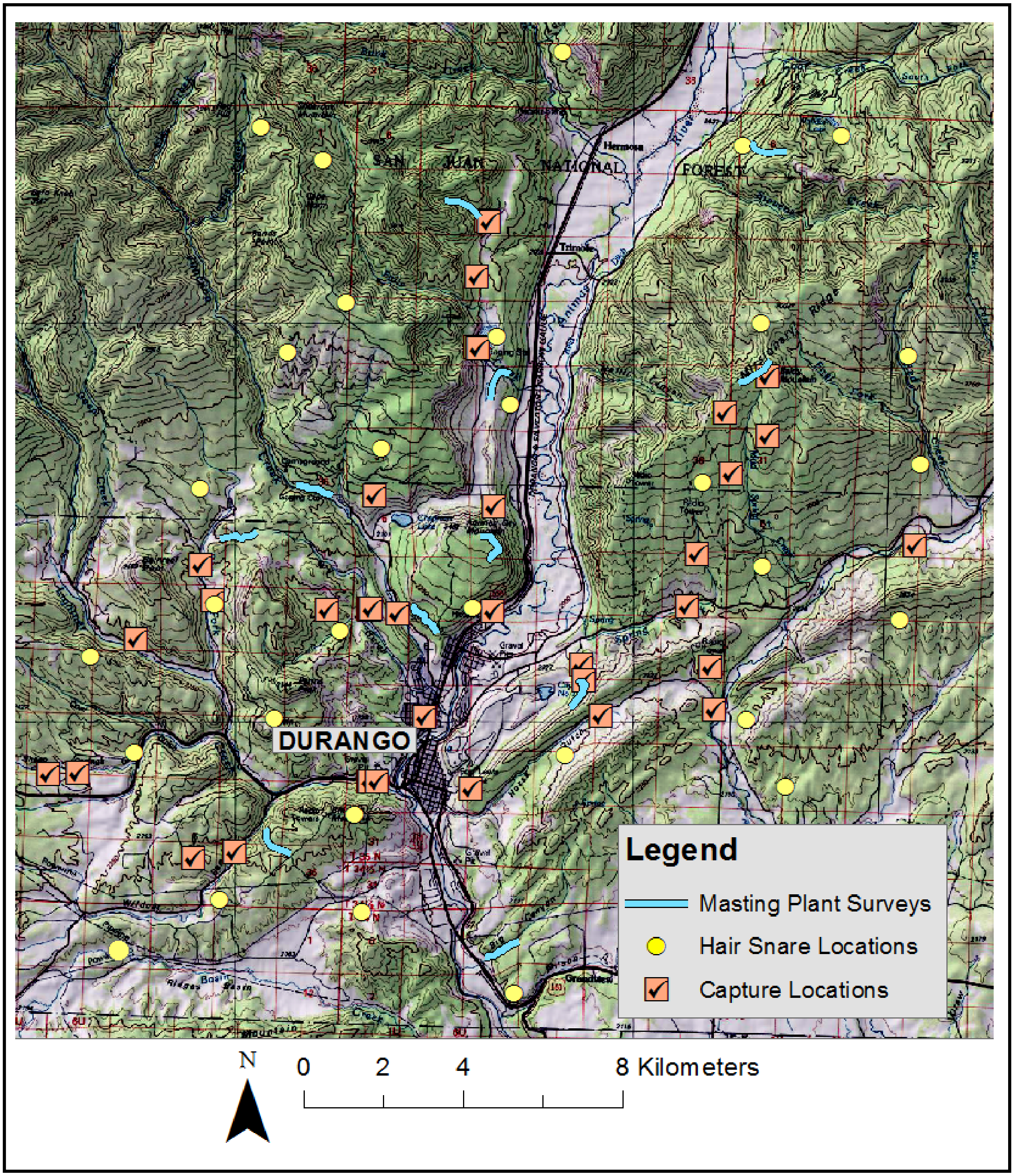


Figure 4. Proposed treatment and control areas for an urban bear-proofing experiment and observations of garbage-related conflicts from pre-treatment monitoring. Red stars indicate evidence of bears foraging on human garbage, circles indicate the availability of human food for bears (green circles represent regular garbage containers and yellow circles represent wildlife-resistant containers).

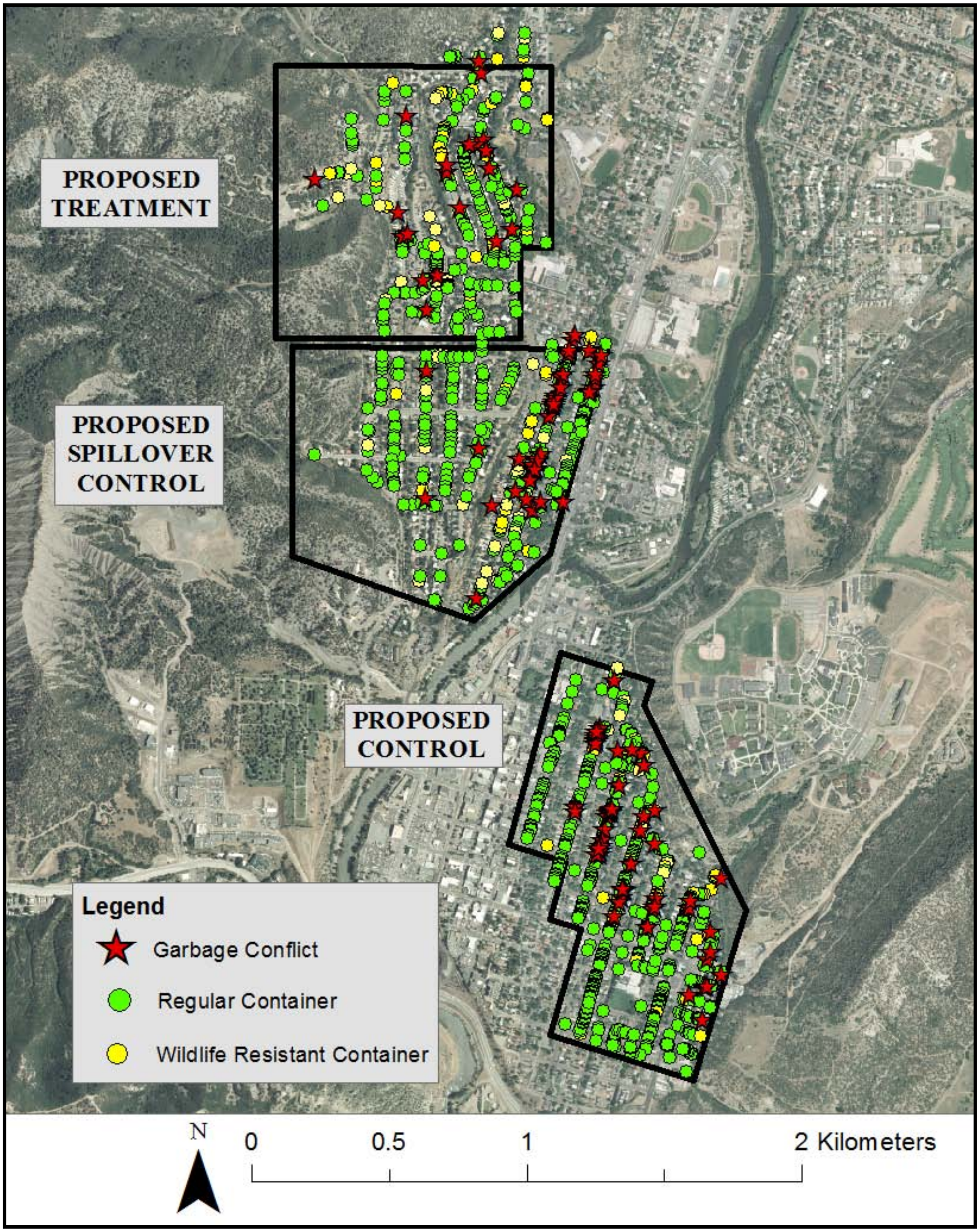
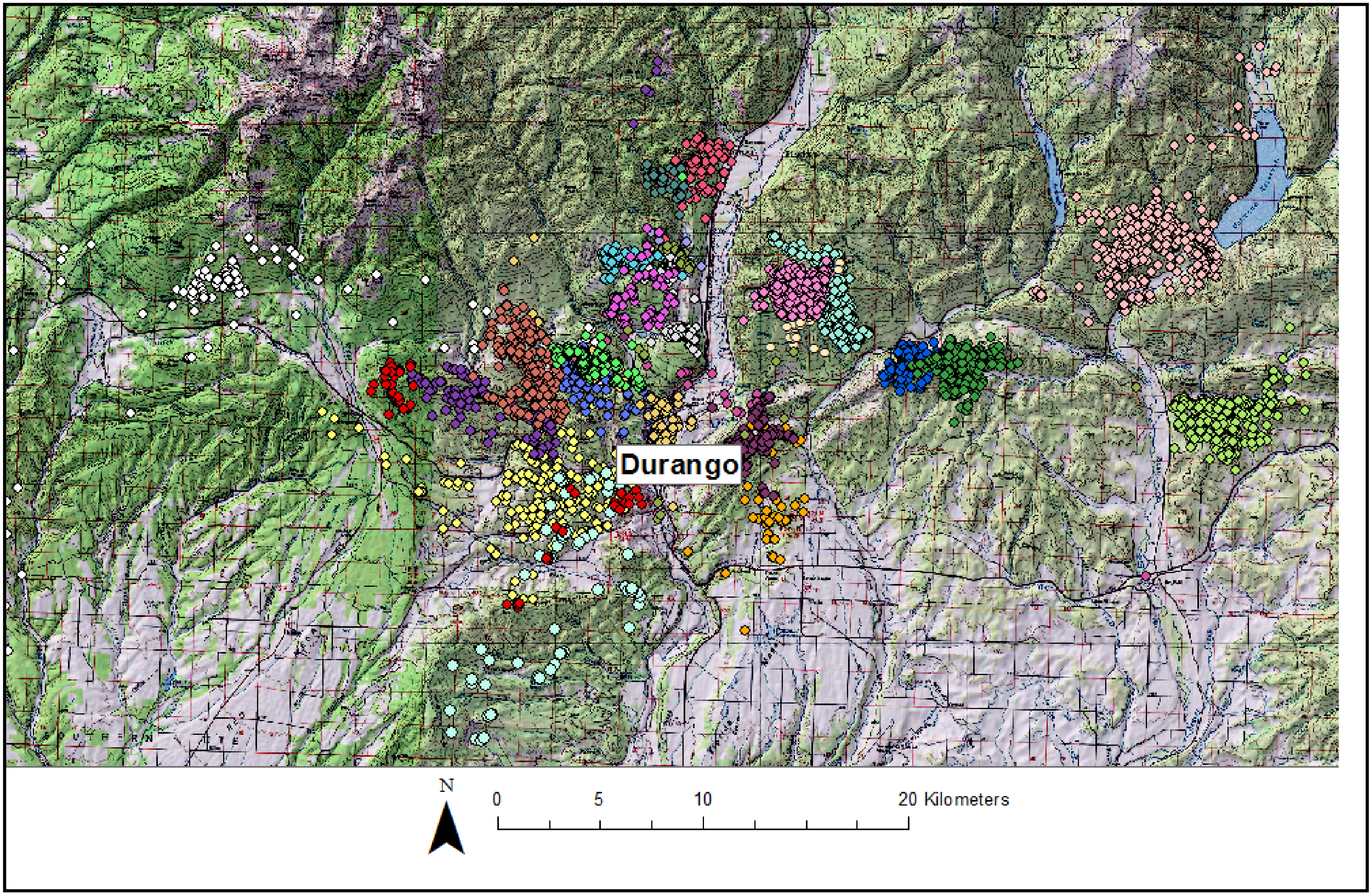


Figure 5. Adult female black bear GPS locations collected between May and September 2011 in the vicinity of Durango, CO (different colored circles represent different individual bears).



APPENDIX I

PROGRAM NARRATIVE STUDY PLAN
FOR MAMMALS RESEARCH
FY 2011-12 – FY 2015-16

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

Black bear exploitation of urban environments: finding management solutions and assessing regional population effects

Principal Investigators
Heather Johnson, Mammals Researcher, Colorado Parks and Wildlife
Chad Bishop, Mammals Researcher Leader, Colorado Parks and Wildlife
Mathew Alldredge, Mammals Researcher, Colorado Parks and Wildlife
John Broderick, Terrestrial Programs Leader, Colorado Parks and Wildlife
Jerry Apker, Carnivore Coordinator, Colorado Parks and Wildlife
Stewart Breck, Research Wildlife Biologist, National Wildlife Research Center
Kenneth Wilson, Professor, Colorado State University
Jon Beckmann, Associate Conservation Scientist, Wildlife Conservation Society

Cooperators
Melissa Reynolds-Hogland, Executive Director, Bear Trust International
Tom Spezze, Southwest Regional Manager, Colorado Parks and Wildlife
Patt Dorsey, Area Wildlife Manager, Colorado Parks and Wildlife

STUDY PLAN APPROVAL

Prepared by:	Heather Johnson	Date:	2/15/2011
Submitted by:	Heather Johnson	Date:	3/12/2011
Reviewed by:	Jon Runge	Date:	3/25/2011
	Chuck Anderson	Date:	3/14/2011
	Danny Martin		4/4/2011
Biometrician:	Paul Lukacs	Date:	3/10/2011
Approved by:	Chad Bishop Mammals Research Leader	Date:	3/10/2011

PROGRAM NARRATIVE STUDY PLAN
FOR MAMMALS RESEARCH

Black Bear Exploitation of Urban Environments: Finding Management Solutions and Assessing Regional Population Effects

A Research Proposal Submitted by:
Heather Johnson, Mammals Researcher, Colorado Parks and Wildlife
Chad Bishop, Mammals Researcher Leader, Colorado Parks and Wildlife
Mathew Alldredge, Mammals Researcher, Colorado Parks and Wildlife
John Broderick, Terrestrial Programs Leader, Colorado Parks and Wildlife
Jerry Apker, Carnivore Coordinator, Colorado Parks and Wildlife
Stewart Breck, Research Wildlife Biologist, National Wildlife Research Center
Kenneth Wilson, Professor, Colorado State University
Jon Beckmann, Associate Conservation Scientist, Wildlife Conservation Society

J. Need

Conflicts among people and black bears (*Ursus americanus*) are increasing nationwide, as the human population grows and urban development expands in and around black bear habitat. In a survey of 41 state wildlife agencies that manage black bears, 30 reported increasing numbers of bear-human conflicts in recent decades (Hristienko and McDonald 2007). While state and federal wildlife agencies are responsible for minimizing bear-human conflicts, they are also responsible for maintaining viable bear populations. Achieving this balance is proving to be difficult, as agencies struggle to find effective management solutions while conflict rates continue to rise, particularly around urban areas (Tavss 2005, Baruch-Mordo et al. 2008). Whether increases in conflicts reflect recent changes in bear population trends or just behavioral shifts to anthropogenic food resources, is largely unknown, as bear population parameters have been exceedingly difficult to estimate (Garshelis and Hristienko 2006).

The primary cause of black bear-human conflicts along the urban-wildland interface has been attributed to the availability of anthropogenic food resources to bears (Fig. 1; Spencer et al. 2007, Beckmann et al. 2008, Greenleaf et al. 2009). Urban areas contain a wealth of reliable, high-calorie foods, in the form of garbage, fruit trees, vegetable gardens, pet food, and bird feeders. As opportunistic foragers, bears readily exploit these resources, resulting in negative interactions with people. These interactions, however, have been highly temporally and spatially variable (Baruch-Mordo et al. 2010), generating uncertainty about the relative influence of natural food availability, conflict management, harvest, and bear population trends on driving annual variation in rates of bear-human conflicts. Without a thorough understanding of the factors that exacerbate nuisance bear behavior, and uncertainty about the relationship between conflict rates and bear dynamics, it has been difficult for wildlife agencies to initiate effective management practices.

Figure 1. Black bear foraging on urban food resources.

Bear use of the urban environment has serious consequences for people, bears, and wildlife managers. For people, bear-human conflicts lead to increased public safety concerns, property damage, and high management costs, while for bears they lead to increased mortality (Beckmann and Berger 2003, Beckmann et al. 2008, Hostetler et al. 2009). For example, in 2007 Colorado data analysis unit (DAU) B-11 reported >500 public safety and property damage conflicts with bears, resulting in >$500,000 expended by the Colorado Division of Wildlife (now Colorado Parks and Wildlife [CPW]) in bear management. This is one of 19 bear DAUs in Colorado, and encompasses the towns of Aspen and Vail, which have been hotspots of bear-human conflicts. That year, in B-11 alone, 44 bears were euthanized for conflict control, 25 were translocated for nuisance behavior, 27 died of road kill, and 30 were legally harvested. Overall, this resulted in >75% of bear mortality attributed to conflicts with people, with unknown consequences for local bear populations. In addition to high management costs, these extreme conflict solutions have critical repercussions for wildlife management agencies. Because managers are obligated to respond to conflict calls, conflict management usurps limited resources and radically reduces those available for other programs. High conflict rates and unpopular management activities (i.e. lethal bear removals) also degrade the credibility of wildlife agencies to the general public, and ultimately reduce the inherent value of black bears in the public eye (Will 1980).

Given expected changes in both human development and climate patterns, bear-human conflicts should rise in the future. As the human population grows, development will continue to permeate bear habitat, creating additional opportunities for conflicts with bears (Kretser et al. 2008). This situation will likely be exacerbated by anticipated changes in annual weather patterns. Drought conditions reduce the availability of natural foods for bears and are associated with an increase in bear-human conflicts (Zack et al. 2003, Baruch-Mordo 2007). Drier, warmer weather, as predicted with climate change, is expected to escalate conflicts with bears in the coming years.

- ***Identify management strategies to reduce bear-human conflicts***

Ultimately, the public will not tolerate ever-increasing conflicts with bears and wildlife agencies must find effective solutions to resolve this pressing problem. Yet, despite the trajectory of increasing black bear-human conflicts, and the severe consequences of those conflicts for both people and bears, best management practices for reducing conflicts remain unclear. Managers commonly employ education (Gore et al. 2008, Baruch-Mordo et al. 2011), aversive conditioning (Beckmann et al. 2004, Mazur 2010), and increased harvest (Treves et al. 2010) to curb conflict rates, yet when the effectiveness of these strategies has been scientifically tested, they have been found to be largely ineffective as implemented. Investigators have suggested alternative approaches for reducing conflicts, such as reducing the availability of anthropogenic food for bears, using models to increase translocation success of nuisance bears, and altering public hunting programs to be spatially or temporally aligned to remove nuisance bears. These techniques may be useful for reducing conflicts, but their efficacy has not been rigorously tested.

Removing anthropogenic food - Given that bears are attracted to anthropogenic food it is believed that eliminating the availability of this resource will dramatically reduce nuisance bear behavior (Peine 2001, Beckmann et al. 2004, Gore et al. 2005, Lyons 2005, Spencer et al. 2007). This strategy has had some success within national parks (Greenleaf et al. 2009), and anecdotally in some communities (Mammoth Lakes CA, Juneau AK, Whistler BC), but no research has ever scientifically tested the costs and benefits of “cleaning up” a town. Given the high price to operationally “bear-proof” a community, municipalities must have definitive evidence that such an effort would significantly decrease conflict activity before initiating major changes to waste storage and collection practices. A thorough, rigorous evaluation of this approach would provide guidance to wildlife agencies and municipalities on the benefit of investing in bear-proofing infrastructure.

Translocation Suitability Modeling - Translocation of nuisance black bears is another common management technique that has been applied with varied results (Rogers 1986, Linnell et al. 1997, Landriault et al. 2009). Often bear translocation decisions are handled by field managers without formal guidance. These professionals are knowledgeable on bear capture and transport techniques, but often lack the flexibility to release bears in other management areas without obtaining approvals from different managers, who are often also experiencing nuisance bear problems. Limitations in selecting a translocation site and the profound movement ability of bears can result in an unsuccessful translocation – where the bear continues to cause conflicts either in its new location or after returning to the capture site. To improve bear management, a strategic translocation approach is needed that applies the best available science on bear habitat quality, conflict potential, and harvest in the selection of bear release sites, while incorporating statewide collaboration among managers.

Targeted Bear Hunting - Wildlife managers frequently increase harvest quotas to reduce bear-human conflicts, but the scientific literature has been equivocal on the effectiveness of this approach (Obbard et al. 1997, Hristienko and McDonald 2007, Treves et al. 2010). Hristienko and McDonald (2007) found that states with higher harvest rates reported fewer conflicts, while other studies evaluating elevated harvest on region-specific spatial scales have concluded either no effect or increases in numbers of conflicts (Obbard et al. 1997, Tavss 2005, Treves et al. 2010). Lack of harvest success has been largely attributed to a mismatch between the timing and location of bear-human conflicts and the timing and location of the hunt, as bear-human conflicts peak during summer months along the urban interface while public hunting occurs during the fall in areas away from development (Treves et al. 2010). As a result, a general increase in harvest likely translates into a reduction in the population at large, not necessarily the removal of nuisance bears. This strategy also inherently assumes that conflict rates reflect bear population sizes, an untested assumption that could potentially lead to overexploitation. To determine whether public harvest can successfully curb conflict rates, hunts need to be spatially and/or temporally coordinated with conflicts as they occur. While this is a strategy that has the potential to reduce management-related conflict mortality, it has yet to be thoroughly evaluated.

- ***Elucidate the dynamics of bear populations along the wildland-urban interface***

To sustainably manage bear populations in the face of a growing human population and changing landscape conditions, it is critical to elucidate the dynamics and drivers of bear populations. Of those factors that influence bear dynamics, the contribution of urban environments is the least understood, most contentious, and has the greatest potential to elicit major population change. While urban environments offer bears the benefit of anthropogenic food, they also inflict the cost of increased mortality from lethal removals, translocations, and other urban factors (i.e. road kills), yielding uncertainty about whether urban environments contribute to the growth or decline of local bear populations. In the two studies that have evaluated bear populations along the wildland-urban interface, bears experienced reduced survival with population-level consequences (Beckmann and Berger 2003, Hostetler et al. 2009). In Florida, Hostetler et al. (2009) found that reduced adult survival caused the “urban” bear population to decrease in size, while the adjacent “wild” population increased, demonstrating the possibility of source-sink dynamics. Meanwhile, in Nevada, Beckmann and Berger (2003) found that bears around urban development were present at higher densities and had greater reproductive rates, but cubs had exceedingly low survival. The researchers suggested that urban areas did not just operate as a sink but as an ecological “trap” as human food attracted bears into town only to lead to their demise and depopulate the adjacent wildlands. While these studies suggest that urban environments may reduce bear populations, many management agencies have assumed that increasing conflicts reflect increasing populations, and that the availability of anthropogenic foods has bolstered demographic rates. So, do urban areas serve as population sources or sinks for bears, and are these impacts static or do they vary under different conditions? Do urban environments operate as ecological traps, attracting bears into habitat that is maladaptive when suitable conditions exist elsewhere?

This question is complicated by the influence of annual variation in natural foods, or environmental stochasticity, on bear behavior and demography. While Beckmann et al. (2004) and McCarthy and Seavoy (1994) report that bears habituated to anthropogenic foods regularly return to them, preliminary data from Aspen, Colorado also suggests that bears increase time spent in urban environments in years of natural food failure and decrease that use when natural foods are readily abundant (Fig. 2; Baruch-Mordo et al. 2010). This pattern implies that bears may avoid urban environments when conditions allow, despite the common assumption that a bear savvy to anthropogenic

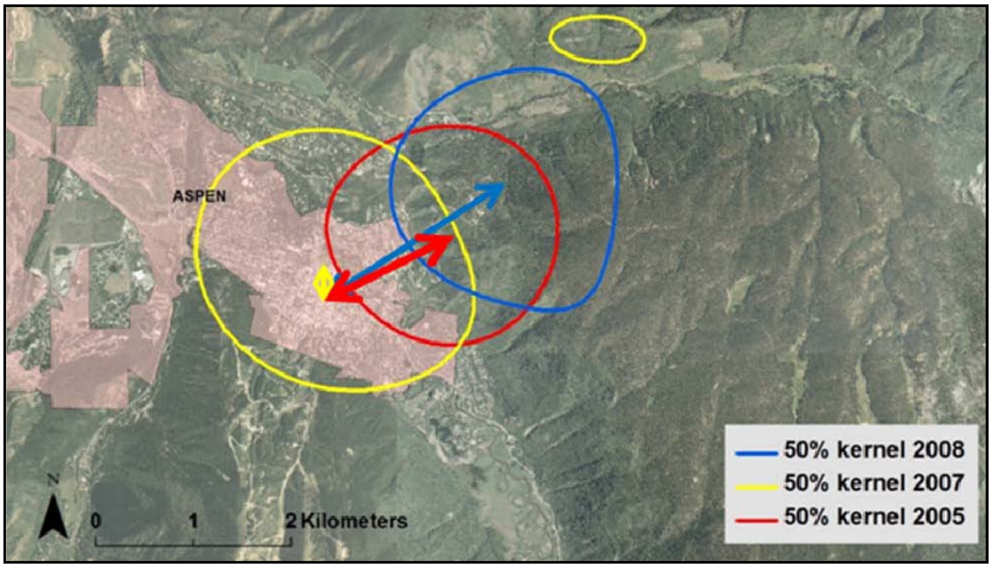


Figure 2. Annual distances between the home range and the center of town for a collared adult female bear in a good natural food year when she had no cubs (2005), a bad natural food year when she had no cubs (2007), and a good natural food year when she had cubs (2008; from Baruch-Mordo et al. 2010).

foods will consistently be a "conflict bear." In a state like Colorado, where human development has effectively permeated almost all tracks of prime bear habitat, the consistency of bear foraging behaviors has key implications for managers. For example, if a small subset of bears consistently causes a majority of the conflicts with people, then the removal of a few key individuals should alleviate the problem. If, however, high rates of conflict coincide with years of natural food failure because a large proportion of the population is seeking alternative food resources, such a removal strategy may be ineffective. Or perhaps a combination of these hypotheses are true, that a subset of bears cause a majority of conflicts until a food-failure "teaches" a new group of bears to use human foods, a pattern that is then repeated in subsequent years, despite natural food conditions. Currently, managers have no information about the proportion of bears that cause conflicts, how the use of urban resources varies among individuals, and how variation in the availability of natural foods drives temporal variation in urban resource-use.

As agencies struggle to define conflict management practices with minimal information on population trajectories, understanding the effects of urban environments on bear demography is critical. Currently, conflict bear management practices (lethal removal and translocations) are based on several inherent assumptions such that 1) there is a correlation between bear-human conflicts and bear population size, 2) conflicts are caused by a few individual bears and their removal will alleviate local problems, and 3) management removals do not significantly influence regional bear dynamics or local harvest opportunities. The validity of these assumptions have yet to be determined, despite their importance for bear management. To develop sustainable management practices for black bears, we must tease apart the relative influences of annual variation in natural bear foods, the availability of anthropogenic foods, conflict-management (lethal removals and translocations) and harvest on bear dynamics and bear-human conflicts.

- ***Develop better tools to monitor the dynamics and drivers of bear populations***

Despite the need to understand the drivers and trends of bear populations to direct management, Garshelis and Hristienko (2006) found that most states have limited data from which to make sound decisions. As a result, state agencies rely on coarse harvest indices that yield little power for detecting population change, and no ability to distill the underlying causes of change. New tools that increase the scientific rigor in monitoring bear populations are desperately needed, so that harvest quotas are biologically-based and designed to meet population objectives.

Recent advances in wildlife statistics have focused on maximizing the use of traditional age/sex-at-harvest data, that which is routinely collected during mandatory harvest reporting. New techniques are available to more effectively extract information about population trend from harvest data (Skalski et al.

2007) and can be augmented with mark-recapture or radio-telemetry data to increase precision in parameter estimation (Fieberg et al. 2010, Johnson et al. 2010). While these approaches hold tremendous promise for supporting biologically-based bear monitoring and management, they are still in their infancy and have yet to be widely implemented. These techniques could be used to identify the value of different data types for tracking populations and to allocate field efforts that most efficiently determine bear population trends across a region of interest. Such information could also be used to inform annual harvest recommendations, elucidate statewide bear dynamics, and reconcile the relationship between bear population trends and conflict rates.

K. Objectives

***1) Test management strategies to reduce bear-human conflicts*.** Bear-human conflicts in urban areas of Colorado echo nationwide trends, as they are increasing in number, frequency, and severity, and have become a high priority management issue in all regions of the state (Baruch-Mordo et al. 2008, Colorado Division of Wildlife unpublished data). In evaluating strategies to reduce conflicts we will:

1A) Experimentally reduce the availability of anthropogenic food to bears in an urban environment to assess the effect on bear-human conflicts and bear behavior.

1B) Develop and evaluate a strategic statewide plan for the translocation of nuisance black bears.

1C) Assess a spatially-targeted bear harvest program designed to reduce the number of nuisance animals.

***2) Determine the influence of urban environments on regional bear population dynamics*.** According to the 2010 U.S. Census, Colorado is the ninth fastest growing state in the country, with associated increases in housing and development (Mackun and Wilson 2011). Despite these trends, there is substantial uncertainty about the effects of urban habitats on bear habitat selection and population dynamics. To elucidate the effects of urban environments on bears we will:

2A) Evaluate the role of annual variation in natural foods on bear movement and resource-use.

2B) Estimate vital rates of urban and wildland bears relative to their resource-use patterns.

2C) Quantify the effects of resource-use, conflict bear management (lethal removals and translocations) and harvest on bear demography.

***3) Develop population and habitat models to support the sustainable management of black bears in Colorado*.** Bear populations have been notoriously difficult to monitor for state wildlife agencies (Garshelis and Hristienko 2006). While meeting other project objectives we will obtain key biological data on bears from which we can:

3A) Use multiple data sources (harvest, DNA mark-recapture, and telemetry data) to develop improved bear population models to guide harvest regulations and inform estimates of population size and trend.

3B) Build regional habitat models to better predict bear density, direct the location of future monitoring efforts, and identify key seasonal resource areas.

L. Expected Results or Benefits

This will be one of the most comprehensive studies to date on bear-human conflicts and the ecology of urban and wildland bears, resulting in crucial information that will be used to manage black bears in Colorado and across the country. Results from this study will:

- Quantify the relative effectiveness of different management strategies (anthropogenic food removal, translocations, and spatially-targeted harvest) for reducing bear-human conflicts, information which will be broadly used by wildlife managers. A reduction in bear-human conflicts will ultimately increase public safety, reduce property damage, decrease wildlife management costs, and gain management credibility for collaborating agencies.

- Identify key differences in the demographic and behavioral patterns of urban and wildland bears to better inform managers about the efficacy of conflict-bear management (lethal removals and translocations) on bear behavior and population dynamics. For example, this study will elucidate the proportion of bears using urban food resources, how that proportion varies due to natural food conditions, the relationship between population performance and conflict rates, and whether "town" serves as a source, sink, or ecological trap.

- Provide robust, data-driven population and habitat models to guide the monitoring and management of bears in Colorado. These models will be used to inform annual harvest regulations, revise statewide estimates of population size and trend, and direct the location of future data collection efforts. Such information will increase the scientific rigor that is applied to the management of bears in Colorado and ensure that management actions to minimize conflicts are consistent with population objectives.

- Advance theory and statistical methodology for linking resource-use patterns of animals to their demographic rates, and ultimately, population growth. To date, habitat and demographic analyses have been largely conducted independently of one another, with a relationship that is often inferred rather than directly measured. Using intensive field population data and GPS collar locations, this study will explicitly link space-use, resource acquisition, and demographic patterns, exploring new conceptual and statistical avenues to elucidate their relationships.

M. Approach

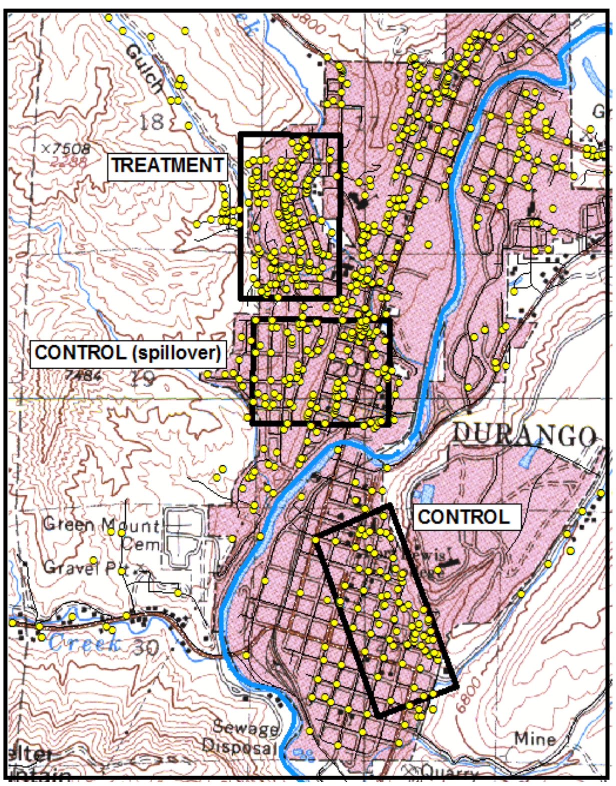


Figure 3. Locations of bear-human conflicts in Durango, Colorado from 2007-2010 are shown with yellow circles and proposed treatment and control areas are represented by black boxes.

1A) Reducing the availability of anthropogenic foods to bears in an urban environment to assess the effect on bear-human conflicts and bear behavior.

To test the effectiveness of reducing the availability of human food on reducing bear-human conflicts, we will conduct a large-scale experiment. We will drastically reduce the accessibility of anthropogenic foods known to attract bears (garbage, bird-feeders, pet food, etc) within a designated 'treatment' area, while simultaneously monitoring comparable 'control' areas where no action will occur. We will perform this experiment in Durango, Colorado, a town with one of the highest bear-human conflict rates in the state as 200-900 conflicts were annually reported between 2007 and 2010 (see Fig. 3). This town has abundant human food resources available to bears and a definitive urban-wildland interface, where urban development is juxtaposed to high quality bear habitat.

Within Durango we will specify a treatment area and 2 control areas focused on the core zones of bear-human conflicts (Fig. 3). Each area will contain approximately 500 structures (residences and businesses) and be roughly the equivalent in size (0.6 km^2). The treatment will occur in northwest section of town, where the highest numbers of conflicts have been reported. In the treatment zone we will provide bear-proof garbage containers, canvass citizens to discourage food availability outside of secure structures (bird-feeders, pet food, etc), conduct daily patrols to remove human food and provide strict enforcement. Our primary control area will occur on the south side of the Animas River (a moderate barrier to bear movement), to facilitate independence among experimental units. Additionally, we will monitor a second "spillover" control area, adjacent to the treatment (north of the river) to measure the influence of the treatment on human behavior in adjacent neighborhoods.

We will monitor treatment and control areas for 1 pre-treatment year and 4 post-treatment years, measuring changes in two key response variables: bear-human conflicts and bear behavior. We will define a "conflict" as any bear-human interaction that results in property damage or a threat to public safety, and compare the number of conflicts and their severity (i.e., a bear in a garbage can versus a bear breaking into a house) between treatment and control areas. Currently, citizens report conflicts to the Colorado Division of Wildlife, the non-profit organization BearSmart Durango, and the city newspaper; we will compile data from all sources for analysis. During the months bears are active, we will also conduct weekly patrols of treatment and control areas. Patrols will occur the morning that residential trash is collected, with an observer recording visible human food resources available to bears and evidence that bears have obtained human foods (i.e. trash cans knocked over and strewn garbage). We will use conflicts from treatment and control areas, and from pre- and post-experiment implementation to measure the effect of bear-proofing on the number and severity of urban bear-human conflicts.

Additionally, we will monitor the influence of the food removal treatment on bear behavior. Bears living on the urban-wildland interface will be collared with global positioning system (GPS) satellite technology (see Objective 2 for capture and collaring details). GPS collars will automatically record the location of each bear every 4 hours, and we will use locations to conduct detailed resource selection analyses (Manly et al. 2002). Using selection indices from "in town" bear locations, we will test for differences in bear use among treatment and control areas (Blomquist and Hunter 2010, Boyce et al. 2010), and whether such use varies over the course of the active bear season. By tracking bear locations relative to our treatment and control sites, we should be able to quantify the benefits of 'cleaning-up' a community for reducing conflicts and modifying bear behavior in urban environments.

1B) Developing and evaluating a strategic plan for the translocation of nuisance black bears.

To develop a strategic, statewide translocation plan, we will use existing information on black bears to map relative habitat quality, resource selection, nuisance potential, and hunter harvest potential across Colorado. These factors will be combined to generate a single layer depicting overall translocation suitability. Nuisance bears will then be allocated to release sites based on this suitability rating and their respective age, sex, reproductive status, management history (i.e. whether the bear was hazed), and distance to capture site. We will compare the success rates of bears translocated using the strategic approach with those of bears translocated following existing procedures, with success defined as a bear that does not engage in new conflict behavior. In all cases, bears will be marked using very high frequency (VHF) or GPS collars to quantify movements and fates following translocation. Additionally, we will augment information from newly captured bears with data from >80 bear translocations that have already occurred in Colorado. Translocation success will be analyzed in a known-fate, time-to-failure framework (Hosmer et al. 2008), where the translocation outcome is modeled as a function of the relevant covariates. If our strategic approach increases translocation success our model will be incorporated into a user-friendly, internet-based tool for wildlife managers to assist with translocation decisions in the field. Specifically, a wildlife manager would enter the bear characteristics and capture site into the internet program and be given a set of optimal release sites. When a bear is released, the wildlife manager would enter the date and location of release into the program, which would be used to update subsequent release-site decisions.

1C) Assessing a spatially-targeted bear harvest strategy designed to reduce nuisance animals.

Managers in southeast Colorado are responding to high numbers of conflicts by increasing harvest rates, however, they are using a novel approach. Rather than implement unit-wide increases in harvest quotas, managers will be spatially targeting hunting pressure in zones adjacent to conflict hotspots. These new harvest management zones are expected to be implemented in fall 2011 with the goal of reducing bear densities in areas bordering the urban interface (see example in Fig. 4). We will measure the success of this strategy for reducing conflicts in the communities of Colorado Springs, Pueblo, and Colorado City; cities which report hundreds of conflicts/year. Using nuisance reports from pre- and post-implementation of this strategy, we will compare the number of conflicts, conflict severity, and numbers of translocated and euthanized bears. Colorado Division of Wildlife has recorded these metrics for the past 16 years, and will continue to collect this data in the future. In addition, we will compare harvested numbers of bears in the DAUs in which these cities are located (B2 and B7) pre- and post-implementation of the new strategy, to determine its effect on meeting annual bear harvest objectives. With ≥3 replications of this approach (around different urban centers) we will examine whether a spatially-targeted harvest approach, executed by the public, significantly decreases urban bear conflicts while increasing hunting opportunities.

2A) Evaluating the role of annual variation in natural foods on bear movement and resource-use.

While anthropogenic food is consistently available to bears in urban environments, the availability of natural foods can dramatically fluctuate based on annual patterns in temperature and precipitation. For example, late frosts and summer droughts can cause failures in the local berry and acorn resources, forcing bears to expand their search for calories and potentially increase their use of urban environments (Zach et al. 2003, Baruch-Mordo 2007, Baruch-Mordo et al. 2010). To determine the influence of annual variation in natural foods, or environmental stochasticity, on bear habitat-use we will evaluate location data from GPS collared adult females.

From June through September, we will capture bears using culvert traps, box traps and Aldrich snares following the techniques described in Jonkel (1993, Appendix 2). Captured adult famles will be fitted with a Vectronics collar with a degradable spacer, ear-tagged, weighed, and measured for morphometric characteristics. Additionally, we will pull a tooth for age determination and obtain a blood sample for DNA. See Detailed capture and handling protocols are provided in Appendix 2. Each year we will attempt to maintain a sample of 50 collared females, with approximately half collared in and around the town of Durango (La Plata county), and the other half in the surrounding wildlands (La Plata, Hinsdale, and Archueta counties). This collaring strategy

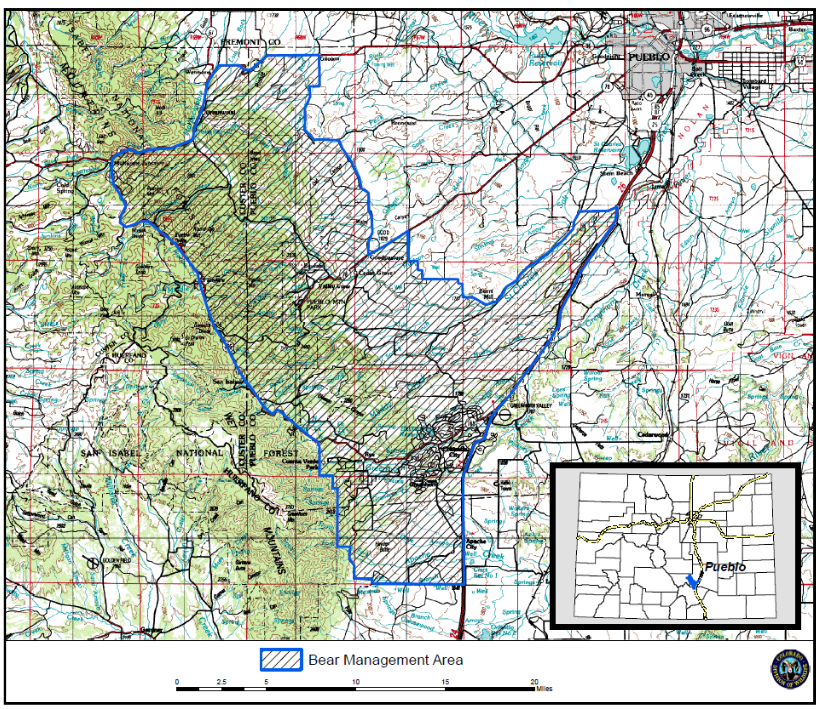


Figure 4. The hatched-blue area represents the proposed bear conflict harvest zone on the wildland-urban interface near Pueblo, CO.

will allow us to track a range of resource-selection patterns of bears, from those that are heavily dependent on human foods to those that rely exclusively on natural foods, quantifying the proportion of bears using urban resources and their frequency of urban habitat-use.

We will also use GPS location data to examine resource selection and movement patterns in response to temporal variation in natural food availability (see Figs. 2 and 6). To do this we will partition location data into weekly intervals and use a repeated-measures resource selection function (RSF) approach (Manly et al. 2002, Börger et al. 2006, Kie et al. 2010, McLoughlin et al. 2010). We will determine those factors that drive temporal resource selection, evaluating the availability of natural foods, changes in weather patterns, distance to town, reproductive status, and conflict management history (i.e. whether the animal was hazed, trapped, etc). We will also evaluate the influence of these covariates on the size of bear home-ranges and their rates of seasonal movements (Jonsen et al. 2005, Morales et al. 2010). Additionally, we will employ a time-to-failure analysis to examine those covariates (listed above) that predict when a bear will “fail” and use urban resources (Cook and Lawless 2007, Hosmer et al. 2008). We will work with colleagues in the Remote Sensing/Ecology program at Colorado State University to develop satellite image signatures to track annual vegetation productivity for natural bear foods. To quantify weather patterns, we will use PRISM spatial data (http://www.prism.oregonstate.edu/) which interpolates monthly temperature and precipitation patterns across landscapes, accounting for elevation and topography. All covariates related to human development will be extracted from existing CPW digital data layers. Ultimately, these analyses will not only allow us to summarize patterns of movement and resource-use, but elucidate the underlying drivers of bear behavior, providing insight for the design of better management strategies to minimize conflicts.

2B) Estimating the vital rates of urban and wildland bears relative to their resource-use patterns.

To assess differences in the population dynamics of those bears that use urban food resources versus those that do not, we will track the demographic trends of female bears collared in adjacent urban and wildland habitats. We are concerned with the vital rates (survival and reproductive rates) of female bears, as they represent the reproductive segment of the population and should provide reliable inference to the population at large. We will monitor ~50 GPS collared bears each year for their annual survival, fecundity, and the survival of their cubs; collecting this data for a total of 5 years. Survival of adult females will be tracked with real-time GPS locations, and all mortalities will be immediately investigated. To estimate annual fecundity and cub survival, we will inspect the winter natal dens of collared females for the presence of newborn and yearling cubs. If a newborn cub is observed with an adult female in year *t*, but is not observed in the den with that female in year *t+1*, we will assume the cub is dead (Obbard and Howe 2008).

Based on power analyses, our target sample size and study timeframe should allow us to detect biologically significant differences among the demographic rates of bears that use urban and wildland habitats, while still being logistically feasible (Fig. 5). In conducting power analyses to determine samples

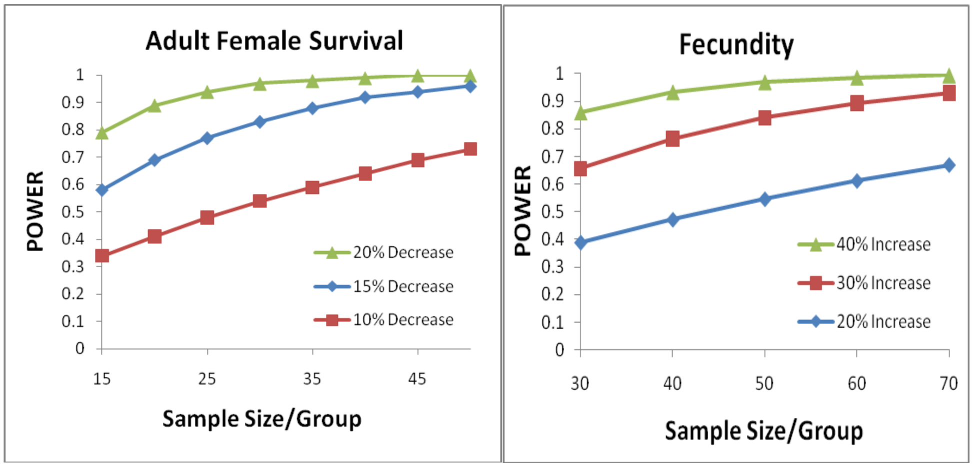


Figure 5. Power to detect significant differences (alpha = 0.05) in vital rates between bears using urban habitats and those that do not, based on the sample sizes of each group.

sizes for adult female survival, we assumed a baseline survival rate of 0.90 with a standard deviation of 0.20 (Beck 1991, Koehler and Pierce 2005, Obbard and Howe 2008, Hostetler et al. 2009). The only study that has measured differences in adult female survival between urban and wildland bears found a 20% reduction in the survival of "urban bears" (Hostetler et al. 2009). With a sample of ~50 collared bears/year (~25 in urban habitat and ~25 in wildland habitat) for 5 years, we should have power ≥ 0.8 to detect at least a 15% difference in the survival of those bears that use urban habitats and those that do not. Similarly, assuming that adult female fecundity is 0.44 (Beck 1991) with a standard deviation of 0.25 (Hebblewhite et al. 2003), we expect to observe >150 cubs in dens over the course of the study. This number will yield power ≥ 0.9 to detect a significant difference of ≥30% in the fecundity rates of urban and wildland bears; Beckmann and Berger (2003) reported >60% difference in fecundity rates of bears in these different habitats.

Using GPS location data, we will model the demographic rates of individual bears as a continuous function of how they use urban and wildland habitat, explicitly linking habitat-use to population performance (McLoughlin et al. 2007, Gaillard et al. 2010). To estimate annual adult female survival we will use Cox proportional hazard models (Therneau and Grambsch 2000, Murray 2006), which allow for staggered entry, continuous-time data collection, and the evaluation of different covariates. We will use multinomial and binomial logistic regression to model fecundity and cub survival rates, respectively (Obbard and Howe 2008), which will rely on annual counts of juvenile bears in winter dens. In these models, we will insert random effects to account for fecundity rates of individual females measured over multiple years, and for the survival of cubs born in the same litter. With all vital rate models we will use GPS data to specifically test whether time in urban habitats, annual availability of natural foods, or density of urban development influences bear population parameters (McLoughlin et al. 2007, Gaillard et al. 2010). Annual variation in natural foods will be tracked with satellite imagery (Pettorelli et al. 2005) and information on urban development will be obtained from existing digital data layers. We will also test for the covariate effects of year (to account for variation in natural foods), age (for adult survival and fecundity models), season (for adult survival models) and reproductive status (for adult survival models). We will build a set of *apriori* candidate models for each vital rate from our covariate set, and identify the best models using model selection (Burnham and Anderson 2002). Additionally, for adult female bears, we will evaluate cause-specific mortality. We will use competing risks analyses (Heisey and Patterson 2006) to examine the differential sources of mortality and their relative importance in urban and wildland habitats.

2C) Quantifying the relative influence of resource-use, conflict bear management practices (lethal removals and translocations) and harvest on bear demography.

Vital rate means and variances measured from Objective 2B will then be inserted into stage-structured matrix projection models (Caswell 2001, Morris and Doak 2002) to assess differences in the population growth rate among those bears that use urban food resources ("urban") and those that do not ("wildland"; Hostetler et al. 2009). The wildland model will serve as a baseline, representing bear demography in the absence of urban food or conflict management, and in the presence of natural food variability. Of those bears that use urban environments, we will then simulate a suite of scenarios to tease apart the inherent effects of anthropogenic food, management-related conflict mortality (i.e. lethal removals and translocations), other urban-related mortality (i.e. road kill, electrocution, etc), and harvest on vital rates, and ultimately, population growth (Fig. 6). First, we will project a matrix with vital rates from bears that used town to estimate the actual (or realized) growth rate. This model will allow us to compare harvest rates among bears that use urban versus wildland habitats. Second, we will quantify the inherent benefit of anthropogenic food for bears *in the absence of all harvest and urban conflict mortality*. To do this we will re-calculate adult female survival censoring all harvest and conflict-related deaths/removals (management and non-management related). We will use the updated values, along with cub survival rates from wildland bears (conservatively assuming that in the absence of human-related mortality "town" cubs would have survival ≥ than those in the wild) to re-project population growth rates (Hostetler et al. 2009). This will allow us to assess the inherent, but hypothetical, benefit of human food on local bear demography without urban-related mortality. Third, we will isolate the impacts of conflict management removals (lethal removals and translocations) on bear populations. For this scenario, we will re-calculate adult and cub survival by censoring all management-related removals (but maintaining harvest and non-management mortality), and insert these new values into a projection matrix. This will allow us to estimate the change in population growth associated with current conflict management practices and estimate their cumulative impacts on local populations. Additionally, for all scenario matrices, we will identify those vital rates with the highest elasticity and those driving overall growth rates (Wisdom et al. 2000, Caswell 2001). This will allow us to better understand how patterns of population growth respond to vital rate-specific changes in natural and human food availability, conflict management, and harvest.

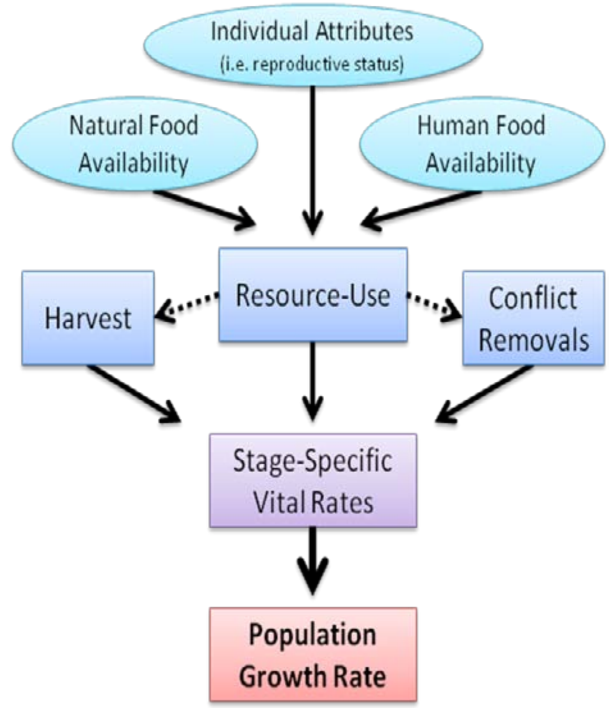


Figure 6. Conceptual model depicting 1) the different factors that affect bear resource-use, 2) that resource-use influences bear susceptibility to harvest and conflict removals, and, 3) how the combined impacts of resource-use, harvest, and conflict removals determine stage-specific vital rates, and ultimately, population growth.

In addition to tracking the drivers of individual bear vital rates, we will also assess changes in population density. Density will be estimated from hair-snare grids using mark-recapture techniques (Woods et al. 1999, Mowat and Strobeck 2000). Bear DNA will be extracted and genotyped from hair to effectively "mark" individual bears and the pattern of "recaptured" animals will be used to estimate population size. We will set up one hair-snare grid around the town of Durango and another grid in adjacent wildland habitat, monitoring each grid for 4 years (Fig. 7). Each grid will be composed of 36 cells that are 4km x 4km in size. We will collect bear hair from two different sampling sources within each cell, a baited scent trap and a natural rub tree. Baited scent stations will be surrounded by barbed wire to collect hair from bears as they climb around the wire to investigate the bait. We will use multiple bait scents, randomly assigned to different traps each sampling occasion to maintain a high hair recapture rate. Additionally, we will attempt to identify 1 natural rub tree/cell. Rub trees will not be baited, but affixed with a piece of barbed wire to facilitate hair collection. By collecting hair from both these sources (baited traps and rub trees) we should increase recapture rates and reduce individual heterogeneity in capture response (Boulanger et al. 2008). We will conduct 6 sampling occasions/summer (mid-June through July), checking baited traps and rub trees for hair once/week, and re-baiting scent traps. At the end of the sampling season hair samples will be sent to the Wildlife Genetics International Laboratory for microsatellite genotyping. We will use genotype data to estimate density using a spatially-explicit Bayesian model for open populations (Gardner et al. 2009, Gardner et al. 2010). Additionally, we use the genotype data to interpolate a spatial density surface that will allow us to identify habitat covariates associated with high and low bear densities in both urban and wildland sampling grids.

We will compare densities among sites to determine whether the availability of human food increases bear density adjacent to town (Beckmann and Berger 2003). Over the course of the study we will also estimate the annual variability in density among urban and wildland habitats. This will elucidate whether densities in each habitat type vary in association with natural food production, and the reliability of the hair-snare technique for "snapshot" density measures for statewide monitoring purposes. Additionally, hair-snare grids will allow us to infer movement of bears from wildland to urban habitats. For example, if high bear densities are maintained along the urban interface despite negative population growth rates (as projected from individual vital rates), it will be suggestive that bears are moving into

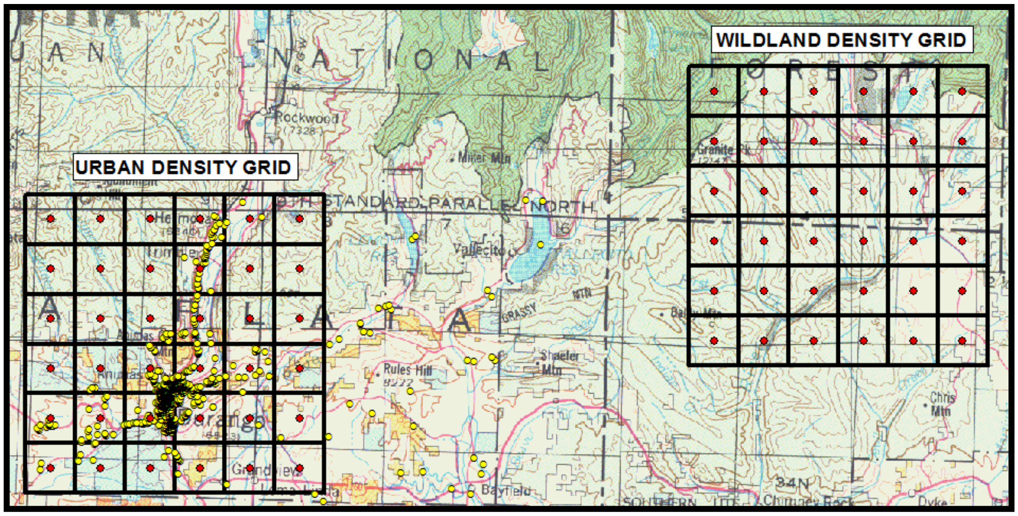


Figure 7. Location of urban and wildand DNA hair snare grids. Red circles represent sampling baited traps sites within each cell. Yellow circles represent conflicts reported around Durango, 2007-2010.

town from adjacent wildlands (Robinson et al. 2008). Ultimately, using data on both the vital rates from collared animals and density from hair-snares, we will be able to discriminate whether town serves as source or sink for local bear populations, whether this influence varies under different environmental conditions.

3A) Using multiple data sources to build bear population models to inform annual harvest management and elucidate population trajectories.

We will use individual vital rate and mark-recapture data from Objective 2, in conjunction with annual harvest data, to develop more precise population models for the management of black bears in Colorado. Currently, it is mandatory for hunters to report all harvested bears to Colorado Division of Wildlife and submit a tooth for age estimation (Willey 1974, Stoneberg and Jonkel 1996). Combining the three different data types we will have available on bears around Durango (sex/age-at-harvest, individual demography from collared bears, and mark-recapture data) we will first estimate baseline population parameters, dramatically increasing precision in those estimates (Fieberg 2010, Johnson et al. 2010). Then, we will identify the value of each data type (based on sample size and years of data collection) for modeling bear dynamics according to the precision required for making management decisions. This information will be used to generate a parsimonious model that adequately describes changes in bear population trends while minimizing unnecessary field data. In doing this, we hope to provide guidance to the Colorado Division of Wildlife on the allocation of field efforts for effectively monitoring populations, and allow managers to set biologically-based harvest quotas. We will test the accuracy and effectiveness of population models using data collected around Durango, Trinidad, and Aspen (all areas where multiple bear data types are available), and simulated data, allowing us to further validate model structure and precision (Fieberg et al. 2010). These models will be used to inform annual harvest regulations, update population trajectories, and revise statewide estimates of population size.

3B) Developing regional habitat models from GPS collar location data.

We will use the wealth of GPS collar data that we will collect around Durango and which is available from ~40 bears around Aspen (CPW, unpublished data) to build detailed regional habitat models. Currently, bear habitat models for Colorado are derived from the perceived value of different vegetation types, as determined by Colorado Division of Wildlife managers. We hope to enhance regional models through analyses of thousands of bear GPS locations, using additional information on elevation, topography, satellite measures of annual primary productivity, and human development variables (i.e. road density, distance to town, etc). We will use a mixed-effects RSF approach to identify habitat characteristics associated with bear occupancy, applying a use-availability design (Manly et al. 2002, Gillies et al. 2006). We will specifically identify second-order habitat selection (Johnson 1980), the conditions under which bears establish their home-ranges, using established model selection procedures (Burnham and Anderson 2002). To test the predictive power of the habitat model, we will use cross-validation (Boyce et al. 2002) and then map expected relative probabilities of selection across the landscape. Additionally, we will use harvest locations and bear sightings from other geographic regions to test the validity of our models for application in other parts of the state. These data-driven habitat models can then be used to provide better estimates of statewide bear density, design more efficient monitoring strategies (Allen et al. 2008), and to identify critical seasonal resources and movement corridors for bears.

N. Location

Data used to meet different objectives of this study will be obtained from various parts of Colorado. The anthropogenic food removal experiment (Objective 1A) and the demography/resource-use portion of the study (Objective 2A-C) will be conducted in the vicinity of Durango, Colorado (La Plata, Hinsdale, and Archuleta counties). Durango was selected as the focal urban environment based on several factors including a history of high bear-human conflicts (Fig. 3), a good record of recent conflict reporting, the feasibility of conducting the food-removal experiment (based on city waste management practices), and minimal city-wide bear-proofing infrastructure. Tracking bear population parameters in this region will require that trapping and hair-snaring will occur on a combination of USFS, BLM, state, city, and private lands.We will test the effectiveness of a spatially-targeted harvest program along the southern Front Range (Objective 1C), and opportunistically throughout the state as changes occur in harvest management. The strategic translocation model will be developed on a statewide basis (Objective 1B), along with population and habitat models (Objectives 3A-B).

O. Schedule of Work

Activity	Timeline
Trap and collar bears	Summer 2011-2015
Monitor bear survival	Summer 2011-2016
Conduct DNA hair-snare grids	Summer 2011-2014
Genotype hair samples	Fall 2011-2014
Distribute bear-resistant containers	Spring 2012
Monitor human-food-removal experiment	Spring-Fall 2012-2015
Translocation modeling and evaluation	Summer-Fall 2012-2015
Implement spatially-targeted harvest program	Fall 2012
Evaluate spatially-targeted harvest program	2012-2015
Conduct winter den checks (reproduction)	Winter 2012-2016
Estimate population parameters (individual vital rates, and population density)	Winter 2012-2016
Develop and test population and habitat models	Winter 2013-2017

P. Estimated Costs

NEED	COST/UNIT	FY2011-12	FY2012-13	FY2013-14	FY2014-15	FY2015-16	TOTAL
INDIVIDUAL DEMOGRAPHY (5 Yrs)							
50 GPS Collars (10 Purchased)	$4,800	$192,000					$192,000
GPS Battery Replacements (2/ea)	$300			$30,000			$30,000
Telemetry Receivers/Ant (3)	$695	$2,085					$2,085
Traps (20)	$1,000	$20,000					$20,000
Snares (10)	$100	$1,000					$1,000
Jab Stick (1)	$800	$800					$800
Misc Equipment		$10,000	$5,000	$5,000	$5,000	$5,000	$30,000
Snowmobiles	3 & Maintenance	$20,000	$5,000	$5,000	$5,000	$5,000	$40,000
Field Technicians							
Spring Trapping Yr 1 (3.5mo)	TechI (3)/TechII (1)	$37,209					$37,209
Spring Trapping Yrs 2-5 (3.5 mo)	TechI (1)/TechII (1)		$19,301	$19,301	$19,301	$19,301	$77,204
Winter Dens Yrs 1-5 (3 mo)	TechI (3)/TechII (1)	$31,984	$31,984	$31,984	$31,984	$31,984	$159,920
2 DNA HAIR-SNARE GRIDS (4 Yrs)							
Field Equipment		$1,200	$250	$250	$250		$1,950
Field Technicians (2.5 mo)	TechI (2)	$12,792	$12,792	$12,792	$12,792		$51,168
Genetic Analysis	$20,000/Grid	$40,000	$40,000	$40,000	$40,000		$160,000
GARBAGE EXPERIMENT (4 Yrs)							
Bear-resistant containers	Residental/Commerical		$250,000				$250,000
Field Technicians (5 mo)	TechI (1)		$12,792	$12,792	$12,792	$12,792	$51,168
TRANSLOCATION PLAN (4 Yrs)							
Store-on-Board GPS Collars (50)	$1,500		$75,000				$75,000
Web Programmer (1 mo)	Programmer (1)				$3,200		$3,200
PROJECT TOTAL		**$369,070**	**$452,119**	**$157,119**	**$130,319**	**$74,077**	**$1,182,704**

Q. Related Federal Projects
There are no related federal projects.

R. Literature Cited

Allen, J.R., L.E. McInenly, E.H. Merrill, and M.S. Boyce. 2008. Using resource selection functions to improve estimation of elk population numbers. Journal of Wildlife Management 72:1798-1804.

Baruch-Mordo, S. 2007. Black-bear human conflicts in Colorado: spatiotemporal patterns and predictors. Thesis, Colorado State University, Fort Collins, Colorado.

Baruch-Mordo, S., S.W. Breck, K.R. Wilson, and D.M. Theobald. 2008. Spatiotemporal distribution of black bear-human conflicts in Colorado, USA. Journal of Wildlife Management 72:1853-1862.

Baruch-Mordo, S., S.W. Breck, K.R. Wilson, and J. Broderick. 2011. The carrot or the stick? Evaluation of education and enforcement as management tools for human-wildlife conflicts. Plos One 6: e15681.

Baruch-Mordo, S., K.R. Wilson, D. Lewis, J. Broderick, J. Mao, and S.W. Breck. 2010. Roaring Fork Valley urban black bear ecology study: progress report to the Colorado Division of Wildlife. Contact Sharon Baruch-Mordo for copy. Email: sharonb_m@yahoo.com

Beck, T.D.I. 1991. Black bears of west-central Colorado. Technical Publication No. 39, Colorado Division of Wildlife, Colorado.

Beckmann, J.P., and J. Berger. 2003. Using black bears to test ideal-free distribution models experimentally. Journal of Mammalogy 84:594-606.

Beckmann, J.P., L. Karasin, C. Costello, S. Matthews, and Z. Smith. 2008. Coexisting with black bears: perspectives from four case studies across North America, WCS Working Paper No. 33, Wildlife Conservation Society, New York, New York.

Beckmann, J.P., C.W. Lackey, and J. Berger. 2004. Evaluation of deterrent techniques and dogs to alter behavior of “nuisance” black bears. Wildlife Society Bulletin 32: 1141-1146.

Blomquist, S.M., and M.L. Hunter. 2010. A multi-scale assessment of amphibian habitat selection: wood frog response to timber harvesting. Ecoscience 17:251-264.

Boulanger, J., K.C. Kendall, J.B. Stetz, D.A. Roon, L.P. Waits, and D. Paetkau. 2008. Mulitple data sources improve DNA-based mark-recapture population estimates of grizzly bears. Ecological Applications 18:577-589.

Börger, L., N. Franconi, G. De Michele, A. Gantz, F. Meschi, and A. Manica. 2006. Effects of sampling regime on the mean and variance of home range estimates. Journal of Animal Ecology 75:1393-1405.

Boyce, M.S., J. Pitt, J.M. Northrup, A.T. Morehouse, K.H. Knopff, B. Dristesu, and G.B. Stenhouse. 2010. Temporal autocorrelation functions for movement rates from global positioning system radiotelemetry data. Philosophical Transactions of the Royal Society Series B 365:2213-2219.

Boyce, M.S., P.R. Vernier, S.E. Nielsen, and F.K.A. Schmiegelow. 2002. Evaluating resource selection functions. Ecological Modelling 157:281-300.

Burnham, K.P., and D.R. Anderson. 2002. Model selection and inference: a practical information-theoretic approach. Springer-Verlag, New York, New York.

Caswell, H. 2001. Matrix population models: construction, analysis, and interpretation. Second Edition, Sinauer Associates, Sunderland, Massachussetts.

Cook, R.J., and J.F. Lawless. 2007. The statistical analysis of recurrent events. Springer Science and Business Media, New York, New York.

Fieberg, J.R., K.W. Shertzer, P.B. Conn, K.V. Noyce, and D.L. Garshelis. 2010. Integrated population modeling of black bears in Minnesota: implications of monitoring and management. Plos One 5:e12114.

Gaillard, J.-M., M. Hebblewhite, A. Loison, M. Fuller, R. Powell, M. Basille, and B. Van Mooter. 2010. Habitat-performance relationships: finding the right metric at a given spatial scale. Philosophical Transactions of the Royal Society Series B 365:2255-2265.

Gardner, B., J. Reppucci, M. Lucherini, and J.A. Royle. 2010. Spatially explicit inference for open populations: estimating demographic parameters from camera trap studies. Ecology 91:3376-3383.

Gardner, B., J.A. Royle, M.T. Wegan, R.E. Rainbolt, and P.D. Curtis. 2009. Estimating black bear density using DNA data from hair snares. Journal of Wildlife Management 74:318-325.

Garshelis, D.L., and H. Hristienko. 2006. State and provincial estimates of American black bear numbers versus agency assessments of population trend. Ursus 17:1-7.

Gillies, C.S., M. Hebblewhite, S.E. Nielsen, M.A. Krawchuk, C.L. Aldridge, J.L. Frair, D.J. Saher, C.E. Stevens, and C.L. Jerde. 2006. Application of random effects to the study of resource selection by animals. Journal of Animal Ecology 75:887-898.

Gore, M.L., W.F. Siemer, J.E. Shanahan, D. Schuefele, and D.J. Decker. 2005. Effects on risk perception of media coverage of a black bear-related human fatality. Wildlife Society Bulletin 33:507-516.

Gore, M.L., B.A. Knuth, C.W. Scherer, and P.D. Curtis. 2008. Evaluating a conservation investment designed to reduce human-wildlife conflicts. Conservation Letters 1:136–145.

Greenleaf, S.S., S.M. Matthews, R.G. Wright, J.J. Beecham, and H.M. Leithead. 2009. Food habitat of American black bears as a metric for direct management of human-bear conflict in Yosemite Valley, Yosemite National Park, California. Ursus 20:94-101.

Hebblewhite, M., M. Percy, and R. Serrouya. 2003. Black bear (*Ursus americanus*) survival and demography in the Bow Valley of Banff National Park, Alberta. Biological Conservation 112:415-425.

Heisey, D.M., and B.R. Patterson. 2006. A review of methods to estimate cause-specific mortality in the presence of competing risks. Journal of Wildlife Management 70:1544-1555.

Hosmer, D.W., S. Lemeshow, and S. May. 2008. Applied survival analysis: regression modeling of time to event data. Jon Wiley and Sons, Hoboken, New Jersey.

Hostetler, J.A., J.W. McCown, E.P. Garrison, A.M Neils, M.A. Barrett, M.E. Sunquist, S.L. Simek, and M.K. Oli. 2009. Demographic consequences of anthropogenic influences: Florida black bears in north-central Florida. Biological Conservation 142:2456-2463.

Hristienko, H., and J.E. McDonald Jr. 2007. Going into the 21st century: a perspective on trends and controversies in the management of the American black bear. Ursus 18:72-88.

Johnson, D.H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61:65-71.

Johnson, H.E, L.S. Mills, J.D. Wehausen, and T.R. Stephenson. 2010. Combining ground count, telemetry, and mark-resight data to infer population dynamics in an endangered species. Journal of Applied Ecology 47:1083-1093.

Jonkel, J.J. 1993. A manual for handling bears for managers and researchers. Office of Grizzly Bear Recovery, United States Fish and Wildlife Service, Missoula, Montana.

Jonsen, I.D., J.M. Flemming, and R.A. Myers. 2005. Robust state-space modeling of animal movement data. Ecology 86:2874-2880.

Kie, J., J. Matthiopoulos, J. Fieberg, R.A. Powell, F. Cagnacci, M.S. Mitchell, J.-M. Gaillard, and P.R. Moorcroft. 2010. The home-range concept: are traditional estimators still relevant with modern telemetry technology? Philosophical Transactions of the Royal Society Series B 365:2221-2231.

Koehler, G.M., and D.J. Pierce. 2005. Survival, cause-specific mortality, sex, and ages of American black bears in Washington State, USA. Ursus 16:157-166.

Kretser, H., P.J. Sullivan, and B.A. Knuth. 2008. Housing density as an indicator of spatial patterns of reported human-wildlife interactions in Northern New York. Landscape and Urban Planning 84:282-292.

Landriault, L.J., G.S. Brown, J. Hamr, and F.F. Mallory. 2009. Age, sex and relocation distance as predictors of return for relocated nuisance black bears *Ursus americanus* in Ontario, Canada. Wildlife Biology 15:155–164.

Linnell, J.D.C., R. Aanes, and J.E. Swenson. 1997. Translocation of carnivores as a method for managing problem animals: a review. Biodiversity and Conservation 6:1245–1257.

Lyons, A.J. 2005. Activity patterns of urban American black bears in the San Gabriel Mountains of southern California. Ursus 16: 255-262.
Mackun, P., and S. Wilson. 2011. Population distribution and change: 2000 to 2010. U.S. Census Bureau, 2010 Census Briefs: http://www.census.gov/prod/cen2010/briefs/c2010br-01.pdf
Manly, B.F.J., L.L. McDonald, D.L. Thomas, T.L. McDonald, and W.P. Erickson. 2002. Resource selection by animals; statistical design and analysis for field studies. Second Edition. Kluwer Academic Publishers, Boston, Massachussetts.
Mazur, R.L. 2010. Does aversive conditioning reduce human-black bear conflict? Journal of Wildlife Management 74:48-54.
McCarthy, T., and R. Seavoy. 1994. Reducing non-sport losses attributable to food conditioning: human and bear behavior modification in an urban environment. International Conference on Bear Research and Management 9:75-84.
McLoughlin, P.D., J.-M. Gaillard, M.S. Boyce, C. Bonenfant, F. Messier, P. Duncan, D. Delorme, B. Van Moorter, S. Said, and F. Klein. 2007. Lifetime reproductive success and composition of the home range in a large herbivore. Ecology 88:3192-3201.
McLoughlin, P.D., D.W. Morris, D. Fortin, E. Vander Wal, and A.L. Contasti. 2010. Considering ecological dynamics in resource selection functions. Journal of Animal Ecology 79:4-12.
Morales, J.M., P.R. Moorcroft, J. Matthiopoulos, J.L. Frair, J.G. Kie, R.A. Powell, E.H. Merrill, and D.T. Haydon. 2010. Building the bridge between animal movement and population dynamics. Philosophical Transactions of the Royal Society Series B 365:2289-2301.
Morris, W.F., and D.F. Doak. 2002. Quantitative Conservation Biology: Theory and Practice of Population Viability Analysis. Sinauer, Sunderland, Massachussetts.
Mowat, G., and C. Strobeck. 2000. Estimating population size of grizzly bears using hair capture, DNA profiling, and mark-recapture analysis. Journal of Wildlife Management 64:183-193.
Murray, D.L. 2006. On improving telemetry-based survival estimation. Journal of Wildlife Management 70:1530-1543.
Obbard, M.E., and E.J. Howe. 2008. Demography of black bears in hunted and unhunted areas of the boreal forest of Ontario. Journal of Wildlife Management 72:869-880.
Obbard, M.E., B.A. Pond, and E.J. Howe. 1997. Analysis of relationships among black bear nuisance activity, food availability, and harvest in Ontario. Nuisance Bear Review Committee, Appendix 10. Ministry of Natural Resources, Ontario, Canada.
Peine, J.D. 2001. Nuisance bears in communities: Strategies to reduce conflicts. Human Dimensions of Wildlife 6:223-237.
Pettorelli, N., J.O. Vik, A. Mysterud, J.-M. Gaillard, C.J. Tucker, and N.C. Stenseth. 2005. Using the satellite-derived NDVI to assess ecological responses to environmental change. Trends in Ecology and Evolution 20:503-510.
Robinson, H.S., R.B. Wielgus, H.S. Cooley, and S.W. Cooley. 2008. Sink populations in carnivore management: cougar demography and immigration in a hunted population. Ecological Applications 18:1028-1037.
Rogers, L.L. 1986. Effects of translocation distance on frequency of return by adult black bears. Wildlife Society Bulletin 14:76–80.
Skalski, J.R., R.L. Townsend, and G.A. Gilbert. 2007. Calibrating statistical population reconstruction methods using catch-effort and index data. Journal of Wildlife Management 71:1309-1316.
Spencer, R.D., R.A. Beausoleil, and D.A. Martorello. 2007. How agencies respond to human–bear conflicts: a survey of wildlife species in North America. Ursus 18: 217–229.
Stoneberg, R.P., and C.J. Jonkel. 1966. Age determination of black bears by cementum layers. Journal of Wildlife Management 30:411-414.
Tavss, E.A. 2005. Correlation of reduction in nuisance black bear complaints with implementation of (a) a non-violent program and (b) a hunt. Final Report, New Jersey Fish and Game Council, New Jersey Public Hearing on the Comprehensive Black Bear Management Policy, New Jersey.
Therneau, T.M., and P.M. Grambsch. 2000. Modeling survival data: extending the Cox model. Springer,

New York, New York.
Treves, A., K.J. Knapp, and D.M. MacFarland. 2010. American black bear nuisance complaints and hunter take. Ursus 21:30-42.
Will, G.B. 1980. Black bear-human conflicts and management considerations to minimize and correct these problems. Proceedings Eastern Workshop on Black Bear Management and Research 5:75-87.
Willey, C.H. 1974. Aging black bears from first premolar tooth sections. Journal of Wildlife Management 38:97-100.
Wisdom, M.J., L.S. Mills, and D.F. Doak. 2000. Life stage simulation analysis: estimating vital-rate effects on population growth for conservation. Ecology 81:628-641.
Woods, J.G., D. Paetkau, D. Lewis, B.N. McLellan, M. Proctor, and C. Strobeck. 1999. Genetic tagging of free-ranging black and brown bears. Wildlife Society Bulletin 27:616-627.
Zack, C.S., B.T. Milne, and W.C. Dunn. 2003. Southern oscillation index as an indicator of encounters between humans and black bears in New Mexico. Wildlife Society Bulletin 31:517-520.

APPENDIX II

CAPTURE AND HANDLING PROCEDURES FOR FREE-RANGING BLACK BEARS

Black bears will be initially captured and collared during the summer months and annually re-captured in their dens during winter months to obtain reproductive information.

Summer

We will capture and collar adult female black bears during summer months (May-Sept) using cage traps and foot snares. We will use cage traps in areas close to Durango or with high human activity, and where there is good road access. Snares will be used for more remote trapping locations, away from human activity and where vehicle access is limited. Once a bear has been captured using either method, field crews will use an identical protocol to process animals.

Cage Traps

We will capture bears with two different trap designs, a cage trap designed and used extensively by Beck (1993), and a newly designed trap to specifically target female bears. The trap developed by Beck is 1.8 m long and 1.0 m in height and width. The frame is constructed of angle iron, all side and top panels are wire mesh of 1.9 x 1.9 in size, and the trap has a floor that is 16-gauge steel. A spring-powered, solid aluminum door is mounted on a full-length hinge at one end and a latching mechanism holds the door closed. The door is triggered via a treadle pedal on the floor, and a standard garage door coil spring provides closing power. A hinged panel along the back of the trap allows access for administering immobilizing drugs via jabpole. In total, the trap weighs approximately 236 kg. In the first study in which these traps were used, only 1 bear in 134 captures was injured, as the individual broke a canine on the wire mesh.

Because we are specifically interested in capturing and collaring female black bears, we worked with Mat Alldredge, Tom Davies, Lyel Willmarth and others to design a smaller, lighter trap that would discourage the capture of large males and increase portability in the field. These traps were built to be slightly larger than those that have been successfully used for cougars (Alldredge et al. personal communication) and are 34in high, 60in long, and 25in wide. The frame is built with 1x1in heavy gauge steel, covered with 1x1in heavy gauge, high tinsel, steel mesh. The smaller dimensions of the mesh will reduce the possibility that animals will break their teeth on the cage. The sides of the trap have additional braces to increase overall strength and support. The door of the trap comprises one end of the structure and is designed drop and latch to the bottom of the frame. Bait is hung from a cable attached to an archery trigger, and the door falls shut when the trigger is released. Due to the smaller size of the trap, it only weighs approximately 60 kg.

Cage traps will be positioned so they are in the shade, and exposure to sun and precipitation is minimized. All cage traps will be clearly marked with warning signs. Cages will be baited with rotting fish, fruit, or road kill. They will be set in the late afternoon or evening and checked by field crews the following morning to minimize the time an animal spends in a trap. If the bear can be clearly identified as a male in the trap, or the bear is a cub or yearling (too small for a GPS collar), it will be released without being immobilized. If the bear is an adult female, or there is uncertainty in the sex of the adult bear, it will be immobilized following procedures described below. Bears will be immobilized with a jabpole, syringe pole, or syringe (hand injection), with the injection targeted into muscle tissue along the shoulder or thigh.

Aldrich Foot Snares

Aldrich foot snares were specifically developed to capture bears and have proven to be safe and effective (Jonkel 1993). The spring activated snare secures a ¼ inch steel cable around the foot of the bear, closing tight with the action of a small piece of angle iron fashioned into a sliding lock mechanism.

The inside of the snare loop is wrapped with duct tape to minimize surface abrasion on the skin of the foot. We will modify snares with additional duct tape and/or surgical tubing over the cable to serve as a "cub stopper" such that small bears (cubs and yearlings) have a low probability of being captured (Jonkel 1993). An in-line swivel is placed in the cable to avoid torsion of the foot and a potential bone fracture. A short lead is attached to the snare to further minimize stress to the leg.

The lead is then secured to an anchor tree at least 10 inches in diameter with a ¼ in steel cable clamped and stapled to the base of the tree so the bear cannot climb it. Branches of the tree are lopped off with a saw or axe about 8 ft up, so the bear cannot hang itself from a branch by the snare cable. An area of ≥5 meters is cleared around the snare site to eliminate potential that the bear is able to twist the snare loop around any obstacles (saplings, brush, etc). Large branches will be angled over the snare to force ungulates to step over or go around it, minimizing the possibility of catching non-target animals. Additional details of setting snares can be found in Jonkel (1993). A disadvantage of using foot snares is that all bears that are caught (even if they are a male bear or too small to collar) must be immobilized to be released. Other non-target animals that are caught (i.e. mountain lions, coyotes, etc) will be immobilized with Telazol and released. Snares will be set in the evening and checked in the morning, operated when ambient temperatures are between 32 and 90°F. Snared bears will be immobilized using a jabpole or CO_2 dart gun with the injection targeted into muscle tissue along the shoulder or thigh.

Animal Processing

During summer months bears will be anesthetized with butorphanol, azaperone, and medetomidine (BAM), a drug combination that has been successful immobilizing black bears and is reversible with atipamezole (a medetomidine antagonist), allowing a faster and safer release of animals around urban environments (Wolfe et al. 2008). BAM will be administered at a volume of 0.4ml/23kg (50 lbs) with a dosage of 0.26mg/kg for butorphaneol, 0.22mg/kg for azaperone and 0.09mg/kg for medetomidine. We will initially give the recommended dose based on estimated animal weight and boost as necessary by ½ and ¼ of the original dose for the first and second boosters, respectively. To reverse immobilization we will intravenously administer atipamezole. We will dispense a volume of 1ml/1ml at a dosage of 5mg/1mg of medetomidine or 0.45mg/kg. One dose should be sufficient to reverse BAM. Bears immobilized with BAM should not be consumed for 45 days afterward, information which will be printed on collars and ear-tags (see below).

Following the injection of BAM, field personnel will approach and gently prod the bear to ensure that the animal is fully anesthetized, administering additional doses as needed. Once anesthetized, the bear will be removed from the trap or snare and placed in a sternally recumbent position with front and rear legs extended. If the bear will not be collared (either because it is a male or too young) it will be subcutaneously injected with a passive integrated transponder (PIT) tag and marked with a single black or brown ear-tag that is labeled with the appropriate consumption date information. Afterwards, the bear will be administered atipamezole and released. Adult female bears will be discriminated from subadults based on weight, and nipple size and coloration (Beck 1991).

Adult female bears will be fully processed. They will immediately be treated with eye ointment and blindfolded to reduce visual stimuli and protect the eyes from debris and bright light. Throughout the time a bear is anesthetized, its vital signs (heart rate, respiration and temperature) will be monitored. Normal ranges for vital rates of adult bears: heart rate = 60-90 beats/minute, respiration = 15-20 breaths/minute, and temperature = 99.6 - 101.0°F (Jonkel 1993). If a bear's body temperature exceeds the normal range, field staff will cool the underside of the bear with water, particularly the arm pits, groin and stomach. If heart rate and respiration values fall outside normal expectations we will reverse the anesthesia and release the bear.

In processing female bears, we will check each animal for any lacerations that occurred in the capture process and treat them with topical antibiotics. Additionally, bears will be given an injection of Oxytetracycline (9mg/lb) or Baytril (7.5 mg/kg) to reduce chances of infection from darting and tooth extraction (described below). Adult female bears will be subcutaneously injected with a PIT tag. If the individual has been identified by CPW Area staff as a "conflict" bear it will be marked in accordance with CPW Administrative Directive W-2. Individuals will be weighed using a portable spring scale and pulley system and their breeding status will be recorded (lactating, cubs present, evidence of suckling, etc). We will take multiple body size measurements including total length, chest girth and neck girth. During winter months we will also use bioelectrical impedance analysis to measure bear body fat (Farley and Robbins 1994, Hilderbrand et al. 1998). Additionally we will draw blood and collect a hair sample. These samples will be used for genetic, stable isotope, and telomere analysis. To age captured bears using tooth cementum annuli counts (Stoneberg and Jonkel 1966, Willey 1974), we will remove the first vestigial premolar (or if unavailable the lower first premolar) using a dental elevator. For tooth extraction, we will topically apply Lidocaine and subcutaneously administer Ketofen for analgesia (1cc/100lb). A piece of foam gel will then be placed on the removal site and left for adhesion and filling of the wound.

We will attach a GPS collar (~700 g) with a ~2 year life expectancy. Collars will be programmed to collect ≥3 locations/day, and will be labeled with the appropriate consumption date based on immobilization. The GPS collar will include a VHF transmitter that allows tracking via standard telemetry equipment and the retrieval of collars. We will recapture each collared female each winter to assess fecundity and cub survival. If we are unable to recapture a bear, however, each collar will have a degradable canvas spacer that should break-down within 1-2 years and allow the collar to fall off. GPS collars will upload the location of each individual every day via a satellite system and the location will be available to researchers in real-time.

When animal processing procedures are completed, the blindfold will be removed and the immobilization reversal will be administered. Field staff will observe the bear from a safe distance to ensure that the animal recovers to a standing position (Wolfe et al. 2008).

Winter

Den Checks

To assess fecundity and cub survival we will recapture collared female bears each winter. Bears will be tracked to their dens using GPS collar locations, and researchers will dig through the snow as needed to access the den. Adult female bears and accompanying yearlings will be anesthetized with Telazol using a jabpole or CO_2 dart gun. Telazol will be administered intramuscularly with a dose of 1.5 – 2.5mg/lb at a lower concentration (5cc at 100mg/ml). Bears will be immobilized at a higher concentration (3cc at 166 mg/ml) if they are particularly agitated or large. We will initially give the recommended dose based on estimated animal weight and boost as necessary by ½ and ¼ of the original dose for the first and second boosters, respectively. Unlike BAM, there is no reversal drug for Telazol. That said, an immobilized bear can be returned to its den for recovery, reducing animal stress and increasing researcher safety.

Once immobilized, bears will be removed from the den, placed on blanket, and processed in a similar manner to that described above. Field staff will check the fit of the GPS collar and make any necessary modifications, and clean up any neck wounds with saline solution. Newborn cubs in the den will be tucked inside the jacket of a field crew member, next to their body, so that the cub says warm and quiet. After processing, bears will be returned to the den; adults and yearlings will be positioned on their side and newborn cubs will be placed on their mother's back. The den entrance will be covered with sticks and boughs and a layer of snow to discourage the bear from leaving the den. We will retain a small opening in the snow to ensure that the bear has a fresh supply of air (Jonkel 1993).

Injuries and Euthanasia

If an animal is seriously injured (e.g. fractured or broken appendage, vertebrae, pelvis, or jaw, severe dislocation, laceration or any other injury that severely compromises its ability to survive and/or causes severe pain or distress) during capture, it will be quickly and humanely euthanized. Bears will be deeply anesthetized with BAM or Telazol and euthanized via a intravenous potassium chloride (KCl; 400-800 mEq) injection or gunshot to the head or neck. Carcasses that are euthanized will be disposed of in a landfill or left in an area appropriate for scavengers.

LITERATURE CITED

Beck, T.D.I. 1991. Black bears of west-central Colorado. Technical Publication 39, Colorado Division of Wildlife, Fort Collins, Colorado.

Beck, T.D.I. 1993. Development of black bear inventory techniques; job progress report. Colorado Division of Wildlife, Project Number W-153-R-6.

Farley, S.D., and C.T. Robbins. 1994. Development of two methods to estimate body composition of bears. Canadian Journal of Zoology 72:220-226.

Hilderbrand, G.V., S.D. Farley, and C.T. Robbins. 1998. Predicting body condition of bears via two field methods. Journal of Wildlife Management 62:406-409.

Jonkel, J.J. 1993. A manual for handling bears for managers and researchers. Office of Grizzly Bear Recovery, US Fish and Wildlife Service, University of Montana, Missoula, Montana.

Stoneberg, R.P., and C.J. Jonkel. 1966. Age determination of black bears by cementum layers. Journal of Wildlife Management 30:411-414.

Willey, C.H. 1974. Aging black bears from first premolar tooth sections. Journal of Wildlife Management 38:97-100.

Wolfe, L.L., C.T. Goshorn, and S. Baruch-Mordo. 2008. Immobilization of black bears (*Ursus americanus*) with a combination of butorphanol, azaperone, and medetomidine. Journal of Wildlife Diseases 44:748-752.

Colorado Division of Parks and Wildlife
July 2010 –June 2011

WILDLIFE RESEARCH REPORT

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

Period covered: July 31, 2010−June 30, 2011

Author: K. A. Logan.

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

ABSTRACT

The Colorado Division of Wildlife (now Colorado Parks and Wildlife [CPW]) initiated a 10-year study on the Uncompahgre Plateau in 2004 to quantify puma population characteristics in the absence (*reference period*, yrs 1-5) and presence (*treatment period*, yrs 6-10) of hunting. The purpose of the study is to evaluate assumptions underlying the Colorado Parks and Wildlife's model-based approach to managing pumas with sport-hunting in Colorado. The *reference period* began December 2004 and ended July 2009, during which we captured, sampled, and marked 109 pumas for population research purposes on the Uncompahgre Plateau (Logan 2009). This report informs on the second year of the *treatment period* (TY2), August 2010 through July 2011, on puma population characteristics and dynamics with hunting as a mortality factor. Puma sport-hunting opened November 22 and closed December 12, 2010 after a quota of 8 independent pumas was harvested. The harvest was designed to test the management assumption that a 15% harvest of independent pumas results in a stable-to-increasing population. A total of 8 pumas were killed: 2 subadult females, 5 adult males, and 1 subadult male. The harvest of 8 independent pumas represented 15.4% of the 52 independent pumas in our *minimum count* during November 2010 to April 2011. Independent females and males comprised 25.0% and 75.0% of the harvest, respectively. Three other radio-collared independent pumas in the study area population were killed during the Colorado puma hunting season; 2 adult females killed on the study area for depredation control and 1 adult male in a GMU adjacent to the study area. The total mortality of 11 independent pumas during the hunting season represented 21.2% of the *minimum count* of independent pumas. Eight independent pumas will be the harvest quota for the 2011-12 hunting season (TY3), based on an expectation of a stable-to-increasing population. Sixty-four hunters requested mandatory permits with an

attached voluntary hunter survey in TY2. Fifty-four of the hunters provided responses to written (*n* = 42) or telephone call follow-up contact (*n* = 12). An estimated 42 hunters actually hunted on the study area, of which about 19% harvested pumas and 38% captured pumas (i.e., harvested plus treed and released). Thirty-three hunters responded that they were selective hunters, and the capture, tracking, and population data indicated that most hunters practiced selection. Puma tracks < 1 day old encountered by hunters and pumas captured by hunters indicated that independent female pumas were more vulnerable than males to detection by hunters. From August 2010 to July 2011 54-55 individual pumas were captured 70 times. Two capture teams with dogs operated over 81 search days from November 16 and December 14, 2010 through April 22, 2011 to find 291 puma tracks, pursue pumas 99 times, and capture 36-37 pumas 52 times. Capture efforts with cage traps resulted in the capture of 1 adult male and 1 subadult male for the first time and the recapture of 2 adult female pumas. Fourteen cubs were observed for the first time at nurseries. A total of 53 pumas were monitored by radiotelemetry in TY2. Search efforts also revealed the presence of at least 15 other independent pumas. Our *minimum count* of independent pumas from November 2010 to April 2011 was 52, including 35 females and 17 males. A preliminary *minimum* estimated density of independent pumas was 3.11/100 km^2. The proportion of radio-collared adult females giving birth in the August 2010 to July 2011 biological year was 0.56 (9/16). Six litters that could be dated to month of birth were produced in April (2), July (2), and August (2). Since 2005 a birth peak has occurred from May through August, involving 80% of nursling litters. We monitored 19 female and 9 male adult radio-collared pumas for survival and agent-specific mortality. Survival rates in TY2 for adult females were within the range during the *reference period*, but substantially lower for males. Causes of mortality were hunting and depredation control. One subadult female was killed and eaten by a male puma during competition for an elk carcass. Of 23 cubs monitored with radiotelemetry, 6 died, 3 from natural causes (including 2 infanticide and cannibalism) and 3 from depredation control. A non-marked female cub was also killed by a vehicle on the boundary of the study area. Puma harvest, capture, and radiotelemetry data provided information on dispersals of 26 pumas initially marked on the study area. Those pumas moved from about 20 to 370 km from initial capture sites. We explored the feasibility of attracting pumas to rub stations to obtain tissue non-invasively for potential use in a genotype mark-recapture structure for estimating abundance. Nine sites with trail cameras, rub devices, and 6 scents produced 39 puma visit events. Puma behavior toward the scents was highly variable. Beaver castorium produced the highest maximum detection probability. Data continue to be gathered for other collaborative projects with Mammals Research and CSU investigators on puma behavior, social organization, population dynamics, and habitat use.

WILDLIFE RESEARCH REPORT

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

KENNETH A. LOGAN

P. N. OBJECTIVE

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

SEGMENT OBJECTIVES

1. Execute the second year of the five-year *treatment period* by working with CPW biologists and managers to manipulate the puma population with sport-hunting and to survey hunters.
2. Continue gathering data on puma population sex and age structure.
3. Continue gathering data for estimates of puma reproduction rates.
4. Continue gathering data to estimate puma sex and age-stage survival rates.
5. Continue gathering data on agent-specific mortality.
6. Explore feasibility of attracting pumas to a rub station and obtaining tissue for potential use in a non-invasive genotype mark-recapture structure.

INTRODUCTION

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

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

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

- Puma population characteristics (i.e., density, sex and age structure).
- Puma population dynamics and vital rates (i.e., birth rates, survival rates, emigration rates, immigration rates, population growth rates).

● Field methods and models for assessing and tracking changes in puma populations.
● Relative vulnerability of puma sex and age classes to hunter harvest.

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

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

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

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

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

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

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

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

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

Describe and quantify puma population sex and age structure.

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

Estimate agent-specific mortality rates.

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

Concurrently with the tasks associated with the objectives above, significant progress will be made toward a 5th objective, which will initially be subject to *pilot study*― develop methods that yield reliable estimates of puma population abundance.

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

TESTING ASSUMPTIONS AND HYPOTHESES

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

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

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

2. Recreational puma hunting management in Colorado DAUs is guided by a model to estimate allowable harvest quotas to achieve one of two puma population objectives: 1) maintain puma population stability or growth, or 2) cause puma population decline (CDOW, Draft L-DAU Plans, 2004, CDOW 2007). Basic model parameters are: puma population density, sex and age structure, and annual population growth rate. Parameter estimates are currently chosen from literature on studies in western states that are judged to provide reliable information. Background material used in the model assumes a moderate annual rate of growth of 15% (*i.e.*,λ = 1.15) for the adult and subadult puma population (CDOW 2007). This assumption is based upon information with variable levels of uncertainty (e.g., small sample sizes, data from habitats dissimilar to Colorado). Parameters influencing λ include population density, sex and age structure, female age-at-first-breeding, reproduction rates, sex- and age-specific survival, immigration and emigration.

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

3. The key assumption is that the CPW can manage puma population growth through recreational hunting on the basis that for a stable puma population hunting removes the annual increment of population growth (i.e., from current judgments on population density, structure, and λ). Puma harvest rate formulations for DAUs assumes that total mortality (i.e., harvest plus other detected deaths) in the range of 8 to 15% of the harvest-age population (i.e., independent pumas comprised of adults plus subadults) with the total mortality comprised of 35 to 45% females (i.e., adults and subadults) is acceptable to manage for a stable-to-increasing puma population (CPW 2007).

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

4. To reduce a puma population, hunting must remove more than the annual increment of population growth. For DAUs with the objective to suppress the puma population, the total mortality guide of

greater than 15 to 28% of the harvest-age population with greater than 45% comprised of females is suggested (CDOW 2007).

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

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

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

Researchers in Wyoming (Anderson and Lindzey 2005) concluded that sex and age composition of the harvest varies predictably with puma population size because the likelihood of a specific sex or age class of puma being harvested with the use of hounds is a product of the relative abundance of particular sex and age classes in the population and their relative vulnerability to harvest. Results of that study suggest that managers could use sex and age composition of the harvest to infer puma population changes (Anderson and Lindzey 2005). The CPW currently uses this approach as one tool to infer potential DAU puma population dynamics (CDOW 2008). This assumes no purposeful selection by hunters for any particular sex or age-stage other than the puma must be legal (i.e., independent subadult or adult, not a lactating female or a female in association with spotted cubs) and that changes in the sex and age structure of the harvested pumas is due solely to changes in the relative abundance of particular sex and age classes in the population and their relative vulnerability to harvest. Theoretically, pumas that travel longer distances with movements that intercept access routes used by hunters (i.e., roads, trails) should be more exposed to detection by hunters and thus more vulnerable to harvest. A key assumption to this method is that pumas are killed as they are encountered and the harvest sex and age composition will reliably indicate whether a population is stable, increasing, or declining even if harvest intensity does not vary. Thus, an alternate view is that a population segment, such as independent females, may be more abundant and have shorter movement lengths, yet be detected more frequently by hunters. However, because the same intensively studied Wyoming puma population was manipulated over 6 years with varying intensities of harvest (Anderson and Lindzey 2005), variations in harvest structure using the same harvest level over a period of years could not be examined. This is a property we will investigate during the *treatment period* on the Uncompahgre Plateau puma study. Moreover, we will directly evaluate to what extent puma harvest might be influenced by hunter selection. A hunter survey is intended to reveal puma hunter behavior, detection of different classes of pumas, and lack of or presence of hunter selection. These data should allow us to examine the credibility of the assumption of non-selection by hunters and the robustness of this technique in gauging puma population dynamics relative to harvest.

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

H_6: No hunter selection is practiced so that the sex and age structure of pumas harvested by hunters in this population protected from hunting during a 5-year *reference period* and subsequently managed for stability or increase with conservative harvest levels will reflect the relative vulnerabilities to detection and capture with dogs during each year in the 5-year *treatment* *period* in this order from high to low vulnerabilities: subadult males, adult males, subadult females, adult females without cubs or with cubs >6 months old, and adult females with cubs ≤6 months old (Barnhurst 1982, Anderson and Lindzey 2005). In each of the 5 years of the *treatment period*, subadults and adult males should comprise the majority of the harvest and reflect the assumed sex and age structure (Anderson and Lindzey 2005) of a puma population managed for a stable to increasing phase and not hunted for 5 previous years (i.e., a puma population source).

Desired outcomes and management applications of this research include:

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

STUDY AREA

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

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

METHODS

Reference and Treatment Periods

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

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

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

During the *treatment period*, years 6—10, recreational puma hunting is occurring on the same study area using management prescriptions structured from information learned during previous years. Using recreational hunting for the treatment is consistent with the CPW's objectives of manipulating natural tendencies of puma populations, particularly survival, to maintain either population stability or increase or suppression (CDOW, Draft L-DAU Plans, 2004). Theoretically, survival of independent pumas is being influenced mainly by recreational hunting, which is being quantified by agent-specific mortality rates of radio-collared pumas. Dynamics of the puma population are being manipulated to evaluate hypotheses that are related to effects of hunting (i.e.,: effects of harvest rates, relative vulnerability of puma sex and age classes to hunting, variations in puma population structure due to hunting). The killing of tagged and collared pumas during the *treatment period* is not hampering operational needs (as it would have during the start-up years), because a majority of independent pumas in the population have already been marked, and sampling methods formalized.

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

Field Methods

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

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

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

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

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

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

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

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

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

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

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

Analytical Methods

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

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

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

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

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

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

RESULTS AND DISCUSSION

Segment Objective 1

Puma harvest: This biological year, August 2010 to July 2011, was the second year of the *treatment period* (TY2) in this study of puma population dynamics on the Uncompahgre Plateau. The hunting season on the study area began on November 22, 2010 and was scheduled to extend to January 31, 2011, unless the harvest quota was taken before then. The design harvest quota was 8 pumas (i.e., 15% harvest of the estimated minimum number of independent pumas), with the objective to manage for a stable to increasing population. This design harvest tests the CPW's current assumption that total mortality (i.e., harvest plus other natural deaths) in the range of 8 to 15% of the harvest-age population (i.e., independent pumas comprised of adults plus subadults) with the total mortality comprised of 35 to 45% females (i.e., adults and subadults) is acceptable to manage for a stable-to-increasing puma population (Assumption and Hypothesis 3 p.5 this report). The initial quota of 8 pumas for TY1 was based on the projected minimum number of 53 independent pumas expected on the study area in winter 2009-10, modeled from a *minimum count* of pumas during winter 2007-08 (Table 1; Logan 2010). The quota of 8 pumas for TY2 was based on the observed *minimum count* of 55 independent pumas during September 2009 to April 2010 in TY1 and that approximately the same number of independent pumas were expected during the puma hunting season for TY2 (an expectation consistent with our observed *minimum count* of 52 independent pumas for TY2, see later in Segment Objective 2).

The hunting structure in TY2 was the same as in TY1. The number of puma hunters on the study area was not limited. Each hunter on the study area was required to obtain a hunting permit from the CPW Montrose Service Center. Permits were free and unlimited. Each permit allowed the individual hunter with a legal puma hunting license in Colorado to hunt in the puma study area for up to 14 days from the issue date. Unsuccessful hunters that wanted to continue hunting past the permit expiration date requested a new permit for another 14 days, or until the hunter killed a puma within the season, or the season on the study area closed due to the quota being reached, or the end of the hunting season. This permit system allowed the CPW to monitor the number of hunters on the study area and to contact each hunter for survey information (see later in this section).

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

The puma hunting season occurred on the study area from November 22 to December 12, 2010, taking 21 days to fill the quota of 8 pumas. This was 5 days less than it took to harvest 8 pumas in TY1 (i.e., 26 days, Nov. 16 to Dec. 11, 2009). Eight pumas were killed, including: 2 subadult females, 5 adult males, and 1 subadult male (Table 2). Of the 8 harvested pumas, 4 were marked: M32, M55, M90, and F108. In addition to the pumas killed on the study area during the Colorado puma hunting season, adult male M133 was killed by a hunter in north GMU62 and adult females F25 and F94 were killed for depredation control reasons on the study area (Table 3).

The harvest of 8 independent pumas on the study area was 15.4% (8/52*100) of the *minimum count* of 52 independent pumas, including 31 females and 24 males, determined by the research team during November 2010 to April 2011 (Table 4). Independent females and males comprised 25.0% (2/8*100) and 75.0% (6/8*100) of the harvest, respectively. This harvest structure was 5.7% (2/35*100) of the independent females and 35.3% (6/17*100) of the independent males.

Considering the mortality of 3 other radio-collared adults (F25, F94, M133, Table 3), a harvest of 11 independent pumas was 21.2% (11/52*100) of the *minimum* number of independent pumas. The harvest composition of 4 females and 8 males was comprised of 36.4% (4/11*100) females and 63.6% (7/11*100) males. This harvest structure was 11.4% (4/35*100) of the independent females and 41.2% (7/17*100) of the independent males in the *minimum count*.

The *minimum count* of 52 independent pumas in TY2 was slightly lower than the minimum count of 55 independent pumas in TY1 (Table 4). *Minimum count* TY2 = 52 independent pumas, including 35 females and 17 males. This count reflected the relatively high adult female survival rate and low adult male survival rate in TY1 (Logan 2010). Because the harvest quota of 8 independent pumas in TY1 resulted in a *minimum count* of 52 independent pumas in TY2 and is expected to result in a stable-to-increasing population trend, we decided to set the quota to harvest 8 independent pumas in the TY3 (2011-12) hunting season to emulate an approximate 15% harvest of independent pumas to achieve a stable to increasing population objective while also considering that a number of independent pumas in the study area population might be killed outside of the study area as in the TY1 and TY2 hunting seasons (Fig. 3). It is still too early in this research to tell if this harvest structure is resulting in a declining, stable, or increasing population trend.

<u>*Hunter permits and survey:*</u> In TY2 mandatory permits with the voluntary survey attached were requested by 64 individual hunters, down from 79 individual hunters in TY1. Seventeen of the hunters requested a second permit after the first one expired after 14 days. Fifty-four hunters (84.4%) provided responses to the voluntary survey either by turning in the printed survey (*n* = 42) or providing information during follow-up telephone calls (*n* = 12) by principal investigator K. Logan. The remaining 10 hunters could not be contacted because either they did not have working phone numbers or they did not return calls. Of the respondents, 19 hunters indicated that they did not hunt on the study area. The proportion of the 54 respondents that hunted extrapolated to the total of 64 hunters (35/54 = 0.648) indicated that about 42 hunters took to the field for pumas on the study area during the 21-day hunting season. This was down from 67 hunters that probably hunted in TY1 (Logan 2010). Considering that 42 hunters were estimated to be afield, then 19% of the hunters harvested pumas (8/42*100) and 38% of hunters captured pumas (16/42*100; see captured and released pumas below and in Table 5).

The 42 puma hunters that turned in the written volunteer survey were asked to answer, “Do you consider yourself a *selective* or *non-selective* hunter?” A *selective* hunter is one that purposely is hunting for a specific type of legal puma, such as a male, large male, or large female. A *non-selective* hunter is one that intends to take whatever legal puma is first encountered or caught, with no desire for sex or size. *Selective* hunter was indicated by 33 respondents. Of the remaining 9 hunters, 5 did not answer the question because they indicated that they did not hunt on the study area and 1 was an outfitter that did not hunt on the study area for himself (i.e., he hunted for his clients). One hunter indicated he was non-selective, and he killed a subadult female puma. Another hunter that did not answer the question killed a subadult female puma, too. The volunteer hunter survey also revealed that hunters treed pumas on the study area, but they chose not to kill them (Table 5). Those hunters reported they treed pumas 8 times, including 7 females and 1 subadult male. Of the 7 females 6 were described as adult, including 1 with at least 1 cub. Two of the adult females were marked with GPS collars (F3, F96). One female was either an adult or subadult. Hunters gave various reasons for not wanting to kill the pumas, including reasons based on puma sex, reproductive status, and size (Table 5).

In an effort to better ascertain the vulnerability of sexes and age-stages (i.e., adult, subadult) of independent pumas to detection by puma hunters to address assumption 6 and hypothesis 6 (previously), the survey was changed in TY2 to ask hunters, "What was the sex of the lion that made the first set of tracks you encountered that were less than one day old?". This question pertained to tracks that could be pursued by dogs and captured with a relatively high probability to allow the hunter an opportunity to harvest the puma. Associated with the question, we asked, "Did you pursue the lion to harvest it?" Hunters responses showed they encountered 30 puma tracks less than one day old. Of those, 20 tracks were of females, and 10 tracks were of males, indicating that during the hunting season females are more detectable than males by a ratio of 2:1, and similar to the sex structure of independent pumas in the *minimum* count on the study area which was 35 females and 17 males (ratio 2.06:1, Table 4). Of the female tracks, 3 female pumas were pursued by hunters with intent to harvest, of which 2 females were actually killed. Seventeen hunters indicated they did not pursue female tracks with intent to harvest; but, hunters captured and released 7 female pumas. Of the male tracks, 7 were pursued by hunters with intent to harvest, of which 6 were actually killed. Three hunters indicated they did not pursue to harvest 3 male tracks; but, 1 subadult male puma was captured and released.

These preliminary survey and harvest data for TY2 indicate independent females were captured by hunters slightly more frequently than independent males by 9 to 7 (i.e., females = 2 harvested + 7 captured and released; males = 6 harvested + 1 captured and released). Moreover, hunters are choosing to kill males more frequently than females. This result is consistent with TY1 where hunters caught females slightly more frequently than males (i.e., 12 females, 10 males; females = 3 harvested + 9 captured and released; males = 5 harvested + 5 captured and released). Also in TY1, hunters indicated a preference to harvest males over females. This preliminary assessment from years TY1 and TY2 puma harvest and hunter survey data suggests that most hunters that captured pumas were selective and influenced harvest sex and age composition and that independent female pumas were detected by hunters at a higher rate than were independent male pumas.

<u>Segment Objective 2</u>

After the design quota was filled, puma research teams immediately activated for capture operations with trained dogs. Two fully-staffed capture teams, one each detailed on the east and west slopes, systematically and thoroughly searched the study area to capture, sample, and GPS/VHF radio-collar pumas the remainder of winter and early spring 2010-11. These efforts along with cage trap efforts and hand-capturing cubs at nurseries maintained samples to quantify population sex and age structure, survival, and agent-specific mortality, and allowed determination of *minimum* population size on the study area.

We made 70 puma captures of 54 to 55 individuals from August 2010 to July 2011 (Tables 6-11); 36 to 37 individual pumas were captured with dogs 52 times. Four pumas were captured in cage traps. Cubs were captured at nurseries 14 times. A total of 53 pumas were monitored with radio-telemetry from August 2010 to July 2011 (some of these had been collared in previous years).

Trained dogs were used as our main method to capture, sample, and mark pumas on November 16, 2010 and from December 14, 2010 to April 22, 2011. Those efforts resulted in 81 search days, 291 total puma tracks detected of which 157 were ≤1 day old, 99 pursuits, and a total of 52 puma captures of 36-37 individual pumas (Table 6). This was the second year we deployed 2 fully-staffed hound capture teams in the treatment period. Search days with dogs was similar in both TY1 (86) and TY2 (81; Table 12). The frequency of tracks (tracks/day) encountered was higher in TY2 than the previous 6 winters.

Also, pursuits increased over all previous years by 6 to 58, with the lowest number of pursuits occurring in the first year of this study (2004-05) when the puma population was probably at its lowest abundance on the study area. The capture rate was also the highest by 26 to 38 captures. Increased capture efforts and captures were probably the result of using 2 fully-staffed relatively more efficient houndsmen teams in TY2 even though the puma population had been reduced due to harvest just before our capture operations.

Researchers in the two hound capture teams on November 16, 2010 and from December 14, 2010 to April 22, 2011 also recorded instances when the first tracks ≤1 day old of independent pumas were encountered on each search route each day to represent encounters with puma tracks that could be detected by houndsmen. The count was: 47 tracks of females, including 11 associated with cubs; 21 tracks of males; 4 tracks of cubs, and 1 track of unspecified sex. Except for 1 female and 1 male track ≤ 1 day old found on November 16, 2010, all other tracks ≤ 1 day old were found after the TY2 puma hunting season when 6 independent males and 2 independent females were harvested. Therefore, the harvested pumas were not present to make tracks for our researchers to observe. The loss of the 6 males and 2 females may reflect the slightly higher ratio of female:male tracks post-hunting season, 2.2:1 than was reported by hunters during the hunting season, 2:1 (previously, Segment Objective 1). Still, the ratios are similar and reflect the greater likelihood of encountering females than males.

Puma capture efforts using ungulate carcasses and cage traps was sporadic from November 8, 2010 to April 18, 2011 (Table 10). We used 12 road-killed mule deer at 10 different sites. Two independent male pumas (M133, M153) were captured for the first time, and 2 adult females (F70, F137) were recaptured and re-collared. Pumas scavenged at 5 of 12 (41.66%) sites where deer carcasses were used for bait.

We sampled 24 cubs, including 10 females and 14 males (Table 11). Nine females and 14 males were captured by us, of which 21 (7 females, 14 males) were radio-collared to monitor survival and agent-specific mortality (Appendix A). Female cub P1026 was sampled with a bio-dart only because she climbed a dangerous tree. Another female cub, P1030, was found dead, hit by a vehicle on state highway 62 in Leopard Creek.

In addition to our direct puma captures with dogs November through April, we detected 18 radio-collared pumas that we were able to identify with GPS or VHF telemetry 28 times, thus, negating the need to capture those pumas directly with dogs (Table 6). Upon detecting puma tracks that were aged at ≤1 day old, we followed the tracks with a radio receiver in an effort to detect if the tracks might be of a puma wearing a functional collar. We assigned tracks to a collared individual if we received radio signals from a puma that we judged to be <1 km from the tracks and in direction of travel of the tracks. This approach allowed us to more efficiently allocate our capture efforts toward pumas of unknown identity on the study area, particularly unmarked pumas or pumas with non-functioning GPS- or VHF- radiocollars.

Our search efforts throughout the study area from December 2010 to April 2011 also revealed the presence of at least 13 other independent pumas, which we classified as 9 females and 4 males. Three females and 2 males were treed by our hounds, but we could not handle the pumas because they climbed dangerous trees (Table 8). Of those, 2 females and 2 males were sampled with biodarts to obtain a tissue sample for genotyping the individuals. We could separate the activity of the other pumas from the GPS- and VHF- collared pumas in time, space, and track size differences between females and males. One puma might have been F75 with a non-functional GPS collar. Moreover, females in association with cubs of different numbers, sizes, and locations enabled us to distinguish 4 adult females followed by 1 to 2 medium-to-large-size cubs. Some tracks we found of these pumas were too old to pursue (i.e., 2+ days old; probability of capture with the dogs was negligible).

Our search and capture efforts during November 2010 through April 2011 and information from the puma hunting season in TY2 enabled us to quantify a *minimum count* of 52 independent pumas detected on the Uncompahgre Plateau study area, including 35 independent females and 17 independent males (Table 4). This count was based on the number of known radio-collared pumas, non-marked pumas harvested by hunters on the study area, observations of marked and non-marked pumas observed by researchers or treed and released by hunters on the study area, and puma tracks observed by researchers that could not be attributed to pumas with functioning radiocollars. The estimated age structure of independent pumas in November 2010 at the beginning of the puma hunting season in TY2 on the Uncompahgre Plateau study area is depicted in Figure 4. In addition to the independent pumas, we also counted a minimum of 39 cubs. Of the 52 independent pumas, 36 to 37 (69-71%) were marked and 15 to 16 (29-31%) were assumed to be unmarked animals. The abundance and sex structure of independent pumas on the east and west slopes of the study area were similar. The east slope count included 25 independent pumas (18 females, 7 males). The west slope count included 27 independent pumas (17 females, 10 males). Considering the *minimum count* of 52 independent pumas, a preliminary *minimum* density for the winter puma habitat area estimated at 1,671 km^2 on the Uncompahgre Plateau study area was 3.11 independent pumas/100 km^2.

Segment Objective 3

During the past 6.7 years of this work we compiled data on puma reproduction that was not previously available on pumas in Colorado (Table 13). Puma reproduction data (i.e., litter size, sex structure, gestation, birth interval, proportion of females giving birth per year) were summarized for the *reference period* in Logan (2009). In TY2 we directly observed 6 litters in nurseries which were born in April (2), July (2), and August (2) 2010, each with 1 to 4 cubs, born to radio-collared females. Data on reproduction we observed in TY1 and TY2 were added to Table 13 which gives the reproductive chronology and information on mates of reproducing females. But those data will not be summarized again until the end of the *treatment period*. The proportion of radio-collared adult females giving birth from August 2010 to July 2011 biological year (TY2) was 0.56 (9/16), similar to TY1 (0.53, 8/15).

Considering our 38 total observed litters with cubs 26 to 42 days old and 2 other litters confirmed by nurseries and nursling cub tracks with GPS-collared females (the latter include F111's cubs caught later when 8.5 months old) (Table 13), the distribution of puma births by month since 2005 indicate births extending from March into September (Fig. 5). Births peak during May, June, July, and August involving 80% of the births (Fig. 5). The data indicate that the large majority of puma breeding activity occurred February through May (i.e., gestation averages about 90-92 days, Logan 2009). In comparison, Anderson et al. (1992:47-48) found on the Uncompahgre Plateau during 1982-1987 that of 10 puma birth dates 7 were during July, August, and September, 2 in October, and 1 in December, with most breeding occurring April through June. The 2 data sets indicated puma births on the Uncompahgre Plateau have occurred in every month except January and November (so far). As we gather more data on the puma births during the *treatment period*, we will examine the distributions in the *reference* and *treatment periods* separately.

Segment Objectives 4 & 5

From December 8, 2004 (capture and collaring of the first adult puma M1) to July 31, 2011, we radio-monitored 19 adult male and 30 adult female pumas to quantify survival and agent-specific mortality rates (Table 14). Survival and agent-specific mortality of adult pumas were summarized for the *reference period* in Logan (2009). Preliminary estimates of adult puma survival rates in the absence of sport-hunting during the *reference period* indicated high survival, with adult male survival generally higher than adult female survival (Table 15).

Preliminary adult puma survival for TY1 and TY2 are also shown in Table 15. So far, adult male survival is substantially lower in the *treatment period* than in the *reference period* and adult female survival may be similar in both periods. These characteristics may be indicative of hunter selection for male pumas (previously in Segment Objective 1). But, no conclusions should be drawn with results from only 2 years in the *treatment period*. The primary research interests include how survival rates influence population growth rates and the strength of factors associated with survival and mortality. This is what ultimately allows us to evaluate the effect of a 15% harvest level on independent pumas for our population management assumptions when the goal is a stable to increasing population.

Human-related causes of mortality dominated deaths of marked adult pumas in TY2, including: sport-hunting harvest (4 males- M32, M55, M90, M133) and depredation control (1 male- M134; 2 females- F25, F94) (Table 14).

We have radio-monitored 19 pumas, including 6 females and 13 males, in the subadult age-stage (independent pumas <24 months old) (Table 16). Four died before reaching adulthood, indicating a preliminary finite survival rate of 0.789 (i.e., 15/19). All 4 subadults apparently died of natural causes. F66 died at 23 months old of trauma to internal organs that caused massive bleeding attributed to trampling by an elk or mule deer. M99 died at about 16 months old; punctures to his skull were consistent with canine bites from another puma and suggested intra-species strife as cause of death. M115 died at about 14 months old due to complications of a broken left foreleg, cause unknown. This injury probably affected his ability to efficiently kill prey. F143 was killed and eaten by a male puma while in competition for an elk carcass that one of the pumas killed. We need to increase our efforts to acquire larger samples of male and female radio-monitored subadult pumas to acquire reliable estimates of their survival.

Harvest data along with our capture and radiotelemetry data provided additional information on fates of 26 marked pumas, 22 males and 4 females. Of those, 21 (2 females, 19 males) were initially captured and marked as cubs, and 5 (2 females, 3 males) were captured and marked as subadults on the Uncompahgre Plateau puma study area (Table 17). Twenty males were killed away from the study area by hunters at linear distances (i.e., from initial capture sites to kill sites) ranging from about 20 to 370 km. Two males with extreme moves were killed in the Snowy Range of southeastern Wyoming (369.6 km) and the Cimarron Range of north-central New Mexico (329.8 km). Female F52 was treed and released by hunters in December 2008 and 2009 south of Powderhorn, Colorado, indicating that she probably established an adult home range there. Three males marked initially as cubs born on the study area (M67, M87, M92) dispersed from their natal ranges and were recaptured as adults on the study area. All were born on the east slope of the Uncompahgre Plateau and moved to the west slope. These pumas represent dispersal moves on and from the Uncompahgre Plateau. Eighteen of the 26 pumas had reached adult ages ranging from 24 to 55 months old.

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

In TY2 we monitored the fates of 23 radio-collared cubs (Appendix A). Six of the cubs (3 females, 3 males) were known to have died. Three cubs with their mother F94 were killed for depredation control to protect a commercial domestic elk operation. Three other cubs died of natural causes. M130 died from a cause associated with injury to his right shoulder during the first move away from his nursery with F96 and 3 other siblings. Two cubs, M139 and F148 (offspring of F8), died of infanticide and cannibalism by a female or subadult male puma. A greater number of cubs over a longer period of time must be sampled before estimating cub survival and agent-specific mortality rates in the *treatment period*.

In addition, a non-marked female puma cub was struck and killed by a vehicle on state highway 62 in Leopard Creek on the south boundary of the study area on February 16, 2011. This mortality made the thirteenth puma death recorded due to vehicle collision on the study area since 2004 (Table 18). Five of the 13 pumas were marked, including 3 adults with GPS/VHF collars. Those 3 adults died during the first year of the *treatment period*.

Thirty-two adult pumas (23 females, 9 males) have worn GPS collars since this project began in 2004 (Table 19). Over 55 thousand GPS locations have been obtained for studies on puma behavior, social organization, population dynamics, movements, habitat use and puma-human relations in collaboration with colleagues in Mammals Research and Colorado State University.

<u>Segment Objective 6</u>

As an extension of our pilot puma camera grid project in 2009 (Logan 2010), we decided to explore the feasibility of attracting wild pumas to a rub station to obtain tissue non-invasively for potential use in a genotype mark-recapture structure for estimating abundance. Our question was basic to such a structure. What might be expected detection probabilities for wild pumas at scent/rub stations? This work operated on minimal resources consisting of 9 trail cameras, opportunistically available scents, and the field work was done primarily by volunteer Linda Sweanor. Thus, we consider this work exploratory to inform how we might continue in future efforts.

Our approach was simple, reflecting available resources. We placed cameras and scent stations with hair capture devices at sites where we thought we could maximize encounters with pumas. Cameras were Reconyx ™ with passive infrared motion detectors and night time infrared illumination each set to take photos each second after the camera was triggered. Our previous approach to locating stations using only trail cameras in a grid resulted in very high detection probabilities of marked pumas during our pilot camera grid project in 2009 (Logan 2010). This allowed us to photographically record behavior of pumas at scent/rub stations. Scents used included: beaver castorium, catnip oil, MT Lynx ™, Obsession for Men ™, Spotted Fever ™, and one combination of catnip oil and Spotted Fever™. Scent/rub stations, camera operation, and camera digital data were examined at approximately 2 to 4 week intervals. At those times, each rub pad (i.e., rub device and carpet swatch) was treated with a different available scent if a puma had visited the scent/rub station and regardless of the puma's response to the scent/rub station. If no pumas visited the rub/scent station, then the carpet swatch was re-treated with the same scent used the previous weeks. Our aim was to expose as many individual pumas as possible to different scents and record their behaviors.

We defined the sampled population of pumas to include only those pumas recorded by the cameras. All pumas photographed passed ≤5 m of the scent/rub station. We defined a *maximum* detection probability for a particular scent as the number of individual pumas that were photographically recorded at scent/rub stations with a particular scent that rubbed and deposited hair that could be collected divided by the total number of individual pumas that were photographically recorded at scent/rub stations with a particular scent. We did not have resources to attempt to assess quality of the DNA and individual puma genotype accuracy; thus, detection was considered to be *maximum* for this exploratory assessment only. In addition, this design did not consider other pumas in the environment that were not detected by the camera/scent/rub stations. Non-detected pumas in the area of the camera/scent/rub stations and DNA that provided inaccurate genotypes would lower the detection probability. Detailed notes were kept on visits and behaviors of all pumas and other wildlife that were recorded by cameras.

Camera scent/rub stations were maintained from November 20, 2010 to August 14, 2011. A total of 9 stations were used. All information in Tables 20, 21 and Appendix B should be considered exploratory and preliminary. Thirty-nine puma visit events were photographed, including one family of 4 pumas (i.e., mother with 3 cubs). Beaver castorium produced the highest maximum detection probability, 0.667, (Table 20). Detection was variable among the scents used and among pumas and appeared to be substantially lower for male than for female pumas (Table 21). These results indicate that more work needs to be done in a more structured manner to sample a greater number of known individual wild pumas, a variety of scents, and with an analysis of DNA quality and genotype accuracy.

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 6.7 years of effort 153 unique pumas have been captured, sampled, marked, and released. Using these animals, we monitored fates of pumas in all sexes and age stages, including: 30 adult females, 19 adult males, 6 subadult females, 12 subadult males, 39 female cubs, 53 male cubs (some individuals occur in more than one age-stage). Data from the marked animals were used to quantify puma population characteristics and vital rates in a *reference period* without sport-hunting off-take as a mortality factor from December 2004 to July 2009. Puma population characteristics and vital rates in a reference condition allowed us to develop a puma population model, and to use population data and modeling scenarios to conduct a preliminary assessment of CPW puma management assumptions and guide directions for the remainder of the puma research on the Uncompahgre Plateau. Moreover, our data and model provide tools currently useful to CPW wildlife biologists and managers for assessing puma harvest strategies. The 5-year *treatment period* began August 2009 in which sport-hunting is a mortality factor. The *treatment period* will be a population-wide test of CPW puma management assumptions. Now 2 years of the *treatment period* are complete (TY1, TY2). Although some data support CPW puma management assumptions, it is still too early in this research to adequately test the assumptions and attendant hypotheses. Although the assumption and hypothesis on harvest structure and hunter selection is not supported with the first 2 years of data in the *treatment period*, this could change with a substantial change in abundance and sex structure of independent pumas available for hunting in TY3 to TY5. The puma harvest quota for TY3 will be 8 independent pumas, and the hunters will be surveyed again. To improve data on puma population vital rates, attention will be given to increasing radio-collared sample sizes across the various life stages and sexes. We will continue to explore methods for estimating puma abundance with accurate and affordable methods. Furthermore, we will continue collaboration with colleagues on investigations of puma population parameter estimation, abundance estimation, puma movements, puma habitat modeling and mapping, and puma-human relations. All of these efforts should enhance the Colorado puma research and management programs.

LITERATURE CITED

Anderson, A. E. 1983. A critical review of literature on puma (*Felis concolor*). Colorado Division of Wildlife Special Report No. 54.

_____, D. C. Bowden, and D. M. Kattner. 1992. The puma on Uncompahgre Plateau, Colorado. Technical Publication No. 40. Colorado Division of Wildlife, Denver.

Anderson, C. R., Jr., and F. G. Lindzey. 2005. Experimental evaluation of population trend and harvest composition in a Wyoming cougar population. Wildlife Society Bulletin 33:179-188.

Colorado Division of Wildlife 2002-2007 Strategic Plan. 2002. Colorado Department of Natural Resources, Division of Wildlife. Denver.

Colorado Division of Wildlife. 2007. Colorado mountain lion management data analysis unit revision and quota development process. Colorado Division of Wildlife, Denver.

Conover, W. J. 1999. Practical nonparametric statistics. John Wiley & Sons, Inc., New York.

Cooch, E., and G. White. 2004. Program MARK- a gentle introduction, 3rd edition. Colorado State University, Fort Collins.

Culver, M., W. E. Johnson, J. Pecon-Slattery, and S. J. O'Brien. 2000. Genomic ancestry of the American puma (Puma concolor). The Journal of Heredity 91:186-197.

Currier, M. J. P., and K. R. Russell. 1977. Mountain lion population and harvest near Canon City, Colorado, 1974-1977. Colorado Division of Wildlife Special Report No. 42.

Heisey, D. M., and T. K. Fuller. 1985. Evaluation of survival and cause specific mortality rates using telemetry data. Journal of Wildlife Management 49:668-674.

Karanth, K. U., and J. D. Nichols. 2002. Monitoring tigers and their prey: A manual for researchers, managers and conservationists in tropical Asia. Centre for Wildlife Studies, Bangalore, India.

Koloski, J. H. 2002. Mountain lion ecology and management on the Southern Ute Indian Reservation. M. S. Thesis. Department of Zoology and Physiology, University of Wyoming, Laramie.

Kreeger, T. J. 1996. Handbook of wildlife chemical immobilization. Wildlife Pharmaceuticals, Inc., Fort Collins, Colorado.

Laundre, J. W., L. Hernandez, D. Streubel, K. Altendorf, and C. L. Lopez Gonzalez. 2000. Aging mountain lions using gum-line recession. Wildlife Society Bulletin 28:963-966.

Logan, K. A., E. T. Thorne, L. L. Irwin, and R. Skinner. 1986. Immobilizing wild mountain lions (*Felis concolor*) with ketamine hydrochloride and xylazine hydrochloride. Journal of Wildlife Diseases. 22:97-103.

_____, L. L. Sweanor, J. F. Smith, and M. G. Hornocker. 1999. Capturing pumas with foot-hold snares. Wildlife Society Bulletin 27:201-208.

_____, and L. L. Sweanor. 2001. Desert puma: evolutionary ecology and conservation of an enduring carnivore. Island Press, Washington, D.C.

_____. 2009. Puma population structure and vital rates on the Uncompahgre Plateau, Colorado. Wildlife Research Report. Colorado Division of Wildlife, Fort Collins.

_____. 2010. Puma population structure and vital rates on the Uncompahgre Plateau, Colorado. Wildlife Research Report. Colorado Division of Wildlife, Fort Collins.

Murphy, K., M. Culver, M. Menotti-Raymond, V. David, M. G. Hornocker, and S. J. O'Brien. 1998. Cougar reproductive success in the Northern Yellowstone Ecosystem. Pages 78-112 *in* The ecology of the cougar *(Puma concolor)* in the Northern Yellowstone ecosystem: interactions with prey, bears, and humans. Dissertation, University of Idaho, Moscow.

Ott, R. L. 1993. An introduction to statistical methods and data analysis. Fourth edition. Wadsworth Publishing Co., Belmont, California.

Pierce, B. K., V. C. Bleich, and R. T. Bowyer. 2000. Social organization of mountain lions: does land a tenure system regulate population size? Ecology 81:1533-1543.

Pollock, K. H., S. R. Winterstein, C. M. Bunck, and P. D. Curtis. 1989. Survival analysis in telemetry studies: the staggered entry design. Journal of Wildlife Management 53:7-15.

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

Ross, P. I., and M. G. Jalkotzy. 1992. Characteristics of a hunted population of cougars in southwestern Alberta. Journal of Wildlife Management 56:417-426.

Seidensticker, J. C., M. G. Hornocker, W. V. Wiles, and J. P. Messick. 1973. Mountain lion social organization in the Idaho Primitive Area. Wildlife Monographs No. 35.

Stoner, D. C. 2004. Cougar exploitation levels in Utah: implications for demographic structure, metapopulation dynamics, and population recovery. Master of Science Thesis. Utah State University.

Sweanor, L. L., K. A. Logan, J. W. Bauer, B. Milsap, and W. M. Boyce. 2008. Puma and human spatial and temporal use of a popular California state park. Journal of Wildlife Management 72:1076-1084.

Williams, B. K., J. D. Nichols, and M. J. Conroy. 2001. Combining closed and open mark-recapture models: the robust design. Pages 523-554 *In* Analysis and management of animal populations. Academic Press, New York.

White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46 (Suppl):S120-S139.

Prepared by: ________________________

Kenneth A. Logan, Wildlife Researcher

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

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

Table 2. Pumas harvested by sport-hunters in Treatment Year 2 (TY2) on the Uncompahgre Plateau Study Area, Colorado, November 22 to December 12, 2010.

Puma sex	Age (yr.)	Previous M/F I.D. or specimen P no. if not marked	Date of kill	Location/UTM	Hunter/status
F	1.5	P1020	11/22/2010	McKenzie Butte/ 13S,255947E,4238054N	Micah Brogden/ Resident
M	2.3	M90	11/23/2010	McKenzie Creek/ 13S,257237E,4238244N	Jack Flowers/ Resident
M	6.3	M55	11/25/2010	Spring Creek Canyon/ 13S,239181E,4248300N	Dennis Rawley/ Non-resident
M	3.5	P1023	11/26/2010	San Miguel River Canyon/ 12S,736610E,4230762N	Michael Compton/ Resident
F	1.5	F108	11/29/2010	Cushman Creek/ 12S,752013E,4263883N	Richard Fischer/ Resident
M	3	P1032	12/1/2010	San Miguel Canyon (E)/ 12S,729439E,4236264N	Nathan Nickle/ Non-resident
M	9.2	M32	12/2/2010	McKenzie Creek/ 13S,257722E,4239169N	Mat Iverson/ Resident
M	1.5	P1024	12/12/2010	Tabeguache Creek/ 12S,735100E,4249600N	Mark Puerschner/ Non-resident

Table 3. Three other independent GPS-collared adult pumas in the *minimum count* for the Uncompahgre Plateau Study Area that died during the 2010-11 Colorado puma hunting season.

Puma sex (M or F)	Age (yr.)	Date of kill	Place of kill/UTM	Hunter/status/other cause
M133	3.5	12/1/2010	Dry Fork Escalante Canyon 12S,731720E,4278128N	Trent Schloegel/ Non-resident
F94	5	2/1/2011	Happy Canyon 13S,246976E,4255108N	Killed by A.P.H.I.S.W.S. agent for depredation on domestic elk
F25	10	2/5/2011	Pleasant Valley 13S,252703E,4225101N	Killed by ranch-hand because puma was seen in vicinity of cattle

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

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

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

Table 5. Pumas captured and released by sport-hunters in Treatment Year 2 (TY2) on the Uncompahgre Plateau Study Area, Colorado, November 22 to December 12, 2010. Data are from puma hunter responses in 54 voluntary surveys, including: 42 original surveys on printed voluntary permits and 12 telephone contacts with hunters that did not return printed surveys on permits. Total response rate from 64 individual hunters was 84.4% (54/64 = 0.894*100).

Puma sex/age stage/mark	Date of capture	Capture location	Hunter name	Reason for releasing the puma given by hunter
F/adult/F3 by collar, no eartags, confirmed with GPS and VHF data	11/25/2010	Spring Creek Canyon	Justin Hill	Did not pursue the female puma with intent to harvest it.
F/adult/F96 by GPS collar, confirmed with GPS data	11/27/2010	Dolores Canyon	Justin Hill	Did not pursue the female puma with intent to harvest it.
F/adult/none	11/23 to 27/2010	McKenzie Creek (west)	Tommie Buckington guided by Ryan Weimer	Female puma with evidence of suckling on nipples. Did not want to kill a female puma with cubs. Cubs not actually seen.
F /adult and cub/none	11/22 to 30/2010	Dolores River Canyon	Ryan Weimer	Not legal to kill a female puma with cubs.
F/adult or subadult/none	11/30/2010	Dolores Creek (east)	John Akerberg & Kris Brown guided by Ben Harris	Did not pursue the female puma with intent to harvest it.
F/adult/none	12/11/2010	Sims Mesa to Happy Canyon	Wade Wilson	Did not pursue the female puma with intent to harvest it.
F/adult/none	11/22 to 12/12/2010	Dry Park to Big Bucktail Creek	Sam Sickels	Did not pursue the female puma with intent to harvest it.
M/subadult/none	11/22 to 12/12/2010	San Miguel Canyon above Goodenough Gulch	Ty Sickels	Did not want to harvest a subadult male; guessed weight 125 lb.

Table 6. Summary of puma capture efforts with dogs from November 16, 2010 to April 22, 2011, Uncompahgre Plateau, Colorado.

Month	No. Search Days	No. & type of puma tracks found[a,b]	No. & type of pumas pursued	No. & I.D. or type of pumas captured, observed, or identified
November	1	2 tracks: 1 male, 1female, 0 cub Tracks ≤1 day old: 1 male, 1 female, 0 cub	1 pursuits: 1 male, 0 female , 0 cub	1 puma captured: M90 recaptured and fit with adult-size VHF collar (cub collar had quit/shed a long time previously).
December	11	35 tracks: 7 male, 17 female, 9 cub, 2 undetermined independent pumas Tracks ≤1 day old: 2 male, 3 female, 2 cub	5 pursuits: 1 male, 3 female, 1 cub	3 pumas captured 3 times: AFP1025 (biodart, dangerous tree), Adult F (not handled due to dangerous tree), M134 cub. In addition, adult female F118, her 3 cubs M126, M127, M128, and adult male M67 were associated with tracks by VHF telemetry.
January	22	109 tracks: 15 male, 60 female, 30 cub, 4 undetermined independent pumas Tracks ≤1 day old: 5 male, 25 female, 24 cub	29 pursuits: 5 male, 14 female, 10 cub	18-19 pumas captured 20 times: F135, F104, AFP1029 (bio-darted, dangerous tree), F136, F137, F28, F23 captured twice, Sub./AMP1028 (possibly M138), M138, and cubs F111's two cubs (not handled, dangerous trees), M112, FP1026, MP1027, M134, M112, F140, M141, M142. In addition, adult females F111, F3 (twice), F96, F136, F116 (twice), and cubs F140, M141, M142 were associated with tracks by VHF telemetry.
February	20	65 tracks: 13 male, 28 female, 24 cub Tracks ≤1 day old: 10 male, 21 female, 22 cub	30 pursuits: 9 male, 11 female, 10 cub	14 pumas captured 15 times: F137, F70, F23, F143, adult F (not handled, dangerous tree), F24 (twice), independent M (not handled, dangerous tree), M138, M87, subMP1031 (bio-darted, dangerous tree), and cubs M150 (twice), P1026, M151. In addition, adult females F96, F70 (twice), F23, F118, F143, adult male M67, and cubs M141, M142 were associated with tracks by VHF telemetry.
March	21	73 tracks: 26 male, 30 female, 17 cub Tracks ≤1 day old: 9 male, 12 female, 7 cub	22 pursuits: 4 male, 11 female, 7 cub	7 pumas captured 7 times: F111, F3, F72, F145, F146, M144, and cub F152. In addition, subadults M144, F145, and cub M142 were associated with tracks by VHF telemetry.
April	6	16 tracks: 3 male, 6 female, 7 cub Tracks ≤1 day old: 2 male, 4 female, 7 cub	12 pursuits: 2 male, 3 female, 7 cub	5 pumas captured 5 times: F24, M92, and cubs F140, M141, F147. In addition, adult M67 was associated with tracks with VHF telemetry.
TOTALS	81	300 tracks: 65 male, 142 female, 87 cub, 6 undetermined Tracks ≤1 day old: 29 male 68 female 62 cub	99 pursuits: 22 male, 42 female, 35 cub	36 to 37 individual pumas were captured 52 times with aid of dogs. In addition, 18 radio-collared pumas were detected 28 times by tracks and identified with VHF telemetry ≤1 km from the tracks.

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

[b] Researchers also recorded instances when the first puma tracks ≤1 day old were encountered on each search route each day. The count was: 47 tracks of females, including 11 associated with cubs; 21 tracks of males; 4 tracks of cubs, and 1 track of undetermined sex.

Table 7. Adult and subadult pumas captured for the first time, sampled, tagged, and released from November 2010 to April 2011, Uncompahgre Plateau, Colorado.

Puma I.D.	Sex	Estimated Age (mo.)	Mass (kg)	Capture date	Capture method	Location
M133	M	42	70	11/12/2010	Cage trap	Roubideau Canyon
F135	F	27	38	1/1/2011	Dogs	Dry Creek Basin
F136	F	30	41	1/20/2011	Dogs	McKenzie Creek (east)
F137	F	24	35	1/21/2011	Dogs	Dry Creek Basin
M138	M	18	50	1/26/2011	Dogs	Spring Creek Canyon
F143	F	24	45	2/15/2011	Dogs	San Miguel Canyon
M144	M	18	63	3/7/2011	Dogs	Little Big Bucktail Creek
F145	F	18	42	3/8/2011	Dogs	North Fork Cottonwood Creek
F146	F	18	36	3/8/2011	Dogs	Tomcat Creek
M153	M	18	55	4/12/2011	Cage trap	McKenzie Mesa

Table 8. Pumas that were captured and observed with aid of dogs, some of which were biopsy-darted and given specimen numbers (e.g., P1025), but were not handled at that time for safety reasons, December 2010 to April 2011, Uncompahgre Plateau, Colorado.

Puma sex & I.D.	Age stage or months	Capture date	Location	Comments
F P1025	adult	12/14/2010	Monitor Mesa, Roubideau Canyon	Puma climbed dangerous tree. Biopsy-darted to obtain tissue sample for genotype. Apparent mother of cub M134.
F28	adult	1/1/2011	San Miguel Canyon	Puma climbed dangerous tree momentarily, then left the tree and took refuge in a deep narrow hole where we could not gain access to her to change the non-functional GPS collar.
Unknown none	cub 7	1/2/2011	Piney Creek	Puma climbed dangerous tree. Cub of F111. Two cub tracks found; one was M151 marked 2/24/2011.
Unknown none	cub 7	1/2/2011	Piney Creek	Puma climbed dangerous tree. Cub of F111. Two cub tracks found; one was M151 marked 2/24/2011.
F P1026	cub 18	1/6/2011	Happy Canyon	Puma climbed dangerous tree. Biopsy-darted to obtain tissue sample for genotype. Probably offspring of F70; sibling of M112 and M150.
M P1027	cub 18	1/7/2011	Happy Canyon	Puma climbed dangerous tree. Biopsy-darted to obtain tissue sample for genotype. Probably M150, offspring of F70; sibling of M112 and P1026.
M P1028	adult	1/12/2011	Roubideau Canyon	Puma climbed dangerous tree. Biopsy-darted to obtain tissue sample for genotype. Possibly M138.
F P1029	adult	1/15/2011	Dolores Canyon (E)	Puma climbed dangerous tree. Biopsy-darted to obtain tissue sample for genotype.
M none	adult	2/3/2011	West Fork Dry Creek Basin	Puma climbed dangerous tree. Too high to biopsy dart.
M P1031	subadult	2/17/2011	North Fork Cottonwood Creek	Puma climbed dangerous trees. Biopsy-darted to obtain tissue sample for genotype.
F none	adult	2/21/2011	San Miguel Canyon above Horsefly Creek	First dart missed puma; puma left tree and evaded dogs on bare ground.
M92	adult	4/22/2011	McKenzie Canyon (W)	Puma climbed dangerous tree. Identified by eartag.

Table 9. Pumas recaptured with dogs and cage traps January 2011 to April 2011, Uncompahgre Plateau, Colorado.

Puma I.D.	Recapture Date	Mass (kg)	Estimated Age (mo.)	Capture Method/ Location	Process
F28	1/1/2011	Observed	94	Dogs/East Fork Dry Creek Basin	F28 first climbed dangerous tree, left the tree, then entered deep narrow hole; could not be handled to replace non-functional GPS collar.
F23	1/6/2011	Observed	77	Dogs/San Miguel Canyon above Pinyon	F23 took refuge in elevated crevice on canyon wall; could not be handled to replace non-functional GPS collar.
M112	1/6/2011	Observed	17	Dogs/Happy Canyon	Observed puma bayed on the ground, fighting the dogs. Dogs caught and puma allowed to escape.
M134	1/8/2011	Observed	19	Dogs/Potter Basin	Not handled.
F104	1/11/2011	36	116	Dogs/Roatcap Canyon	GPS collar replaced with VHF radiocollar.
M112	1/24/2011	42	17	Dogs/Horsefly Canyon	M112 fit with VHF radiocollar with expansion link.
F23	1/26/2011	45	77	Dogs/San Miguel Canyon below Pinyon	Replaced non-functional GPS collar with new VHF radiocollar.
F137	2/1/2011	Observed	25	Dogs/East Fork Dry Creek	Observed and released.
F23	2/8/2011	Observed	78	Dogs/Tomcat Creek	Observed and released.
M87	2/9/2011	65	31	Dogs/Big Bucktail Creek	M87 fit with VHF radiocollar.
M138	2/9/2011	Observed	19	Dogs/Roatcap Canyon	Observed and released.
F70	2/18/2011	Observed	70	Dogs/Spring Creek Canyon	F70 climbed dangerous tree; could not be handled.
F70	2/21/2011	46	70	Cage trap/Pinyon Hills, Happy Canyon	Old GPS collar replaced with new GPS collar.
F24	2/22/2011	38	119	Dogs/Dry Park, Cottonwood Creek	Replaced non-functional GPS collar with new VHF radiocollar.
F24	2/24/2011	Observed	119	Dogs/San Miguel Canyon above Pinyon	F24 observed and released. Effort to capture 2 cubs failed; lost tracks on bare ground in ledges.
F111	3/4/2011	41	41	Dogs/Cushman Canyon	Old GPS collar replaced with new GPS collar.
F3	3/15/2011	Observed	116	Dogs/Spring Creek Canyon	F3 climbed dangerous tree. Could not be handled to replace old, working GPS collar.
F72	3/18/2011	Observed	60	Dogs/Fisher Creek	F72 climbed dangerous tree. Could not be handled to replace non-functional GPS collar.
F140	4/1/2011	22	8	Dogs/Coal Canyon	Recollared with large expandable cub collar to replace the collar that was shed earlier.
M141	4/1/2011	Observed	8	Dogs/Coal Canyon	M141 left tree before we could handle him; escaped the dogs on bare ground.
F137	4/11/2011	42	27	Cage trap/Dry Creek Basin	Replaced VHF radiocollar with GPS collar.
F24	4/21/2011	Observed	121	Dogs/McKenzie Canyon (west)	F24 observed and released. Captured, sampled, and radio-collared cub F147 (one of two cubs).
M92	4/22/2011	Observed	32	Dogs/McKenzie Canyon (west)	M92 climbed dangerous tree. Could not be handled to fit with radiocollar.

Table 10. Summary of puma capture efforts with cage traps from November 8, 2010 to April 18, 2011, Uncompahgre Plateau, Colorado.*

Month	No. of Sites	Carnivore activity & capture effort results
November	6	Captured adult male puma M133 that scavenged mule deer doe carcass in Roubideau Canyon 11/12/2010. Set cage trap in mouth Linscott Canyon on 11/18/2010 in effort to capture male puma that scavenged mule deer carcass; but, the male puma did not return.
January	0	All capture efforts with dogs.
February	1	Puma F70 was recaptured at a mule deer kill on 2/21/2011 on Pinyon Hills, Happy Canyon.
March	3	No pumas scavenged the mule deer carcasses.
April	4	Puma F137 was recaptured when she returned to scavenge on a mule deer buck carcass in Dry Creek Basin on 4/11/2011. Puma M153 was captured when he returned to scavenge a mule deer doe carcass on McKenzie Mesa on 4/12/2011. Puma F70 scavenged a mule deer buck carcass on 4/16-17/2011; no effort was made to recapture her.

* We used 12 road-killed mule deer at 10 different sites. Of the road-killed deer baits, 5 of 12 (41.66%) were scavenged by pumas.

Table 11. Puma cubs sampled August 2010 to July 2011 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)
M122[b]	M	7/8/2010	35	2.2	F104	110
F123	F	7/15/2010	29	1.8	F94	60
F124	M	7/15/2010	29	1.9	F94	60
M125	M	7/15/2010	29	2.0	F94	60
M126	M	8/8/2010	28	1.6	F118	27
M127	M	8/8/2010	28	1.9	F118	27
M128	M	8/8/2010	28	2.0	F118	27
F129	F	8/21/2010	35	1.6	F96	55
M130	M	8/21/2010	35	1.9	F96	55
M131	M	8/21/2010	35	1.8	F96	55
F132	F	8/21/2010	35	1.6	F96	55
M134	M	6/2009	547	64	Unknown	Unknown
M139	M	4/18/2011	36	2.25	F8	95
F148	F	4/18/2011	36	2.25	F8	95
F140	F	8/2010	152	13	Unknown	Unknown
M141	M	8/2010	152	15	Unknown	Unknown
M142	M	8/2010	152	14	Unknown	Unknown
F147[c]	F	9/2010	214	16	F24	114
F149	F	4/22/2011	45	2.9	F23	80
M150[d]	M	8/31/2009	547	53	F70	52
P1026[d]	F	8/31/2009	516	NH	F70	52
M151[e]	M	6/16/2010	253	23	F111	32
F152[f]	F	6/16/2010	261	25	F93	90
P1030	F	8/2010	183	21	Unknown	Unknown

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

[b] Three sets of cub tracks (including M122) observed in association with F104 when she was recaptured 1/11/2011 in Roatcap Canyon.

[c] Three sets of cub tracks (including F147) observed in association with F24.

[d] Cubs M150 and P1026 are siblings of M112. F70 had at least 3 cubs in the litter. Birth date based on GPS data on F70's collar.

[e] Two cubs were observed in association of F111.

[f] F93 had two cubs in this litter.

Table 12. Summary of puma capture efforts with dogs, December 2004 to April 2011, Uncompahgre Plateau, Colorado.

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

Table 13. Individual puma reproduction histories, Uncompahgre Plateau, Colorado, 2005-2011.

Consort pairs and estimated ages[a]				Dates pairs consorted[b]	Estimated birth date[c]	Estimated birth interval (mo.)	Estimated gestation (days)	Observed number of cubs[d]
Female	Age (mo.)	Male	Age (mo.)					
F2	53				05/28/05			3
F2	67				07/29/06	14.0		2
F2	89				05/19/08	22.0		4
F3	36				08/01/04			1
F3	50	M6	37	06/22-24/05	09/26/05	13.8	93-95	2
F3	62				09/17/06	11.7		3
F3	84	M51	60	03/31/08	07/03/08	21.5	94	3
F3	107	M55	69	03/28-31/10	06/28/10	23.8	89-92	2
F7	67				05/19/05			2
F7	82				08/13/06	14.9		4
F7	106				07/10/08	23.9		3
F8*[e]	24				06/26/05			2
F8	37				08/13/06	13.4		4
F8	60	M73	49	02/28-29/08	05/29/08	22.5	90-91	2
F8	95				04/18/11	34.7		
F16	32				09/22/05			4
F16	52				05/24/07	19.9		4
F16	75	M6	80	01/13-14/09	04/15/09	22.7	91-92	3
F23*	21				05/30/06			3
F23	45	M27 or M29[f]	78 107	02/19-25/08	05/23/08	23.8	87-93	3
F23	80				04/22/11	Non-funct.GPS		1
F24	75	M29	92	04/12-15/07	06/14/07		90-93	4
F24	114				09/10	Non-funct.GPS		3
F25	74				08/01/05			1
F25	94				04/16/07	20.5		1
F25	110				08/19/08	16.1		2
F25	129				3/10	Non-funct.GPS		3
F28*	36				06/09/06			2
F28	48	M29	88	12/27-29/06	03/30/07	11.7	92-93	≥2 tracks
F28	68				11/08			1
F30*	48	M55	34	04/16-20/07	07/17/07		88-92	3
F50	21				07/01/06			1
F54	24				07/01/06			1
F70*	38	M51	60	03/10/08	06/05/08		87	3
F70	52				08/31/09	14.8		3
F72*	28				07/09/08			1
F72	51				06/12/10	23.1		2
F75	32				06/01/07			1
F75	55	M73	61	02/11/09	05/07/09	23.2	93	2
F93	56				08/07			2
F93	90				06/16/10			2
F94*	46				05/27/09			3
F94	60	M55	70	04/15/10	07/15/10	13.3	91	3
F96	55	M55	71	05/21/10	08/21/10			4
F104	110				07/08/10			3
F111*	32				06/16/10			2
F116[g]	36-48				2009			2
F118	27				08/08/10			3
F119	66				08/09			2

[a] Ages of females were estimated at litter birth dates. Ages of males were estimated around the dates the pairs consorted.
[b] Consort pairs indicate pumas that were observed together based on GPS data or VHF location data.
[c] Estimated birth dates were indicated by GPS data of mothers at nurseries or by back-aging cubs to approximate birth date.

[d] Observed number of cubs do not represent litter sizes as some cubs were observed when they were 5 to 16 months old after postnatal mortality could have occurred in siblings. Only cub tracks were observed with F28.
[e] Asterisk (*) indicates first probable litter of the female, based on nipple characteristics noted at first capture of the female.
[f] A radio-collared, ear-tagged male puma was visually observed with F23 on 2/25/08. Both M27 and M29 wore non-functional GPS collars in that area at the time.
[g] When captured on 1/20/10, puma F116 was in association with 2 large cubs which were not captured.

Table 14. Summary for individual adult puma survival and mortality, December 8, 2004 to July 31, 2011, Uncompahgre Plateau, Colorado.

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

Table 14 continued.		
Puma I.D.	**Monitoring span**	**Status: Alive/Lost contact/Dead; Cause of death**
M134	06-01-11 to 06-10-11	Dead. M134 was offspring of unmarked female puma in Roubideau Canyon. Independent by about 03-28-11. Shot dead by USDA, APHIS, WS agent while in the act of attacking domestic sheep on 06-10-11 when he was 24 months old at start of adult life stage.
M138	07-01-11 to 07-31-11	Alive.
F2	01-07-05 to 08-14-08	Dead; killed by another puma (sex of puma unknown; male suspected) 08-14-08. F2 was about 92 months old at death.
F3	01-21-05 to 07-31-10	Lost contact− failed GPS/VHF collar.
F7	02-24-05 to 08-03-08	Dead. Killed by U.S. Wildlife.Services agent 08-03-08 for predator control of depredation on domestic sheep. F7 was about 107 months old at death.
F8	03-21-05 to 07-31-11	Alive.
F16	10-11-05 to 09-11-09	Dead. F16 was struck and killed by a vehicle on Ouray County Road 1 southwest of Colona, CO on 09-11-09. F16 was about 80 months old at death.
F23	02-05-06 to 07-31-11	Alive. Lost radio contact after12-02-09. F23 recaptured on the study area 01-26-11; her non-functional GPS collar was replaced with a VHF radiocollar.
F24	01-17-06 to 07-31-11	Alive. Lost radio contact after 09-03-08− failed GPS/VHF collar. F24 recaptured on 02-22-11; her non-functional GPS collar was replaced with a VHF radiocollar.
F25	02-08-06 to 02-03-11	Dead. Lost radio contact after 09-04-09– failed GPS/VHF collar. Photographed alive with three ~9 month old cubs on 12-03-10 on Loghill Mesa. F25 shot dead by a ranch hand on 02-03-11 in Pleasant Valley, Dallas Creek because she was seen among cattle. F25 was about 138 months old at death and in excellent physical condition (49 kg).
F28	03-23-06 to 01-01-11	Lost radio contact after 09-25-07− failed GPS/VHF collar. Recaptured F28 on the study area 02-01-10 and 01-01-11, but could not be handled to replace non-functional GPS collar.
F30	04-15-06 to 07-29-08	Dead. Killed by another puma (sex of puma unknown) 07-29-08. F30 was about 60 months old at death.
F50	12-14-06 to 03-26-07	Dead of natural causes 03-26-07; probably injury or illness-related; exact agent unknown. F50 was about 30 months old at death.
F54	01-12-07 to 08-18-07	Dead; killed by a male puma while in direct competition for prey (i.e., mule deer fawn) 08-18-07. F54 was about 49 months old at death.
F70	01-14-08 to 07-31-11	Alive.
F72	02-12-08 to 03-18-11	Lost radio contact after 12-02-10. F72 recaptured in Fisher Creek on 03-18-11, but could not be handled to replace non-functional GPS collar.
F75	03-26-08 to 02-10-10	Lost radio contact after 09-29-09– failed GPS/VHF collar. F75 in association with her cubs M105 and F106 when F106 was recaptured on 02-10-10 on the study area.
F93	12-05-08 to 07-31-11	Alive.
F94	12-19-08 to 02-01-11	Dead. Shot dead on 02-01-11 by USDA, APHIS, WS agent for predation on domestic elk in Happy Canyon. F94 was about 74 months old at death.
F95	08-01-09 to 07-31-11	Alive.
F96	01-28-09 to 07-31-11	Alive.
F104	05-21-09 to 07-31-11	Alive.
F110	09-21-09 to 02-25-10	Dead. Killed by a puma hunter on 02-25-10 in GMU 70 East. F110 was about 41 months old at death.
F111	01-01-10 to 07-31-11	Alive.

Table 14 continued.

Puma I.D.	Monitoring span	Status: Alive/Lost contact/Dead; Cause of death
F113	01-26-10 to 06-06-10	Dead. F113 died 06-06-10 of injuries consistent with being struck by a vehicle. GPS data indicated that F113 had crossed highway 550 and roads on Loghill Mesa north of Ridgway 24-30 hours before she died in McKenzie Creek. F113 was about 42 months old at death.
F116	01-20-10 to 07-31-11	Alive.
F118	02-25-10 to 07-31-11	Alive.
F119	03-25-10 to 07-31-11	Alive.
F135	01-01-11 to 07-31-11	Alive.
F136	01-20-11 to 07-31-11	Alive.
F137	01-21-11 to 07-31-11	Alive.
F143	02-15-11 to 07-31-11	Alive.

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

Biological Year	**Females**			**Males**		
	S	**SE**	***n***	***S***	**SE**	***n***
Reference Annual 2 8/1/2005 to 7/31/2006	1.000	0.0000	10	0.667[a]	0.2222[a]	6[a]
Reference Annual 3 8/1/2006 to 7/31/2007	0.909	0.0867	11	1.000	0.0000	5
Reference Annual 4 8/1/2007 to 7/31/2008	0.831	0.0986	14	1.000	0.0000	7
Reference Annual 5 8/1/2008 to 7/31/2009	0.875	0.1031	13	1.000	0.0000	8
Treatment Annual 1 8/1/2009 to 7/31/2010	0.784	0.1011	19	0.667	0.1924	8
Treatment Annual[b] 8/1/2009 to 7/31/2010 With mortalities of all marked adult males				0.333[b]	0.1361[b]	12[b]
Treatment Annual 2 8/1/2010 to 7/31/2011	0.947[c]	0.0568	19	0.250	0.1082	9

[a] Adult male annual *S* 2005 to 2006 is probably underestimated with poor precision because 3 of the 6 pumas were GPS/VHF-monitored for 4 to 5 months at the end of the interval; 1 of 6 adult males died.
[b] This second estimate of adult male puma survival 8/1/2009 to 7/31/2010 includes 5 males that had non-functional (4) or shed (1) radiocollars. All adult males with non-functional or shed radiocollars in this study survived into *treatment year* 1 (TY1), which was expected considering adult male survival in 3 previous years. All 5 of those adult males were detected and killed by hunters in TY1.
[c] Only 1 of 2 adult female puma mortalities is represented in this survival analysis for 8/1/2010 to 7/31/2011, that of F94 killed for depredation control. One other adult female mortality, F25, is not represented because she wore a non-functional GPS collar making it impossible for us to monitor her survival. F25 was shot by a ranch hand on 2/3/2011 when he saw her among cattle.

Table 16. Summary of subadult puma survival and mortality, December 2004 to July 2011, Uncompahgre Plateau, Colorado.

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

Table 16 continued			
Puma I.D.	**Monitoring span**	**No. days**	**Status**
F95	12-29-08 to 07-31-09	214	Alive. F95 is the offspring of F93, born about August 2007. She became an independent subadult by about 18 months old (02-11-09 aerial location) and an adult by about 24 month old (Aug. 2009). F95 established an adult home range adjacent to and overlapping the northern portion of her natal area.
M99	02-27-09 to 04-22-09	54	Dead. M99 probably killed by another puma (canine punctures in skull including braincase) in Jan. 2010 when he was about 16 months old. His radiocollar quit after 54 days.
M112	02-10-11 to 04-18-11	67	M112 was offspring of F70. Lost contact of M112 after 04-18-11; he may have dispersed or radiocollar quit. M112 associated with F96 and her two radio-collared cubs F129 and M130 during 02-10-11 to 04-18-11.
M115	01-13-10 to 07-21-10	189	Dead. M115 was offspring of F28, born in Nov. 2008. He was about 14 months old when first captured on Jan. 13, 2010. When he was recaptured on 03-18-10, he had previously suffered a broken left ulna. M115 was probably independent by 07-15-10 when he was located outside of his natal area on a probably dispersal move. M115 died on about 07-21-10 apparently from complications of his broken left foreleg; probably not allowing him to kill prey sufficiently for survival. M115 was about 20 months old at death.
M134	03-28-11 to 06-10-11	74	M134 was offspring of unmarked female puma in Roubideau Canyon. Independent by about 03-28-11. Shot dead by USDA, APHIS, WS agent while in the act of attacking domestic sheep on 06-10-11 when he was 24 months old at start of adult life stage.
M138	01-26-11 to 06-30-11	155	Alive on the study area. Entered adult life stage 07-01-11.
M144	03-07-11 to 07-13-11	128	Dispersed. Last contact on 07-13-11 in Blue Creek, northwest Uncompahgre Plateau.
F145	03-08-11 to 04-28-11	51	Dispersed. Last contact on 04-28-11 in UC Creek, Deep Canyon, northwest Uncompahgre Plateau.
F146	03-08-11 to 03-23-11	15	Dead. F146 was killed and eaten by a male puma while in competition for an adult bull elk carcass that one of the pumas killed in Coal Canyon on the study area. F146 was about 19 months old at death.
M150	03-28-11 to 04-11-11	14	Dispersed. M150 was offspring of F111, born on 08-31-09. He was independent by 03-28-11 when he was 19 months old. Lost contact after 04-11-11 when M150 was in Cow Creek southeast of the study area.
M153	04-12-11 to 07-31-11	110	Alive on the study area.

Table 17. Records of pumas that dispersed from the Uncompahgre Plateau study area, December 2004 to July 2011.

Puma I.D.	1st capture date on study area	1st capture location→kill or resight location (UTM, NAD27)	Estimated linear dispersal distance (km)*	Puma Information
M5	02-04-05	13S,240577E, 4251037N→ 12S,665853Ex 4277125N	102.2	M5 was offspring of F3, born August 2004. Independent and dispersed from natal area at 13 months old. Established adult territory on northwest slope of Uncompahgre Plateau at the age of 24 months (protected from hunting mortality in buffer area) and ranged into the eastern edge of Utah (vulnerable to hunting). Killed by a puma hunter on 02-20-09 in Beaver Creek, Utah at about 54 months old.
M11	06-27-05	13S,248278E, 4239858N→ 12S,741882Ex 4161575N	84.8	M11 was offspring of F2, born May 2005. Shed expandable radiocollar 10-24 to 11-08-05. Recaptured and re-collared 04-02-06. Independent at 13 months old. Dispersed from natal area at 14 months old. Moved to Dolores River valley, CO, by 12-14-06. Killed by a puma hunter on 12-02-07 when about 30 months old.
M31	04-19-06	12S,746919E, 4225441N→ 13S,500000Ex 4050000N	329.8	M31's estimated age at capture was 20 months. Dispersed to northern New Mexico and was killed by a puma hunter on 12-11-08 in Middle Ponil Creek, Cimarron Range. He was about 52 months old.
M38	09-08-06	13S,249200E, 4239703N→ 12S,703371E, 4316856N	104.1	M38 was offspring of F2, born July 29, 2006. Shed his expandable radiocollar by 03-06-07. Photographs by trail camera in McKenzie Cr. of M38 & Unm. F sibling with F2 on 07-16 to 17-07 at 352-353 days old. M38 was killed by a hunter in Ladder Creek southwest of Grand Junction, CO on 01-07-11. He was 54 months old at death.
M39	09-11-06	12S,724270E, 4243610N→ 12S,709889E, 4313490N	71.3	M39 was offspring of F8, born August 2006. M39 was killed by a puma hunter in Bangs Canyon, GMU 40 on 03-12-10 when he was 43 months old.
M43	09-15-06	12S,760177E, 4242995N→ 12S,739859E, 4308557N	68.6	M43 was offspring of F7, born August 2006. He shed the expandable radiocollar 11-7 to 17-06, after which direct contact was lost. M43 was killed by a puma hunter 01-28-09 in Deer Creek, west slope of Grand Mesa, CO when he was 29 months old.
M48	10-18-06	12S,756676E, 4247777N→ 12S,704982E, 4248998N	52.0	M48 was the offspring of F3, born September 2006. M48 was killed by a puma hunter in Tabeguache Creek, GMU 61 North on 12-27-09 when he was 39 months old.
M49	12-05-06	12S,757241E, 4258259N→ 12S,693350E, 4274559N	66.1	M49 was offspring of F50, born July 2006. Orphaned at about 9 months old, when F50 died of natural causes. Dispersed from his natal area at about 10 months old and ranged on the northeast slope of the Uncompahgre Plateau. When M49 was about 15 months old, he shed his expandable radiocollar on about 10-01-07 at a yearling cow elk kill on the northeast slope of the Uncompahgre Plateau. He was killed by a puma hunter in Blue Creek in the protected buffer zone north of the study area on 01-24-09; he was about 29 months old.
M58	06-27-07	13S,258543E, 4238071N→ 13S,274670E, 4309488N	73.2	M58 was offspring of F16, born May 2007. M58 was killed by a puma hunter on 12-27-09 in the North Fork of the Gunnison River north of Paonia, GMU 521; he was 31 months old.

Table 17 continued.				
Puma I.D.	**1st capture date on study area**	**1st capture location→kill or resight location (UTM, NAD27)**	**Estimated linear dispersal distance (km)***	**Puma Information**
M63	08-17-07	12S,738144E, 4233628N→ 12S,689111E, 4277908N	66.1	M63 was offspring of F24, born July 14, 2007. He was not radio-collared as a cub. M63 was killed by a hunter in Calamity Creek on northwest Uncompahgre Plateau on 01-01-11. M63 was 42 months old at death.
M65	08-17-07	12S,738144E, 4233628N→ 12S,684084E, 4314200N	97.0	M65 was offspring of F24, born July 2007. M65 was killed by a USDA, APHIS, WS agent for depredation on llamas in the Little Dolores River on 11-07-09. M65 was 28 months old.
M67	08-23-07	13S,257371E, 4235231N→ 12S,725113E, 4242447N	57.7	M67 was offspring of F30, born July 17, 2007 in Fisher Creek on the east slope of the study area. He was not radiocollared as a cub. M67 dispersed from the natal area and was recaptured in Tomcat Creek on the west slope of the study area on 02-24-10 when he was 31 months old. M67 is a resident adult in that area (07-31-11).
M68	08-23-07	13S,257371E, 4235231N→ 12S,711262E, 4198681N	80.7	M68 was offspring of F30, born July 2007. He was orphaned at 12 months old when his mother was killed by a puma. He was killed by a puma hunter in the Disappointment Valley in southwest CO on 12-30-08; he was 17 months old.
M69	01-11-08	13S,248191E, 4246810N→ 13T,378900E, 4591990N	369.6	M69 was captured on the study area when about 14-18 months old. Emigrated from the study area as subadult by 03-19-08. Last VHF aerial location was southwest of Waterdog Peak, east side of Uncompahgre River Valley on 04-07-08. M69 was killed by a puma hunter on 11-06-08 in Pass Creek in the Snowy Range, WY when he was 24 to 28 months old.
M82	07-05-08	12S,726901E, 4243463N→ 13S,255316E, 4216768N	60.5	M82 was offspring of F8, born May 29, 2008; sibling of M83 below. He shed his expandable cub radiocollar after 03-20-09. M82 was killed by a hunter on 12-10-09 in the Beaver Creek fork of East Dallas Creek, GMU 65. M82 was 19 months old.
M83	07-05-08	12S,726901E, 4243463N→ 12S,670949E, 4314779N	90.7	M83 was offspring of F8, born May 29, 2008; sibling of M82 above. He was not radiocollared as a cub. M82 was killed by a hunter on 01-18-11 in Coates Creek west of Glade Park, CO. He was 30 months old at death.
M87	07-31-08	13S,239006E, 4248601N→ 12S,724325E, 4244118N	39.2	M87 was offspring of F3, born July 3, 2008 on the east slope of the study area; sibling of M88 below. He was not radiocollared as a cub. M87 dispersed from the natal area. He was recaptured on the west slope of the study area on 02-09-11 when he was 31 months old. M87 is a resident adult on the west slope of the study area to 07-31-11.
M88	07-31-08	13S,239006E, 4248601N→ 12S,704835E, 4197839N	77.6	M87 was offspring of F3, born July 3, 2008 on the east slope of the study area; sibling of M87 above. He was not radiocollared as a cub. M87 dispersed from the natal area. He was killed by a hunter in Dawson Creek, Disappointment Valley on 11-30-10 when he was 29 months old.
M92	09-29-08	13S,246359E, 4226949N→ 12S,750871E, 4222921N	21.9	M92 was offspring of F25, born August 19, 2008. He was radiocollared as a cub; last contact on 12-12-08. M92 dispersed from the natal area and was recaptured in McKenzie Creek, west slope of the study area on 04-22-11 when he was 32 months old. He could not be handled to fit a new radiocollar because of a dangerous tree.
M107	06-28-09	13S,242359E, 4252618N→ 12S,754886E, 4341330N	89.2	M107 was offspring of F94, born May 25, 2009; sibling of F108 below. He was not radiocollared as a cub. M107 dispersed from the nata area. He was killed by a hunter in Cottonwood Creek near Molina, CO on 12-09-10 when he was 19 months old.

Table 17 continued.				
Puma I.D.	**1st capture date on study area**	**1st capture location→kill or resight location (UTM, NAD27)**	**Estimated linear dispersal distance (km)***	**Puma Information**
M117	02-05-10	12S,731840E, 4232346N→ 12S,743909E, 4216633N	19.7	M117 was offspring of F119. He wore an expandable cub collar, but shed the collar by 07-15-10 on the natal area when about 11 months old. M117 was killed by a puma hunter in Beaver Creek, San Miguel River at the southern extreme of his natal area on 01-01-11. He was 17 months old at death. It is unknown if M117 was independent from his mother F119 at the time of his death.
M144	03-07-33	12S,727173E, 4242012N→ 12S,696439E, 4276888N	46.6	M144 was initially captured as an independent subadult in association with subadults F145 and F146 on the study area. Mother is unknown. He moved off the study area on 03-15-11. M144's last aerial radio location was in Blue Creek on northwest Uncompahgre Plateau on 07-13-11; he was about 22 months old.
F52	01-10-07	13S,258058E, 4236260N→ 13S,319217E, 4240467N	61.1	F52 was captured on the study area when about 18-20 months old. Dispersed from study area as a subadult by Jan. 16, 2007. F52's last VHF aerial location was Crystal Creek, a tributary of the Gunnison River east of the Black Canyon 05-15-07. She was treed by puma hunters on 12-29-08 on east Huntsman Mesa, southeast of Powderhorn, CO. She was about 41-43 months old . F52 was treed again by puma hunters on about 12-16-09 south of Powderhorn: 13S,319480E,4233219N. F52 was about 53-55 months old. This suggests that F52 has an adult home range in that area.
F106	06-14-09	12S,736451E, 4240278N→ 13S,258089E, 4235866N	46.9	F106 was offspring of F75, born May 7, 2009. She wore an expandable cub collar, but shed it about 03-23-10. F106 dispersed from the natal area and moved to the east slope of the study area where she was photographed at one of our scent station cameras at the mouth of Fisher Creek from 02-27-11 to 03-03-11. She was identified by her eartag. F106 was 21 months old.
F108	06-28-09	13S,242359E, 4252618N→ 12S,752013E, 4263883N	18.2	F108 was offspring of F94, born May 25, 2009; sibling of M107 above. She was fitted with an expandable cub collar; but, shed the collar in the original nursery due to failure of the fastener. F108 dispersed from the natal area. She was killed by a hunter on the study area on 11-29-10 when she was 17 months old.
F145	03-18-11	12S,727181E, 4241468N→ 12S,701196E, 4270127N	38.6	F145 was originally captured in association of M144 and F146; they may be siblings. Mother unknown. She moved off the study area with M144 on 03-15-11. F145's last aerial radio location was in UC Creek, Deep Canyon, North Fork Mesa Creek on northwest Uncompahgre Plateau on 04-28-11. She was about 19 months old.

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

Table 18. Recorded deaths of non-marked and marked pumas struck by vehicles and other unusual causes, in chronological order, on the Uncompahgre Plateau puma study area, Colorado, from 2004 to 2011.

Puma sex & ID if marked	Estimated age (mo)	Date recorded	Cause of death	General physical condition	Location & UTM NAD27
M	12	09-24-04	Vehicle collision	Good	Pleasant Valley, County Road 24 13S,252870E,4227520N
F	49	07-28-05	Vehicle collision	Good Not pregnant or lactating	Highway 62 east of Dallas divide 13S,250000E,4222500N
F17[a]	11	08-18-06	Vehicle collision	Good	Highway 550 south of Colona 13S,257602E,4242185N
F	18-24	11-06-06	Vehicle collision	Good	Highway 550 east of Ridgway State Park 13S,259843E,4235985N
F	6	01-30-07	Vehicle collision	Good	Highway 62 west of Dallas divide 12S,762286Ex4218992N
F P1005	36	09-16-08	Asphyxia, lodged in fork of tree	Unknown, decomposed	Davis Point, Roubideau Canyon 12S, 743718E,4255277N
M	12-24	08-13-08	Vehicle collision	Good	Highway 145 west of Placerville 13S,756490E,4212336N
F61[a]	18	11-13-08	Vehicle collision	Good	Highway 550 east of Ridgway State Park 13S,259843E,4235985N
F	12	08-10-09	Vehicle collision	Good	Highway 145 east of Norwood 12S,745739E,4222548N
F16[b]	80	09-11-09	Vehicle collision	Good	Ouray County Road 1 13S,253733E,4240060N
M6[b]	99	05-21-0	Vehicle collision	Good	Highway 550 south of Colona 13S,258610E,4236805N
F113[b]	42	06-06-10	Vehicle collision	Good Not pregnant or lactating	F113 crossed Highway 550 and roads on Loghill Mesa 24-30 hours before she died in McKenzie Creek 13S,257272E,4238435N
M P1018[c]	24	08-25-10	Vehicle collision	Excellent	Highway 62 Leopard Creek 12S,237747E,4220330N
F P1030[c]	6	2/16/2011	Vehicle collision	Good	Highway 62 Leopard Creek 12S,760953E,4216683N

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

Table 19. Numbers of GPS locations and spans of monitoring for pumas captured on the Uncompahgre Plateau, Colorado, December 2004 to August 2011.

Puma I.D.	**Sex**	**Age stage**	**Dates monitored** [a]	**No. locations**
M1	M	adult	12-08-04 to 07-20-06	1,797
M4	M	adult	01-28-05 to 01-14-06	958
M6	M	adult	02-18-05 to 05-14-08	1,035
M27	M	adult	03-12-06 to 06-21-06	313
M29	M	adult	04-14-06 to 01-01-08	1,599
M51	M	adult	01-07-07 to 07-15-08	1,643
M55	M	adult	01-21-07 to 11-25-10	3,523
M100	M	adult	03-27-09 to 01-16-10	923
M133	M	adult	11-12-10 to 12-01-10	45
F2	F	adult	01-07-05 to 08-14-08	3,516
F3	F	adult	01-21-05 to 04-19-11	4,862
F7	F	adult	02-24-05 to 08-03-08	3,922
F8	F	adult	03-21-05 to 10-10-06	1,541
F16	F	adult	10-12-05 to 09-10-09	3,801
F23	F	subadult,	01-04-06 to 02-04-06	113
		adult	02-05-06 to 09-04-09	2,281
F24	F	adult	01-17-06 to 07-25-07	1,812
F25	F	adult	02-09-06 to 09-09-09	3,653
F28	F	adult	03-24-06 to 08-15-07	1,499
F30	F	adult	03-30-07 to 02-22-08	1,057
F50	F	adult	12-14-06 to 03-26-07	352
F52	F	subadult	01-10-07 to 05-08-07	383
F54	F	adult	01-12-07 to 08-18-08	723
F70	F	adult	01-14-08 to 06-09-11	3,359
F72	F	adult	02-12-08 to 07-07-10	2,842
F75	F	adult	03-26-08 to 06-03-09	1,112
F96	F	adult	01-28-09 to 04-20-11	1,619
F104	F	adult	05-29-09 to 11-04-10	1,632
F111	F	adult	01-01-10 to 07-12-11	1174
F113	F	adult	01-27-10 to 06-06-10	445
F135	F	adult	01-01-11 to 08-15-11	787
F136	F	adult	01-20-11 to 08-08-11	649
F137	F	adult	04-12-11 to 08-15-11	235

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

Table 20. Summary results of exploratory use of scents and hair snags to detect individual wild pumas, November 2010 to August 2011, Uncompahgre Plateau, Colorado.

Scent used	No times scent used at 9 sites	No. puma visits	No. individual puma visits .	No. times pumas rubbed	No. times hair was collected from device	No. individual pumas detected	Max. detection probability (defined in text)
Beaver castorium	16	8	3 (Unm F, F72, F106)	5	5	2 (Unm F, F106)	0.667 (2/3)
Catnip oil	5	2	2 (unm M, M153)	0	0	0	0.0
Catnip/Spotted Fever	1	1	1 (unk sex & age)	0	0	0	0.0
MT Lynx	7	8	4-5 (M153, 1-2 of unk sex & age, 2 unm M)	1	1	1 (unm, unk sex and age)	0.200-0.250 (1/5 to 1/4)
Obsession for Men	11	16	5-6 (F72, F106, F136, M153, unm M, unidentifiable)	3	3	2(F106, F136)	0.333-0.400 (2/6 to 2/5)
Spotted Fever	7	4	4 (F3, F25 & 3 cubs, F96, M32)	1	1	1 (F25 & cubs)	0.250 (1/4)
	Totals	39		10	10		

Table 21. Variation in individual puma response to scents, November 2010 to August 2011, Uncompahgre Plateau, Colorado.

Individual	Scent	No. times rubbed/ No. of visits
F3	Spotted Fever	0/1
F25 (& 3 cubs)	Spotted Fever	1/1
F72	Beaver Castorium	0/2
F72	Obsession for Men	0/3
F96	Spotted Fever	0/1
F106	Beaver Castorium	4/5
F106	Obsession for Men	1/1
F136	Obsession	2/7
Unmarked Female, unk age	Beaver Castorium	1/1
M32	Spotted Fever	0/1
M153	Obsession for Men	0/2
M153	Catnip	0/1
M153	MT Lynx	0/2
Unmarked Male, unk age	Obsession	0/2
Unmarked Male, unk age	MT Lynx	0/2
Unmarked Male, unk age	MT Lynx	0/1
Unmarked Male, unk age	Catnip	0/1
Unmarked, unk sex and age	Spotted Fever & Catnip	0/1
Unmarked, unk sex and age	MT Lynx	0/2
Unmarked, unk sex and age	MT Lynx	1/1
Unknown if marked, unk sex and age	Obsession	0/1

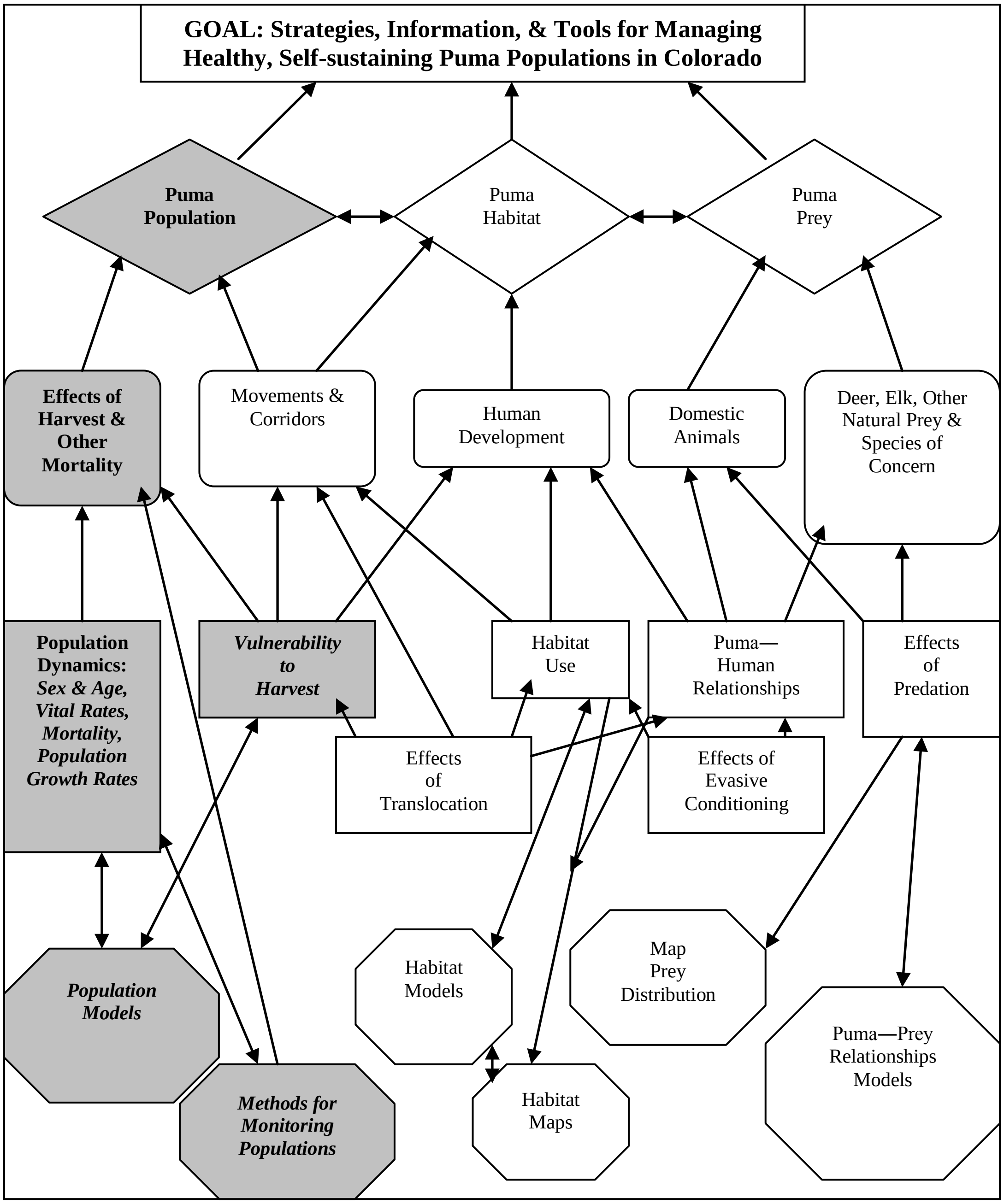


Figure. 1. An ecologically-based conceptual model of the Colorado Puma Research Program that provides the contextual framework for this and proposed puma research in Colorado. Gray-shaded shapes identify areas of research addressed by this puma research on the Uncompahgre Plateau for the puma management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

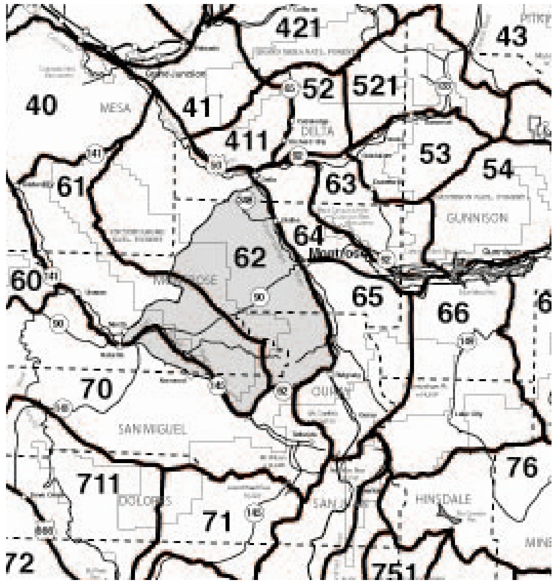


Figure 2. The puma study area on the southern half of the Uncompahgre Plateau, Colorado (shaded in gray) comprising the southern portions of Game Management Units (GMUs) 61 and 62 and a northern portion of GMU 70.

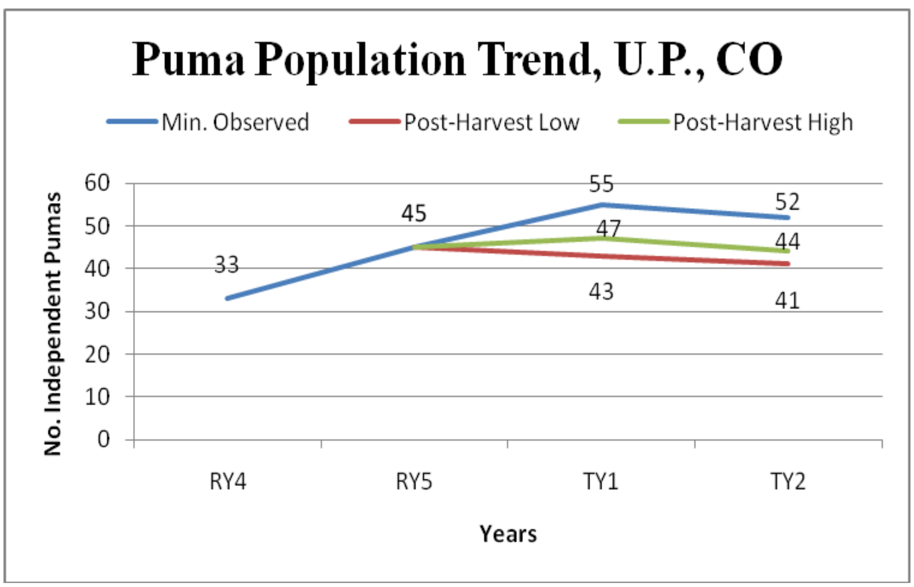


Figure 3. Trends in the population of independent pumas on the Uncompahgre Plateau Puma Study Area, including Reference Years 4 and 5 (RY4, RY5) and Treatment Years 1 and 2 (TY1, TY2). Numbers represent minimum counts that include all pumas from known radio-collared pumas, visual observations of non-marked pumas, harvested non-marked pumas, and track counts of suspected non-marked pumas on the study area during fall to spring hunting and research capture seasons, except RY5 (45), which had to be modeled from RY4 observation data (33) because the hiring freeze that year affected search and capture efforts. The actual minimum count for RY5 was 37 independent pumas. The quota of 8 pumas for TY1 represented a 15% harvest of the model projected 53 independent pumas expected in TY1 and was used to set the quota ahead of the hunting season. Starting in TY1, two capture teams were deployed to

count pumas on the study area because the hunting season shortened our fall-winter-spring research period. We deployed a team on each the east and west sides of the study area. The minimum count for TY1 was actually 55 independent pumas, consistent with the model expected 53. We made further team changes for TY2, which made our efforts more efficient and successful. Yet, in TY2 we counted slightly less (52) independent pumas than in TY1 (55).

Post-harvest high trend line represents the population of independent pumas after pumas harvested only on the study area by hunters. This trend line represents 14.5% to 15.4% harvest of independent pumas.

Post-harvest low trend line represents the population of independent pumas after pumas harvested on the study area and pumas harvested when they ranged onto adjacent GMUs open to hunting. The TY2 post-harvest low also includes 2 adult female pumas killed February 1, 5, 2011 on the study area to protect livestock (F25 killed while seen by a ranch hand among cattle; F94 killed for preying on domestic elk). This trend line represents 21.2% to 21.8% harvest of independent pumas.

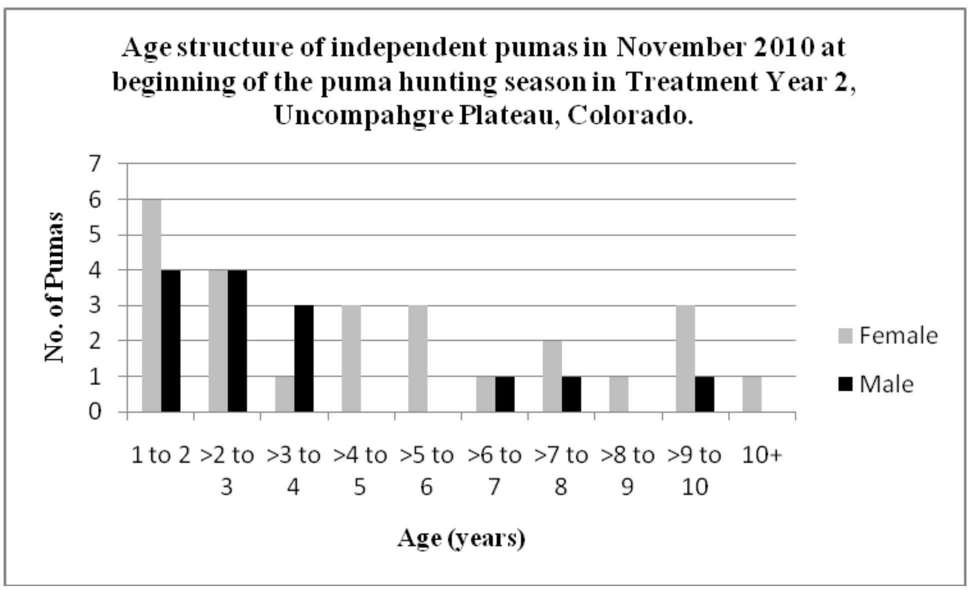


Figure 4. Estimated age structure of independent pumas in November 2010 at the beginning of the puma hunting season in Treatment Year 2 (TY2) on the Uncompahgre Plateau, Colorado. All these pumas were captured and sampled by researchers or harvested by hunters and examined by researchers. Mean ± *SD* of female and male ages, respectively: 4.87 ± 3.11 yr. (58.40 ± 37.26 mo.), n = 25; 3.51 ± 2.59 yr. (42.07 ± 31.08 mo.), n = 14.

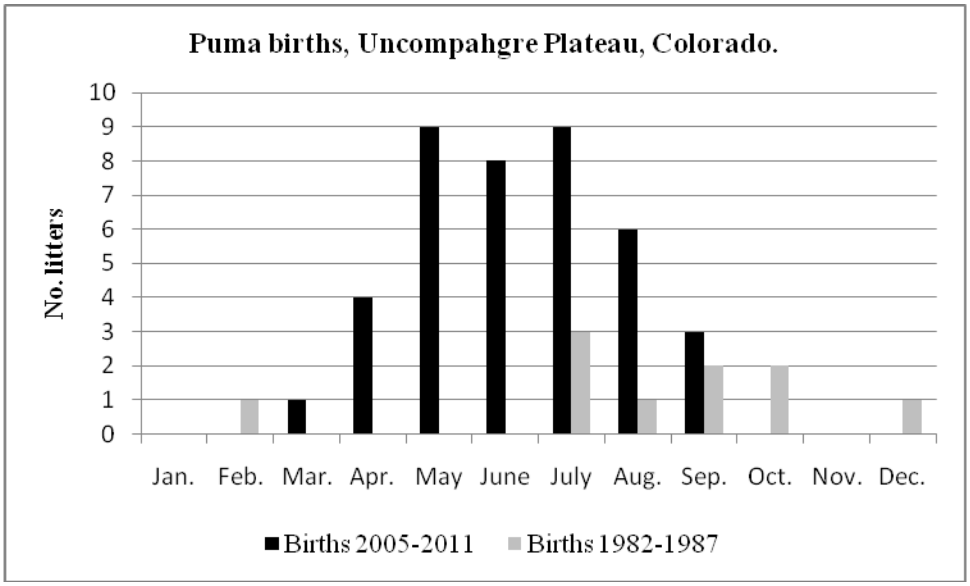


Figure 5. Puma births (black bars) detected by month from May 19, 2005 to April 22, 2011 (*n* = 40 litters of 21 females; 38 of the litters were examined at nurseries when cubs were 26-42 days old and 2 litters confirmed by tracks of $\geq$1 cubs following GPS-collared mothers F28 and F111 when cubs were $\leq$42 days old). Also shown (gray bars) are results of the earlier effort by Anderson et al. (1992:48; 1982 to 1987, *n* = 10 litters of 8 females, examined when cubs were <1 to 8 months old), Uncompahgre Plateau, Colorado.

Appendix A. Summary of individual puma cub survival and mortality, 2005 to 2010, Uncompahgre Plateau, Colorado.

Puma I.D.	Estimated Age at capture (days)	Est. Birth date	Est. survival span from 1st capture to fate or last monitor date	Age to last monitor date alive or at death (days, birth to fate)	Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death	Mother I.D.
M5	183	~8-1-04	02-04-05 to 04-07-08	~1,345	Survived to subadult stage by 09-16-05; independent at ~13 mo. old. Dispersed from natal area by 09-29-05 at 14 mo. old. Established territory on NW U.P. Killed by hunter in Beaver Creek, UT 02-20-09 at 4.5 years old.	F3
F9	31	5-28-05	06-27-05 to 4-19-06	326-333	Lost contact— shed radiocollar 04-19-06 to 04-26-06.	F2
F10	31	5-28-05	06-27-05 to 11-20-05— 12-29-05	176-215	Lost contact— shed radiocollar 08-10-05; last tracks of F10 with mother F2 & siblings F9 & M11 observed 11-20-05. F10 disappeared by 12-30-05.	F2
M11	31	5-28-05	06-27-05 to 12-2-07	918	Survived to subadult stage by 06-21-06, independent at 13 mo. old. Dispersed from natal area by 07-11-06 at 14 mo. old. Killed by a hunter in SW CO 12-2-07 at 918 days (30 mo.) old.	F2
F12	42	5-19-05	07-01-05 to 12-08-05— 01-26-06	203-252	Lost contact— shed radiocollar 07-28-05—08-01-05. Tracks of F12 found in association with mother F7 on 12-08-05. F12 disappeared by 01-27-06 when she was not visually observed with F7, and her tracks were not seen in association with F7's tracks.	F7
F13	42	5-19-05	07-01-05 to 08-28-05	101	Dead; killed and eaten by a puma (sex unspecified) about 8-28-05.	F7
F14	26	6-26-05	07-22-05 to 02-07-06— 03-10-06	226-257	Lost contact— shed radiocollar 01-20-06 to 01-25-06. Tracks of F14 were observed with tracks of mother F8 & sibling M15 on 02-07-06. Disappeared by 03-11-06, only tracks of F8 & M15 were found.	F8
M15	26	6-26-05	07-22-05 to 06-06 to 14-06	345-353	Lost contact— shed radiocollar 06-06-06 to 06-14-06.	F8
F17	34	9-22-05	10-26-05 to 08-18-06	330	Dead. Lost contact— shed radiocollar 06-06-06 to 06-14-06. Killed by a car on highway 550 on 08-18-06. Probably dependent on F16.	F16
F18	34	9-22-05	10-26-05 to 07-20 to 27-06	301-308	Dead; probably killed by another puma. Multiple bite wounds to skull. 10 mo. old.	F16
M19	34	9-22-05	10-26-05 to 07-27 to 08-02-06	308-314	Lost contact— shed radiocollar 07-27-06 to 08-02-06.	F16
M20	34	9-22-05	10-26-05 to 05-24-06	244-245	Lost contact— shed radiocollar 05-24-06—05-25-06.	F16
F21	37	9-26-05	11-02-05 to 08-16-06	324	Lost contact; radiocollar quit. Last aerial location 8-16-06, live signal.	F3

Appendix A continued

Puma I.D.	Estimated Age at capture (days)	Est. Birth date	Est. survival span from 1st capture to fate or last monitor date	Age to last monitor date alive or at death (days, birth to fate)	Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death	Mother I.D.
M22	37	9-26-05	11-02-05 to 12-21-05—12-22-05	86-87	Dead; killed and eaten by male puma 12-21-05—12-22-05.	F3
M26	183	8-1-05	02-08-06 to 03-21 to 24-06	~232-235	Lost contact— shed radiocollar 03-21-06—03-24-06.	F25
F33	31	5-30-06	06-30-06 to 07-31-06	63-65	Dead. Probably killed and eaten by a male puma 08-01 to 03-06. GPS data on M29 indicate he was *not* involved.	F23
F34	31	5-30-06	06-30-06 to 07-31-06	63-65	Dead. Probably killed and eaten by a male puma 08-01 to 03-06. GPS data on M29 indicate he was *not* involved.	F23
F35	31	5-30-06	06-30-06 to 07-07-06	38	Dead; research-related fatality.[a]	F23
F36	29	6-9-06	07-08-06 to 07-28-06	74	Dead. Killed and eaten by a male puma 08-22-06. GPS data on M29 indicate he was *not* involved.	F28
M37	29	6-9-06	07-08-06 to 07-28-06	74	Dead. Killed and eaten by a male puma 08-22-06. GPS data on M29 indicate he was *not* involved.	F28
M38	41	7-29-06	09-08-06 to 07-16 to 17-07	352-353	Lost contact— shed radiocollar found 03-06-07. Photo (trail camera in McKenzie Cr.) of M38 & Unm. F sibling with F2 on 07-16 to 17-07 at 352-353 days old.	F2
M39	29	8-13-06	09-11-06 to 09-20-06 to 04-25-07	9 255	Lost contact— shed radiocollar by 09-20-06, but seen alive on that date. Tracks of 2 cubs following F8 on 04-25-07. Survived to adult stage; dispersed from natal area. Killed by a puma hunter 03-12-10 in GMU 40 when 43 months old.	F8
F40	29	8-13-06	09-11-06 to 09-20-06 to 04-25-07	9 255	Lost contact— shed radiocollar by 09-20-06, but seen alive on that date. Tracks of 2 cubs following F8 on 04-25-07.	F8
F41	29	8-13-06	09-11-06 to 10-05-06	53-61	Assumed dead. Lost Contact— shed radiocollar or died (blood on collar) between 10-05-06 (last live signal) & 10-13-06 (collar found).	F8
M42	29	8-13-06	09-11-06 to 11-27-06	106	Dead; research-related fatality.[b]	F8
M43	33	8-13-06	09-15-06 03-01-07	200	Lost contact− shed radiocollar by 11-7 to 17-06. Treed 03-01-07. Killed by a puma hunter 01-28-09 in Deer Creek, west slope of Grand Mesa, CO at 29 months old. Survived to adult stage; dispersed from natal area. Killed by a puma hunter 01-28-09 in GMU 41 when 29 months old.	F7

Appendix A continued

Puma I.D.	Estimated Age at capture (days)	Est. Birth date	Est. survival span from 1st capture to fate or last monitor date	Age to last monitor date alive or at death (days, birth to fate)	Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death	Mother I.D.
M44	33	8-13-06	09-15-06 to 02-14-07	479	Lost contact− shed radiocollar by 10-27-06. Treed, visually observed 02-14-07; sibling (?) M56 also captured, sampled, & marked for 1st time. Killed by Wildlife Services for depredation control on 12-05-07, for killing 4 domestic sheep. He was still dependent on F7.	F7
F45	33	8-13-06	09-15-06 to 5-20 to 23-07	280-283	Dead. Multiple puncture wounds on braincase— parietal & occipital regions; consistent with bites from coyote. F45 switched families, moving from F7 to F2 about 12-19 to 20-06. Last date F45 was with F2 was 04-17-07.	F7
M46	31	9-17-06	10-18-06 to 12-15-06	89 360	Lost contact— shed radiocollar. Tracks of all cubs observed following F3 12-15-06. Tracks & GPS data indicated that F3 apparently with ≥1 of her male cubs (M46, M47, M48) at 360 days old on 09-12-07 in Puma Canyon.	F3
M47	31	9-17-06	10-18-06 to 12-15-06 to 09-12-07	89 360	Lost contact— shed radiocollar. Tracks of all cubs observed following F3 12-15-06. Tracks & GPS data indicated that F3 apparently with ≥1 of her male cubs (M46, M47, M48) at 360 days old on 09-12-07 in Puma Canyon.	F3
M48	31	9-17-06	10-18-06 to 12-15-06 to 09-12-07	89 360	Lost contact— shed radiocollar. Tracks of all cubs observed following F3 12-15-06. Tracks & GPS data indicated that F3 apparently with ≥1 of her male cubs (M46, M47, M48) at 360 days old on 09-12-07 in Puma Canyon. Survived to adult stage; dispersed from natal area. Killed by a puma hunter 12-27-09 in GMU 61 when 39 months old.	F3
M49	153	7-1-06	12-05-06 to 07-31-07 to 01-01-07	~456	M49 was orphaned when his mother died on about 03-26-07; he was ~268 days old. M49 dispersed from natal area and onto NE slope of U.P. Shed radiocollar at a yearling cow elk kill about 10-01-07; he was ~428 days old. Killed by a puma hunter in Blue Creek, northwest Uncompahgre Plateau (GMU 61 N) 01-24-09 when ~29 months old.	F50
F53	183	7-1-06	01-12-07 to 02-23-07	42 ~428 subad.	Lost contact— shed radiocollar 2-23-07. F53 visually observed by P. & F. Star, on 9-2-07, when F53 was ~14 months old and an independent subadult.	F54

Appendix A continued						
Puma I.D.	**Estimated Age at capture (days)**	**Est. Birth date**	**Est. survival span from 1st capture to fate or last monitor date**	**Age to last monitor date alive or at death (days, birth to fate)**	**Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death**	**Mother I.D.**
M56[c]	183	~8-13-06	02-14-07 to 03-01-07	200	Lost contact— shed radiocollar 2-27-07. M56 observed 03-01-07.	F7 (?)
F57	35	4-16-07	05-21-07 to 06-06-07	52	Lost contact— shed radiocollar 06-07-07. Live mode 06-06-07.	F25
M58	34	5-24-07	06-27-07	 324 434	Not radio-collared. Tracks of 3 cubs observed with F16's tracks on 04-12-08, McKenzie Butte-Pinon Ridge Pass. 3 cubs observed with F16 on 08-08-08 by B. & T. Traegde. Survived to adult stage; dispersed from natal area. Killed by a puma hunter 12-27-09 in GMU 521 when 31 months old.	F16
F59	34	5-24-07	06-27-07 to 08-21-07	55 324 434	Alive. Observed alive 11-20-07 with F16, but without siblings M58 & F61. Tracks of 3 cubs observed with F16's tracks on 04-12-08, McKenzie Butte-Pinon Ridge Pass. 3 cubs observed with F16 on 08-08-08 by B. & T. Traegde.	F16
M60	34	5-24-07	06-27-07 to 07-11 to 12-07	48-49	Dead; research-related mortality.[d]	F16
F61	34	5-24-07	06-27-07 to 06-29-07	 324 434 538	Radiocollar malfunction. Tracks of 3 cubs observed with F16's tracks on 04-12-08, McKenzie Butte-Pinon Ridge Pass. 3 cubs observed with F16 on 08-08-08 by B. & T. Traegde. Dead. Died probably as independent subadult at 538 days old; struck by car on Hwy 550 mi. marker 111 N. of Ridgway, CO, euthanized by gunshot on 11/13/08.	F16
M62	34	7-14-07	08-17-07		Not radio-collared.	F24
M63	34	7-14-07	08-17-07		Not radio-collared.	F24
M64	34	7-14-07	08-17-07	 262	Not radio-collared. Two out of potential of 4 of F24's male cubs were visually observed with her on 4/1/08. Assume that 2 male cubs died before the age of 8.5 mo. Eartags were seen on both cubs, but the numbers were not.	F24
M65	34	7-14-07	08-17-07	 262	Not radio-collared. Two out of potential of 4 of F24's male cubs were visually observed with her on 4/1/08. Assume that 2 male cubs died before the age of 8.5 mo. Eartags were seen on both cubs, but the numbers were not. Survived to adult stage; dispersed from natal area. Killed by Wildlife Services for depredation control on 11-07-09 when 28 months old.	F24

Appendix A continued

Puma I.D.	Estimated Age at capture (days)	Est. Birth date	Est. survival span from 1st capture to fate or last monitor date	Age to last monitor date alive or at death (days, birth to fate)	Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death	Mother I.D.
F66	37	7-17-07	08-23-07 to 11-05-07	111 681	Radio-collared. Lost contact; last location 11/5/07. No signals after that date. F66 was photographed with one male sibling, either M67 or M68, & F30 on 5/31-6/1/08. F66 was recaptured and radio-collared as a subadult on 11/25/08. She died from massive trauma & bleeding of internal organs possibly resulting from being trampled by an elk or mule deer on about 05-28-09 as an independent subadult 23 months old.	F30
M67	37	7-17-07	08-23-07	1475	Not radio-collared. M67 or M68 was photographed with sibling F66 & mother F30 on 5/31-6/1/08. Dispersed from natal area. Established adult home range on west side of Uncompahgre Plateau. Alive as of 07-31-11.	F30
M68	37	7-17-07	08-23-07	532	Not radio-collared. M67 or M68 was photographed with sibling F66 & mother F30 on 05-31 to 06-01-08. Survived to subadult stage; dispersed from natal area. Killed by a puma hunter in Disappointment Valley, CO (GMU 71) 12-30-08 at 17 months old.	F30
F74	259	6-1-07	03-12-08 to 07-09-08	403	Radio-collared. Shed radiocollar between 7-9-08 and 7-15-08, probably while still dependent on mother F75.	F75
M76	30	5-19-08	06-18-08	~87	Not radio-collared. Probably dead; if not killed when sibling M79 was killed, then probably would starve to death.	F2
M77	30	5-19-08	06-18-08	~87	Not radio-collared. Probably dead; if not killed when sibling M79 was killed, then probably would starve to death.	F2
F78	30	5-19-08	06-18-08	~87	Not radio-collared. Probably dead; if not killed when sibling M79 was killed, then probably would starve to death.	F2
M79	30	5-19-08	06-18-08	87	Not radio-collared. Dead. Chewed-off anterior portions of the nasals, maxilla, palate, dentaries, and pieces of the braincase, with 6 or 9 portion of yellow ear-tag and intestines and bits of skin found ~45 m from mother F2's death site on 8/14/08. Cub death probably due to puma-caused infanticide with cannibalism at ~87 days old. Male puma scrapes, about 8, under a rock rim ~50m distance from cub remains, and made ~ time of pumas' deaths.	F2

Appendix A continued						
Puma I.D.	**Estimated Age at capture (days)**	**Est. Birth date**	**Est. survival span from 1st capture to fate or last monitor date**	**Age to last monitor date alive or at death (days, birth to fate)**	**Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death**	**Mother I.D.**
F80	40	5-23-08	07-02-08		Not radio-collared. Apparently died before 2-4-09; no tracks found in association with F23 & siblings F81 & F97.	F23
F81	40	5-23-08	07-02-08 to 07-29-09	424	Radio-collared. Last live location 7-29-09.	F23
F97	8 ½ mo.	5-23-08	02-04-09	354	Radio-collared. Lost contact after 05-12-09; shed collar at elk kill cache on Mailbox Park.	F23
M82	37	5-29-08	07-05-08 to 03-20-09 or 04-02-09	295-308	Radio-collared. Survived to subadult stage; dispersed from natal area. Killed by a puma hunter in 12-10-09 GMU 65 when 19 months old.	F8
M83	37	5-29-08	07-05-08		Not radio-collared. Apparently died; no tracks found in association with F8 & sibling M82 2-10-09.	F8
M84	36	6-5-08	07-11-08 to 02-11-09	251	Radio-collared 7-11-08 to 7-22-08; collar removed because of malfunction. Not radio-collared after 7-22-08. Eartag of M84 was found by E. Phillips on 8-25-08 when mother F70's GPS locations located here on either side of the eartag in the East fork Dolores Cyn. M84 recaptured radiocollared again 1-29-09 in Dolores Cyn. in association with F70 & F96's family. Shed radiocollar again about 2-11-09.	F70
F85	36	6-5-08	07-11-08		Radio-collared. Dead. Probably died of predation or infanticide about 10-1-08 near elk calf kill.	F70
F86	36	6-5-08	07-11-08 to 07-23 to 08-03-08	~48-59	Radio-collared 7-22-08. Dead. Radio-collar, orange ear-tag #86 with pinna with green tattoo #86 found by J. Timmer 9-1-08. F86 died ~7-23 to 8-3-08 when mother F70's GPS locations located her at F86 remains. Probable predation.	F70
M87	28	7-3-08	07-31-08	1123	Not radio-collared. Dispersed from natal area. Recaptured as adult on west slope of study area on 02-09-11. Alive as of 07-31-11.	F3
M88	28	7-3-08	07-31-08		Not radio-collared.	F3
F89	28	7-3-08	07-31-08		Radio-collared.	F3
M90	36	7-9-08	08-14-08	867	Radio-collared. Recaptured as young adult on study area, adjacent to natal area, on 11-16-10. Killed by a puma hunter during TY2 on 11-23-10.	F72

Appendix A continued

Puma I.D.	Estimated Age at capture (days)	Est. Birth date	Est. survival span from 1st capture to fate or last monitor date	Age to last monitor date alive or at death (days, birth to fate)	Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death	Mother I.D.
Male 7A	28-35	7-10-08	~08-07-08 to 08-14-08	28 to 35	Not radio-collared. F7's cubs died from starvation after they were orphaned. F7 was shot on 8-3-08 for killing domestic sheep.	F7
Male 7B	28-35	7-10-08	~08-07-08 to 08-14-08	28 to 35	Not radio-collared. F7's cubs died from starvation after they were orphaned. F7 shot on 8-3-08 for killing domestic sheep.	F7
Female 7C	28-35	7-10-08	~08-07-08 to 08-14-08	28 to 35	Not radio-collared. F7's cubs died of starvation after orphaned. F7 shot on 8-3-08 for killing domestic sheep.	F7
M91	35	8-19-08	09-29-08		Radio-collared.	F25
M92	35	8-19-08	09-29-08	976	Radio-collared. Lost contact after 12-12-08. Dispersed from natal area. Recaptured in McKenzie Creek, west slope of study area on 04-22-11 when 32 months old.	F25
F95	16 mo.	June-07	12-29-08		Radio-collared. Survived to adult stage. Established adult home range overlapping mother F93's home range.	F93
F98	4-5 mo.	Sep-Oct-08	02-12-09 to 03-08-09	146-176	Radio-collared. Died, probably killed by male puma (infanticide).	Unm.F
M99	5 mo.	Sep-Oct-08	2-27-09 to 01-2010	488	Radio-collared. Last location 4-22-09 on Paterson Mt. Died as 16-month old subadult in San Miguel Canyon. Probably killed by another puma.	Unm.F
M101	35	4-15-09	05-20-09 to 09-19-09	157	Radio-collared. Died; killed by puma M55 after cub was orphaned due to death of mother F16 by vehicle strike.	F16
M102	35	4-15-09	05-20-09		Radio-collared. Lost contact after 9-4-09. Did not find evidence of M102 associated with deaths of siblings M101 and F103. But M102 probably died.	F16
F103	35	4-15-09	05-20-09 to 09-17-09	159	Radio-collared. Died; killed by puma M55 after cub was orphaned due to death of mother F16 by vehicle strike.	F16
M105	38	5-7-09	06-14-09 to 02-09-10	278	Radio-collared. Lost contact after 2-9-10 due to shed collar.	F75
F106	38	5-7-09	06-14-09 to 02-27-11	275 661	Not radio-collared at nursery; F75 returned to nursery during handling. Radio-collared later on 2-10-10. Lost contact due to shed collar 3-16 to 29-10. F106 dispersed from natal area and was photographed at 21 months old at camera and scent-rub station on east slope of Uncompahgre Plateau on 02-27-11.	F75
M107	34	5-25-09	06-28-09 to 02-24-10	241	Not radio-collared; too small. Recaptured 2-24-10; not collared.	F94

Appendix A continued

Puma I.D.	Estimated Age at capture (days)	Est. Birth date	Est. survival span from 1st capture to fate or last monitor date	Age to last monitor date alive or at death (days, birth to fate)	Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death	Mother I.D.
F108	34	5-25-09	06-28-09 to 03-05-10	553	Shed radiocollar at nursery; fastener failed. Recaptured and re-collared 2-24-10. Shed collar ~3-5-10. Dispersed from natal area. Killed by a puma hunter on the study area during TY2 on 11-29-11.	F94
M109	34	5-25-09	06-28-09		Not radio-collared; too small.	F94
M112	145	8-31-09	05-04-10	528 595	Radio-collared. Lost contact after 5-4-10 (last live signal) possibly due to failed transmitter. Recaptured and re-radio-collared on 01-24-11. Independent subadult during 02-10-11 to 04-18-11. Lost contact after 04-18-11; he may have dispersed or radiocollar quit.	F70
M115	14 mo.	Nov.-08	07-21-10	610	Radio-collared. M115 died as a subadult (~20 mo. old) due to complications of a broken left foreleg (natural cause).	F28
M117	6 mo.	Aug.-09	02-05-10	275	Radio-collared. Lost contact after 5-14-10 (last live signal); shed collar found on 7-15-10 in the natal area.	F119
P1016(M)	39	6-12-10	06-12-10 to 07-21-10	39	Not radio-collared. Monitored at nursery via mother's GPS/VHF collar. Found dead at nursery due to infanticide by puma M32 on same day as our investigation of nursery.	F72
P1017(M)	39	6-12-10	06-12-10 to 07-21-10	39	Not radio-collared. Monitored at nursery via mother's GPS/VHF collar. Found dead at nursery due to infanticide by puma M32 on same day as our investigation of nursery.	F72
M120	30	6-28-10	07-28-10 to 12-02-10	157	Radio-collared. Lost radio contact after 12-02-10.	F3
M121	30	6-28-10	07-28-10 to 03-28-11	273	Radio-collared. Lost radio contact after 03-28-11.	F3
M122	35	7-8-10	08-12-10 to 04-28-11	274	Radio-collared. Lost radio contact after 04-28-11. Tracks of 2 other siblings of M122 observed on 01-11-11 (neither cub marked).	F104
F123	29	7-15-10	08-13-10 to 02-17-11	217	Radio-collared. Killed on 02-17-11 for depredation control on domestic elk by Wildlife Services agent.	F94
F124	29	7-15-10	08-13-10 to 02-16-11	216	Radio-collared. Killed on 02-16-11 for depredation control on domestic elk by elk farm manager.	F94
M125	29	7-15-10	08-13-10 to 02-01-11	201	Radio-collared. Killed on 02-01-11 for depredation control on domestic elk by Wildlife Services agent.	F94
M126	28	08-08-10	09-05-10 to 03-17-11	221	Radio-collared. Lost radio contact after 03-17-11; shed his radiocollar at a mule deer cache.	F118
M127	28	08-08-10	09-05-10 to 07-01-11	327	Radio-collared. Lost radio contact after 07-01-11; shed his radiocollar about 07-01-11.	F118

Appendix A continued						
Puma I.D.	**Estimated Age at capture (days)**	**Est. Birth date**	**Est. survival span from 1st capture to fate or last monitor date**	**Age to last monitor date alive or at death (days, birth to fate)**	**Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death**	**Mother I.D.**
M128	28	08-08-10	09-05-10 to 02-22-11	198	Radio-collared. Lost radio contact after 02-22-11; radiocollar probably quit.	F118
F129	35	08-21-10	09-25-10 to 04-28-11	250	Radio-collared. Fate unknown. Transmitter on mortality mode on 04-28-11. Unable to get to collar until 06-23-11 due to high spring run-off, by then the transmitter had quit.	F96
M130	35	08-21-10	09-25-10 to 10-23-10	63	Radio-collared. Died of natural causes associated with injury to right shoulder during first move away from nursery about 10-23-10.	F96
M131	35	08-21-10	09-25-10 to 07-21-11	334	Radio-collared. Lost contact after 07-21-11. Shed his radiocollar about 07-27-11.	F96
F132	35	08-21-10	09-25-10	35	Not radio-collared. Too small for collar design. Fate unknown.	F96
M134	~18 mo.	~June-09	12-14-10 to 06-10-11	731	Radiocollared as dependent large cub. Independent by about 03-28-11. Dead; killed for depredation control by Wildlife Services agent on 06-10-11.	Unm. F
M139	36	04-18-11	05-24-11 to 07-29-11	102	Radio-collared. Dead of infanticide and cannibalism along with sibling F148; killed and eaten by female or subadult male puma about 07-29-11.	F8
F148	36	04-18-11	05-24-11 to 07-29-11	102	Radio-collared. Dead of infanticide and cannibalism along with sibling M139; killed and eaten by female or subadult male puma about 07-29-11.	F8
F140	~5 mo.	~Aug.-10	01-02-11 to 04-18-11	258	Radio-collared. Lost contact. Shed first collar about 01-24-11. Recaptured and re-collared on 04-01-11. Shed second collar after 04-18-11.	Unk./ F28?
M141	~5 mo.	~Aug.-10	01-02-11 to 04-01-11	241	Radio-collared. Lost contact; shed radiocollar about 03-29-11. Recaptured, but could not be handled safely on 04-01-11.	Unk./ F28?
M142	~5 mo.	~Aug.-10	01-02-11 to 04-18-11	258	Radio-collared. Lost contact after 04-18-11 due to shed collar.	Unk./ F28?
P1030	~ 6 mo.	~Aug.-10	02-16-11	183	Struck by vehicle and killed on state highway 62 in Leopard Creek, south boundary of study area on 02-16-11.	Unk.
F147	~7 mo.	~Sep.-10	04-21-11 to 07-31-11	315	Radio-collared.	F24
F149	45	04-22-11	06-06-11 to 07-31-11	100	Radio-collared.	F23
M150	525	08-31-09	02-07-11 to 04-11-11	588	Radio-collared. M151 was independent by 03-28-11 at 19 mo. old. He dispersed from the natal area by 04-11-11 at 19.5 mo. old. Contact lost after 04-11-11.	F70

Appendix A continued

Puma I.D.	Estimated Age at capture (days)	Est. Birth date	Est. survival span from 1st capture to fate or last monitor date	Age to last monitor date alive or at death (days, birth to fate)	Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death	Mother I.D.
M151	253	06-16-10	02-24-11 to 03-07-11	264	Radio-collared. Lost contact after 03-07-11 (GPS location of mother F111 at shed collar of M151).	F111
F152	271	06-06-10	03-14-11 to 03-21-11	271	Radio-collared. Lost contact after 03-21-11; shed collar.	F93

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

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

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

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

Appendix B. Summary of exploratory use of scents and hair snags to detect individual pumas, 2010 to 2011, Uncompahgre Plateau, Colorado. Details on behaviors of pumas and other wildlife that visited the camera-scent stations are not included in this appendix, but are in original data file.

Camera site I.D.	**Date**	**MS Time**	**Puma**	**Sex**	**Age stage**	**Female Repro-ductive Status**	**Time puma was at site (min.)**	**No. photos of puma**	**Time lapse between scent treatment and puma visit (days)**	**Scent type/name**	**Closest puma distance estimate to scent pad-hair snag (m)**	**Rub response by puma (yes, no)**	**Hair on snag collected**
HS01	11/27/2010	9:39	F96	F	Adult	Cubs 6 mo. old	1	2	7	Spotted Fever	0.3	no	
HS01	12/8/2010	16:40	unmarked	F	Adult	Unk	5	114	2	Beaver Castor	0	**yes**	**yes**
HS02	11/29/2010	15:40	F3	F	Adult	Cubs 5 mo. old	1	6	9	Spotted Fever	0.6	no	
HS03	2/27/2011	6:10	F106	F	Adult	No cubs	3	95	12	Beaver Castor	0	**yes**	**yes**
HS03	2/27/2011	17:45	F106	F	Adult	No cubs	5	48	12	Beaver Castor	0	**yes**	**yes**
HS03	2/28/2011	18:38	F106	F	Adult	No cubs	74	572	13	Beaver Castor	0	**yes**	**yes**
HS03	3/1/2011	6:31	F106	F	Adult	No cubs	1	15	14	Beaver Castor	0	no	
HS03	3/2/2011	18:37	F106	F	Adult	No cubs	13	297	15	Beaver Castor	0	**yes**	**yes**
HS03	3/3/2011	18:23	F106	F	Adult	No cubs	4	107	16	Obsession	0	**yes**	**yes**
HS03	3/7/2011	20:26	F136	F	Adult	No cubs	1	18	4	Obsession	3	no	
HS03	3/11/2011	4:41	F136	F		No cubs	5	54	8	Obsession	0	**yes**	**yes**
HS03	4/11/2011	0:31	unmarked	M	Adult		1	3	3	Catnip	1.5	no	
HS03	4/13/2011	22:18	M153	M	Sub-adult		1	3	5	Catnip	0.6	no	
HS03	5/16/2011	21:54	unmarked	Unk	Unk		1	4	4	Catnip/Spotted Fever	0.6	no	
HS03	6/11/2011	22:56	unmarked	M	Adult		1	9	2	Obsession	0.3	no	
HS03	7/6/2011	17:59	unmarked	Unk	Unk		1	11	0	MT Lynx	0.1	no	
HSO4	11/22/2010	5:34	M32	M	Adult		1	10	4	Spotted Fever	0.6	no	
HS04	12/3/2010	17:40	F25 & 3 cubs	F	Adult	Cubs 8-9 mo. old	7	243	3	Spotted Fever	0	**yes**	**yes**

Appendix B continued.

Camera site I.D.	Date	MS Time	Puma	Sex	Age stage	Female Repro-ductive Status	Time puma was at site (min.)	No. photos of puma	Time lapse between scent treatment and puma visit (days)	Scent type/name	Closest puma distance estimate to scent pad-hair snag (m)	Rub response by puma (yes, no)	Hair on snag collected
HS04	2/24/2011	16:04	F72	F	Adult	No cubs	3	44	9	Beaver Castor	0	no	
HS04	2/25/2011	15:36	F72	F	Adult	No cubs	1	15	10	Beaver Castor	0	no	
HS04	3/8/2011	6:33	F72	F	Adult	No cubs	1	21	5	Obsession	0	no	
HS04	3/8/2011	20:51	F72	F	Adult	No cubs	1	21	5	Obsession	3.5	no	
HS04	3/16/2011	3:29	F72	F	Adult	No cubs	1		13	Obsession	3.5	no	
HS04	3/18/2011	21:32	Not identifiable	Unk	Unk	Unk	1	9	15	Obsession	3	no	
HS04	4/14/2011	2:03	F136	F	Adult	No cubs	1	9	6	Obsession	3.5	no	
HS04	4/15/2011	4:40	F136	F	Adult	No cubs	1	15	7	Obsession	0.3	no	
HS04	4/16/2011	4:40	F136	F	Adult	No cubs	1	6	8	Obsession	3	no	
HS04	4/18/2011	18:20	F136	F	Adult	Pregnant	1	15	10	Obsession	0	**yes**	**yes**
HS04	4/25/2011	23:52	M153	M	Sub-adult		1	15	17	Obsession	0.3	no	
HS04	5/2/2011	19:31	unmarked	M	Adult		1	27	24	Obsession	0	no	no
HS04	5/9/2011	15:36	VHF male 150 or M153	M	Sub-adult		1	9	31	Obsession	3	no	
HS04	5/10/2011	1:07	F136	F	Adult	Pregnant	1	12	32	Obsession	2.3	no	
HS04	7/15/2011		unmarked	M				4		MT Lynx	1.5	no	
HS06	6/29/2011	1:39	M153	M	Sub-adult		1	33	7	MT Lynx	0.3	no	
HS06	7/4/2011	18:21	unmarked				1	6	12	MT Lynx	0.3	no	
HS06	7/15/2011	19:36	unmarked	M			1	3	23	MT Lynx	0.3	no	
HS07	7/8/2011	3:02	M153	M	Sub-adult		1	15	16	MT Lynx	0	no	
HS09	7/24/2011	21:01	unmarked	Unk			1	9	25	MT Lynx	1.3	no	

Appendix B continued.

Camera site I.D.	Date	MS Time	Puma	Sex	Age stage	Female Repro-ductive Status	Time puma was at site (min.)	No. photos of puma	Time lapse between scent treatment and puma visit (days)	Scent type/name	Closest puma distance estimate to scent pad-hair snag (m)	Rub response by puma (yes, no)	Hair on snag collected
HS09	8/6/2011	5:44	unmarked	Unk			2	21	38	MT Lynx	0	**yes**	**yes**

Colorado Division of Parks and Wildlife
July 2010 - June 2011

WILDLIFE RESEARCH REPORT

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

Period Covered: July 1, 2010 - June 30, 2011

Author: M.W. Alldredge

Personnel: E. Joyce, T. Eyk, J. Halseth, G. Coulombe, R. Platte, K. Blecha, K. Yeager, L. Nold, K. Griffin, D. Kilpatrick, M. Paulek, B. Karabensh, D. Wroe, M. Miller, F. Quartarone, M. Sirochman, L. Wolfe, J. Duetsch, C. Solohub, K. Cannon, J. Koehler, L. Rogstad, R. Dewalt, J. Murphy, D. Swanson, T. Schmidt, T. Howard, D. Freddy CPW; B. Posthumus, Jeffco Open Space; D. Hoerath, K. Grady, D. Morris, A. Hatfield Boulder County Open Space; H. Swanson, R. Hatfield, J. Reale Boulder Open Space and Mountain Parks; S. Oyler-McCance, USGS.

ABSTRACT

Sampling cougar feces in the field may be a feasible non-invasive sampling method to estimate cougar populations. We finished analyzing cougar fecal samples collected from the 3 sibling cougars in captivity at the Foothills Wildlife Research Facility. Feces were stored at controlled temperatures after deposition and sub-sampled at monthly intervals. Genetic material has been found in samples up to 6 months post-deposition, but genotyping error rates have not yet been assessed. We are investigating degradation rates further by sampling feces in natural, uncontrolled, environments deposited at known times from known individuals. All samples have been obtained and genotyped, and final analysis and a summary report is in progress.

The use of telomeres as a method to determine the age structure of bear and cougar populations has continued to be examined. Further refinement of the age-to-length relationship for both species is warranted based on preliminary results. We have begun a Ph.D. project with the University of Wisconsin to examine telomeres in detail for bears. This project will also look at stable isotopes to examine foraging ecology and bear use of human food sources. Some pilot work is also being done to examine stable isotopes for cougars relative to predation on domestic animals.

Our principal research objective is to assess cougar population ecology, prey use, movements, and interactions with humans along the urban-exurban front-range of Colorado. This year capture efforts focused on re-collaring previously collared cougars, and capturing previously unmarked independent age cougars and cubs. We collared an additional 17 independent age cougars. Mortality remained high over the year with 6 additional mortalities for independent age cougars (predominantly human related). Home-

range patterns remained consistent to previous years. The effectiveness of aversive conditioning is still showing mixed results, which is likely a factor of the opportunistic nature of cougars using urban environments and a lack of habituation to them. Cougar/human interactions were minimal this year compared with previous years. Relocation of cougars as a management tool has had limited assessment, but given some success, still warrants further investigation. Mule deer are the predominant prey in cougar diets, although males will also utilize elk regularly.

WILDLIFE RESEARCH REPORT

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

MATHEW W. ALLDREDGE

P.N. OBJECTIVE

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

SEGMENT OBJECTIVES

Section A: Genetics

1. Evaluate differences in DNA quantity from either a scat surface collection or a cross-sectional collection.
2. Evaluate differences in DNA quantity from successive feces depositions to determine the variation in quantities of genetic material in scats. Quantify differences in epithelial shedding rates.
3. Evaluate temporal, environmental, and seasonal effects on fecal DNA quantity and quality for both controlled and uncontrolled conditions.

Section B: Telomeres and Stable Isotopes

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

Section C: Front-range cougars

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

SECTION A: GENETICS

BY M. ALLDREDGE

INTRODUCTION

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

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

STUDY AREA

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

METHODS

Fecal samples were collected from the 3 sibling cougars located at the Foothills Wildlife Research Facility. Sixty feces per cougar were collected and samples were placed at random into one of three treatment groups (-5 C, +5 C, and +15 C). Genetic samples were extracted from feces at the time of initial collection and at 2 weeks, and 1, 2, 3, 4, and 6 months post deposition. DNA was extracted and then stored at -20 C

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

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

RESULTS AND DISCUSSION

All samples have been collected and samples have been genotyped. Approximately 30 samples were collected in the field from radio-marked cougars over a range of deposition times and these have been genotyped as well. This work is still ongoing so an assessment of genotyping error rates has not been made. However, sufficient genetic material for genotyping has been found in samples up to 6 months old. Genetic degradation appears to occur at a slower rate than initially expected. This would indicate that scat surveys for individual identification of cougars may be a viable non-invasive sampling technique, if an efficient means of finding cougar scat in the field is available.

SECTION B: BEAR TELOMERES AND STABLE ISOTOPES

BY M. ALLDREDGE

OVERVIEW

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

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

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

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

SECTION C: FRONT-RANGE COUGARS

BY M. ALLDREDGE

INTRODUCTION

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

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

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

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

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

STUDY AREA

The original pilot study was conducted in Boulder and Jefferson counties, in an area near Interstate 70 north to approximately Lyons, Colorado, which was also a likely area for addressing long-term research objectives (see Figure 1). The study area for the long term study includes this original area but was expanded south to highway 285. Research efforts in the additional southern portion are generally limited to capturing cougars that are in the urban setting and/or have interacted directly with humans. The study area is comprised of many land ownerships, including private, Boulder city, Boulder County, Jefferson County, and state and federally owned lands. Therefore, we have been directly involved with Boulder city and Boulder and Jefferson county governments to obtain agreements from these entities on conduct of research and protocols for dealing with potential human/cougar interactions prior to conducting any research efforts. We have also acquired permission to access numerous private properties to investigate cougar clusters and to trap cougars.

METHODS

Baiting, using deer and elk carcasses, has been conducted throughout the year, with a focus on areas that do not allow the use of hounds. Bait sites are monitored using digital trail cameras to determine bait site activity. Cage traps were generally used for capture when cougars removed the bait and cached it. Beginning in November, 2010 and continuing through January, 2011, hounds were also used several times per week to capture cougars. Snares were used in situations where hounds could not be used and cougars would not enter cage traps. Captured cougars were anesthetized, monitored for vital signs, aged, measured, and ear-tagged. All independent cougars (> 18 months old) were fitted with GPS collars. All cubs greater than 15 kg (approximately 6 months or older) were ear-tagged with 22 g ear-tag transmitters or 22g ear-tag ptt Argos transmitters.

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

Most incidents prompting response from a DWM occur in neighborhoods, where relocating the cougar is necessary prior to any application of an aversive conditioning treatment. For these situations, all treatments require the relocation of the offending individual to an adjacent open-space property or similar area. Following relocation we either chase the cougar off using rubber bullets or beanbag rounds, pepper spray, or hounds. For first time offenders we initially try rubber bullets or beanbag rounds. Second time offenders may be chased with hounds. If rubber bullets or beanbag rounds are not affecting cougar behavior, we consider using pepper spray on first time offenders.

In other situations a cougar can be directly conditioned or chased from the area without relocation. We mimic the above approach as much as possible, and use rubber bullets or beanbag rounds on first time offenders. If possible we chase individuals with hounds on their second offense, although this is not always practical. Pepper spray is not practical either in many situations. As a second level treatment where direct hound chases are not practical, we attempt to capture, relocate, and aversive condition the individual.

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

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

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

The clustering routine was designed to identify clusters in five unique selection sets (S_1, S_2,…, S_5) in order to identify clusters containing two or more points, those that contained missing GPS locations, and those that were represented by single points. S1 clusters consist of multiple GPS locations with a 4 day window and within 200 m, while other sets are single points close together in time within varying distance bands. The clustering algorithm was written in Visual Basic and was designed to run within ARCGIS (Alldredge and Schuette, CDOW unpubl. data 2006). The widths of the spatial and temporal sampling windows were user specified, in order to meet multiple applications and research needs. This also enabled adjustment of the sampling frames to improve cluster specifications as needed.

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

RESULTS AND DISCUSSION

Collared cougars from the previous year (N=10) were captured and re-collared to replace exhausted batteries throughout the year. An additional 17 independent age cougars were also captured and collared during the year (Table 1). Currently there are 28 independent age cougars in the study with functioning GPS collars. Additionally, 9 cubs between 6 and 10 months old were captured and marked with ear-tags and either ptt or VHF ear-tag transmitters.

Home ranges for collared cougars have been determined using minimum convex polygons (MCP) to depict the general pattern of use and potential overlap, but likely over-represent the actual area used by an individual. Home ranges exhibit similar patterns to previous years (Figures 2 and 3), being fairly linear in a north-south direction. Adult male home ranges (Figure 4) are much larger than adult female home ranges (Figure 5). Subadult male home ranges are smaller than adult male home ranges, but are also characterized by large movements and significant overlap with adults. Female home ranges are smaller with sizes between 80 and 120 km^2. Female home ranges also have significant overlap, especially among related individuals. We have also seen significant long-range movements and dispersals (Figure 6). Long-range movements are significant movements outside of a cougar's typical home range with the individual returning to the original area. Dispersals are similar movements but the individual does not return to its original area.

There were a total of 6 mortalities for adult collared cougars during the 2010-11 year (Table 1). Causes of death included vehicle collision, unknown sources, hunting, and management or landowner euthanasia.

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

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

From Aug 1, 2008 through September 1, 2011 we have visited ~2800 clusters (S1-S5 types). However, only 1563 of these clusters were considered to be random samples, and thus preliminary inferences have only been drawn from this subset. For this annual report, we focused on summarizing only the field investigations of 29 cougars who had available data for GPS clusters created from November 1, 2010 through September 1, 2011. During this 10 month time period a total of 1032 clusters were visited, with 463 designated as random S1 samples.

Of the 463 randomly chosen S1 clusters, pooled over cougars, 44% were determined by field investigations to represent feeding events. This percentage was similar to the mean of 46.4% calculated for the previous two years, and within the range of variability (Table 3).

For prey composition, we calculated the frequency of occurrence (percentage) of food items, averaged over the sample of collared cougars. To assess variaion, we calculate 95% confidence intervals assuming a normal distribution. Of the clusters determined to be feeding activities, mule deer were the primary prey item, being represented in 66.5% (±7.7%) of the clusters (Figure 7). Elk were represented in 13.5% (±6.6%) of the feeding event clusters (Figure 7). Non-cervid prey items, which included approximately 15 other species, were represented in 19.9% (±4.6%) (Figure 7). Non-cervid species most frequently observed at these feeding events included raccoon, birds, housecat, and domestic dogs. Species composition estimates calculated during this time period were similar to preliminary estimates calculated in the Aug 1, 2008 – July 31, 2010 time period (Alldredge and Blecha 2010) (Table 3).

Kevin Blecha started his Masters of Science degree program at CSU this year, which will incorporate current efforts and data associated with these kill site investigations. Kevin will examine many aspects of cougar predator-prey dynamics in relation to habitat type and human density including prey selection, opportunistic take of livestock, diet composition, and predation rates. For a detailed description of his study see the attached study plan (Appendix II).

We have also initiated two additional graduate projects at CSU to focus on other aspects of the Front-range Cougar Study. First we have begun a Ph.D. project with Mevin Hooten at CSU through the statistics department to develop movement models and examine cougar GPS data for various movement patterns relative to roads, human density/activity, and other landscape/environmental features (Appendix III). The other project that we have begun is a M.S. project with Bill Kendall at CSU through the Fish, Wildlife, and Conservation Biology Department to examine techniques to develop non-invasive population estimation methodology for cougars (Appendix IV).

SUMMARY

Genetic analysis for cougar feces revealed that DNA is still present in samples after feces have been in controlled temperature environments for up to 6 months. Genotyping error rates still need to be assessed. However, the presence of DNA in these samples suggests that field detection of cougar scats may be a viable non-invasive population sampling technique. We have added known-age samples collected from natural environments from known cougars marked in the front-range cougar project.

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

In addition to re-collaring previously collared cougars, an additional 17 independent age cougars were collared during the year. Mortality remained high over the year. Home-range patterns remained consistent to previous years. The effectiveness of aversive conditioning is still showing mixed results, which is likely a factor of the opportunistic nature of cougars using urban environments and a lack of habituation to them. Relocation of cougars as a management tool has had limited assessment, but given some success, still warrants further investigation. Mule deer are the predominant prey in cougar diets, although males also utilize elk regularly.

LITERATURE CITED

Alldredge, M.W. 2007. Cougar demographics and human interactions along the urban-exurban front range of Colorado. Wildlife Research Report July: 153-202. Colorado Division of Wildlife, Fort Collins, USA.

Anderson, C. R., F. G. Lindzey, and D. B. McDonald. 2004. Genetic structure of cougar populations across the Wyoming Basin: metapopulation or megapopulation. Journal of Mammalogy 85:1207-1214.

Boutin-Ganache, I., M. Raposo, M. Raymond, and C. F. Deschepper. 2001. M13-tailed primers improve the readability and usability of microsatellite analyses performed with two different allele-sizing methods. Biotechniques, 31:25-28.

Cawthon, R. M. 2002. Telomere measurement by quantitative PCR. Nucleic Acids Research 30:e47.

Cougar Management Guidelines Working Group. 2005. *Cougar Management Guidelines*, 1st ed. WildFutures, Bainbridge Island, Washington, USA.

Ernest, H. B., M. C. T. Penedo, B. P. May, M. Syvanen, and W. M. Boyce. 2000. Molecular tracking of mountain lions in the Yosemite Valey region in California: genetic analysis using microsatellites and faecal DNA. Molecular Ecology 9:433-441.

Harrison, R. L., P. B. S. Clarke, and C. M. Clarke. 2004. Indexing swift fox populations in New Mexico using scats. American Midland Naturalist 151:42-49.

Haussmann, M.F., D.W. Winkler, K.M. O'Reilly, C.E. Huntington, I.C.T. Nisbet, and C.M. Vleck. 2003. Telomeres shorten more slowly in long-lived birds and mammals than in short-lived ones. Proceedings of the Royal Society of London Series B 270:1387-1392.

Hemann, M. T., and C. W. Greider. 2000. Wild-derived inbred mouse strains have short telomeres. Nuclei Acids Research 28: 4474-4478.
Hoss, M., M. Kohn, S. Paabo, F. Knauer, and W. Schroder. 1992. Excrement analysis by PCR. Nature 359:199.
Logan, K.A. 2006. Cougar population structure and vital rates on the Uncompahgre Plateau, Colorado. Wildlife Research Report July:95-122. Colorado Division of Wildlife, Fort Collins, USA.
Menotti-Raymond, M. and S. J. O'Brien. 1995. Evolutionary conservation of ten microsatellite loci in four species of Felidae. Journal of Heredity 86:319-322.
Menotti-Raymond, M., V. A. David, L. A. Lyons, A. A. Shcaffer, J. F. Tomlin, M. K. Hutton, and S. J. O'Brien. 1999. A genetic linkage map of microsatellites in the domestic cat (Felis catus). Genomics 57:9-23.
Meyne, J, R. L. Ratliff, and R. K. Moyzis. 1989. Conservation of the human telomere sequence $(TTAGGG)_n$ among vertebrates. Proceedings of the National Academy of Sciences 86: 7049-7053.
Nakagawa, S., N.J. Gemmell, and T. Burke. 2004. Measuring vertebrate telomeres: applications and limitations. Molecular Ecology 13:2523-2533.
Sinclair, E. A., E. L. Swenson, M. L. Wolfe, D. C. Choate, B. Bates, and K. A. Crandall. 2001. Gene flow estimates in Utah's cougars imply management beyond Utah. Animal Conservation 4:257-264.
Smith, D. A., K. Ralls, B. L. Cypher, and J. E. Maldonado. 2005. Assessment of scat-detection dog surveys to determine kit fox distribution. Wildlife Society Bulletin 33:897-904.
Taberlet, P., and J. Bouvet. 1992. Bear conservation genetics. Nature 358:197.
Watson, J.D. 1972. Origin of concatameric T4 DNA. Nature-New Biology 239:197-201.

Prepared by ____
Mathew W. Alldredge, Wildlife Researcher

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

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

AF19	F	8+	3/4/08	Heil Valley Ranch	Capture effort	Hounds	On-site	NA	Alive
		8+	3/18/09	North Boulder	Deer Kill	Cage	Heil Valley Ranch	Beanbag	Alive
			4/13/09	Left Hand Canyon	Deer Kill	Cage	Heil Valley Ranch	NA	Alive
		8+	1/20/09	Dowe Flats	Deer Kill	Cage	On-site	NA	Alive
			11/5/10	Foothills Hwy, N. Boulder	Roadkill				Dead
AF11	F	1.5	3/5/08	South Table Mesa	Deer Kill	Cage	On-site	NA	Alive
			8/20/08	US-40/Empire	Roadkill				Dead
AM20	M	4	3/6/08	White Ranch	Capture effort	Hounds	On-site	NA	Alive
			5/18/08	West of White Ranch	Livestock Depredation	Shot			Dead
AF15	F	6	3/18/08	Coffin Top	Capture effort	Hounds	On-site	NA	Alive
		7	4/2/09	Hall Ranch	Replace Collar	Hounds	On-site	NA	Alive
			3/25/10	Coffin Tip	Replace Collar	Hounds	On-site	NA	Alive
		8-9	2/4/11	Hall Ranch	Deer Kill	Snare	On-site	NA	Alive
AF17	F	9+	3/29/08	Sugarloaf	Pet depredation	Cage	Within 1 mile	Beanbag	Alive
			5/20/08	Four-mile Canyon	Unknown mortality				Dead
AF12	F	2	5/8/08	N. Boulder	Deer Kill	Cage	US Forest Boulder Canyon	Beanbag	Alive
			5/29/08	N. Boulder	Livestock depredation	Cage	Near Ward	Beanbag	Alive
			2/13/09	N. Boulder	Deer Kill	Snare	None	Euthanized	Dead
AM13	M	2	5/8/08	Sugarloaf	Livestock depredation	Cage	On-site	Beanbag	Alive
			12/17/08	Heil Valley Ranch	Replace Collar	Hounds	On-site	NA	Alive
		3	12/17/09	Heil Valley Ranch	Replace Collar	Hounds	On-site	NA	Alive
AM14	M	2	5/15/08	South Boulder	Seen under deck	Free-dart	Lindsey	None	Alive
			5/20/08	South Boulder	Deer kill	Free-dart	West of Rollinsville	Beanbag	Alive
			4/14/09	Rollins Pass	Replace Collar	Hounds	On-site	NA	Alive
		3	2/16/10	Left Hand Canyon	Replace Collar	Hounds	On-site	NA	Alive
			6/21/11	Allens Park	Elk kill/Replace Collar	Cage	On-site	NA	Alive
AF34	F	1.5	12/5/08	Heil Valley Ranch	Capture effort	Hounds	On-site	NA	Alive
			3/18/09	N. Boulder	Deer kill	Cage	Heil Valley Ranch	Beanbag	Alive

		2.5	1/4/10	Heil Valley Ranch	Replace Collar	Hounds	On-site	NA	Alive
		3.5	12/31/11	Hall Ranch	Replace Collar	Hounds	On-site	NA	Alive
AM18	M	1.5	12/24/08	Evergreen	Deer kill	Cage	Mt. Evans SWA	None	Alive
			3/14/09	Evergreen	Livestock depredation	Cage	None	Euthanized	Dead
AF16	F	3	12/29/08	Evergreen	Deer Kill	Snare	Flying J Open Space	None	Alive
			3/20/09	Evergreen	Livestock depredation	Cage	Mt. Evans SWA	Beanbag	Alive
AF45	F	5	1/2/09	Gold Hill	Deer kill	Cage	On-site	NA	Alive
			11/24/10	N.Boulder	Euthanized/Lisa Wolfe			NA	Dead
AF40	F	1.5	1/27/09	White Ranch	Capture effort	Hounds	On-site	NA	Alive
		2.5	2/22/10	White Ranch	Replace Collar	Snare	On-site	NA	Alive
AF24	F	10+	2/12/09	North Boulder	Deer Kill	Cage	Hall Ranch	None	Alive
			2/25/09	Hwy 7	Replace Collar	Hounds	On-site	NA	Alive
			4/4/09	North Boulder	Raccoon Kill	Free-dart	Heil Valley Ranch	None	Alive
			5/31/09	North Boulder	Encounter	Shot			Dead
AM31	M	1.5	12/31/08	Evergreen	Chicken coop	Hounds	On-site	None	Alive
			3/29-09	Conifer	Livestock depredation	Cage	Mt. Evans SWA	None	Alive
		2.5	2/16/10	Douglas, WY	Hunter				Dead
AF37	F	1.5	12/31/08	Evergreen	Chicken coop	Free-dart	On-site	None	Alive
			8/11/09	I-70	Roadkill				Dead
AM21*	M	1.5	8/29/09	N. Boulder	Encounter	Free-dart	Ward	None	Alive
		2	3/???/10	Loveland??	Livestock depredation				Dead
AF32	F	1.5	9/28/09	Indian Hills	Livestock depredation	Cage	Within 1 mile	None	Alive
		3.5	11/28/10	Golden	In neighborhood	Free-dart	White Ranch	None	Alive
		3.5	12/1/10	Golden	In neighborhood	Cage	Radium	None	Alive
			9/23/11	Green Mtn. Res.	Found dead				
AM46	M	2	11/13/09	Evergreen	Elk kill	Cage	On-site	None	Alive
			3/5/10	Genesee	Livestock depredation	Shot			Dead
AF50	F	3	11/24/09	West of Boulder	Deer kill	Cage	On-site	NA	Alive

AM44	M	6	12/15/09	White Ranch	Capture effort	Hounds	On-site	NA	Alive
			3/18/10	White Ranch	Replace collar	Hounds	On-site	NA	Alive
		7-8	3/20/11	White Ranch	Elk kill	Snare	On-site	NA	Alive
AM606	M	2	1/6/10	Boulder	Seen in town	Free-dart	MacGregor Ranch	None	Alive
			9/23/11	Laporte	Shot killing goat				Dead
AF54	F	4	1/14/10	White Ranch	Capture effort	Hounds	On-site	NA	Alive
			5/16/11	White Ranch	Deer kill/Replace collar	Cage	On-site	NA	Alive
AF52	F	4	1/28/10	Hall Ranch	Capture effort	Hounds	On-site	NA	Alive
		5-6	3/24/11	Hall Ranch	Deer Kill	Cage	On-site	NA	Alive
AM51	M	1.5	1/28/10	Hall Ranch	Capture effort	Hounds	On-site	NA	Alive
AF56	F	1.5	2/22/10	Conifer	Livestock depredation	Cage	Mt. Evans SWA	Beanbag	Alive
AF55	F	4	2/23/10	Conifer	Livestock depredation	Cage	Mt. Evans SWA	Beanbag	Alive
			3/13/10	Conifer	Pet Depredation	Cage	Euthanized		Dead
AM53	M	4	3/13/10	Genesee	Elk Kill	Cage	On-site	NA	Alive
			3/3/11	Medved property	Shot/hunter				Dead
AM60	M	2	3/29/10	Walker Ranch	Baiting	Cage	On-site	NA	Alive
AF58	F	1.5	4/4/10	Table Mesa	Baiting	Cage	On-site	NA	Alive
			6/3/10		Roadkill				Dead
AF62	F	5	4/13/10	Walker Ranch	Elk Kill	Cage	On-site	NA	Alive
		6	4/13/11	Walker Ranch	Baiting	Cage	On-site	NA	Alive
AF59	F	5	4/22/10	Blue Jay/Jamestown	Deer Kill	Cage	On-site	NA	Alive
		5	1/6/11	N. Boulder	Deer Kill	Cage	On-site	NA	Alive
AM63	M	1	9/22/10	Paradise Park	Deer Kill	Cage	White Ranch	None	Alive
			9/30/10		Road Kill				Dead
AF57	F	3	11/3/10	Lacy Property	Baiting	Snare	On-site	NA	Alive
AF61	F	4-5	11/18/10	Flagstaff	Deer Kill	Free-dart	On-site	NA	Alive
		4-5	3/2/11	Coal Creek Canyon	Raccoon Kill	Cage	Walker Ranch	None	Alive
AF64	F	1.5	1/20/11	Heil Valley Ranch	Baiting	Cage	On-site	NA	Alive
AM67	M	1.2	12/16/10	White Ranch	Baiting	Cage	On-site	NA	Alive

		5							
AF69	F	1.5	12/1/10	N. Boulder	Deer Kill	Free- dart	On-site	NA	Alive
		2	4/6/11	N.Boulder/Town	Deer Kill	Free- dart	Reynolds Ranch	None	Alive
AM70	M	3	1/23/11`	Gold Hill	Deer Kill	Cage	On-site	NA	Alive
			3/2/11	Boulder Heights	Dog Kill	Cage	Reynolds Ranch	None	Alive
AM71	M	2	1/27/11	Heil Valley Ranch	Baiting	Cage	On-site	NA	Alive
AM72	M	4	2/6/11	Heil Valley Ranch	Baiting	Snare	On-site	NA	Alive
AF73	F	4	3/6/11	Sunshine Canyon	Baiting	Cage	On-site	NA	Alive
AM74	M	4	2/23/11	White Ranch	Baiting	Cage	On-site	NA	Alive
AM76	M	2-3	3/6/11	Heil Valley Ranch	Baiting	Cage	On-site	NA	Alive
AF77	F	5	3/9/11	Morrison Mountain	Baiting	Cage	On-site	NA	Alive
AM78	M	2	3/18/11	W. Evergreen	Deer Kill	Cage	On-site	NA	Alive
			5/12/11	Soda Creel—I-70	Road kill				dead
AF79	F	4	3/18/11	Mt. Evans	Dumpsite	Cage	On-site	NA	Alive
AM80	M	1.7 5	3/18/11	Mt. Evans	Dumpsite	Cage	On-site	NA	Alive
AM84	M	2	4/9/11	Shield Park HOA	Sheep depredation	Cage	Deer Creek Canyon	None	Alive
SW023	F	1	4/9/09		Rehab	Release	Pike forest	None	Alive
			11/14/09	Lost Valley Ranch	Found dead				Dead
SW026	M	1	10/20/09		Rehab	Release	Hermit Park	NA	Alive
			8/20?/11		Shot/hunter		New Mexico		Dead
SW107	M	1	5/7/10		Rehab	Release	Radium	NA	Unkn
			3/22/11		Shot/hunter				Dead

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

Cougar ID	Sex	Age	Mother	Date	Location	Occurrence	Capture	Release Loc	Conditioning	Status
AF35	F	3	AF16	12/29/08	Evergreen	Deer Kill	Cage	Flying J Open Space		Alive
				12/31/08	Evergreen	Roadkill				Dead
AM36	M	3	AF16	12/29/08	Evergreen	Deer Kill	Cage	Flying J Open Space		Alive
				1/8/09	Evergreen	Starvation				Dead
AM30	M	8	AF01	1/30/09	S. Boulder	Deer Kill	Cage	On-site		Alive dead
AM38	M	8	AF01	1/30/09	S. Boulder	Deer Kill	Cage	On-site		Alive
				3/27/09	S. Boulder	Encounter	Free-dart	Lindsey	Beanbag	Alive
				3/30/09	S. Boulder	Pet Depredation	Free-dart	Centennial Cone	None	Alive
				4/9/09	Morrison	Encounter	Free-dart	None	Euthanized	Dead
AM29	M	6	Euth.	2/11/09	N. Boulder	Deer Kill	Free-dart	Hall Ranch	None	Alive
		12		6/15/09	N. Boulder	Encounter	Free-dart	Masonville	Beanbag	Alive
				10/23/09	Big Thompson	Goat Depredation	Shot			Dead
AM21* collared	M	12	Unkn	3/25/09	Table Mesa	Baiting	Cage	On-site	NA	Alive dead
AF25	F	12	Unkn	5/22/09	Indian Hills	Deer Kill	Cage	On-site	None	Alive
				9/13/09		Raccoon	Free-dart	Perforated intestine		Dead
AM41	M	12	Unkn	5/22/09	Indian Hills	Deer Kill	Free-dart	On-site	None	Alive
					Indian Hills	Encounter	Shot			Dead
AM65	M	4-5	AF32	11/28/10	Golden	In Neighborhood	Free-dart	White Ranch	None	Alive

AM66	M	4-5	AF32	11/28/10	Golden	In Neighborhood	Free-dart	White Ranch	None	Alive
				12/1/10	White Ranch	Recapture	Hounds	Radium	None	Alive
AM67	M	15	AF01	12/16/10	White Ranch	Baiting	Cage	On-site	NA	Alive
AF68	F	10	AF50	2/9/11	Flagstaff	Deer Kill	Cage	On-site	NA	Alive
AM70	M	3yrs	AF59	1/23/11	Gold Hill	Deer Kill	Cage	On-site	NA	Alive
				3/2/11	Boulder Heights	Dog Kill	Cage	Reynolds Ranch	None	Alive
AM80	M	20	AF79	3/18/11	Mt. Evans	Dumpsite	Cage	On-site	NA	Alive
AM83	M	9	AF52	3/24/11	Hall Ranch	Deer Kill	Cage	On-site	NA	Alive
AM85	M	9	AF62	4/13/11	Walker Ranch	Baiting	Cage	On-site	NA	Alive
AF86	F	9	AF62	4/13/11	Walker Ranch	Baiting	Snare	On-site	NA	Alive

Table 3: Comparison between previous two years and current year of the proportion of clusters representing feeding events and the proportion of feeding events represented by deer, non-cervids, and elk. Means and Simple 95% confidence intervals (assuming normal distribution) were calculated by using the collared subject as the sample.

	2008 - 2010		2010 -2011	
	Mean	95% C.I.	Mean	95% C.I.
Proportion of clusters classified as feeding event	0.440	(0.28 - 0.60)	0.44	(0.37 - 0.50)
Deer proportion	0.675	(0.56 - 0.79)	0.665	(0.58 - 0.74)
Non-cervids proportion	0.191	(0.08 - 0.30)	0.202	(0.15 - 0.25)
Elk proportion	0.133	(0.05 - 0.21)	0.134	(0.68 - 0.20)

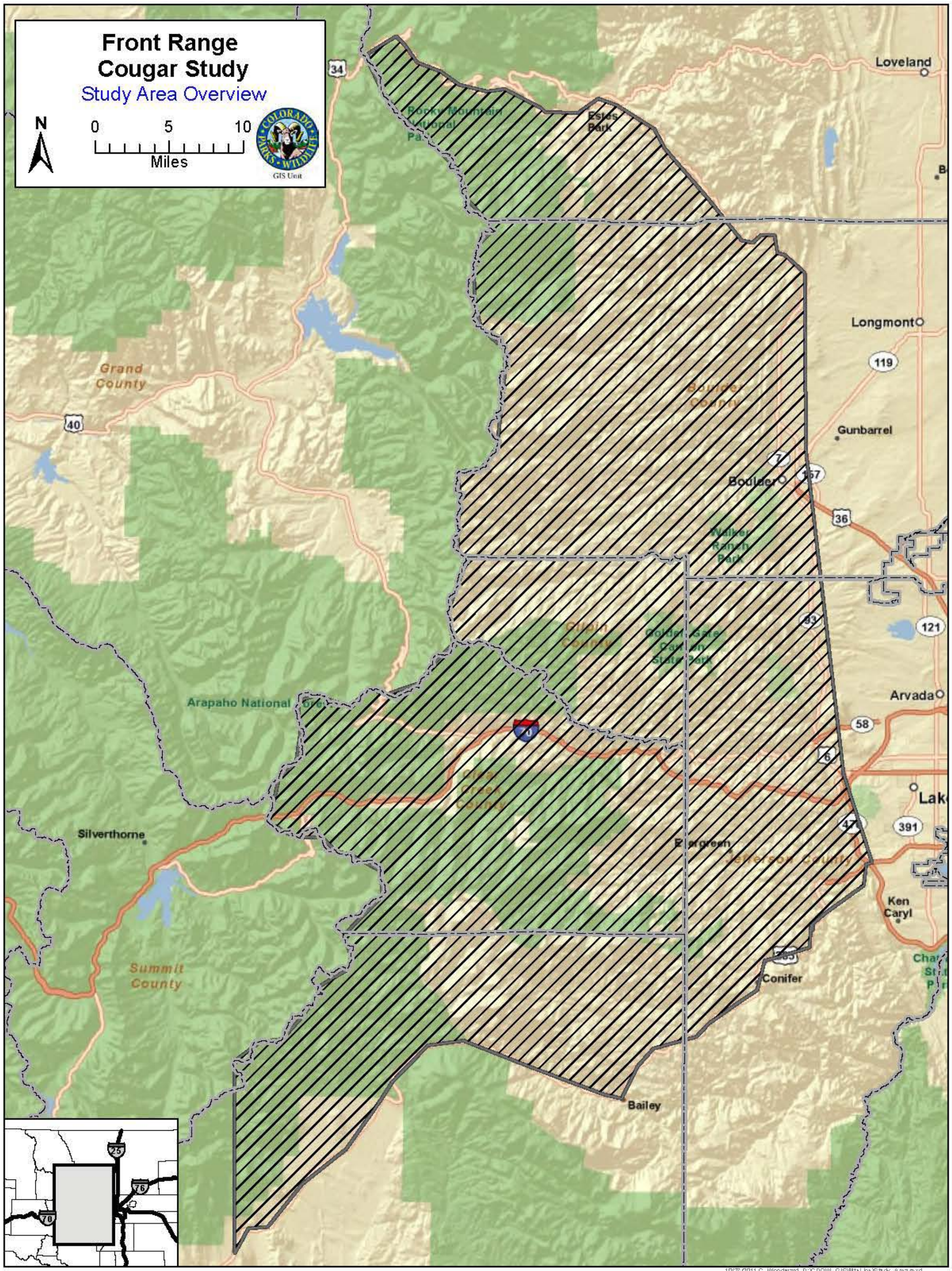


Figure 1: Study area for the main Front-range cougar study where most capture effort and field work is conducted.

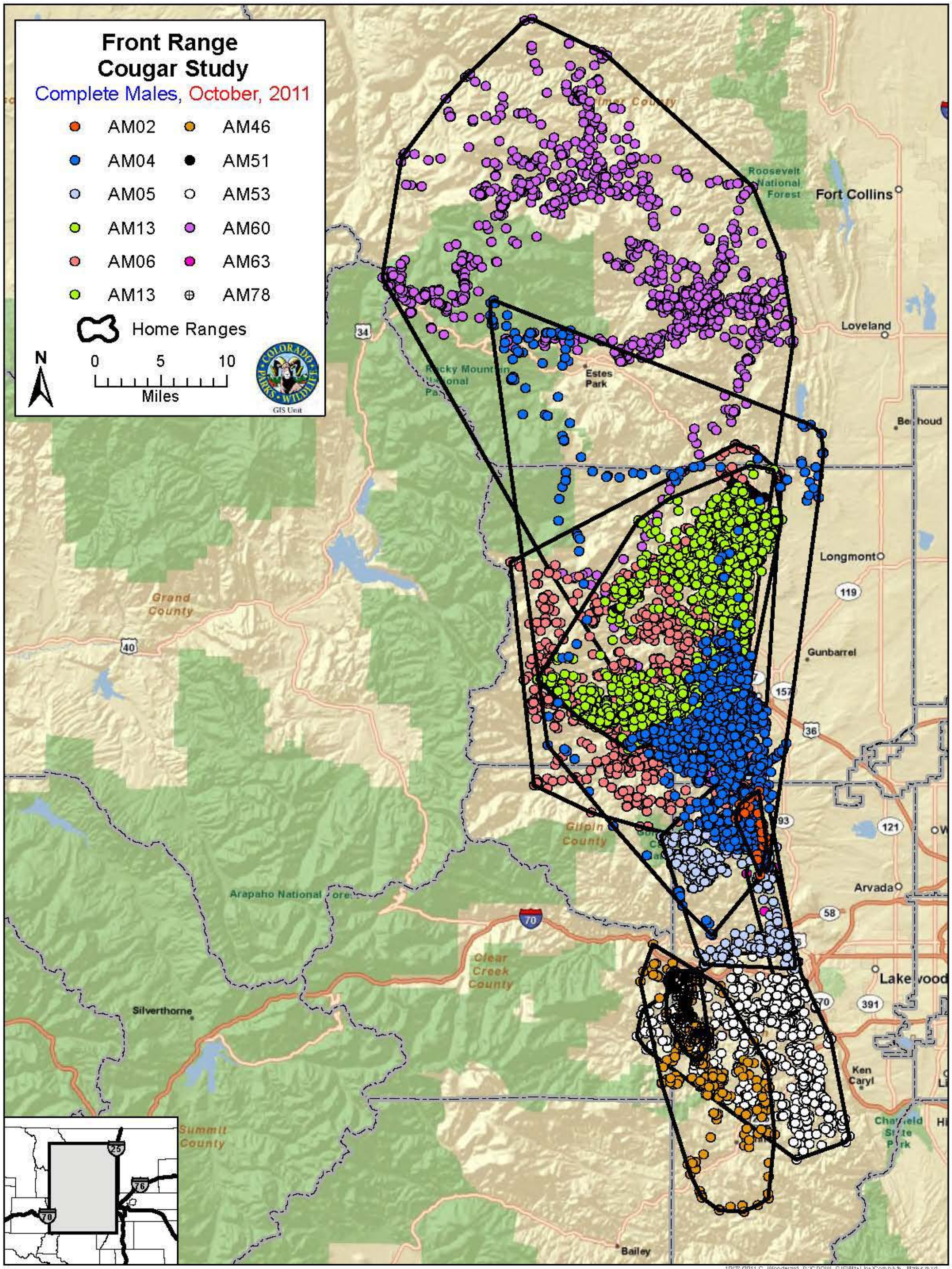


Figure 2: MCP home-ranges for male cougars that have previously been collared but are no longer in the study because of mortality or dispersal.

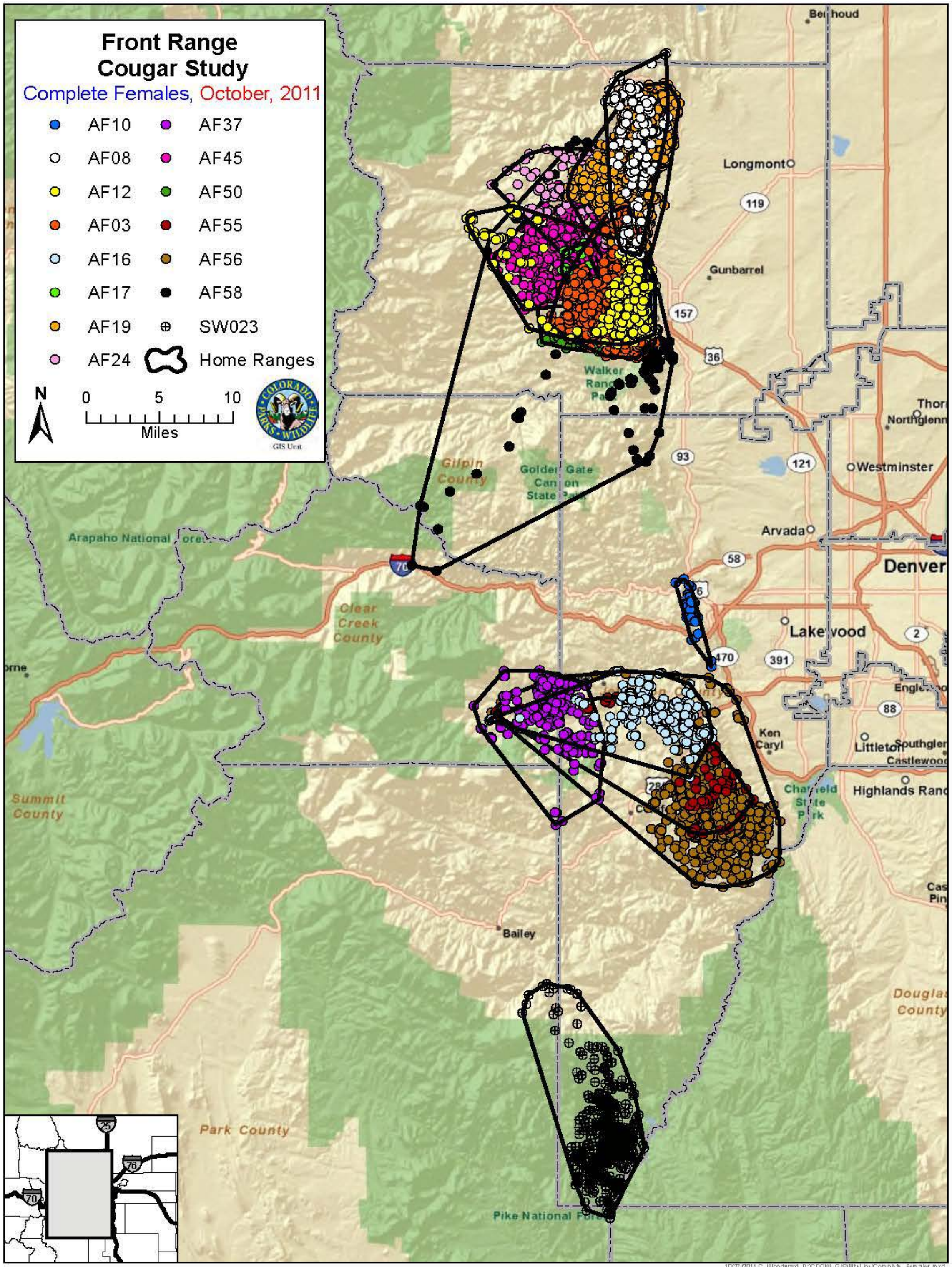


Figure 3: MCP home-ranges for female cougars that have previously been collared but are no longer in the study because of mortality or dispersal.

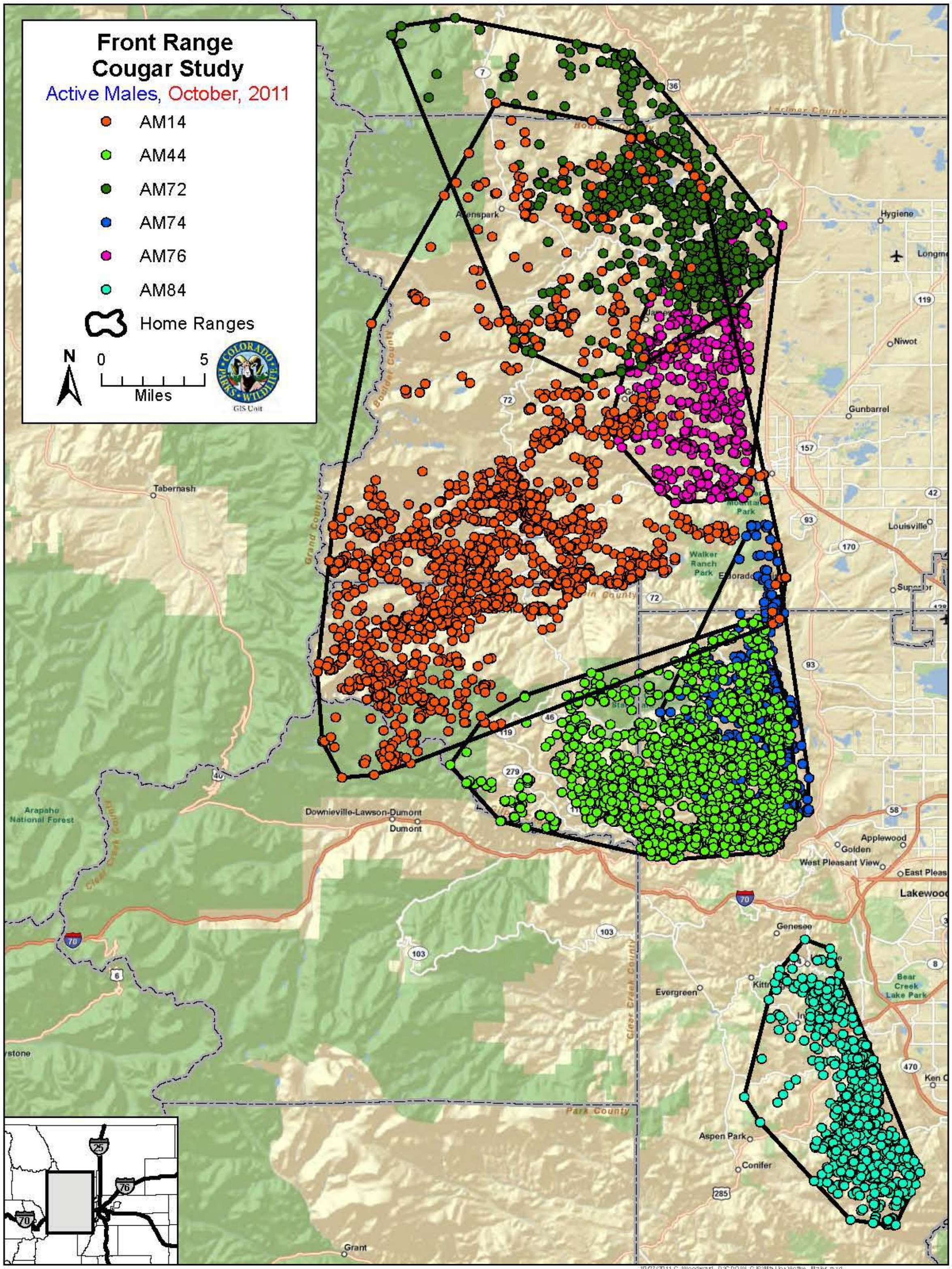


Figure 4: MCP home-ranges for male cougars that are currently in the study and being monitored.

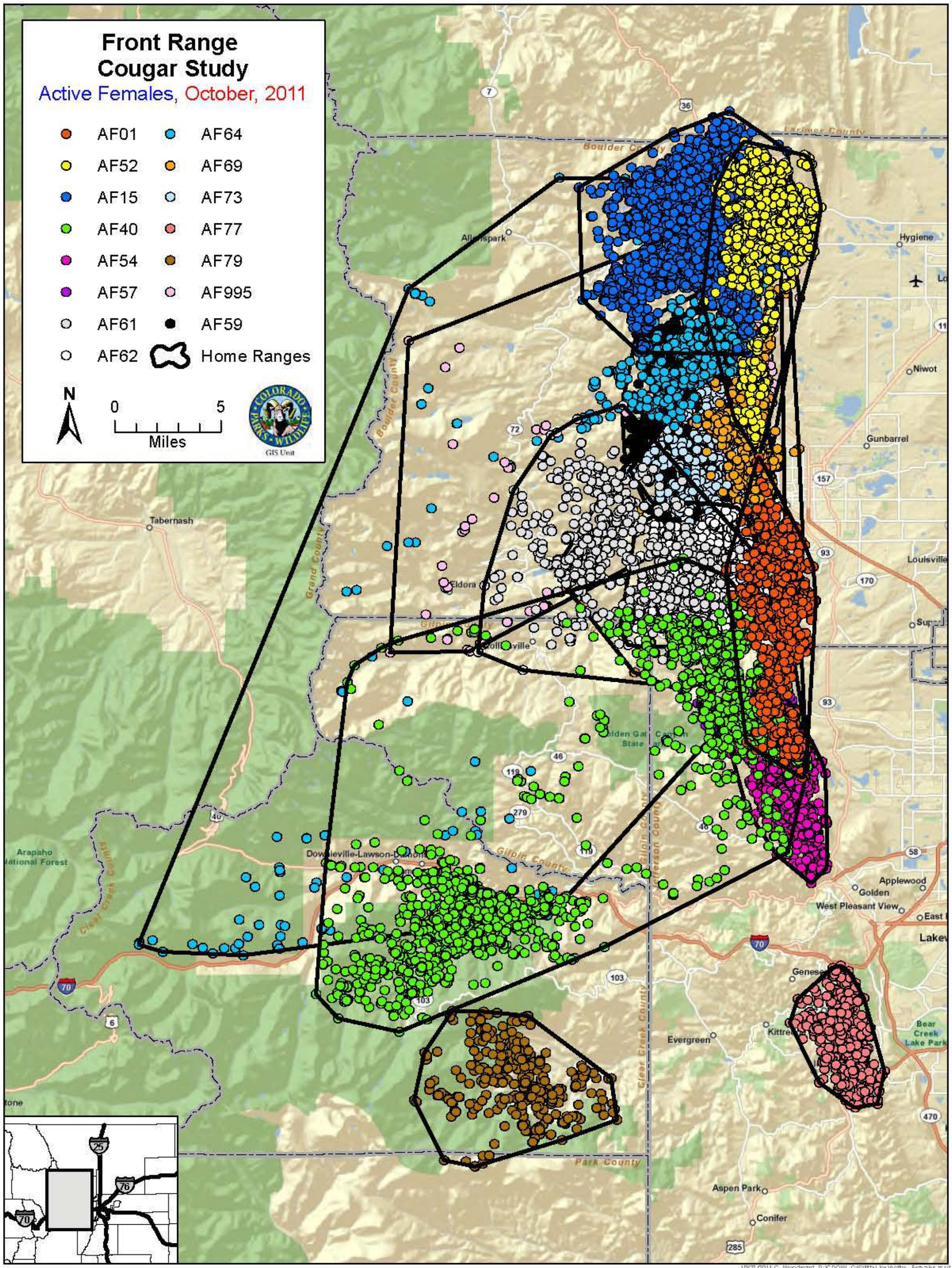


Figure 5: MCP home-ranges for male cougars that are currently in the study and being monitored.

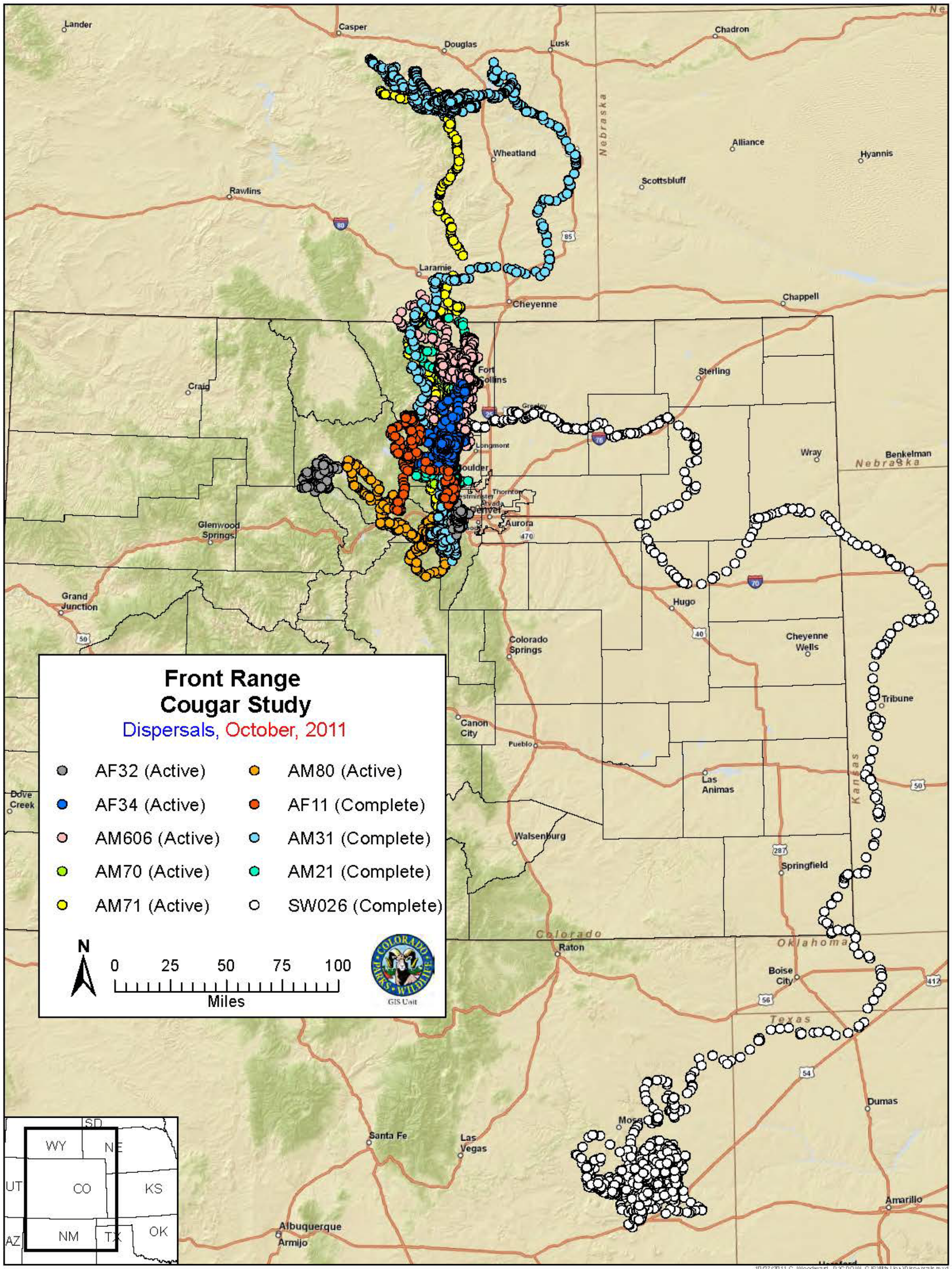


Figure 6: Dispersal/movement paths for cougars collared within the study area but traveled large distances outside of the study area.

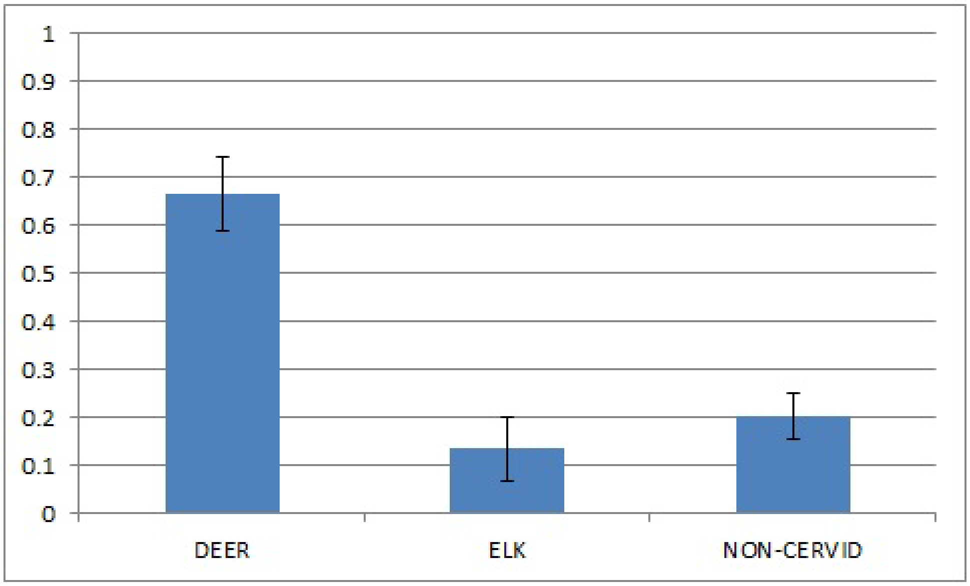


Figure 7: Mean proportion of Deer, Elk, and non-cervid prey remains found at feeding sites. Mean proportion drawn from the mean of 31 subject cougars (*n*=31). Error bars represent 95% Confidence Limits with an assumed normal distribution.

APPENDIX I

Black Bear Telomere and Stable Isotope Research Project

Jon Pauli, University of Wisconsin
Mat Alldredge, Colorado Parks and Wildlife
Dave MacFarland, Wisconsin Department of Natural Resources

<u>Background Information:</u>

We are pursuing a telomere/stable isotope project in conjunction with the Wisconsin DNR and the University of Wisconsin. We have been working with Dr. Jonathan Pauli (University of Wisconsin) on this project for the last 2 years developing the original telomere age to length relationships for bears and cougars. Our goal is to examine the length to age relationship for telomeres and to investigate the use of stable isotopes to identify consumption of human food sources in the diet of bears. Cursory analyses have been conducted over the past two years for both bears and cougars. These analyses have demonstrated a significant age to length relationship in telomeres for both bears and cougars. In conjunction with John Broderick (Colorado Parks and Wildlife) we have decided to pursue this project in detail for bears because the potential benefits are greater for bears based on current bear projects across the state. If we successfully develop this relationship for bears then we would be able to apply this technique to all bear hair-snag surveys and not only have population size but also have an estimate of the age structure for these populations. The stable isotope analysis will also benefit the urban bear research project recently initiated in Durango and our understanding of bear conflicts by providing valuable information about diet components of bears that are in different areas of the study or state. This project is being conducted through the University of Wisconsin as this is where previous research was done and is one of the only labs in the country that has expertise in this area. Wisconsin DNR is also a collaborator on this project and is helping to fund the research. Costs for this project are reasonable and will involve the cost of analyzing samples from Colorado and support for a Ph.D. student.

<u>Telomeres to age black bears:</u>

Telomeres are repetitive $[(T_2AG_3)_n]$ and highly conserved DNA sequences that cap eukaryotic chromosomes (Meyne et al. 1989). During each cell cycle telomeric repeats are lost because DNA polymerase is unable to completely replicate the 3' end of linear DNA (Watson 1972). Thus, telomeres progressively shorten with each cell division. Consequently, telomeres typically become shorter as individuals age (e.g. Hausmann et al. 2003, Hemann and Greider 2000). Recently, Pauli et al. (*in press*) used telomere lengths, quantified via real-time quantitative polymerase chain reaction (Q-PCR), to age American (*Martes americana*) and Pacific marten (*M. caurina*) collected throughout North America. They found that although telomere and age exhibited weak and non-linear relationship, accurate estimates of age class were obtainable when accounting for a few covariates (e.g., geographic location, sex). Indeed, the accuracy of age estimation via telomere length exceeded those obtained from counts of cementum annuli. Thus, quantification of telomere length could be a promising tool to age carnivores and estimate demographic structure for studies collecting hair samples non-invasively for DNA-based analyses (Pauli et al. *in press*).

Under a previous collaborative effort with the Colorado Division of Wildlife (now Colorado Parks and Wildlife [CPW]), we quantified telomere length for black bears of known-age in Colorado and Wyoming with Q-PCR. We found that high amplification efficiencies and reliable standard curves enabled a robust estimate of relative telomere length, and that relative telomere length declined with increasing animal age (Fig 1). Samples analyzed were obtained from

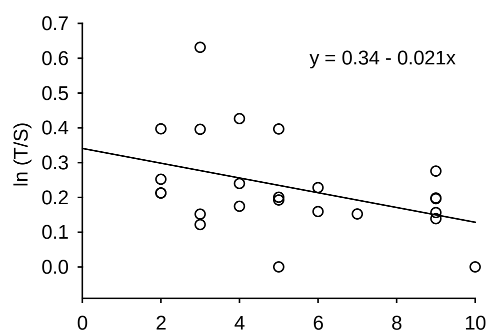


Fig 1. Relationship between age and telomere length (T/S) for blood samples of black bears from Wyoming and Colorado, 2008.

blood, hair and muscle tissue of bears; since telomere length varies across tissue-types, preliminary regression analyses were limited to blood samples only. Although we found considerable variation in telomere lengths by age, an interesting and potentially useful relationship between animal age and relative telomere length was observed.

Now that quantification of telomere length via Q-PCR is achievable for black bears, we propose to collect tissue samples from a proportion of the hunted bears in Colorado (~800 harvested annually) and Wisconsin (~5,000 harvested annually). From each individual, we will collect deep muscle, coagulated blood and pluck hair from each individual for the quantification of telomere length. We will compare telomere length estimates among the three tissue types and explore tissue-specific differences as well as validate telomere length obtained from externally plucked hair. We will then quantify the relationship between telomere length and age (obtained from counts of cementum annuli) for all individuals using a Bayesian Network approach that accounts for the covariates sex, location (or Game Management Unit), body condition, and structural size (via zygomatic width), all of which will be recorded at the time of sample collection. Upon developing models for aging from telomeres and relevant covariates, we will quantify the telomere length for the 400-500 bear samples already collected for monitoring by the CPW and estimate individual age for the quantification of demographic structure.

Assessing the importance of human-derived foods for black bears:

The use of stable isotopes, particularly those of nitrogen, carbon and hydrogen, has enabled biologists to quantify a myriad of cryptic ecological processes: trophic interactions and dietary overlap, organismal physiology and nutrient allocation, and animal movement and behavior (Kelly 1999). Stable isotopes analyses have been particularly important in quantifying the proportional contribution of food resources for free-ranging vertebrates (Hobson 1999). Because dietary analysis using stable isotope relies on the abundance of two elements $\delta^{13}C$ and $\delta^{15}N$, it avoids pitfalls of traditional methods (e.g., analysis of scat or stomach contents) that fail to detect highly digestible materials, and provide only a snapshot of resource use. Thus, for an array of carnivores, including black bears, the quantification of stable isotope provides a powerful analytical tool to understand diet and resource use.

There is growing interest on the importance of human-derived foods on free-ranging animal populations. Particularly for carnivores, managers are seeking to quantify the proportional importance of human-derived food items – agriculture (principally from corn), intentionally deployed baits, or unintentional waste – to better understand the consequent effects on nutritional condition, survival and reproductive success (Partridge et al. 2001). Especially among populations of bears, which can become strongly habituated to these resources (McCarthy and Seavoy 1994), quantifying individual reliance on such items and consequent effects on individual attributes and population dynamics is highly desired.

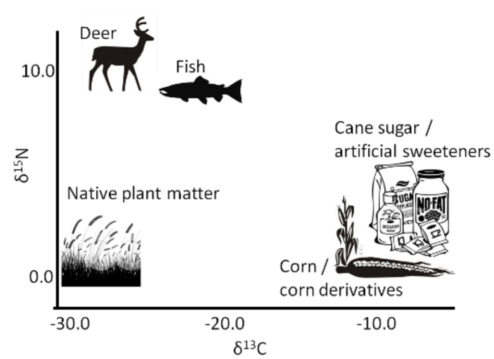


Fig 2. Illustration of carbon and nitrogen isotopic signatures of potential black bear food resources. Human foods, either from cultivation or artificially sweeteners, are highly enriched relative to natural diet items. As such, we can quantify the reliance of bears on human-derived resources via isotopic-based analyses.

Because of differences in photosynthetic pathways, corn, sugar cane and artificial sweeteners have distinctly different carbon signature ($\delta^{13}C$) compared to native plants and heterotrophs that inhabit temperate North America (Fig. 2; Jahren et al. 2006). Consequently, the percent of diet obtained from human-derived foods with unique isotopic signatures can be calculated for black bears (e.g., Noyce 2007). Bears reliant on human-derived foods would exhibit enriched levels of ^{13}C; via isotopic mixing models (Phillips et al. 2005), the percent of diet obtained from native plants, heterotrophs and human-derived food items will be calculated. Our approach to quantifying the importance of human-derived food for black bears inhabiting Wisconsin and Colorado will coincide with our efforts to quantify telomere lengths. Because the tissue types we are obtaining to quantify telomere lengths possess different metabolic turnover rates, those same tissues also provide different windows into food consumption via stable isotopes. For black bears, plasma represents diet items consumed during the previous 10 days and red blood cells reflect food consumed over the previous two months (Hildebrand et al. 1996). Collagen extracted from bone reflects the isotopic signature of foods consumed over an individual's lifetime, whereas hair reflects items consumed during active phases of hair growth. Bear underfur reflects autumn diet (Jones et al. 2006), while guard hair can be cut into smaller segments to provide a finer temporal scale within the molt (Pauli et al. 2008). Ultimately, isotopic signatures and percent diet from human-derived foods will be related back to indices of body condition (e.g., Cattet et al. 2002) obtained from bear carcasses. Such an isotopic approach will quantify the importance of human-derived food, in the form of agricultural corn or sweetened foods used in baiting, for black bears.

Anticipated Benefits:

This project will provide new information on the applicability of a molecular marker, telomere length, to estimate the individual age of black bears. Ultimately, such an aging approach will allow estimation of demographic structure from non-invasively collected hair samples. Further, through the collection of ecologically-relevant covariates (e.g., sex, location, body size and nutritional condition), we will be able to better understand factors driving telomeric attrition in wild vertebrates. Through the use of stable isotopes, it will be the first to quantify the relative importance of human-derived food (agricultural corn, bear baits, and human foods in trash) among black bears across seasons and relate the consequence of these diet items on the nutritional condition of bears. Additionally, through fieldwork and contact with hunters and managers, this project will allow graduate students to interact with local residents on issues of wildlife ecology and management. Ultimately, results will be disseminated via scientific and popular articles, professional meetings, and lectures to the public.

Management Benefits for CPW:

1. Ability to estimate age structure to coincide with population estimates from the non-invasive hair snag surveys currently being conducted.
2. Ability to examine regional (state-wide or multiple state) age structure of bear populations from harvested bears.
3. Ability to examine the use of human derived food sources in the diets of bears for ongoing bear research projects.
4. Ability to examine the use of human derived food sources in the diets of bears involved in human conflict across the state and across years as natural foods vary in quantity and quality.

Literature Cited:

Haussmann, M.F., D.W. Winkler, K.M. O'Reilly, C.E. Huntington, I.C.T. Nisbet, and C.M. Vleck. 2003. Telomeres shorten more slowly in long-lived birds and mammals than in short-lived ones. Proceedings of the Royal Society of London Series B 270:1387-1392.

Hemann, M. T., and C. W. Greider. 2000. Wild-derived inbred mouse strains have short telomeres. Nuclei Acids Research 28: 4474-4478.

Meyne, J, R. L. Ratliff, and R. K. Moyzis. 1989. Conservation of the human telomere sequence $(TTAGGG)_n$ among vertebrates. Proceedings of the National Academy of Sciences 86: 7049-7053.

Watson, J.D. 1972. Origin of concatameric T4 DNA. Nature-New Biology 239:197-201.

Pauli, J.N., J.P. Whiteman, B.G. Marcot, T.M. McClean and M. Ben-David. in press. A DNA-based approach to age martens (Martes *americana* and *M. caurina*). Journal of Mammalogy

Pauli, J.N., M. Ben-David, S.W. Buskirk, W.P. Smith, and J.E. DePue. 2009. An isotopic technique to mark mid-sized vertebrates non-invasively. Journal of Zoology 278:141-148.

Hildebrand, G.V., S.D. Farley, C.T. Robbins, T.A. Hanley, K. Titus, and C. Servheen. 1996. Use of stable isotopes to determine diets of living and extinct bears. Canadian Journal of Zoology 74:2080-2088.

Partridge, S.T., D.L. Nolte, G.J. Ziegltrum, C.T. Robbins. 2001. Impacts of supplemental feeding on the nutritional ecology of black bears. Journal of Wildlife Management 65:191-199.

Jahren, A.H., C. Saudek, E.H. Yeung, W.H.L. Kao, R. A. Kraft, and B. Caballero. 2006. An isotopic method for quantifying sweetners derived from corn and sugar cane. American Journal of Clinical Nutrition 84:1380-1384.

McCarthy, T.M., and R.J. Seavoy. 1994. Reducing nonsport losses attributable to food conditioning: human and bear behavior modification in an urban environment. International Conference on Bear Research and Management 9:75-84.

Jones, E.S., D.C. Heard, M.P. Gillingham. 2006. Temporal variation in stable carbon and nitrogen isotopes of grizzly bear guardhair and underfur. Wildlife Society Bulletin34:1320-1325.

Cattet, M.R.L., N.A. Caulkett, M.E. Obbard, and G.B. Stenhouse. 2002. A body-condition index for ursids. Canadian Journal of Zoology 80:1156-1161.

Noyce, K.V. 200. Use of stable isotopes of carbon, nitrogen, and oxygen in studies of diet and nutrition of Minnesota black bears. Summaries of Wildlife Research Findings, 2006, Minnesota Department of Natural Resources. Pp.140-146

Phillips, D.L., S.D. Newsome, J.W. Gregg. 2005. Combining sources in stable isotope mixing models: alternative methods. Oecologia 144:520-527.

Kelly, J.F. 1999. Stable isotopes of carbon and nitrogen in the study of avian and mammalian trophic ecology. Canadian Journal of Zoology 78: 1-27.

Hobson, K.A. 1999. Stable-carbon and nitrogen isotope ratios of songbird feathers grown in two terrestrial biomes: Implications for evaluating trophic relationships and breeding origins. Oecologia 101:799-805.

APPENDIX II

Puma foraging behavior in an urban to rural landscape

Kevin Blecha

(Study Plan for submission as 2010-2011 Annual CPW Mammals Research Report)

Introcuction:

The rocky mountain Front Range of Colorado has experienced drastic human population increases in the last two decades, and thus suburban and exurban landscapes are sprawling into areas occupied by cougar (*Puma concolor*). Some evidence suggests that cougar avoid areas of high human density. However, cougar use of landscapes developed by humans still occurs at some level with conflicts resulting between cougars and humans. This study examines cougar predation characteristics and prey selection in reference to landscape features such as prey availability, anthropogenic development, and hobby livestock.

A current paradigm in cougar management revolves around the idea that cougar density, distribution, and habitat use is correlated with densities of primary prey. Front Range cougar use of exurban, suburban, and even urban landscapes still occurs, which sparks human/cougar interactions. Exurban and suburban landscapes of the Front Range are often free of human harvest pressures on deer, which possibly cause elevated levels of cougar's primary prey (deer). It is in these areas that it is speculated that cougar are being drawn to because cougar are more likely to increase their encounter with potential prey. This idea is supported by other research indicating that landscape features used by a primary prey species may be the primary driver for selection of feeding locations of cougar (Pierce et al. 1999, Pierce et al. 2000, Atwood et al. 2007). However, the idea that increased cougar use of a landscape is a function of increasing prey availability is only grounded partially in theory, as other recent studies have found that cougar exhibit avoidance to/select against areas of high human activity (Mattson 2007, Burdett et al. 2010, Kertson 2011). Therefore, it is unclear which primary factor may drive landscape use by cougar in the Colorado Front Range. Many studies on other vertebrate species point out that an animal forages optimally, in which it may sacrifice hunting in areas with high prey availability for the security provided by areas further away from human disturbance. However, whether or not cougar forage optimally in reference to prey availability and human disturbance factors is untested. Testing whether the likelihood of cougar feeding events on the landscape changes in various combinations of low/high prey encounter probability and low/high human disturbance levels, may: 1) shed light on the degree of optimal foraging behavior in cougar, 2) whether or not cougar are feeding in exurban areas based on high availability of prey.

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

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

Questions/Objectives:

1. Do cougar feed in landscapes with relatively higher prey occurrence? 2) Do cougar avoid landscapes with higher human density when feeding? 3) Do cougar forage optimally by balancing the acquisition of prey while minimizing risks posed by humans?
2. Do cougar use parcels containing hobby livestock opportunistically or select (or even avoid) for these areas when hunting? Can this selection/opportunism differ between certain cougar sex/age classes and seasons? Are cougar that have a history of committing a depredation on a hobby livestock item more likely to use parcels containing hobby livestock? Prior to killing a hobby livestock prey item, do cougar select for areas known to hold hobby livestock?
3. Does human development influence the composition of prey consumed by cougar? Can human development cause a decrease in cougar foraging rates on primary prey such as ungulates?

Segment Objectives:

1. Examine whether cougar select prey resources more frequent than availability suggest (*3rd order selection:* Johnson 1980) in reference to: (main effect A) landscapes with higher probability of encountering prey, (main effect B) landscape with lower levels of human activity, or (interaction effect C) optimal landscapes with higher prey availability and lower human activity.
2. Assess if cougar are selecting, avoiding, or opportunistically using parcels of land containing hobby livestock when hunting, and assess if any difference in selection occurs between cougars of different:
    a. Sex/maternal class
    b. Age class
    c. Season
    d. Known livestock depredation history
3. Compare species composition (frequency of occurrence/overlap indices) of cougar diets in reference to:
    a. Various levels of human population density
    b. Cougar sex, age, maternal class
    c. Season
    d. Other landscape variables
4. Compare predation rates on mule-deer and secondary items in reference to:
    a. Various levels of human population density
    b. Cougar sex, age, maternal class
    c. Season
    d. Other landscape variables

Methods:

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

The 2862 km^2 extent of the study area, shown in Figure 1, encompasses a majority of Boulder County, north Jefferson County, and portions of Larimer, Clear Creek and Gilpin Counties. This area is characterized by a patchwork of private and publicly owned land held by federal, state, and municipal governing agencies. However, if a subject leaves the study area, standard GPS tracking and field data will be collected on the subject until establishing what appears to be a maintained home range. All objectives listed below require using cougar fitted with GPS radio collars, and thus only subjects captured in the parent project are utilized in this project.

The use of GPS radio collars allows us to study predator-prey relationships. The collars collect GPS locations 7 to 8 times/day, at 3 or 4 hour intervals. GPS locations are divided into selection sets based on the likelihood of the set of locations (clusters) representing a kill site. A random sample of these clusters is investigated to determine what a cougar was doing at the site, and whether or not it represents a feeding site. Feeding sites are thoroughly investigated to determine as much information as possible about what was eaten/killed at the site. All of the analysis below is dependent on identifying confirmed or likely kill events from characteristics of GPS location clusters representing cougar feeding sites (Anderson and Lindzey 2003). A standard algorithm was created to group GPS points together into clusters providing a sound sampling frame from which statistical inferences could be made about GPS clusters that are not physically investigated.

The clustering routine was designed to identify clusters in five unique selection sets (S1, S2, S3, S4, and S5) in order to identify clusters containing two or more points, those that contained missing GPS locations, and those that were represented by single points. The clustering algorithm was written in Visual Basic and was designed to run within ArcGIS (Alldredge and Schuette, CPW unpubl. Data 2006). The widths of the spatial and temporal sampling windows were user specified, in order to meet multiple applications and research needs. This also enabled adjustment of the sampling frames to improve cluster specifications as needed.

The following protocol to investigate cougar GPS clusters is used in the field. For S1 clusters, we investigate each cougar GPS location in the cluster by spiraling out a minimum of 20 m from the GPS waypoint while using the GPS unit as a guide, and visually inspecting overlapping field of view in the area for prey remains. Normally this is sufficient to detect prey remains and other cougar sign, (e.g., tracks, beds, latrines) associated with cougar. If prey remains are not detected within 20 m radius of the cluster waypoints, then we expand our search to a minimum of 50 m radius around each waypoint. For S2 through S5 clusters, we visit each cougar GPS location and spiral out to a maximum of 50 m around each waypoint, while using the GPS unit as a guide. Depending on the number of locations, topography, vegetation type and density, we spend a minimum of 1 hour and up to 3 hours per cluster to judge whether the cluster was a feeding site.

<u>Objective 1</u> (Examination of cougar selection of prey in reference to prey availability and human activity)

Detailed spatial and temporal prey availability data is not attainable for the large spatial and temporal extent of the FRCP, as obtaining abundance estimates for even conspicuous animals is difficult in the exurban areas of the Front Range [i.e., deer (CDOW 2006)]. Therefore, I will use an array of $\geq$111 camera trap units (Reconyx HyperFire, Holmen, Wisconsin) distributed throughout the study area to sample encounter rates of prey across the various landscape types. Estimated photographic rates will be interpreted as the probability of encountering a particular prey species, instead of a direct density or abundance metric. Royle and Nichols (2003) show that heterogeneity in the detection probability parameter of a typical occupancy modeling framework (MacKenzie et al. 2002) is usually most dependent on underlying localized abundance of a surveyed site, especially if all other variables influencing detectability are accounted for. Using camera traps to derive repeated presence-absence data are a novel approach at deriving detection probability estimates that are less influenced by variables other than the localized abundance of a targeted species at a site. Camera traps are less likely to be influenced by observers or sight-ability as the detection of a subject is automated (O'Brien 2010). Although encounter rates derived from camera traps, may be subject to heterogeneity across ambient temperatures, seasons, species, and body mass of a targeted animal (Rowcliff et al. 2011), changes in encounter rates between camera traps/sites reflect relative changes in abundance assuming that detection probabilities are constant among these camera traps/sites (O'Brien 2010). In addition, previous work has shown correlations between camera trapping rates and abundance measures in various ungulate studies (O'Brien et al. 2003, Rowcliffe et al. 2008, Rovero and Marshal 2009). Measures taken to limit inter-site heterogeneity in detection probability will include blocking study periods into shorter discrete seasons, in order to account for differences in ambient temperatures, movement behaviors, and animal congregation behaviors (e.g.: seasonal grouping of deer). Additionally, making cross-species comparisons will be limited to account for inter-species detection heterogeneity.

Camera-trap photograph encounter rates (number of independent photographs per unit time), for each particular prey species of interest, will be measured on a localized scale (25x25 m grid resolution) (Figure 2). This high resolution scale was chosen as it fits the fine scale decisions that cougar may make regarding hunting and feeding locations, especially considering cougar are shown to select for edge habitats when killing deer (Laundre and Hernandez 2003). Sunquist & Sunquist (1989) suggest that most large stalking felid species must approach within 30 m of a prey item before attacking. Past work characterizing cougar hunting habits in relation to habitat edge, characterize "edge habitats" as a distance band 15-20 m from the interface of two habitat types (Altendorf et al. 2001, Holmes and Laundre 2006). This high resolution was also chosen based on the resolution of the readily available major land-cover data. A ground-truthed land-cover dataset from the Colorado Vegetation Classification BASINWIDE project (CDOW 2003) was chosen for representing major vegetation types. The temporal extent of this study (Approximately 1 year) will be divided into monthly study periods in order to account for any major changes in animal movement, congregation behavior, or weather (i.e. snow/temperature) (Rowcliffe et al. 2011). The spatial extent of this study consists of Boulder County, Gilpin County, northern Jefferson County, and Clear Creek Counties of the Front Range region of Colorado. The study area extent was chosen to reflect a majority of the home ranges inhabited by cougars fitted with GPS collars.

To gather sighting data used to calculate encounter rates, camera traps will be placed on a stratified random sample of 25 m grid cell sites ($n \geq 111$). Sites will be defined by single 25x25 m cells, delineated with the boundaries of the 25 m grid cells used in the BASINWIDE project (CDOW 2003) (Figure 2). Because there is potential to model a variety of species potentially preyed upon by cougar, each with differing movement and habitat selection patterns, sites chosen for surveys will be randomly placed (Kays et al. 2010, O'Brien et al. 2010). This is particularly important in multi-species assessments, as placing cameras in habitats targeting certain species with low detection probabilities (as commonly done) may violate assumptions, thus causing biased results (Tobler et al. 2008). A stratified random design will be utilized in which seven major land-cover types, two non-urban housing density levels, and three levels characterizing the proximity to roofed structures are represented with an approximately equal number of samples (Table 1). Not all combinations of strata are present within the study area. Additionally, some strata levels overlap in describing particular sites (i.e. The "Low" level of the SUB-SUBSTRATA, and the "Urban" level of the MAJOR strata) and thus some levels between strata were combined. Examining all 12 categorical descriptions used in the multi-level sampling scheme shows that each category will be represented by a sample size ranging from 6 – 48 sites (Table 2). Some of these categories may eventually be measured as continuous variables when included in final analysis, and thus these levels and strata are only used to guide the placement of cameras to ensure broad and even sampling across a range of possible habitat conditions.

Placement of the camera unit within the 25 x 25 m site will be chosen by a randomly generated point location (Figure 2) and a randomly chosen azimuth (0-359º). In forested habitats, or habitats providing a stable structure for mounting a trail camera, the unit will be placed on the tree/structure closest to the randomly generated point. Some pruning of shrubbery/branches is permitted if maximum visibility is limited and if no more than 10% of the camera's detection zone is obstructed. If maximum visibility range of the camera sensor is limited, and pruning is not an option, the camera's direction may be adjusted to a new randomly chosen azimuth. If no alternative azimuth is available because of complete 360 º obstruction, then the camera may be moved to an alternative random location within the 25x25 m cell. If moving the camera to alternative random locations still does not allow placement of the camera, then a alternative randomly chosen 25 x 25 m site may be used. Trail cameras will be elevated 50 cm from the ground to standardize the angle and viewing range of the infrared sensor and/or camera lens. However, camera heights may be slightly modified to accommodate snow accumulations and growth of low lying vegetation. Cameras will be positioned so that the unit is parallel with the ground while the planar detection zone is perpendicular to the ground. Camera units will be set to record pictures 1/second, as long as the units trigger is being activated by a subject. Care must be taken to have cameras placed so that vegetation movements in the wind will not give false triggers, as false triggers will consume memory and battery life.

A General Linearized Modeling technique will be used to model the encounter rates of each particular prey species across un-sampled sites of the study area, given *a-priori* selected landscape covariate data such as major land-cover (BASINWIDE vegetation data set), elevation, aspect, hydrology, NDVI, edge proximity, etc. A distribution map of predicted encounter rates for each of the prey species, for each month, will be used to infer spatial relative encounter rate estimates. Relative encounter rate estimates across species may not be readily compared using this technique unless efforts are made to assess the probability of detection among targeted species. Particular focus, sampling effort, and analysis time may be placed on the late winter period and late summer periods. The late winter period (i.e. March – May) is of special interest as this is a period of relative stability in ungulate behaviors, as well as the presumed lowest period of prey availability for cougar. The late summer period (August-Sep), which will initiate after the ungulate birthing pulse, will represent a period of relatively stable ungulate behavior and highest presumed prey availability. Significant covariates with high predictive capabilities will be used to interpolate encounter rates at other non-sampled 25 m cells across the study area of interest, for each monthly time period of interest, for each of the six most common prey species [elk (*Cervus elaphus),* muledeer, raccoon, housecat (*Felis catus*), red fox (*Vulpes vulpes*), coyote (*Canis latrans*)] of cougar on the front range. Study period lengths and encounter rate definitions (i.e.: change photographs/day to photographs/week) may be manipulated to simplify calculations and modeling. Ultimately, whichever statistical modeling technique is used, the metric shall be interpreted as the probability a cougar could encounter the prey item at that given cell on the landscape within the monthly time period of interest.

***Objective 2* (Cougar selection of hunting areas near hobby livestock)**

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

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

Road-side observations and personal landowner visitations may be conducted to verify any presence/absence data collected above.

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

I will utilize a use vs. available design (Manley et al. 2002) to assess whether cougar, while carrying out potential hunting behaviors, exhibit 3rd order selection (Johnson 1980) for parcels of land containing commercial/hobby livestock in a Resource Selection Function analysis. This type of analysis requires distinguishing sites used by cougar for hunting behaviors, and sites available for cougar to carry out hunting behaviors. Characteristics of the landscape (presence/absence of livestock) for each USE site will be compared to landscape characteristics of paired AVAILABLE sites to examine whether cougar select for or against landscapes of a given type, when hunting.

Sites used by cougar (USE) will be defined as a "path" of GPS locations collected by collared subjects $\leq$ 24 hours prior to conducting a confirmed feeding event. As aforementioned, confirmed feeding events are randomly sampled, and verified in the field, from all potential feeding events conducted by a subject over each monthly time intervals. Two clusters of GPS points (any two or more GPS points located within 200 m and 4 days of one another) are randomly sampled each month for each subject. If prey remains are not found at these first two randomly sampled clusters, then another cluster is randomly picked and searched. The goal for each monthly sampling interval is to find at least two feeding events, for each subject, that can be reasonably confirmed kill events. I assume that killing behaviors would most likely be carried out when a cougar is hungry and thus searching for a prey item. Scavenging behaviors are not uncommon in Front Range cougar, and can be observed when one subject shares a killed item with another collared cougar, when a subject stumbles across a road/hunter killed ungulate, when a subject acquires a prey item from another predator, or when a subject visits localized area where humans frequently deposit carrion. It is unknown if prey searching behaviors are similar between a feeding event that involves a killing behavior and a feeding event involving a scavenging behavior. Therefore, paths of GPS locations, determined by field investigators, to lead to scavenging behaviors, may not be used in this analysis.

To represent areas available to cougar for hunting, a paired set of AVAILABLE locations will be generated based on the "path" of USE locations, by converting these USE points to a contorting line feature. Next, this contorted line feature will be randomly transposed (random azimuth, rotation, and distance) to a new location within the home range of the subject cougar (Figure 3). This AVAILABLE set of locations must be completely contained by the Minimum Convex Polygon (or 95% fixed kernel) home range of the respective subject cougar.

A-priori independent landscape variables that have potential influence on cougar hunting behavior will be attributed to each USE (hunting) and AVAILABLE site. A 50 m buffer will be created around each USE and AVAILABLE site in order to measure the percent coverage of landscape variables of interest. The percentage of the buffer containing the following variables will be measured:

- Areal coverage inhabited by hobby livestock (as discussed above)
- Distance to specific hobby livestock husbandry structure (if available)
- Land-cover
- Terrain ruggedness
- Human density factors (Exurban/Rural)

Each hunting path will consist of 1 - 7 distinct GPS locations, thus the independent variable measures of the landscape will be averaged over all 1-7 locations in the path. Using the data collected on USE and AVAILABLE paths locations, a generalized-linear-mixed model (GLMM) with a random intercept will be used within the RSF framework (Gillies et al. 2006). In this model, individual cougar are random effects that occur as random intercepts (Gelman and Hill 2007). Nesting the hunting path within each individual cougar under this two-level GLMM will give population level inferences, where the primary sampling unit is based on individual subjects, thus avoiding pseudo-replication from using the individual hunting paths. In addition, this approach handles continuous and categorical independent variables, as well as unbalanced data within the subjects. Dependent variable data is described as binomially distributed as 1 or 0 (1=USE, 0=NON-USE) and thus probability of selection is modeled with the equation:

$$w(x) = \frac{\exp(\beta_0 + \beta_1 x_{1ij} + \beta_2 x_{2ij} \ldots \beta_n x_{nij} + \gamma_{0j})}{1 + \exp(\beta_0 + \beta_1 x_{1ij} + \beta_2 x_{2ij} \ldots \beta_n x_{nij} + \gamma_{0j})}$$

Where i = feeding sites $1,\ldots,n$ within individual cougar $j = 1,\ldots.\ m$

The primary independent variables of interest to test for main effects will be the aerial coverage of parcels containing hobby livestock. Maximum likelihood estimation techniques will be used to obtain estimates of slope coefficients of independent variables. Significant positive β estimates will indicate selection for that variable. Separate analysis may be conducted for each respective cougar age/sex class, season, known livestock depredation history (1 = subject has previous known history of preying on domestic species, 0 = no history), and species found in kill event following hunting path (wild/domestic/ungulate/large prey/small prey).

Objective 3: ***Compare species composition of cougar diets***

This component of the study will utilize the larger long term data set of approximately 800 randomly selected confirmed feeding events by collared cougars spanning 2008-2012. Measures of the relative frequency of occurrence for each prey species will be assessed, utilizing a data set composed of 800 randomly sampled GPS location cluster investigations of confirmed feeding events. For each subject cougar, the number of feeding events for each particular prey species will be divided by the total number of confirmed feeding events. A sample will consist of an individual cougar in order for the variance to represent inter-subject variability. Baseline estimates for the frequency of occurrence of each prey species, and for the reclassified small/large prey, will be calculated by:

1.) Cougar sex and age
2.) Season
3.) Human disturbance measures (human density and distance-to-structure)

To test whether human development influences the composition of prey consumed by cougar, I will use niche overlap or dietary breadth overlap (Colwell and Futuyma 1971, Colwell 2006) indices. Significant shifts in diet composition toward smaller species in landscapes with higher human density will indicate that human development could be associated with altered cougar predation behavior. Cougar sex, age, and seasonal differences will be tested in a similar manner.

<u>Objective 4:</u> Compare predation rates on mule-deer and secondary items

Feeding rates (feeding events/week) will be derived from the data set of randomly sampled GPS location clusters verified in the field as either being "absent, large-prey present, small-prey present". Using multinomial logistic regression (Hosmer and Lemeshow 2000, Knopff et al. 2009), the probability of a small mammal or large-mammal feeding event, and associated standard errors, will be modeled for each cluster produced by each subject cougar from spatial and temporal characteristics of GPS locations collected within a particular cluster. Using techniques of Anderson and Lindzey (2003), modeled (predicted) probabilities and standard errors associated with all clusters of an individual subject will be summed, by small-prey events and large-prey events. The summed probabilities and summed standard errors will be divided by the total number of days monitored for the subject at hand. Coefficients of variation will be averaged across multiple subjects to obtain 95% confidence intervals, for both small-prey and large-prey feeding rates by:

1.) Cougar sex, age, and maternal status
2.) Season
3.) Human disturbance measure (human density only)

<u>Results and Discussion (Anticipated Results):</u>

Simultaneously answering questions relating cougar use of the landscape relative to prey distribution and human disturbance will give valuable insights to how a large top tier carnivore fits predictions of optimal foraging theory. Specifically, insight to how a top tier predator perceives its landscape and whether or not tradeoffs are being made between maximizing food intake and reducing risks posed by humans is important to advancing knowledge of how animals use resources and perceive their environment. Applications of optimal foraging theory to large carnivorous species are rare, and thus would add knowledge to whether or not predictions drawn from model species are scalable to the highest trophic levels. In addition, results from this study are important to conservation and management of the landscapes occupied by cougar. A study that simultaneously examines the influences of human development and prey distributions on cougar is important to predicting how well foraging behaviors of cougar may adapt to future urban sprawl. Finally, this study will provide knowledge on speculations regarding whether or not elevated prey resource levels are a driver of cougar use of exurban and suburban landscapes.

Currently, analysis in the camera trap portion of this study allows for the assessment of cougar use for a particular prey species on an individual species basis. Much focus will be placed on species most commonly preyed upon by cougar, such as deer and elk. Pending sufficient camera trap detections of other species [i.e., raccoon, fox, coyote, wild turkey (*Meliagris gallapova*), skunk (*Mephitis/Spilogale* sp.), and housecat], spatial distributions of these alternative species may be modeled as well. Incorporating a wider range of species, in addition to accounting for detectability differences between species, would potentially allow future analysis to assess the selection of one particular species over other available species. In addition, fine scale species distribution data are rare, and thus these data may be useful to other wildlife/land managers and researchers.

Increasing harvest rates of species involved in human/wildlife conflicts are a common practice for CPW managers. However, increasing the harvest quota may not be a suitable management method to decrease human/cougar conflicts for various reasons. First, increases in the quota for maximum harvest have not resulted in a substantial increase of harvested cougar (CDOW 2004). Second is that other research has found that small areas with high harvest may only exhibit increased immigration rates especially from younger age classes (Cooley et al. 2009), with no significant overall decrease in density. Thus, a population skewed toward a younger age structure may occur (Cooley et al. 2009). If speculations are true that younger cougar, relative to older cougar, are more likely to prey on hobby livestock, then hobby livestock owners may suffer an increased level of losses in the future.

Knowing if cougar seek hobby livestock in certain seasons is important to predicting cougar/human conflicts. It is suspected that the spring periods are when livestock depredations are most reported. Speculations exist that cougar are seeking alternative prey sources during the spring months when primary prey sources (ungulates) are at their lowest availability.

Results of this study have bearing on the conservation of cougar overlapping hobby livestock owners. Knowing whether or not a cougar may seek hobby livestock while hunting may have bearing on decisions made by agency wildlife managers and hobby livestock owners. Little is known about behaviors of cougar in the proximity of livestock. Nonetheless, decisions are sometimes made based on how the agency wildlife manager or livestock owner perceives the intended behavior of cougar travelling in the vicinity of livestock. For instance, when a cougar is found on a parcel of land containing hobby livestock, the landowner may legally euthanize the cougar if he/she believes that their livestock are endangered. Therefore, any cougar passing through parcels of land containing livestock may be killed if the landowner assumes that the cougar was seeking their livestock. When cougar are caught killing a hobby livestock item, it is unknown if the cougar was selecting for landscapes known to hold hobby livestock items, or if the cougar was hunting opportunistically in regard to hobby livestock distribution.

Showing differences in prey-species composition indices and frequency of occurrences of individual species between differing sex and age classes is important to management/conservation of the prey species. Management techniques that change the sex or age structure of the cougar population may impact populations of certain prey species. For instance, if younger cougar are more likely to feed on small prey species, then using techniques that shift the cougar population to a younger age structure may have a large impact on populations of smaller prey.

Testing for seasonal differences in prey-species composition indices and frequency of occurrence of individual species may have relevance to prey-switching abilities of cougar. Following these assumptions:

- Early spring season (March-May) represents the time period with lowest primary prey (deer) availability.
- Late summer season (August – October) represents the highest availability of primary prey.
- Energetic demands are equal throughout the year.

One may utilize the seasonal differences as a proxy to test whether or not cougar switch from using predominately deer or other natural prey items, to other prey species when faced with lower levels of primary prey availability.

Assessing whether differences exist in cougar dietary composition and feeding rates of deer, between levels of high and low human density may be relevant toward discussions of whether or not suburban/exurban landscapes have an impact on cougar fitness, or on the contrary, how cougar may adapt to these potential human disturbances. Describing feeding rates on certain species such as deer and elk are important to wildlife managers in the Front Range. Knowing the impact of cougar on populations of prey items, that are also harvestable by humans, is important to the management of these particular game species.

Liturature Cited:

Ackerman, B.B., F.G. Lindzey, and T.P. Hemker. 1986. Predictive energetic models for cougars. In S.D. Miller and D.D. Everett, (eds.): Cats o the world: biology, conservation, and management. National Wildlife Federation, Washington D.C., U.S.A.

Altendorf, K.B., J.W. Laundre, C.A. Lopez Gonzalez, J.S. and J.S. Brown. 2001. Assessing effects of predation risk on foraging behavior of mule deer. Journal of Mammalogy 82:430-439.

Anderson, C.R. and F.G. Lindzey. 2003. Estimating cougar predation rates from GPS location clusters. The Journal of Wildlife Management 2:307-316.

Atwood, T.C., E.M. Gese, and K.E. Kunkel. 2007. Comparative patterns of predation by cougars and recolonizing wolves in Montana's Madison Range. Journal of Wildlife Management 71:1098-1106.

Blumstein, D.T., E. Fernandez-Juricic, P.A. Zollner, and S.C. Garity. 2005. Inter-specific variation in avian responses to human disturbance. Journal of Applied Ecology 42:943-953.

Burdett, C.L., K.R. Crooks, D.M. Theobald, K.R. Wilson, E.E. Boydston, L.M. Lyren, R.N. Fisher, T.W. Vicers, S.A. Morrison, and W.M. Boyce. 2010. Interfacing models of wildlife habitat and human development to predict the future distribution of cougar habitat. Ecosphere 1(1):art4. doi:1890/ES10-0005.1.

CDOW. 2003. Colorado Vegetation Classification project. http://ndis.nrel.colostate.edu/coveg/

CDOWb. 2004. Mountain lion data analysis unit management plan, North-Central Front Range: DAU L-12. Accessed online 4-12-2011 http://wildlife.state.co.us/NR/rdonlyres/B7D2773F-3389-481C-9231-FE2EB51C709D/0/L12DAUPlan112004.pdf

CDOW. 2006. Baily deer herd management plan: Data Analysis Unit D-17. Prepared by Linstrom, A. accessed online 4-12-2011 http://wildlife.state.co.us/NR/rdonlyres/0D501E5C-2ADD-4606-8F53-C8A5BC151FD0/0/D17DAUPlan_Bailey.pdf

Colwell, R.K. and D.J. Futuyma. 1971. On the measurement of niche breadth and overlap. Ecology 52: 567-576.

Cooley, H.S. H.S. Robinson, R.B. Wielgus, and C.S. Lambert. 2008. Cougar prey selection in a white-taild deer and mule deer community. Journal of Wildlife Management 72:99-106.

Cooley, H.S. H.S. Robinson, R.B. Wielgus, G.M. Koehler, H.S. Robinson and B.T. Maletzke. 2009. Does hunting regulate cougar populations? A test of the compnesatory mortality hypothesis. Ecology 90:2913-2921.

Frid, A., and L. Dill. 2002. Human-caused distrubance stimuli as a form of predation risk. Conservation Ecology 6(1): 11. [online] URL: http://www.consecol.org/vol6/iss1/art11

Gelman, A. and J. Hill. 2007. Data analysis using regression and multilevel/hierarchical models. Cambridge University press, Cambridge, UK.

Gill, J.A. and W.J. Sutherland. 2000. The role of behavioural decision making in predicting the consequences of human disturbance. In: Gosling, L.M. and W.J. Sutherland (Eds.), Behaviour and Conservation. Cambridge University Press, Cambridge.

Gillies, C.S., M. Hebblewhite, S.E. Nielsen, M.A. Krawchuk, C.L. Aldridge, J.L. Frair, D.J. Saher, C.E. Stevens and C.L. Jerde. 2006. Applications of random effects to the study of resource selection by animals. Journal of Animal Ecology 75: 887--898.

Holmes, B.R. and J.W. Laundre. 2006. Use of open, edge and forest areas by cougars in winter: are cougars foraging optimally? Wildlfie Biology 12:201-209.

Hosmer, D.W. and S. Lemeshow. 2000. Applied logistic regression. 2nd edition. John Wiley and Sons, Inc., New York, USA.
Johnson, D.H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61:65-71
Kays, R., S. Tilak, B. Kranstauber, P.A. Jansen, C. Carbone, M.J. Rowcliffe, T. Fountain, J. Eggert, and Z. He. 2010. Monitoring wild animal communities with arrays of motion sensitive camera traps. IEEE International Workshop on Practical Issues in Building Sensor Network Applications. Accessed online 4-12-2011 http://arxiv.org/abs/1009.5718
Kertson, B.N. 2010. Cougar ecology, behavior, and interactions with people in a wildland-urban environment in western Washington. Ph.D. Dissertation. University of Washington, Pullman. pp. 149.
Kertson, B.N., R.D. Spencer, J.M. Marzluff, J. Hepinstall-Cymerman, and C.E. Grue. 2011. Cougar space use and movements in the wildland-urban landscape of western Washington. Ecological Applications in-press doi:10.1890/11-0947.1.
Knopff, K.H., A.A. Knopff, M.B. Warren, and M.S. Boyce. 2009. Evaluating Global Positioning System telemetry techniques for estimating cougar predation parameters. Journal of Wildlife Mangement 73:586-597.
Knopff, K.H., A.A. Knopff, A. Kortello, M.S. Boyce. 2010. Cougar kill rate and prey composition in a multiprey system. Journal of Wildlife Management 74:1435-1447.
Laundre, J.W. 2005. Cougar energetics: A recalculation. The Journal of Wildlife Mangement 69:723-732.
Laundre, J.W. 2008. Summer predation rates on ungulate prey by a large keystone predator: how many ungulates does a large predator kill? Journal of Zoology 275:341-348.
Laundre, J.W. and L. Hernandez. 2003. Winter hunting habitat of cougars Cougar concolor in northwestern Utah and southern Idaho, USA. Wildlife Biology 9:123-129.
MacKenzie, D.I., J.D. Nichols, G.B. Lachman, J.A. Royle, C.A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 8:2248-2255.
Manley, B.F.J., L.L. McDonald, D.L. Thomas, T.L. McDonald, and W.P. Eerickson. 2002. Resource selection by animals: statistical analysis and design for field studies, 2nd edition. Kluwer Academic Publishers, Boston, MA.
Mattson, D.J. ed., 2007. Mountain lions of the Flagstaff Uplands 2003-2006. Progress Report: U.S. Geological Survey Open-File Report 2007-1050.
Michalsiki, F., R.L.P. Boulhosa, A. Faria, and C.A. Peres. 2006. Human-wildlife conflicts in a fragmented Amazonian forest landscape: determinants of large felid depredation on livestock. Animal Conservation 9:179-188.
Murphy, K.M. 1998. Ecology of the cougar (Cougar concolor) in the northern Yellowstone ecosystem: Interactions with prey, bears, and humans. Ph.D. Dissertation, University of Idaho, Moscow.
O'Brien, T.G. 2010. Abundance, density, and relative abundnace: a conceptual framework. In O'Connell et al. (eds.), Camera Traps in Animal Ecology: Methods and Analysis., Newyork, Springer.
O'Brien, T.G., M.F. Kinnaird, and H.T. Wibisono. 2010. Estimation of species richness of large vertebrates using camera traps: An example from an Indonesian rainforest. In O'Connell et al. (eds.), Camera Traps in Animal Ecology: Methods and Analysis., Newyork, Springer.
Pierce B.M., V.C. Bleich, J.D. Wehausen, R.T. Bowyer. 1999. Migratory patterns of mountain lions: Implications for social regulation and conservation. Journal of Mammalogy 80:986-992.
Pierce B.M., V.C. Bleich, and , R.T. Bowyer. 2000. Social organization of mountain lions: Does a land-tenure system regulate population size? Ecology 81:1533-1543.
Pyke, G.H., H.R. Pulliam, and E.L. Charnov. 1977. Optimal foraging: A selective review of theory and tests. The Quarterly Review of Biology. 52:137-154.
Rovero, F. and A.R. Marshall. 2009. Camera trapping photographic rate as an index of density in forest ungulates. Journal of Applied Ecology 46:1011-1017.
Rowcliffe, J.M., J. Field, S.T. Turvey, and C. Carbone. 2008. Estimating animal density using camera traps without the need for individual recognition. Journal of Applied Ecology 45: 1228-1236.

Rowcliffe, J.M., C. Carbone, P.A. Jansen, R. Kays, and B. Kranstauber. 2011. Quantifying the sensitivity of camera traps: an adapted distance sampling approach. Methods in Ecology and Evolution. doi: 10.1111/j.2041-210X.2011.00094.x

Royle, J.A. and J.D. Nichols. 2003. Estimating abundance from repeated presence-absence data or point counts. Ecology 84:777-790.

Schoener, T.W. 1971. Theory of feeding strategies. Annual Review of Ecology and Systematics 2:369-404.

Sunquist, M.E. , and F.C. Sunquist. 1989. Ecological constraints on predation by large felids. Page 283-301 in J.L. Gittleman, editor. Carnivore behavior, ecology, and evolution. Cornell University Presss, Ithaca.

Tobler, M.W., S.E. Carillo-Percastegui, R.L. Pitman, R. Mares, and G. Powell. 2008. An evaluation of camera traps for inventorying large- and medium-sized terrestrial rainforest mammals. Animal Conservation 11:169-178.

Torres, S.G., T.M. Mansfield, J.E. Foley, T. Lupo, and A. Brinkhaus. 1996. Mountain lion and human activity in California: Testing Speculations. Wildlife Society Bulletin 24:451-460.

Figure 1: Proposed study area (2862 km^2) (blue polygon), in the Front Range of Colorado. Study is primarily conducted in Boulder, Jefferson, Gilpin, and Clear Creek Counties (red polygons). Actual extent of study area used for analysis of prey distributions will be determined by a minimum convex polygon drawn around all cougar GPS locations collected concurrently with prey distribution camera monitoring component.

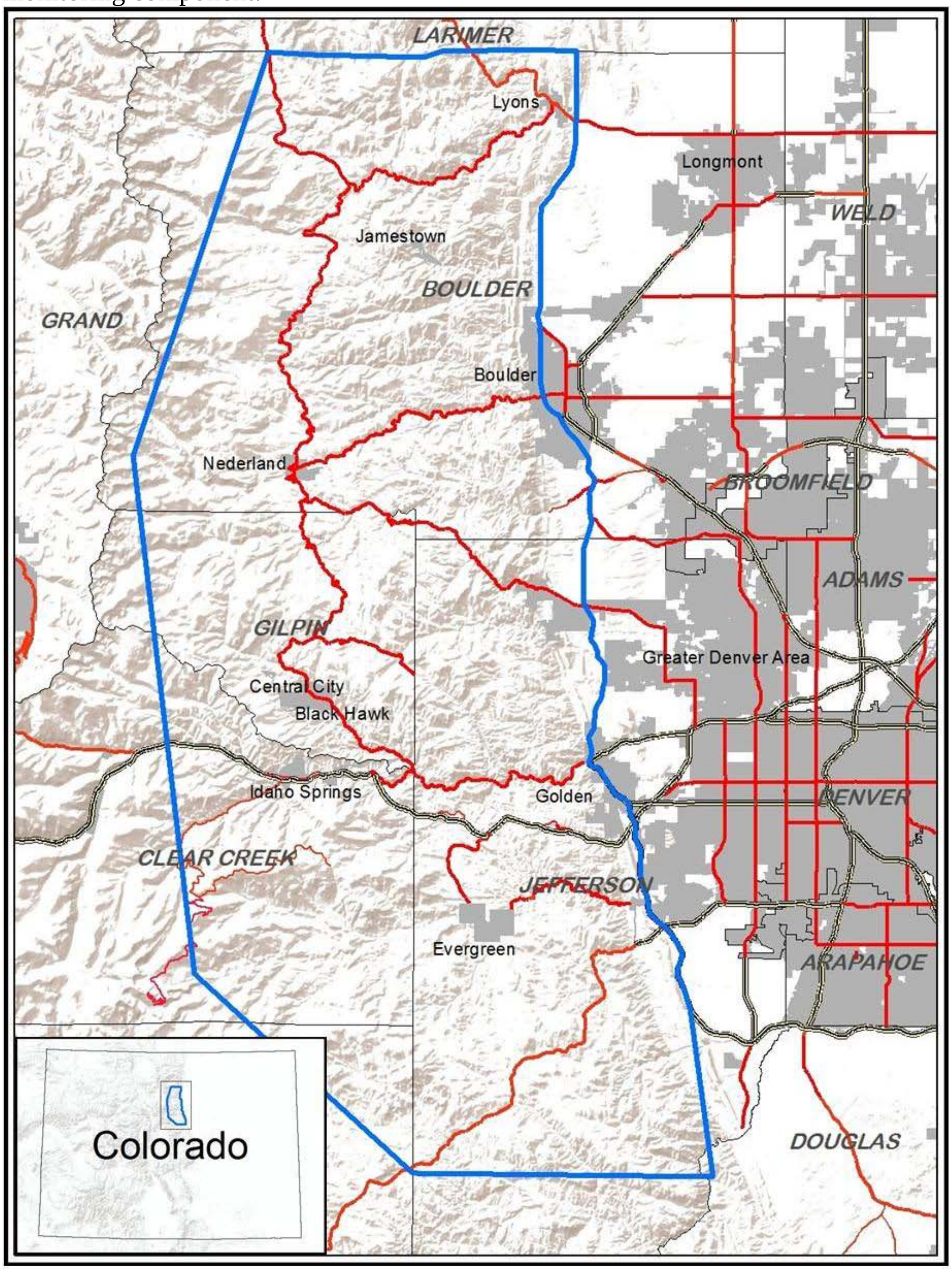


Figure 2: Top left pane: NAIP imagery. Top right pane: Colorado Vegetation Classification BASINWIDE project layer overlaid on NAIP imagery. Bottom left: 25x25 m grid overlaid on top of 25x25 m grid cells of BASINWIDE raster layer. Within a habitat strata (forest for example) a site is randomly selected (blue grid cell). Bottom right: Points are randomly generated within a site to ensure random placement of camera trap.

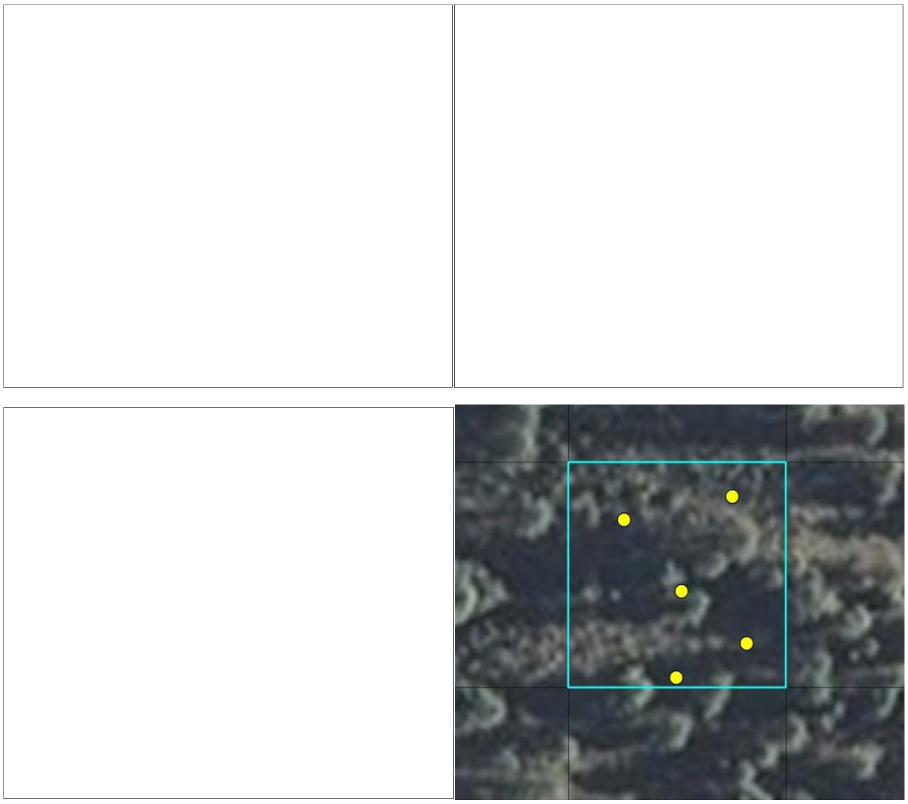


Figure 3: Example of GPS locations and corresponding movement path of a subject cougar. USE sites will be defined by confirmed feeding locations derived from GPS cluster analysis. Paired NON-USE sites will be selected from confirmed or highly probable travelling locations.

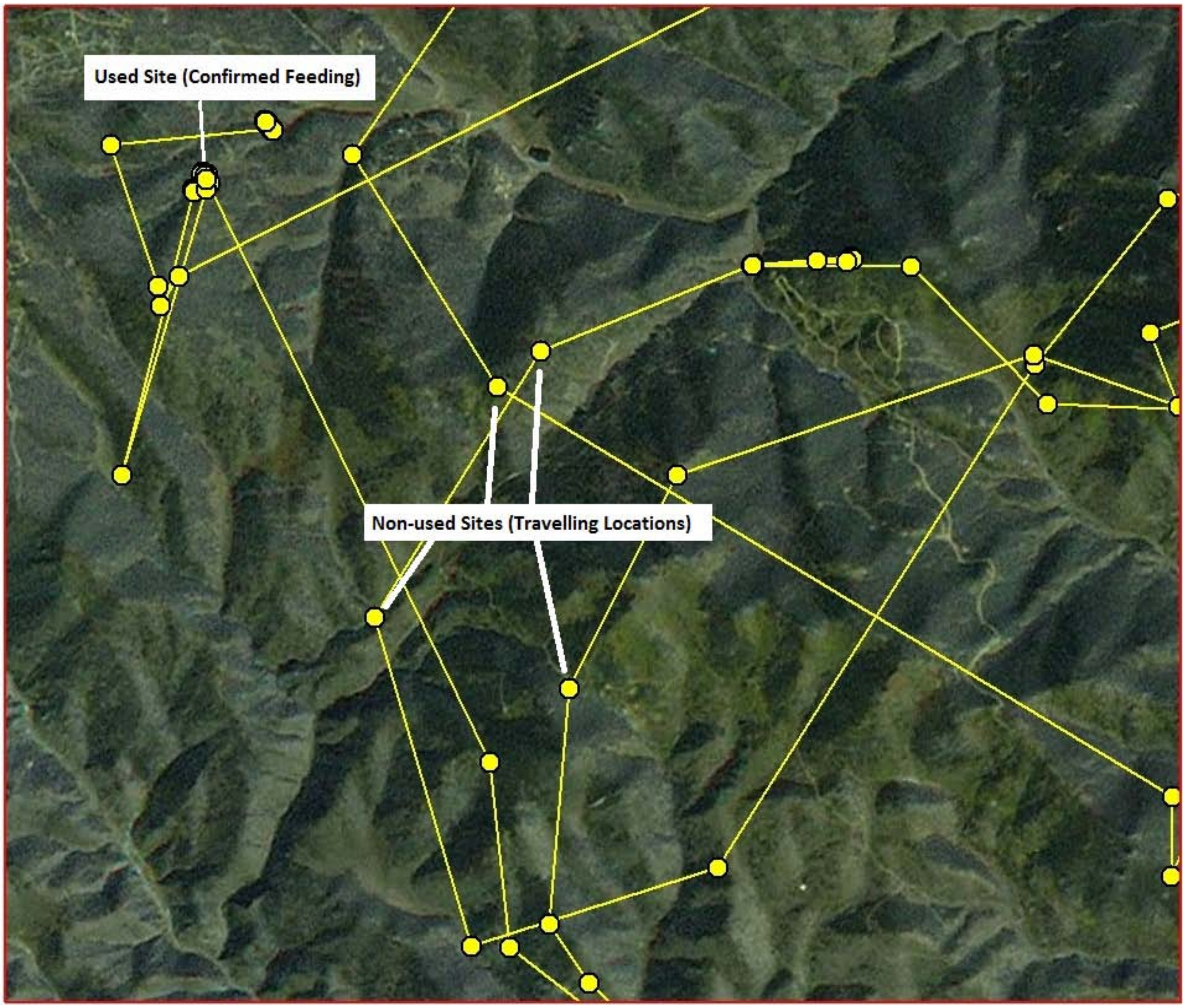


Table 1: Sampling of the landscape for potential prey species will be conducted in a # tier multi-level stratification scheme. Major sampling strata, which describe the dominate land-cover of the site (Urban/Suburban included as major habitat type), followed by the substrata that describe the relative housing density (exurban and rural). Lastly, all combinations of substrata and major strata are classified by a distance-to-structure metric (Low = 0 – 200 m, Med = 200 – 700 m, and High = > 700 m).

MAJOR Strata	*Quantity per major strata*	SUBSTRATA (housing density)	*Quantity per major&sub-strata combination*	SUB-SUBSTRATA (distance to structure)	*Quantity per major & sub-strata & sub-substrata*
Deciduous/Mixed Forest	**18**	exurban, rural	**9**	Low, Med, High	**3**
Grassland	**18**	exurban, rural	**9**	Low, Med, High	**3**
High Elevation Coniferous	**18**	exurban, rural	**9**	Low, Med, High	**3**
Low Elevation Coniferous	**18**	exurban, rural	**9**	Low, Med, High	**3**
Shrubland	**18**	exurban, rural	**9**	Low, Med, High	**3**
Urban	**15**	none	---	none	---
Non-Vegetated	**6**	none	---	Med, High	**3**

Table 2: List of the tentative number of camera sites sampling each categorical description of a site. Complete descriptions of each site take on 1 – 3 of these categories.

Categorical Descriptions	*Camera Sites per class*
Deciduous/Mixed Forest	**18**
Grassland	**18**
High Elevation Coniferous	**18**
Low Elevation Coniferous	**18**
Non-Vegetated	**6**
Shrubland	**18**
Urban/Suburban	**15**
Exurban	**48**
Rural	**48**
Distance to House: Low (0-200 m)	**39**
Distance to House: Med (200-700 m)	**36**
Distance to House: High (>700 m)	**36**

APPENDIX III

Front-range Cougar Movement Analysis

Mat Alldredge
Mevin Hooten

Introduction:

Despite numerous cougar studies across the Western United States, human understanding of cougar biology/ecology is nascent, largely because of the difficulty and expense of studying such an elusive, wide-ranging, and solitary species (Papouchis 2004). Technological advances, such as GPS telemetry, will increase the ability of researchers to gather valuable information on cougars, but such research has just begun, such as the Uncompahgre Plateau research project (Logan 2005). Even less information is known about cougar biology/ecology within urban/exurban environments.

Other studies have documented the impacts of urban environments on cougar temporal and spatial use patterns. Ordenana et al. (2010) documented an overall decrease in cougar occurrence associated with proximity and density of urban landscapes. Other studies have shown that dense housing developments can act as movement barriers to cougars (Orlando et al. 2008) or that cougars will become more nocturnal in urban areas (Kertson 2010). Similarly, studies have shown selection of home ranges, use within home ranges, general movements, and dispersal can be affected by roads, road densities and/or traffic volumes (Van Dyke et al. 1986, Belden and Hagedorn 1993, Beier et al. 1995, Sweanor et al. 2000, Dickson and Beier 2002, Orlando et al. 2008). Preliminary investigations suggest that cougars in the front-range of Colorado are similarly affected by urbanization as nocturnal behaviors and changes in use relative to human density have been observed with GPS collared cougars during the study.

One of the main objectives of the Front-range Cougar study is to examine how cougars are using the urban environments. This includes temporal and spatial use patterns, responses to novel environments, and responses to human activity and structures. Historical types of analyses would involve use versus availability and resource selection function (RSF) type analyses. However, with fine scale, highly accurate GPS data there is the potential to look at these use patterns in much more detail. If GPS data are at a fine enough scale it would be possible to know exactly what an animal was using and exactly how an animal moved through the environment. With logistical constraints associated with GPS acquisitions, battery life, and data storage, it is rare that this much detail is obtained. However, with a regular GPS fix interval, such as every 3 hours, it is possible to model the movement paths of an individual through its environment and obtain very detailed information on how an animal is using an area both spatially and temporally (e.g., Johnson et al. 2008, Hooten et al. 2010).

Our intent with this project is to perform detailed movement analyses with regard to demographic/population effects, environmental factors, and technological innovations. All of these analyses will provide pertinent information towards better management of cougars, especially in urban areas, or provide information that will improve research techniques for studying cougars. These analyses will also provide valuable information for other analyses being done as part of the ongoing Front-range Cougar research project.

Movement patterns of cougars are likely to differ among sex and age classes of cougars and be affected as individual cougars interact with other cougars across the landscape. Sub-adult cougars are likely to have different movement patterns than adults as they are exploring new environments, establishing home ranges and interacting with other cougars. Adult males may also differ as they are defending territories more rigidly, and looking for mates. There may also be seasonal difference in movement patterns with regard to environmental changes, changes in prey distributions, and changes in behavior of individual animals. Adult females may have large differences in movement patterns as they transition through life stages. For example, movements of an adult female may be very different as she gives birth to cubs, raises young cubs, teaches older cubs to hunt, and then becomes solitary again. An understanding of how movement patterns are affected relative to demographic factors, life stages, and intra-specific interaction will be useful to cougar management and will potentially provide a better understanding of cougar-human interactions.

Movement patterns of cougars are also likely to be affected as individuals interact with their environment. At a broad scale it may be possible to examine differences in movement patterns between cougars on the front-range of Colorado and the Uncompahgre Plateau. Finer-scale analyses will be conducted to examine how landscape features, especially those related to human use or development affect movements of cougars. Of interest would be how cougars respond to roads, areas of high human use, and areas of high human density. Mortality of cougars on the front-range is very high with respect to vehicle collisions, yet little is known about how cougars are responding to roads and traffic volumes. Cougars are also utilizing areas with high human use and high housing densities, but it is unknown if they use these areas differently than areas with little human presence. Although we do know that cougars use these urbanized areas, it is not known how they are using these areas with regard to potential avoidance of point sources of human presence. Similar questions can be asked about movement patterns of cougars with regard to human recreation and peaks in human activity on open space or other recreational areas.

We also hope to gain some technical knowledge from movement analyses with regards to data collection and the use of activity data to improve movement analyses. Understanding how cougars move through their environment or utilize their home ranges will improve our ability to survey cougar populations in the future. The use of camera traps to survey animals is becoming more common and these analyses will aid our understanding of proper camera placement and expected detection probabilities from the traps. The GPS collars being used in the front-range cougar study are equipped with accelerometers, which provide information on an individual cougar's behavior. Such information may prove useful in refining more detailed analyses of movement data as the activity between two successive points will be available as well. We also hope to provide some insight into optimal GPS fix rate with regard to balancing the trade-offs between battery life and number of fixes for GPS collars using these movement analyses.

Objectives:

1. Demographic/population level movement analyses.
    a. Relative to age and sex.
    b. Intra-specific interactions.
    c. Seasonal patterns.
    d. Prey distributions.
    e. Life stage (i.e. caring for offspring).
2. Environmental level movement analyses.
    a. Comparisons between front-range and Uncompahgre cougars.
    b. Effect of human related environmental attributes.
        i. Housing density.
        ii. Human activity.
        iii. Roads.
        iv. Avoidance of humans or human structures within urban areas.
        v. Reaction to human recreation.
3. Technical applications.
    a. Information for cougar population surveys
        i. Placement of camera traps
        ii. Detection rates
    b. Use of activity to improve movement models

c. Optimal GPS fix rates relative to animal movement

Approach:

Our intent is to use existing GPS data from the front-range cougar study and possibly from the Uncompahgre Plateau study to examine cougar movements relative to demographic/population level factors and environmental factors and to provide methodological advances in research techniques. We will also utilize various GIS layers, such as habitat data, housing density, roads, etc, to inform the analyses. No additional field data should be required for the analysis.

Formal statistical approaches to studying animal movement as well as the environmental and anthropogenic drivers of animal movement have advanced tremendously in the past 5 years. Specifically, the most important developments have utilized the wealth of recently available fine-scale high-accuracy telemetry data (e.g., GPS) and have constructed hierarchical models that allow for inference on both individual and population-level parameters (Johnson et al. 2008; Hooten et al. 2010; Hanks et al. 2011).

For this study, the first 2 objectives dealing with demographic/population level analyses and environmental analyses can both be accomplished using these existing sophisticated modeling approaches in general. However, it should be noted that a few of the sub-objectives will require a generalization of current models. Specifically, no current technology is available to rigorously account for intra-specific interaction between individuals. Similarly, although current methods can account for demographic differences between animals (e.g., Hanks et al., 2011), how to deal with changes in a single individual's demographic status within a rigorous statistical framework is still an unsolved problem. The existing modeling methodology will need to be extended to accommodate these features.

In general, the critical aspects of our modeling efforts are 1.) the ability to "connect the dots" along animal paths while properly accounting for the uncertainty at unobserved locations (Fig. 1), and 2.) to use the continuous information in these "path distributions" to make statistical inference on the desired quantities (e.g., demographics, environmental drivers, intra-species interactions). In order to obtain a distribution for the animal paths, we use the correlated random walk model proposed by Johnson et al. (2008), we then are able to connect the paths to the underlying spatial environment (or other individuals) by incorporating these path distributions into a likelihood for a larger hierarchical model that allows for various influential effects on movement (Fig. 2).

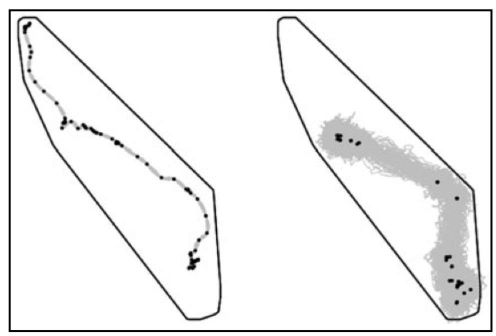


Figure 1: Two example paths with the black dots representing telemetry locations and the gray shading representing the uncertainty in the actual continuous path itself.

These methods allow us to formally ask questions pertaining to the differences in space use and movement between various demographic components of the population and determine how individuals may be responding to landscape features and human land use (e.g., road corridors, urban open space, suburban neighborhood geometry). Additionally, Hanks et al. (2011) have developed methods that allow us to answer broader synthetic questions about the differences within and between populations of animals. For example, we will be able to assess how front range cougars are using space and interacting with each other differently

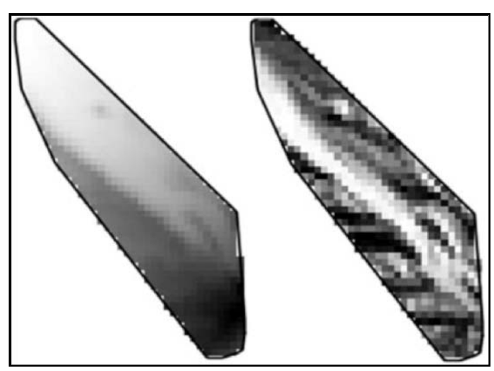


Figure 2: Example spatial covariates, the effects of which may be of interest for animal movement (e.g., elevation and aspect).

than the Uncompahgre Plateau cougars or, alternatively, if any differences are due mainly to individual-level variation.

Finally, the available cougar telemetry data provide some unique opportunities for advancing methodology pertaining to the collection and use of similar types of data. For example, given that camera trapping can provide a cost-effective alternative to telemetry methods, we can develop methods that fuse the two types of data, where available, to better learn about how to construct camera trapping grids for cougars. Moreover, by reconciling the two forms of data in a single model, we may be able to borrow strength from both forms of data to answer movement-based questions about animals that are not collared, given information from the animals that are both collared and observed on camera. This is a completely novel idea that has not yet been described in the literature, but will be very useful for future monitoring efforts because it could provide a justification for the use of more non-invasive observational approaches.

Another example of an area that shows great potential for use is with the duty cycling of telemetry devices. Since these devices (e.g., collars or tags) are often set in an arbitrary fashion to either maximize battery life or minimize the resolution, a tool that could help provide some guidance on the management of the these devices is needed. Further, given recent advances in optimal monitoring methods (Hooten et al. 2008; Hooten et al. 2011) there is an opportunity to translate these types of efficient effort saving approaches for monitoring to help create a dynamic adaptive rule set for managing the duty cycling. That is, on an individual or species-level basis, there may be times when it is most effective (and efficient) to switch the devices back and forth between transmit mode. Current procedures for this are somewhat arbitrary and our methods will allow the data themselves to help inform the duty cycling settings of these telemetry devices. The result would be better scientific inference on the movement processes of interest while maintaining a longer lasting battery life.

Literature Cited:

Beier, P., D. Choate, and R.H. Barrett. 1995. Movement patterns of mountain lions during different behaviors. Journal of Mammalogy 76:1056-1070.

Beldon, B.C. and B.W. Hagedorn. 1993. Feasibility of translocating panthers into northern Florida.Journal of Wildlife Management 57:388-397.

Dickson, B.G. and P. Beier. 2002. Home-range and habitat selection by adult cougars in southern California. Journal of Wildlife Management 66:1235-1245.

Hanks, E.M., M.B. Hooten, D.S. Johnson, and J. Sterling. (2011). Velocity-based movement modeling for individual and population-level inference. PLOS-One. In Review.

Hooten, M.B., C.K. Wikle, S. Sheriff, and J. Rushin (2009). Optimal spatio-temporal hybrid sampling designs for ecological monitoring. *Journal of Vegetation Science*, 20: 639-649.

Hooten, M.B., Johnson, D.S., Hanks, E.M., and J.H. Lowry. (2010). Agent-based inference for animal movement and selection. *Journal of Agricultural, Biological and Environmental Statistics,* 15: 523-538.

Hooten, M.B., B.E. Ross, and C.K. Wikle. (2011). Optimal spatio-temporal monitoring designs for characterizing population trends. Gitzen, R.A., J.J. Millspaugh, A.B. Cooper, and D.S. Licht (eds). In: *Design and Analysis of Long-Term Ecological Monitoring Studies*. In Press.

Johnson, D. S., London, J. M., Lea, M.-A., and Durban, J. W. (2008). Continuous-Time Correlated Random Walk Model for Animal Telemetry Data. *Ecology*, 89, 1208–1215.

Kertson, B. 2010. Cougar ecology, behavior, and interactions with people in a wildland-urban environment in Western Washington, Ph.D. Dissertation, University of Washington.

Logan, K.A. 2005. Cougar population structure and vital rates on the Uncompahgre Plateau, Colorado. Wildlife Research Report, July: 105-126. Colorado Division of Wildlife, Fort Collins, USA.

Ordenana, M.A., K.R. Crooks, E.E. Boydston, R.N. Fisher, L.M. Lyren, S. Siudyla, C.D. Haas, S. Harris, S.A. Hathaway, G.M. Turschak, A.K. Miles, and D.H. Van Vuren. 2008. Effects of urbanization on carnivore species distribution and richness. Journal of Mammalogy 91:1322-1331.

Orlando, A.M., S.G. Torres, W.M. Boyce, E.H. Girvetz, E.A. Laca, and M.W. Demment. Does rural development fragment cougar habitat? Toweill, D., S. Nadeau, and D. Smith (eds) In: Proceedings of the 9th Mountain Lion Workshop, Cougars: Past, Present and Future Challenges.

Papouchis, C.M. 2004. Conserving mountain lions in a changing landscape, *in* People and Predators: From Conflict to Coexistence, ed. N. Fascione, A. Delach, and M. E. Smith, 219-239. Island Press, Washington, D.C.

Sweanor, L.L., K.A. Logan, and M.G. Hornocker. 2000. Cougar dispersal patterns, metapopulation dynamics and conservation. Conservation Biology 13:798-808.

Van Dyke, F.G., R.H. Brocke, and H.G. Shaw. 1986. Use of road track counts as indices of mountain lion presence. Journal of Wildlife Management 50:102-109.

APPENDIX IV

Colorado Cougar Population Estimation

Mat Alldredge
Bill Kendall

Introduction:

In order to set harvest quotas, evaluate management practices and understand the dynamics of predator-prey systems, it is desirable to have reliable estimates of population size. Unfortunately, as with many predators, it can be very difficult and expensive to obtain these estimates. This is especially true with cougars because of their low densities, secretive nature, and unpredictable response to lures, baits and/or calls. Most reliable estimates of population size for cougars have come from intensive capture and monitoring studies, which were expensive and time consuming (Logan 1983, Lindzey et al. 1994, Murphy 1998, Logan and Sweanor 2001).

One approach that is used to estimate cougar population size is the two-sample Lincoln Petersen estimator in conjunction with an ongoing marking study (Anderson and Lindzey 2005). However, this method does require a marked population and is subject to all of the Lincoln-Petersen model assumptions, which include constant probability of capture among all individuals and time periods and closure (Williams et al. 2002). To demonstrate the logistics of using this estimator we will assume a cougar population at maximum density [3.6 independent cougars per 100km^2 (Hopkins et al. 1986)]. If we survey an area of 1,000 km^2 then our true population is 36. If we then assume a capture probability of 0.5 we should capture 18 individuals during each capture period and 27 unique individuals during both periods. To achieve capture of so many individuals during a time period when the closure assumption can be met, capture effort would be extremely high. However, if all of the assumptions were met, the expected value for the population size would be 36 cougars with a 95% CI of ± 10.1 cougars or a range of 26 to 46 cougars. If we double our survey area to 2,000km^2 and maintained all of the same assumptions we would capture 36 cougars during each sampling period or 54 unique individuals during the study. The expected values for this survey are a population size of 72 with a 95% CI of ± 15.4 cougars or a range of 67 to 87 cougars. To improve these estimates it would be necessary to use multiple recapture occasions, which would require even greater effort and expense. Additionally, estimates with these techniques are likely to be biased as violations of model assumptions are likely.

Because of the difficulty and expense associated with typical mark-recapture techniques for estimating carnivore abundance, alternate techniques have been developed. Many of these techniques involve noninvasive genetic sampling, which is a type of mark-recapture sampling. Noninvasive genetic sampling (Hoss et al. 1992, Taberlet and Bouvet 1992) has the potential to provide a realistic method for sampling a population of interest. Noninvasive sampling techniques include the use of hair snares and scat collections (Ernest et al. 2000, Harrison et al. 2004, Smith et al. 2005). The use of scats for sampling cougar populations may be particularly useful and provide a representative sample of the population. Scat collections can either be done by searching transects with human observers (Harrison et al. 2004) or with trained dogs (Smith et al. 2005). Scats could also be collected from kill sites.

Track counts have also been used to assess cougar population trends (Smallwood and Fitzhugh 1991, 1995, Smallwood 1994, Cunningham et al. 1995), but actual relationships to population size are generally weak (Van Dyke et al. 1986, Van Sickle and Lindzey 1992). For example, Cunningham et al. (1995) failed to detect an estimated 33% decline in cougar abundance using track surveys. Based on computer simulations, sampling effort required to detect a change in cougar populations is very high (Beier and Cunningham 1996). Difficulty detecting tracks in dense vegetation or rocky slopes in conjunction with access limitations to some areas may limit the utility of this approach (Anderson 2003). Probability based sampling (Becker 1991) may be a useful alternative to sample snow tracks of cougars over large areas using aircraft (Van Sickle and Lindzey 1992, Anderson 2003). Either transect based probability sampling (TPS) (Becker 1991) or a sampling block design (BPS) (Becker et al. 1998) can be used, but Anderson (2003) found better accuracy and precision using the TPS approach adjusted for short track sets (cougars at kill sites with near zero probabilities of detection during the survey).

Although the use of scats for noninvasive genetic sampling may sound appealing, based on personal experience, the actual encounter rate of scats may be prohibitively low to make this a viable option. Track surveys are also appealing but do require specific tracking conditions and can be dangerous as they involve flying over mountainous terrain at low altitude. The alternative approach would be to collect hair or tissue from cougars that are lured into a site. Although the use of hair snags and lures have proved effective on many species, such as bears, the technique has not been rigorously evaluated for cougars. Lures have been found relatively ineffective at luring cougars to a specific site, even when cougars are known to be in close proximity (Long et al. 2003, Choate et al. 2006). The types of lures that have been tried are various scents, food sources, and animal calls. Having a significant number of cougars GPS collared in an area provides a unique opportunity to evaluate the effectiveness of a variety of lures, because we will be able to map the location of known individuals in relation to various lures and assess detection rates based on evidence found at lure sites.

In order to be able to accurately estimate cougar population size using non-invasive sampling techniques, a thorough understanding of the detection process will be required. The detection process is comprised of the probability that an individual is available for detection (p_a). This may be the probability that the animal is within a sampling grid or within a given distance of a sampling location. The second part of the detection process is the probability of detecting an individual given that it is available for detection (p_d), or the probability that you can lure an individual to a sampling location. The final component of the detection process is the probability of obtaining a non-invasive sample from an individual given that it is available and is lured to the sampling location (p_s). Given these components, we could estimate population size ($\hat{N}$) as,

$$\hat{N} = \frac{n}{p_a p_d p_s}.$$

Where n is the number of individuals sampled (Williams et al. 2002).

<u>Objectives:</u>

1. Evaluate various lures (scents, baits, and calls) to attract cougars in relation to known cougar locations with regard to:
    a. Sex and/or age of the individual cougar.
    b. Temporal effects (season).
2. Investigate the detection process for cougars with regard to:
    a. Probability of being available for detection (on the grid).
    b. Probability of being detected given that it is available.
3. Assess methods for obtaining genetic samples given a detection with regard to:
    a. Various extraction methods.
    b. Genetic quantity.
    c. Genetic quality.

<u>Expected Benefits:</u>

The ability to estimate population size or track population changes is critical to the management of a species, especially when harvest quotas are being set for that species. This study is designed to develop tools that can be implemented in areas where cougars are not actively being studied and marked that will allow biologists/managers to gain a better idea of population size and population response to management prescriptions. Such estimates, in conjunction with harvest data will allow managers to better understand the cougar populations they manage, set appropriate harvest quotas and defend our management actions to the public.

Approach:

Our intention with this portion of the study is to gain insight into the detection process in order to develop methods that may be useful to estimating population size. We have no intention of actually estimating population size until the components of this approach have been evaluated.

To assess the availability of a cougar to be sampled we will examine existing GPS data with regard to movement within grids. An alternative approach is to examine availability as a function of distance from a sampling location. Movement patterns will be examined as part of a separate study but results may be incorporated here.

In order to assess the probability of a cougar being attracted to a lure we will mimic the design of an actual population survey. In an actual population survey the area of interest would likely be sampled using a grid approach with a grid size equal to a quarter of the average home-range size (Otis et al. 1978, White et al. 1982, Williams et al. 2002). Within each grid a lure would be placed by randomly selecting a location that is deemed to be a likely place for the species to occur within the grid based on expert opinion.

We will use a grid size equivalent to one quarter of the average female home-range size, because females have significantly smaller home-range sizes than males. This may create heterogeneity in the probability of detection between males and females because of the greater number of lures within a male's home-range and their larger movement patterns. For the purpose of evaluating the probability of a cougar being attracted to a lure we will not grid the entire study area but will grid individual properties on which we have permission to work. Within each grid we will randomly choose from a set of locations, previously identified by expert opinion, that should optimize our chances of luring a cougar to the location. We will randomly assign lure types (scent, call, bait, etc.) at each location. Trail cameras will be set at each location to verify the presence of a cougar. These pictures will also provide information on how cougars react to various lures, which may provide useful information on how to collect non-invasive genetic samples.

The main variable of interest is the probability of detection given that an individual cougar is in the area. GPS information from collared cougars will be used to verify that a cougar was within the sampling grid. Location data will also be used to approximate distance between a cougar and a lure, which could be used as a covariate in estimating the detection rate. Non-detection rates will also be of interest, especially with regard to distance from the lure, as this will provide information on the ability of a lure to attract an individual. For example, an individual cougar may travel very close to a lure but never approach the lure. A repeated measures analysis will also be used to determine if there is any behavioral effect associated with reward versus non-reward lures. Cougars may avoid lures (calls or scents) after the first experience if no reward is provided, or conversely, approach lures more if a reward is provided.

We will also examine various methods (hair snags, scratch pads, etc) for obtaining non-invasive genetic samples from individual cougars. Felids have proven difficult to obtain good genetic samples from so we will try to develop an effective approach for obtaining a genetic sample from a free-ranging cougar that provides sufficient quality and quantity of DNA. This work will begin at the Fort Collins Wildlife Research Center where the 3 captive cougars will be used to determine the most effective methods for obtaining these samples. Based on the results of this investigation we will then proceed to examine any methods that were promising in the captive situation in a field setting.

Location of Work:

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

Schedule of Work:

Time	Activity
Fall, 2011, ongoing	Evaluation of lures & probability sampling
August 2012, ongoing	Summary report of findings

Estimated Costs:

Salaries of permanent employees, as well as many other logistical costs (vehicles and lures) will be covered by existing project funds in the CPW carnivore research (approx. $250,000) and terrestrial management programs.

Literature Cited:

Anderson, C.R., Jr. 2003. Cougar ecology, management and population genetics in Wyoming. Dissertation, University of Wyoming, Laramie, Wyoming, USA.

Anderson, C.R., Jr., and F.G. Lindzey. 2005. Experimental evaluation of population trend and harvest composition in a Wyoming cougar population. Wildlife Society Bulletin 33:179-188.

Becker, E.F. 1991. A terrestrial furbearer estimator based on probability sampling. Journal of Wildlife Management 55:730-737.

Becker, E.F., M.A. Spindler, and T.O. Osborne. 1998. A population estimator based on network sampling of tracks in the snow. Journal of Wildlife Management 62:968-977.

Beier, P., and S.C. Cunningham. 1996. Power of track surveys to detect changes in cougar populations. Wildlife Society Bulletin 24:540-546.

Choate, D.M., M.L. Wolfe, and D.C. Stoner. 2006. Evaluation of cougar population estimators in Utah. Wildlife Society Bulletin 34:782798.

Cunningham, S.C., L.A. Haynes, C. Gustavson, and D.D. Haywood. 1995. Evaluation of the interaction between mountain lions and cattle in the Aravaipa-Klondyke area of southeast Arizona. Arizona Game and Fish Department Technical Report No. 17, Phoenix, Arizona, USA.

Ernest, H. B., M. C. T. Penedo, B. P. May, M. Syvanen, and W. M. Boyce. 2000. Molecular tracking of mountain lions in the Yosemite Valley region in California: genetic analysis using microsatellites and faecal DNA. Molecular Ecology 9:433-441.

Harrison, R. L., P. B. S. Clarke, and C. M. Clarke. 2004. Indexing swift fox populations in New Mexico using scats. American Midland Naturalist 151:42-49.

Hopkins, R.A., M.J. Kutilek, and G.L. Shreve. 1986. The density and home-range characteristics of cougars in the Diablo Range of California. Pages 223-235, *in* S.D. Miller and D.D. Everett, editors. Cats of the world: Biology, Conservation and Management. National Wildlife Federation, Washington, D.C., USA.

Hoss, M., M. Kohn, S. Paabo, F. Knauer, and W. Schroder. 1992. Excrement analysis by PCR. Nature 359:199.

Lindzey, F.G., W.D. Vansickle, B.B. Ackerman, D. Barnhurst, T.P. Hemker, and S.P. Laing. 1994. Cougar population dynamics in southern Utah. Journal of Wildlife Management 58:619-624.

Logan, K.A. 1983. Mountain lion population and habitat characteristics in the Big Horn Mountains of Wyoming. Thesis, University of Wyoming, Laramie, Wyoming, USA.

Logan, K.A. and L.L. Sweanor. 2001. Desert cougar: evolutionary ecology and conservation of an enduring carnivore. Island Press, Washington, D.C.

Long, E.S., D.M. Fecske, R.A. Sweitzer, J.A. Jenks, B.M. Pierce, and V.C. Bleich. 2003. Efficacy of photographic scent stations to detect mountain lions. Western North American Naturalist 63:529-532.

Murphy, K.M. 1998. The ecology of the cougar (*Cougar concolor*) in the northern Yellowstone ecosystem: interactions with prey, bears, and humans. Dissertation, University of Idaho, Moscow, Idaho, USA.

Otis, D.L., K.P. Burnham, G.C. White, and D.R. Anderson. 1978. Statistical inference from capture data on closed animal populations. Wildlife Monographs 62:1-135.

Smallwood, K.S. 1994. Trends in California mountain lion populations. Southwestern Naturalist 39:67-72.

Smallwood, K.S., and E.L. Fitzhugh. 1991. The use of track counts for mountain lion population census. Pages 59-67 *in* C.E. Braun, editor, Mountain Lion-Human Interactions Symposium and Workshop. Colorado Division of Wildlife, Denver, Colorado, USA.

Smallwood, K.S., and E.L. Fitzhugh. 1995. A track count for estimating mountain lion *Felis concolor californica* population trend. Biological Conservation 71:251-259.

Smith, D. A., K. Ralls, B. L. Cypher, and J. E. Maldonado. 2005. Assessment of scat-detection dog surveys to determine kit fox distribution. Wildlife Society Bulletin 33:897-904.

Taberlet, P., and J. Bouvet. 1992. Bear conservation genetics. Nature 358:197.

Van Dyke, F.G., R.H. Brocke, and H.G. Shaw. 1986. Use of road track counts as indices of mountain lion presence. Journal of Wildlife Management 50:102-109.

Van Sickle, W.D., and F.G. Lindzey. 1992. Evaluation of road track surveys for cougars (*Felis concolor*). Great Basin Naturalist 52:232-236.

White, G.C., D.R. Anderson, K.P. Burnham, and D.L. Otis. 1982. Capture-recapture removal methods for sampling closed populations. Los Alamos National Laboratory Publication LA-8787-NERP. Los Alamos, NM.

Williams, B.K., J.D. Nichols and M.J. Conroy. (2002) Analysis and Management of Animal Populations. Academic Press. San Diego, CA.

Colorado Division of Parks and Wildlife
July 2010 – June 2011

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of Parks and Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	7210	:	Customer Services/Research Support
Task No.:	1	:	Library Services
Federal Aid Project No.	N/A		

Period Covered: July 1, 2010 – June 30, 2011

Author: Kay Horton Knudsen

Personnel: Kay Horton Knudsen, Chad Bishop

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

ABSTRACT

The Colorado Division of Wildlife (now Colorado Parks and Wildlife [CPW]) Research Center Library has existed for several decades in the Ft. Collins office. A library housed in the Denver office was moved to Ft. Collins many years ago. Early librarians, Marian Hershcopf and Jackie Boss, can be credited with the physical organization of the Library including seven decades of Federal Aid reports, almost 50 years of Wildlife Commission reports and a unique book and journal collection.

Jackie Boss retired in April 2007 and the Library was temporarily closed to all services. Kay Horton Knudsen was hired as the new Research Center Librarian and began employment with CPW on August 30, 2008. The goal, as stated by a former supervisor, was to reopen the Library and expand the electronic and digital capabilities of library services to the entire CPW.

Chad Bishop became the Mammals Research Team Leader in July 2009. His duties include supervision of the Research Center Library.

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

WILDLIFE RESEARCH REPORT

COLORADO PARKS AND WILDLIFE RESEARCH LIBRARY SERVICES

KAY HORTON KNUDSEN

P.N. OBJECTIVE

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

SEGMENT OBJECTIVES

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

SUMMARY OF LIBRARY SERVICES

The Research Center Library celebrates its third full year of operation since reopening in 2008. Work continues on upgrading website features, filling literature research requests and taking a more long-term view on improving Library services.

During the first year, in additional to cleaning and physical organization, a priority task was choosing and implementing a web-based Integrated Library System (ILS) and purchasing statewide access for CPW staff to online research databases. The second year emphasis was on meeting CPW staff and promoting the Library in a series of training demonstrations. Moving into the third year of operation, major projects were purchase of a new federated search feature for the Library website, digitization of CPW publications and continued contact with staff statewide to meet their bibliographic research needs. Since the Library serves as a historic archive for CPW publications, each meeting with staff also includes a request to be included in the dissemination of white papers, journal articles and internal reports. Day-to-day duties continue to be responding to research and document retrieval requests, cataloging newly acquired material and maintaining the serial collection.

EOS International is the vendor for the ILS. It was decided to initially purchase the basic modules (a hosted system with library catalog, circulation, cataloging and serials control.) The Library website was released to CPW staff in March 2009. The next module purchased from EOS was Indexer – this feature allows for full-text searching of PDFs linked to bibliographic records and was implemented in December 2009. The latest modules are Knowledge Builder and Classification Management. They will be used to archive and index historic research documents.

In addition to the catalog of books and reports housed in the Ft. Collins Library, the Library website also gives CPW staff access to research databases. Current subscriptions include BioOne, four of EBSCO's specialty databases (Environment Complete, Fish and Fisheries Worldwide, Wildlife and Ecology Studies Worldwide and Criminal Justice with Full Text), SORA (Avian journals) and the JSTOR Life Sciences collection. Through several of the print periodical subscriptions, the Library also has access to the publisher's full-text online archives. Backfiles of major wildlife and aquatic journals were purchased to expand the full-text capability. CPW staff statewide are authenticated through WildNet (intranet) eliminating the need for individual usernames and passwords.

A federated, or integrated, search feature for the Library website was on the wish-list from day one. Federated searching combines access to the Research Library catalog, all of the third-party databases listed above, as well as most of the online journals into one all-in-one search. It took extensive planning and working with various vendors to finally make this available. EBSCOHost's Integrated Search (EHIS) was chosen in the fall of 2010 and the link was made available on the Library website in the spring of 2011. Library handouts were updated and a new handout created to explain the features and offer tips on the use of the all-in-one search. The entire federated search industry is evolving and the librarian will continue to work with EBSCO staff to resolve problems and maintain links to all resources.

The next major project envisioned at the reopening of the Library was the digitization of CPW publications. Research on various digitization options took place in 2009/2010. An HP printer/scanner with optical character recognition software was purchased, installed and tested by summer 2010. The first document series to be digitized was *Outdoor Facts*. The resulting PDFs are attached to bibliographic records for each title within the series and are available via the Library catalog for download by CPW staff throughout the state. Following the digitization, the remaining print copies of *Outdoor Facts* were distributed to staff for their historic collections. The second series digitized was the much larger *Special Reports* collection. The first report in this collection was published in 1962 and all 82 reports represent the work of terrestrial and aquatic staff. They are available as fully searchable PDFs on the Library website.

Other projects in the Library this year included: 1) processing journal subscription renewals and updates to include full-text online access, 2) beginning a project to catalog the backlog of theses/dissertations, 3) sending *Colorado Outdoors* magazines to bindery to continue long-term archival collection, 4) continuing to add links to PDF formats into the catalog's bibliographic file, 5) printing and cataloging the Data Analysis Unit (DAU) reports to maintain a historic record in the Library collection, 6) writing a Collection Development policy for the Library and 7) conducting a survey of CPW staff on their impressions and expectations of the Library using Survey Monkey research tool; received 113 responses.

NOTE: the Library was physically closed to all staff access from November 2010 through January 2011 due to extensive remodeling of the building's heating and air conditioning systems. The librarian worked from a borrowed office during this time.

The librarian attended the following conferences and workshops: 1) Cyber Infrastructure workshop at CSU, August 2010, 2) Colorado Association of Libraries annual conference in Loveland, October 2010, 3) Presentation Skills workshop in Denver CPW office, December 2010, 4) the American Fisheries Society/The Wildlife Society, Colorado chapters meeting in Ft. Collins, February 2011, 5) InterLibrary Loan conference, CSU, April 2011, 6) Data Curation Profile workshop, CSU, April 2011, 7) Financial Planning workshop in Denver CPW office, June 2011. There was also the opportunity throughout the year to participate in several online "webinars" sponsored by various vendors and library agencies to expand knowledge on trends in the library field.

With expanded library services, the number of requests for documents or research assistance has grown. Most questions received in the Library are from CPW staff or from outside researchers (generally consultants and out-of-state natural resources employees). The Library is not open on a walk-in basis to the general public but the librarian does assist the Help Desk at the Denver office with questions they receive. CPW employees generally request journal articles or items from the Library collection; outside researchers most often want a copy of a CPW publication. The chart below shows the number of reference questions and document requests handled by the librarian during the past 3 years. Please note that one request from a CPW staff member may be for multiple journal or book titles.

	Reference Requests			Reference Requests			Reference Requests
			July 2009	20		July 2010	45
August 2008	15		August 2009	25		August 2010	34
September 2008	21		September 2009	30		September 2010	37
October 2008	33		October 2009	38		October 2010	41
November 2008	14		November 2009	28		November 2010	46
December 2008	28		December 2009	32		December 2010	34
January 2009	33		January 2010	62		January 2011	48
February 2009	30		February 2010	43		February 2011	43
March 2009	35		March 2010	36		March 2011	46
April 2009	24		April 2010	23		April 2011	30
May 2009	13		May 2010	17		May 2011	51
June 2009	20		June 2010	26		June 2011	27

STATISTICS: As of June 30, 2011, the Research Center Library holds 18,572 titles and 24,174 items (these are the multiple copies of a title) and has 126 registered patrons (CPW staff). There were 2,314 searches conducted in the Library catalog during the year. Usage statistics for the research databases are given in the chart below. For BioOne and EBSCO the numbers are for the total searches run; for JSTOR the statistics are for the number of successful full-text article requests.

	BioOne	EBSCO searches	JSTOR
July 2010	37	138	148
August 2010	98	147	97
September 2010	107	637	203
October 2010	62	585	195
November 2010	57	465	115
December 2010	73	1221	203
January 2011	151	1855	277
February 2011	230	2675	358
March 2011	157	1616	174
April 2011	197	1405	217
May 2011	259	2562	339
June 2011	141	1169	192
TOTAL	**1569**	**14,475**	**2518**

Prepared by ______________________________
Kay Horton Knudsen