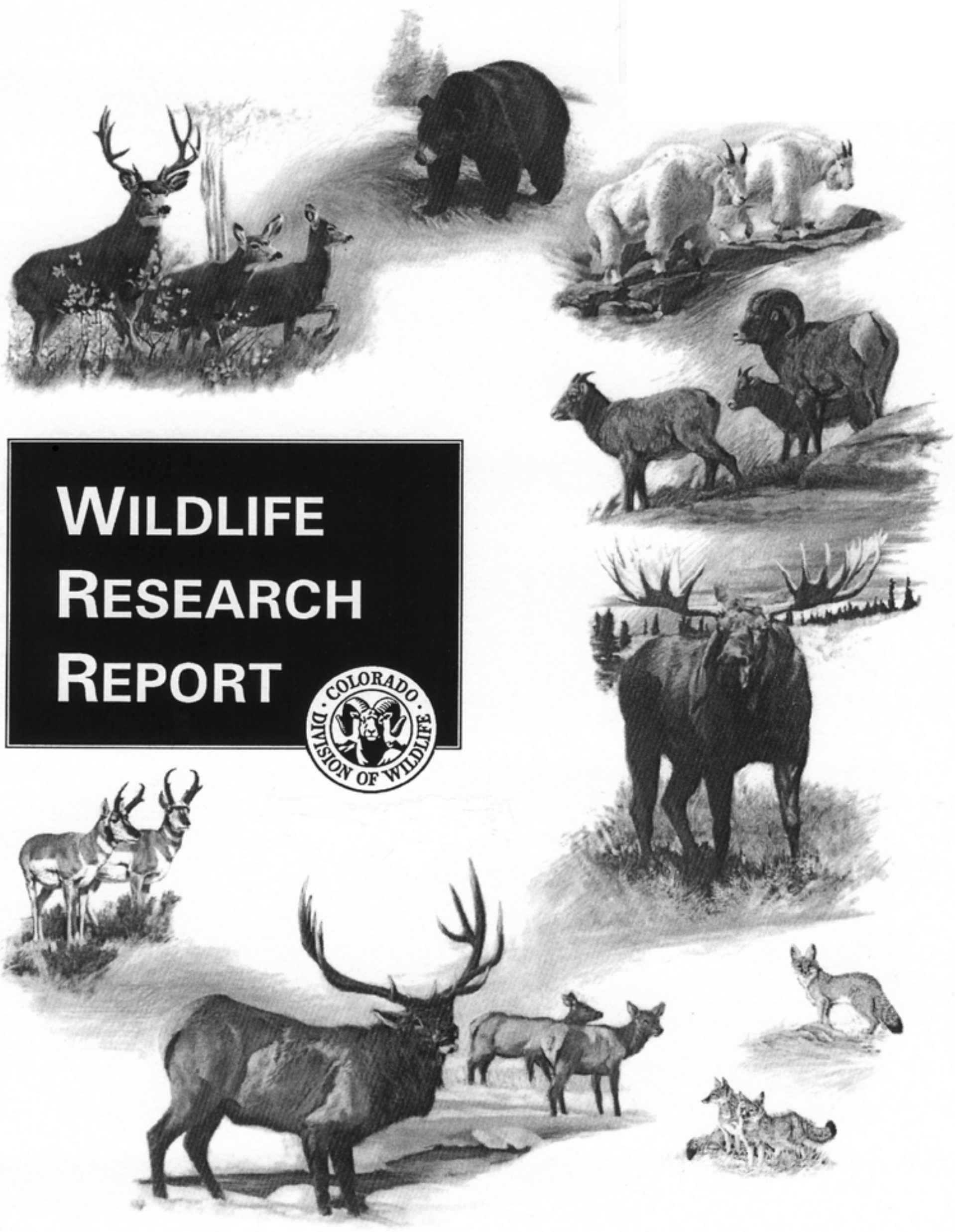
MAMMALS - JULY 2010



WILDLIFE RESEARCH REPORTS

JULY 2009 – JUNE 2010

MAMMALS PROGRAM

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

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Colorado Division of Wildlife
July 2009 – June 2010

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MAMMALS WILDLIFE RESEARCH REPORTS

[1] Mindy Rice is a spatial ecologist in the Avian Research Section of the Colorado Division of Wildlife

Colorado Division of Wildlife
July 2009–June 2010

WILDLIFE RESEARCH REPORT

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

Period Covered: July 1, 2009 – June 30, 2010

Author: T. M. Shenk

Personnel: O. Devineau, R. Dickman, P. Doherty, L. Gepfert, J. Ivan, R. Kahn, A. Keith, P. Lukacs, G. Merrill, B. Smith, T. Spraker, S. Waters, G. White, L. Wolfe

ABSTRACT

In an effort to establish a viable population of Canada lynx (*Lynx canadensis*) in Colorado, the Colorado Division of Wildlife (CDOW) initiated a reintroduction effort in 1997 with the first lynx released in February 1999. From 1999-2006, 218 wild-caught lynx from Canada and Alaska were released in Colorado. Post-release monitoring was critical to assess and modify the release protocols as they were implemented to improve the survival of released individuals. Average monthly mortality rate in the reintroduction area during the first year post-release decreased with time in captivity from 0.205 [95% CI 0.069, 0.475] for lynx spending up to 7 days in captivity to 0.028 [95% CI 0.012, 0.064] for lynx spending > 45 days in captivity before release. Under the final release protocol, lynx were held in captivity and fed a high quality diet for a minimum of three weeks before release. Results suggested that keeping lynx in captivity beyond 5 or 6 weeks accrued little benefit in terms of monthly survival. We documented survival, movement patterns, reproduction, and landscape habitat-use through aerial (n = 11,580) and satellite (n = 29,258) tracking. Monthly mortality rate was estimated as lower inside the reintroduction area than outside the reintroduction area, and slightly higher for male than for female lynx, although 95% confidence intervals for sexes overlapped. Mortality was higher immediately after release (first month = 0.0368 [SE = 0.0140] inside the study area, and 0.1012 [SE = 0.0359] outside the study area), and then decreased according to a quadratic trend over time. Given the importance of adult survival in the dynamics of long-lived species, the long-term, high survival rates estimated for the reintroduced lynx both inside (0.9315, SE = 0.0325) and outside (0.8219, SE = 0.0744) the reintroduction area are promising for the establishment of a viable population of lynx in Colorado. From 1999-June 2010, there were 122 known mortalities of released adult lynx. Human-caused mortality factors were the highest causes of death with approximately 29.7% attributed to collisions with vehicles or gunshot. Starvation and disease/illness accounted for 18.6% of the deaths while 37.3% of the deaths were from unknown causes. Reproduction was first documented in 2003 with subsequent successful reproduction

in 2004, 2005, 2006, 2009, and 2010. No dens were documented in 2007 or 2008. Reproduction followed a pattern of good and bad years followed by a return to good years in both the reintroduction area and outside the reintroduction area suggesting there may be a cyclic pattern to reproductive output of lynx in Colorado. If the pattern of annual reproductive and survival parameters estimated to date for lynx within the core reintroduction area would repeat over the next 20 years, the population currently in the core reintroduction area would sustain itself at existing densities. To document the continued viability of lynx in Colorado beyond the reintroduction period, some form of long-term monitoring will be needed. A site-occupancy monitoring program using cost-effective, minimally invasive techniques is currently being developed to estimate the extent, stability and potential distribution of lynx throughout Colorado.

WILDLIFE RESEARCH REPORT

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

TANYA M. SHENK

P. N. OBJECTIVE

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

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

Three additional objectives were emphasized after lynx displayed site fidelity to an area:

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

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

SEGMENT OBJECTIVES

1. Complete winter 2009-10 field data collection on lynx habitat use at the landscape scale, hunting behavior, diet, mortalities, and movement patterns.
2. Complete data collection for the pilot study designed to estimate lynx detection probabilities using non-invasive techniques.
3. Complete spring 2010 field data on lynx reproduction.
4. Summarize and analyze data and publish information as Progress Reports, peer-reviewed manuscripts for appropriate scientific journals, or CDOW technical publications (see Appendix I).
5. Complete field research on the post-release monitoring of lynx reintroduced to Colorado and prepare a final report describing status of the lynx reintroduction.

INTRODUCTION

The Colorado Division of Wildlife implemented the largest Canada lynx (*Lynx canadensis*), and one of the largest carnivore, reintroductions programs undertaken to date. Thus, evaluating success of this program is critical, and assessing the methods used may prove useful for other ongoing or future carnivore reintroductions. The reintroduction effort was begun in Colorado in 1997, with the first lynx released in the state in 1999. The goal of the Colorado lynx reintroduction program was to establish a self-sustaining, viable population of lynx in this state. The approach taken to reach this goal was to first establish a viable lynx population within a core reintroduction area in southwestern Colorado. From this core reintroduction area, it was hoped that lynx would remain in this area and disperse on their own into suitable habitat throughout the state. Thus, 218 wild-caught lynx from Canada and Alaska were reintroduced in the core reintroduction area from 1999-2006.

There were 7 critical criteria established for achieving a viable lynx population in Colorado: 1) development of release protocols that lead to a high initial post-release survival of reintroduced animals, 2) long-term survival of lynx in Colorado, 3) development of site fidelity by the lynx to areas supporting good habitat in densities sufficient to breed, 4) reintroduced lynx must breed, 5) breeding must lead to reproduction of surviving kittens 6) lynx born in Colorado must reach breeding age and reproduce successfully, and 7) recruitment must equal or be greater than mortality over an extended period of time. These criteria were evaluated incrementally over time to gauge whether the reintroduction effort was progressing toward success (Shenk and Kahn 2002). All seven criteria have now been met.

STUDY AREA

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

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

METHODS, RESULTS AND DISCUSSION

Development of Release Protocols

Post-release monitoring was critical to assess and modify the release protocols as they were implemented to improve the survival of released individuals (Shenk 1999). Under the final release protocol, lynx were held in captivity and fed a high quality diet for a minimum of three weeks before release. Thus, they were released in good body condition and one could expect that the longer the captivity, the lower the post-release mortality. This final protocol resulted in high initial post-release survival.

Later, detailed analysis of lynx mortality was completed to evaluate how the different release protocols affected mortality within the first year post-release. From this analysis, it was documented that the average monthly mortality rate in the reintroduction area during the first year post-release decreased with time in captivity from 0.205 [95% CI 0.069, 0.475] for lynx spending up to 7 days in captivity to 0.028 [95% CI 0.012, 0.064] for lynx spending > 45 days in captivity before release (Devineau et al. 2010a). The results also suggested that keeping lynx in captivity beyond 5 or 6 weeks accrued little benefit in terms of monthly survival. On a monthly average basis, lynx were as likely to move out (probability = 0.196, SE=0.032) as to move back on (probability = 0.143, SE=0.034) the reintroduction area during the first year after release. Mortality was 1.6x greater outside of the reintroduction area suggesting that permanent emigration and differential mortality rates on and off reintroduction areas should be factored into sample size calculations for an effective reintroduction effort. Our results will be useful in the development of release and post-release monitoring protocols for future lynx, as well as other carnivore, reintroductions.

Long-Term Survival

Viability of a reintroduced population requires long-term survival and site fidelity of individuals to the reintroduction area. Over a 10-year period of the reintroduction effort (1999-2009), monthly mortality rate was estimated as lower inside the reintroduction area than outside the reintroduction area, and slightly higher for male than for female lynx, although 95% confidence intervals for sexes overlapped (Devineau et al. 2010). Mortality was higher immediately after release (first month = 0.0368 [SE = 0.0140] inside the study area, and 0.1012 [SE = 0.0359] outside the study area), and then decreased according to a quadratic trend over time. Given the importance of adult survival in the dynamics of long-lived species, the long-term, high survival rates estimated for the reintroduced lynx both inside (0.9315, SE = 0.0325) and outside (0.8219, SE = 0.0744) the reintroduction area are promising for the establishment of a viable population of lynx in Colorado (Figure 2, Devineau et al. 2010b). The higher mortality outside the reintroduction area may have been influenced by habitat fragmentation, increased road density and more opportunities for human interactions.

From 1999-June 2010, there were 122 known mortalities of released adult lynx. Human-caused mortality factors are currently the highest causes of death with approximately 29.7% attributed to collisions with vehicles or gunshot. Starvation and disease/illness accounted for 18.6% of the deaths while 37.3% of the deaths were from unknown causes. Lynx mortalities were documented throughout all areas lynx used, including 31 (26.3%) occurring in other states.

Reproduction

Reproduction is necessary to achieve a self-sustaining viable population of lynx in Colorado. Reproduction was first documented from the 2003 reproduction season and again in 2004, 2005 and 2006. Lower reproduction occurred in 2006, although a Colorado-born female gave birth to 2 kittens, documenting the first recruitment of Colorado-born lynx into the Colorado breeding population. No reproduction was documented in 2007 or 2008. The cause of the decreased reproduction from 2006 -08 is unknown. One possible explanation would be a decrease in prey abundance. Reproduction was again observed in 2009 with 5 dens and 10 kittens found in Colorado. Litter size was smaller than previously documented with only 2 kittens found in each litter in comparison to a mean of 2.8 found in previous years. In addition, a sex bias towards female kittens was evident in 2009 which was not evident in prior years. Two litters found in 2009 had both parents born in Colorado, resulting in the first documented third generation Colorado lynx from the reintroduction. The percent of females having dens increased in 2010 to 33%, similar to the highest years documented in 2004-2005. The average number of kittens per litter also returned to the previously observed mean of 2.8. Breeding males and females in 2010 included Colorado-born lynx that have established territories and are now contributing to the breeding population.

Reproduction has followed a pattern of good and bad years followed by a return to good years in both the reintroduction area (Figure 3) and outside the reintroduction area suggesting there may be a cyclic pattern to reproductive output of lynx in Colorado. Such a pattern matches the classic Canada lynx-snowshoe hare (*Lepus americanus*) cycle (Elton 1942). Long-term studies spanning an additional10-20 years would be required to document such a cycle in Colorado.

Viability

The current lynx population in Colorado is comprised of surviving reintroduced adults, lynx born in Colorado from the reintroduced animals and their offspring and possibly some naturally occurring lynx. To achieve a self-sustaining, viable population of lynx, enough kittens need to be born and recruited into this population to offset the mortality that occurs and hopefully even exceed the mortality rate to achieve an increasing population. If the pattern of annual reproductive and survival parameters estimated to date for lynx within the core reintroduction area would repeat over the next 20 years, the population currently in the core reintroduction area would sustain itself at existing densities (Figure 4).

FUTURE DIRECTIONS

Research and monitoring efforts over the last 11 years, since the first lynx were released, have focused primarily on monitoring reintroduced animals through VHF and satellite telemetry and estimating demographic parameters of these animals. However, as more of these animals become unavailable for monitoring due to failed telemetry collars, death or movement out of the core reintroduction area, it becomes more difficult to accurately evaluate the status of the entire lynx population in Colorado, including the core reintroduction area.

To document the continued viability of lynx in Colorado beyond the reintroduction period, some form of long-term monitoring will be needed to determine viability for a period of time long enough to encompass possible snowshoe hare cycles. In addition, a challenge facing Colorado Division of Wildlife is how efforts should be allocated between monitoring persistence of lynx that have established within the core reintroduction area and lynx that may be pioneering and expanding into other portions of the state.

A site-occupancy monitoring program using cost-effective, minimally invasive techniques is currently being developed to estimate the extent, stability and potential distribution of lynx throughout Colorado (Shenk 2009, Appendix 2). The primary objectives of this monitoring program would be to document the distribution of lynx throughout Colorado and the stability, growth or shrinkage of this distribution over time, and to identify potential areas lynx may occupy in the future. Minimally invasive techniques (e.g., genetic identification, cameras) would be used to detect changes in lynx persistence and distribution as a foundation for assessing whether lynx continue to persist in Colorado. Such non-invasive techniques are widely desirable because they require minimal impact to the animals and are cost-effective. The protocols developed will also be made available to any other agencies or entities that want to monitor lynx. Methods to extend this monitoring effort to estimate lynx density are currently being pursued.

ADDITIONAL EFFORTS

Additional goals of the post-release monitoring program for lynx reintroduced to the southern Rocky Mountains included refining descriptions of habitat use and movement patterns of lynx once lynx established home ranges that encompassed their preferred habitat. This work is ongoing.

The program also investigated the ecology of snowshoe hare in Colorado. A study comparing snowshoe hare densities among mature stands of Engelmann spruce (*Picea engelmannii*)/subalpine fir (*Abies lasiocarpa*), lodgepole pine (*Pinus contorta*) and Ponderosa pine (*Pinus ponderosa*) was completed in 2004 with highest hare densities found in Engelmann spruce/subalpine fir stands and no hares found in Ponderosa pine stands (Zahratka and Shenk 2008). A study to evaluate the importance of young, regenerating lodgepole pine and mature Engelmann spruce/subalpine fir stands in Colorado by examining density and demography of snowshoe hares that reside in each was completed in 2010. Small lodgepole stands supported the highest densities of hares as well as the highest and most consistent recruitment rates. Hares survived best in spruce/fir stands while density and recruitment in these stands were intermediate. Thus, small lodgepole and mature spruce/fir likely provide the most important hare habitat in Colorado; while thinned, medium lodgepole stands appear to be relatively unimportant based on the density and demography measures in this study (J. Ivan, Colorado State University, unpublished data, Appendix 3). However, within the study area, small lodgepole stands occupied only 10% of the area covered by mature spruce/fir, and we suspect a similar pattern statewide. Additionally, the structure provided by mature spruce/fir stands is less transient than that provided by regenerating lodgepole. Thus, while density and recruitment estimates in spruce/fir stands were somewhat inferior to those collected in small lodgepole, the areal coverage and longevity of spruce/fir likely renders it as important, if not more important, to snowshoe hare and lynx management in Colorado as regenerating lodgepole (J. Ivan, Colorado State University, unpublished data, Appendix 3).

Lynx is listed as threatened under the Endangered Species Act (ESA) of 1973, as amended (16 U. S. C. 1531 et. seq.)(U. S. Fish and Wildlife Service 2000). Colorado is included in the federal listing as lynx habitat. Thus, an additional objective of the post-release monitoring program is to develop conservation strategies relevant to lynx in Colorado. To develop these conservation strategies, information specific to the ecology of the lynx in its southern Rocky Mountain range, such as habitat use, movement patterns, mortality factors, survival, and reproduction in Colorado have been and will continue to be provided to regulatory agencies.

SUMMARY

From results to date it can be concluded that the Colorado Division of Wildlife developed release protocols that ensured high initial post-release survival of lynx, and on an individual level, lynx demonstrated they can survive long-term in areas of Colorado. We also documented that reintroduced lynx exhibited site fidelity, engaged in breeding behavior and produced kittens that were recruited into the Colorado breeding population. Following the successful reproduction in 2010, we have now documented that if the population would repeat the reproduction and mortality patterns documented over the last 10 years the lynx population would continue into the future at sustainable numbers. Thus, the final criterion of a successful reintroduction, documenting recruitment necessary to offset annual mortality, is now supported. To build upon the success of this reintroduction effort, effective conservation and management strategies will need to be developed and implemented to ensure the long-term viability of Canada lynx in Colorado.

ACKNOWLEDGEMENTS

The Colorado Lynx Reintroduction Program required the continued efforts of numerous personnel in the Colorado Division of Wildlife, other agencies and the general public. Such sustained dedication has resulted in the successful reintroduction of this species to our ecosystems. Funding for the reintroduction program was provided by Colorado Division of Wildlife, Great Outdoors Colorado (GOCO), Vail Associates, Colorado Wildlife Heritage Foundation, Turner Endangered Species Foundation and the U.S.D.A. Forest Service.

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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.

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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.

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.

Prepared by ____

Tanya Shenk, Wildlife Researcher & Jake Ivan, Wildlife Researcher

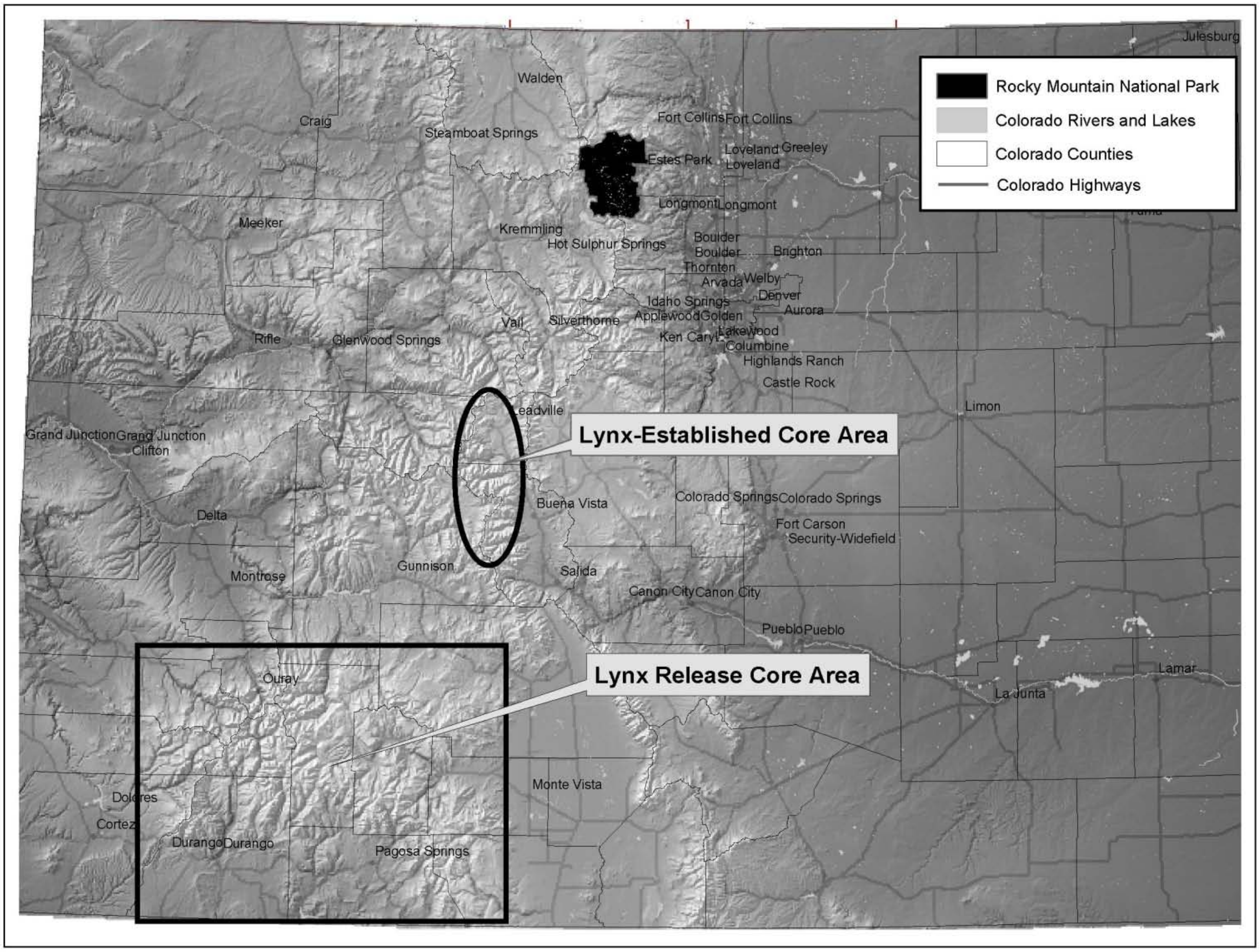

Figure 1. Lynx are monitored throughout Colorado and by satellite throughout the western United States. The lynx core release area, where all lynx were released, is located in southwestern Colorado (outlines in white). A lynx-established core use area has developed in the Taylor Park and Collegiate Peak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

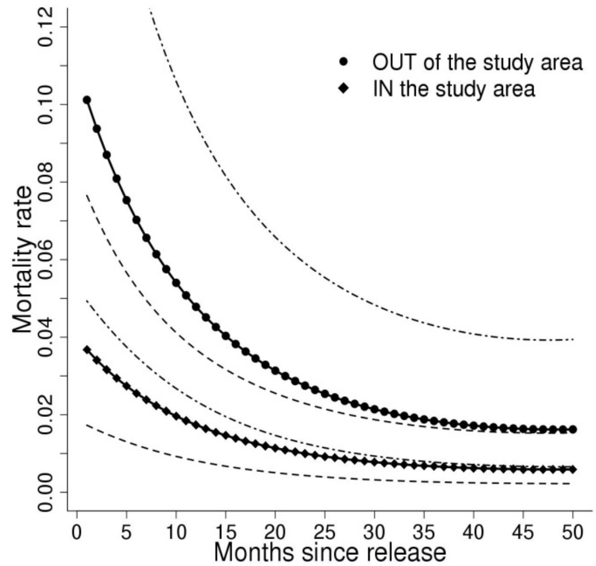

Figure 2. Variation of monthly mortality rate with time since release for Canada lynx reintroduced to Colorado, inside and outside of the study area, according to the best-AICc model (from Devineau et al. 2010). Only the first 50 months following release are shown.

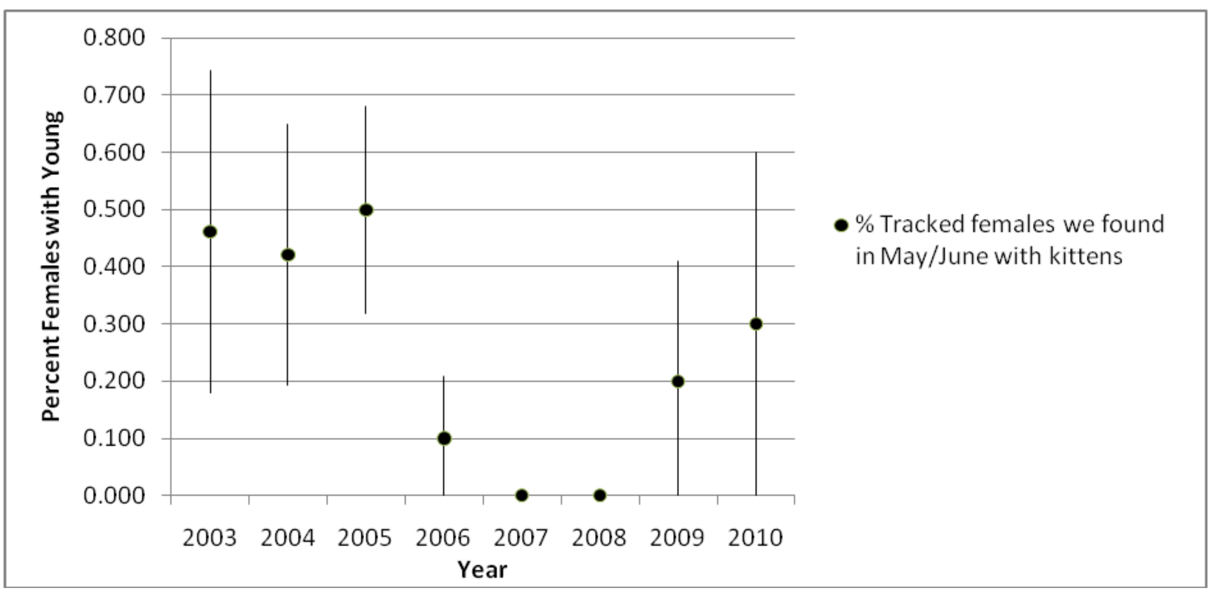

Figure 3. Percent of tracked Canada lynx females in the reintroduction area found with kittens in May or June from 2003 through 2010.

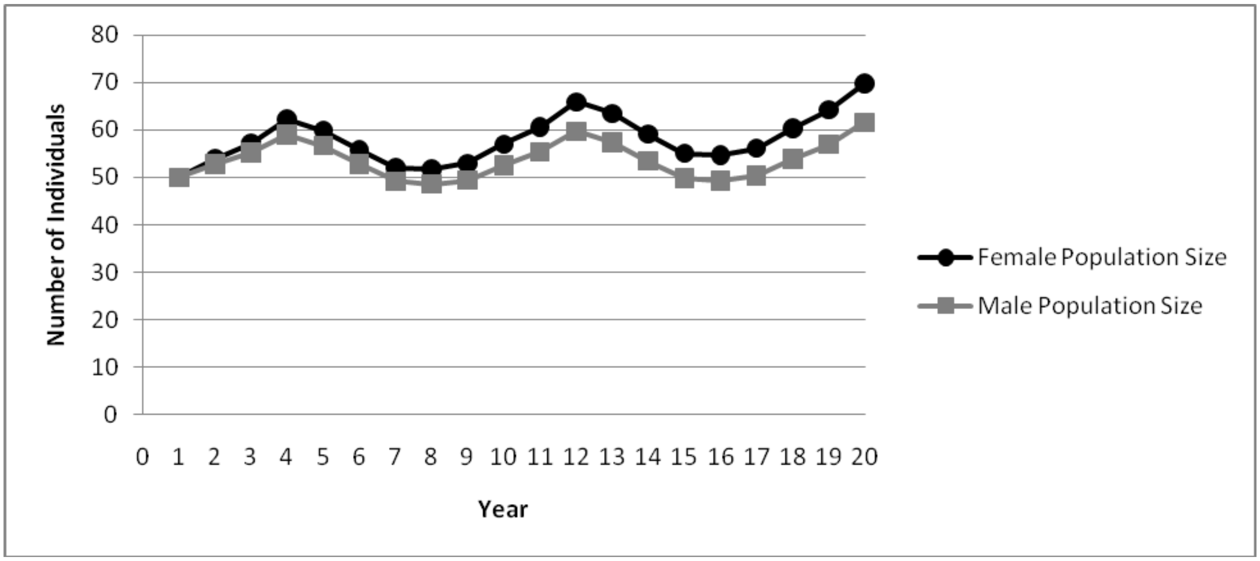

Figure 4. Projected Canada lynx population trend in the core reintroduction area over 20 years if the pattern of reproductive and survival parameters observed over the last 8 years would repeat. The initial population sizes of 50 males and 50 females for this projection was not based on a current population estimate, however, they are not unreasonable assumptions for the study area. Using alternative initial population sizes would not change the projected pattern.

APPENDIX I

STATUS OF PUBLICATIONS ASSOCIATED WITH THE COLORADO LYNX REINTRODUCTION PROGRAM

Five papers have been published:

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.

Shenk, T. M., R. H. Kahn, G. Byrne, D. Kenvin, S. Wait, J. Seidel, and J. Mumma. 2009. Canada lynx (*Lynx canadensis*) reintroduction in Colorado. Pages 410-421 *in* A. Vargas, C. Breitenmoser, and U. Breitenmoser, editors. Iberian Lynx Ex situ Conservation: An Interdisciplinary Approach. Fundacion Biodiversidad, Madrid, Spain.

Shenk, T. M and, R. H. Kahn. 2009. Reintroduction of the Canada lynx (*Lynx canadensis*) to Colorado. *in* Proceedings of the Third Iberian Lynx Symposium. *eds*. A. Vargas, C. Breitenmoser, U. Breitenmoser, Fundacion Biodiversidad and IUCN Cat Specialist Group. Fundacion Biodiversidad, Spain.

Wild, M. A., T. M. Shenk, and T. R. Spraker. 2006. Plague as a mortality factor in Canada lynx (*Lynx canadensis*) reintroduced to Colorado. Journal of Wildlife Diseases 42:646–650.

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.

Five additional papers are currently in review:

Devineau, O., T. M. Shenk, P. F. Doherty, Jr., G. C. White, and R. H. Kahn. In review. Assessing release protocols used for the Canada lynx (Lynx Canadensis) reintroduction in Colorado: Recommendations for future efforts. Journal of Wildlife Management.

Devineau, O., T. M. Shenk, P. F. Doherty, Jr., et al. In review. Modeling known-fate and nest survival data within the multistate framework: increased flexibility for telemetry studies. Journal of Applied Ecology.

Wolfe, L. L., T. M. Shenk, B. Powell, and T. E. Rocke. In review. Safety of and serum antibody responses to a recombinant F1-V fusion protein vaccine intended to protect Canada lynx (Lynx Canadensis) from plague. Journal of Wildlife Diseases.

Fanson, K., T. M. Shenk, et al. In review. Patterns of testicular activity in captive and wild Canada lynx. General and Comparative Endocrinology.

Fanson, K., T. M. Shenk, et al. In review. Patterns of ovarian and luteal activity in captive and wild Canada lynx. General and Comparative Endocrinology.

One paper is in the process of being submitted for publication and requires no additional work from CDOW personnel:

Fanson, K., T. M. Shenk, et al. In prep. Patterns of stress physiology in reintroduced Canada lynx and implications for reintroduction success. General and Comparative Endocrinology.

Six publications are currently in preparation and require the continued efforts of Tanya Shenk and/or Jake Ivan to complete:

Theobald, D., and T. M. Shenk. In prep. Lynx habitat use at site-specific and landscape scales.

Shenk, T. M. In prep. Lynx denning habitat and reproduction in Colorado.

Ivan, J. S., G. C. White, and T. M. Shenk. In Prep. Using telemetry to correct for bias: an approach to estimating density from trapping grids. Ecology.

Ivan, J. S., G. C. White, and T. M. Shenk. In Prep. Comparison of methods for estimating density from capture–recapture data. Journal of Applied Ecology.

Ivan, J. S., G. C. White, and T. M. Shenk. In Prep. Density and demography of snowshoe hares in west-central Colorado. Ecological Monographs.

Ivan, J. S., G. C. White, and T. M. Shenk. In Prep. Daily and seasonal movements of snowshoe hares in west-central Colorado. Journal of Mammalogy.

APPENDIX II

PROGRAM NARRATIVE STUDY PLAN
FOR MAMMALS RESEARCH
FY 2010-11

State of:	Colorado	:	Division of Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	0670	:	Lynx Conservation
Task No.:	4	:	Estimating Potential Changes in Distribution of
		:	Canada Lynx in Colorado: Initial Implementation in the Core Lynx Research Area
Federal Aid Project No.	N/A		

Principal Investigator
Jacob S. Ivan, Wildlife Researcher, Mammals Research
Tanya M. Shenk, Landscape Ecologist, NPS

Cooperators
Paul M. Lukacs, Biometrician, CDOW
Grant J. Merrill, Research Associate, CSU Cooperative Research Unit
Chad Bishop, Mammals Research Leader, CDOW

STUDY PLAN APPROVAL

Prepared by:	________________	Date:	________
Submitted by;	________________	Date:	________
Reviewed by:	________________	Date:	________
	________________	Date:	________
	________________	Date:	________
Biometrician Review	________________	Date:	________
Approved by:	________________	Date:	________

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Mammals Research Leader

PROGRAM NARRATIVE STUDY PLAN
FOR MAMMALS RESEARCH
FY 2010-11

Estimating the Extent, Stability and Potential Distribution of Canada Lynx (*Lynx canadensis*) in Colorado: initial implementation in the core lynx research area

A Research Proposal Submitted By

Jacob S. Ivan, Wildlife Researcher, Mammals Research
Tanya M. Shenk, Landscape Ecologist, National Park Service

A. Need:

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). Thus, Colorado is included in the federal listing as lynx habitat. Lynx were extirpated or reduced to a few animals in Colorado, however, by the late 1970's (U. S. Fish and Wildlife Service 2000), most likely due to multiple human-associated factors, including predator control efforts such as poisoning and trapping (Meaney 2002). Given the isolation of and distance from Colorado to the nearest northern populations of lynx, the Colorado Division of Wildlife (CDOW) considered reintroduction as the only option to attempt to reestablish the species in the state.

Therefore, a reintroduction effort was begun in 1997, with the first lynx released in Colorado in 1999. To date, 218 wild lynx were captured in Alaska or Canada and released in southwestern Colorado. The goal of the Colorado lynx reintroduction program is to establish a self-sustaining, viable population of lynx in this state. Evaluation of incremental achievements necessary for establishing viable populations is an interim method of assessing the success of the reintroduction effort. There were 7 critical criteria established for achieving a viable lynx population in Colorado: 1) development of release protocols that lead to a high initial post-release survival of reintroduced animals, 2) long-term survival of lynx in Colorado, 3) development of site fidelity by the lynx to areas supporting good habitat in densities sufficient to breed, 4) reintroduced lynx must breed, 5) breeding must lead to reproduction of surviving kittens 6) lynx born in Colorado must reach breeding age and reproduce successfully, and 7) recruitment must equal or be greater than mortality over an extended period of time. These criteria were evaluated incrementally over time to gauge whether the reintroduction effort was progressing toward success (Shenk and Kahn 2003). All seven criteria have now been met and a Canada lynx population currently exists in Colorado (Shenk and Kahn 2010). To document sustained viability of the Canada lynx population in Colorado, some form of long-term monitoring must be implemented.

Lynx were released in a core reintroduction area in the San Juan Mountains of southwestern Colorado. It was hoped lynx would become established in this area and then disperse on their own throughout suitable habitat in the state. Research and monitoring efforts over the last 11 years, since the first lynx were released, have focused primarily on monitoring reintroduced animals through VHF and satellite telemetry and estimating demographic parameters of these animals (e.g., Devineau et al. 2010). However, as more of these animals become unavailable for monitoring due to failed telemetry collars, death, or movement out of state, it has become impossible to accurately evaluate the status of the lynx population in Colorado, including the Core Research Area.

A minimally-invasive monitoring program is needed to estimate the distribution, stability, and persistence of lynx. Occupancy estimation, the use of presence/absence survey data to estimate the proportion of survey units occupied within a study area, is appropriate for such a program. In the past, biologists referred to presence/absence as present/not detected, because absence cannot be absolutely determined. This term, however, confuses the status of being present or not present with the activity of either detecting or not detecting an animal. This monitoring program proposed here adopts the term presence/absence with the argument that although absence cannot be determined, it can be estimated statistically using a known or estimated detection probability. The indicator used to determine the distribution of occurrence of lynx is Ψ, the proportion of primary sampling units (PSU's) (MacKenzie et al. 2006) with lynx presence. A PSU is a square sampling unit of $75km^2$, the approximate mean size of a lynx winter home range as estimated by a 90% kernel utilization distribution (Shenk 2007).

In order to design the most efficient statewide monitoring program, we first evaluated the detection probabilities and efficacy of 3 methods of detection (Shenk 2009) via survey work in areas where lynx were known to occur. The most efficient methods of detection were snow-tracking (daily detection probability = 0.70) and camera surveillance (daily detection probability = 0.085). Hair snares were found to be ineffective in detecting the presence of lynx (daily detection probability = 0).
In addition to identifying purported lynx tracks, snow-tracking implemented at the maximum effort should also include backtracking until scat or hair samples can be collected. Such samples are used to validate that the discovered tracks were indeed lynx tracks. Furthermore, such an approach allows for individual identification (from scat only), which could be used to monitor individual movement patterns across PSU's, reproduction, social structure and possibly apparent survival rates. A genetic library of most lynx released during the reintroduction program (some samples were missing) and most kittens found in Colorado (some samples were insufficient for individual identification) has been established and is housed with USGS Conservation Genetics Lab in Fort Collins, Colorado. This genetic library will be used to identify individuals from the scat samples collected during the monitoring program.

Below we outline the objectives and approach for the estimating the distribution of lynx in the Core Research Area. Results from this study will enable us to design a larger-scale monitoring program to detect changes in lynx persistence and distribution throughout Colorado. The primary objectives of a statewide monitoring program would be to document the annual distribution of lynx throughout Colorado, the stability, growth or shrinkage of this distribution over time, and to identify potential areas lynx may occupy in the future

A statewide monitoring program based on our pilot study (below) will not provide a means of estimating total population size in the state because detection of a lynx may represent a single territorial animal, a breeding pair or a family unit. To obtain a statewide lynx abundance estimate, further efforts would be needed to establish the actual or estimated number of lynx in a PSU. Furthermore, the occupancy estimation approach outlined below is not designed to provide information on reproductive success or to estimate survival.

B. Objectives:
The primary objectives of this study are to:
1. Estimate the distribution of lynx in the Core Research Area.
2. Further refine detection probabilities of snow-tracking and camera surveillance methods in detecting lynx.
2. Develop a standardized, valid monitoring protocol for estimating the distribution, stability and persistence of Canada lynx throughout Colorado.

C. Expected Results or Benefits:

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

D. Approach

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

Sampling Frame and Primary Sampling Unit Selection

The sampling frame will be the Core Research Area, a 20,684 km^2 study area which included the core reintroduction area, release sites and surrounding high elevation sites (> 2,591 m). The area encompasses the southwest quadrant of Colorado and is bounded on the south by New Mexico, on the west by Utah, on the north by interstate highway 70, and on the east by the Sangre de Cristo Mountains (Figure 1). The sampling frame will be randomly overlayed with a contiguous grid of 75 km^2 squares. The size of the square reflects a mean annual home range size of a reproducing lynx in Colorado (Shenk 2007) and is similar to home range estimates obtained for lynx in Montana (Squires and Laurion 1999). If a grid square meets the following criteria it will be identified as a PSU:

1. If ≥ 50% of the grid is located within the Core Research Area,
2. If ≥ 50 % of the grid contains conifer or montane/alpine habitat, as identified by the SWReGAP LandCover Dataset (http://earth.gis.usu.edu/swgap/swregap_landcover_report.pdf) and
3. If ≥ 50 % of the grid is 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 grid will be assigned a random number based on a spatially balanced randomized sample (RRQRR; Theobald et al. 2007) and then stratified by accessibility in winter (accessible or not accessible). An accessible grid is defined as one that can be easily and safely reached in winter by truck or snowmobile. The grids with the lowest 30 random numbers for each stratum will then be identified as the grids to be sampled for this study. Should a grid be found to have been placed in the wrong accessibility strata once approached in the field, its designation will be changed and the next lowest random numbered grid will replace it.

The assumptions that must be met in estimating occupancy are 1) surveyed sites can be occupied by the species of interest throughout the duration of the study, with no sites becoming occupied or unoccupied during the survey period (i.e., the system is closed), 2) species are not falsely detected, but can remain undetected if present, and 3) species detection at a site is assumed to be independent of species detection at other sites (MacKenzie et al. 2006). For study, there will be 2 different methods of detection (snow-tracking and camera surveillance).

Field Methods

Temporal aspects of the sampling design

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

Camera data collection will be conducted from September- June, although only photos obtained from October-March will be used in the analysis because this time period is when lynx typically maintain fidelity to a winter home range and when breeding occurs, the period of interest for document long-term persistence of lynx. All snow-tracking data will be collected from January – March, meeting the period of interest for occupancy.

Lynx Detection Data Collection

Two methods will be used to document the presence of lynx, based on winter accessibility of the PSU. These methods include 1) documenting the presence of lynx tracks in the snow coupled with a DNA sample collection (hair or scat found through snow-tracking) in PSU's that are accessible in winter or 2) a photograph of a lynx captured by a surveillance camera in PSU's that are inaccessible in winter. Camera work or snow tracking will be focused in areas of a selected PSU that a lynx would most likely use. Based on lynx habitat use in Colorado (Shenk 2005), focus areas will include mature Engelmann spruce-subalpine fir forest stands with 42-65% canopy cover and 15-20% conifer understory cover, mean slopes of 16° and elevations above 2591 m. In addition, selection of specific camera detection stations will be based on natural travel routes or the presence of lynx sign (i.e., tracks or scat). Chances of detecting lynx at these locations will be further enhanced by placing scent and visual lures at these sites. Other feline species may be attracted to these same lures, however, the probability will be low as the study will be conducted in winter and the deep snows at these elevations should preclude species such as mountain lion (*Puma concolor*) and bobcat (*Lynx rufus*) from using these areas.

Establishing Detection Stations & Travel Routes

To eliminate bias, any known lynx locations in the selected PSU's will be withheld from field technicians as they select camera station locations and snowmobile/snowshoeing routes. Field personnel will, however, be provided commonly available information to select camera locations and survey routes that are feasible and most likely areas to detect lynx within a PSU (see above).

Snow-Tracking

Searches for tracks will be attempted by snowshoeing, driving, or snowmobiling in the PSU once enough snow has accumulated. Once tracks are observed, personnel will follow the tracks for up to 1km or until either lynx hair or scat are found and collected. All hair found in day beds or a single scat will constitute a sample. Because lynx are a federally listed species, which can result in regulatory protection, we will eliminate doubt about the presence of lynx by submitting hair or scat sampled to a conservation genetics lab to confirm species identification (see McKelvey et al. 2006). All hair and fecal samples will be submitted to the USGS Conservation Genetics Lab in Fort Collins, Colorado for identification to species and individual, if possible. The distance a track is followed will be limited to 1 km to increase efficiency in lynx detection within the PSU (i.e., it will be assumed it is quicker to find a new lynx track to follow to locate hair or scat than to pursue a single track for more than 1 km; see McKelvey et al. 2006). To evaluate the efficiency of this method and better estimate detection probability, we will record the total distance searched before a track is encountered for each day of survey effort, along with the total distance each lynx track is followed to collect a scat or hair sample.

All selected accessible PSU's will be snow-tracked for a maximum of 3 days. However, once a track has been found in a PSU detection efforts will stop. Snow-tracking will be conducted in a minimum of 25 accessible PSU's. If time permits, up to 30 accessible PSU's will be surveyed.

Camera Traps

Digital infrared surveillance cameras (RECONYX RapidFire™ Professional PC85) will be placed at 4 randomly selected detection stations among those that appear the most likely places where lynx would encounter them within the PSU, as defined above. Commercial scent lures and visual lures (e.g., CD's, waterfowl wings) will be used at each camera detection station to enhance the probability of drawing a lynx into the station. Cameras will be strategically placed at microsites least likely to be effected by accumulating snow (e.g., we will use large trees with broad canopies that will form "tree wells" during winter).

Cameras will be attached to a tree with a Master Lock ™ Python™ cable lock and powered by 12 AA lithium batteries which should ensure functionality for the duration of the study. Cameras will be placed in a minimum of 25 PSU's. If time permits, up to 30 PSU's will be surveyed.

Cameras will be collected in May and June when access to the PSU's are feasible. Only photos of lynx taken from October 1 – March 31 will be considered a detection.

Data Analysis

We will estimate the occupancy of lynx within the Core research Area. Further evaluation of each of the detection methods will be completed to refine detection probabilities (p) using data from the continued monitoring of lynx with active radio collars to document presence of lynx in some of the sampled PSU's. A final monitoring protocol will be developed and published for use on a statewide or rangewide basis.

Project Schedule

Aug. 2010

- Complete sampling frame and selection of primary sampling units.
- Purchase and test equipment.
- Hire fall field crews.

Sep. – Oct 2010

- Set up camera detection stations
- Hire winter field crews.

Jan.–Mar. 2011

- Conduct lynx snow-tracking surveys.
- Process and submit all genetic samples collected during surveys to the USGS Conservation genetics Lab.

May-Jun 2011

- Collect cameras.
- Data entry.

Jul-Sep 2011

- Data analyses and complete report.

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

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

Field Technicians
Responsibilities: Establish camera detection stations, conduct all snow-tracking and collect cameras.

Data Analysis:
Jake Ivan, Wildlife Researcher, CDOW
Tanya Shenk, Landscape Ecologist, NPS
Paul Lukacs, Biometrician CDOW
Gary White, Professor Emeritus, CSU
Paul Doherty, Associate Professor, CSU

Estimated Budget:

September 2010 – June 2011	
Salary (Tech III)	$ 43,500
Salary (6 Field Technicians Fall, Tech I)	$ 32,500
Salary (6 Field Technicians, Winter, Tech II)	$ 35,000
Salary (4 Field Technicians Spring, Tech I)	$ 14,000
Misc. Supplies/Operating	$ 8,000
Equipment Repair, maintenance (snowmobiles)	$ 9000
Detection cameras (30 @$1000 each)	$ 30,000
Processing of genetic samples collected during monitoring	$ 2,000
Vehicles (6)	$ 8,000
Total	**$182,000.00**

E. Location:

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

F. Literature Cited:

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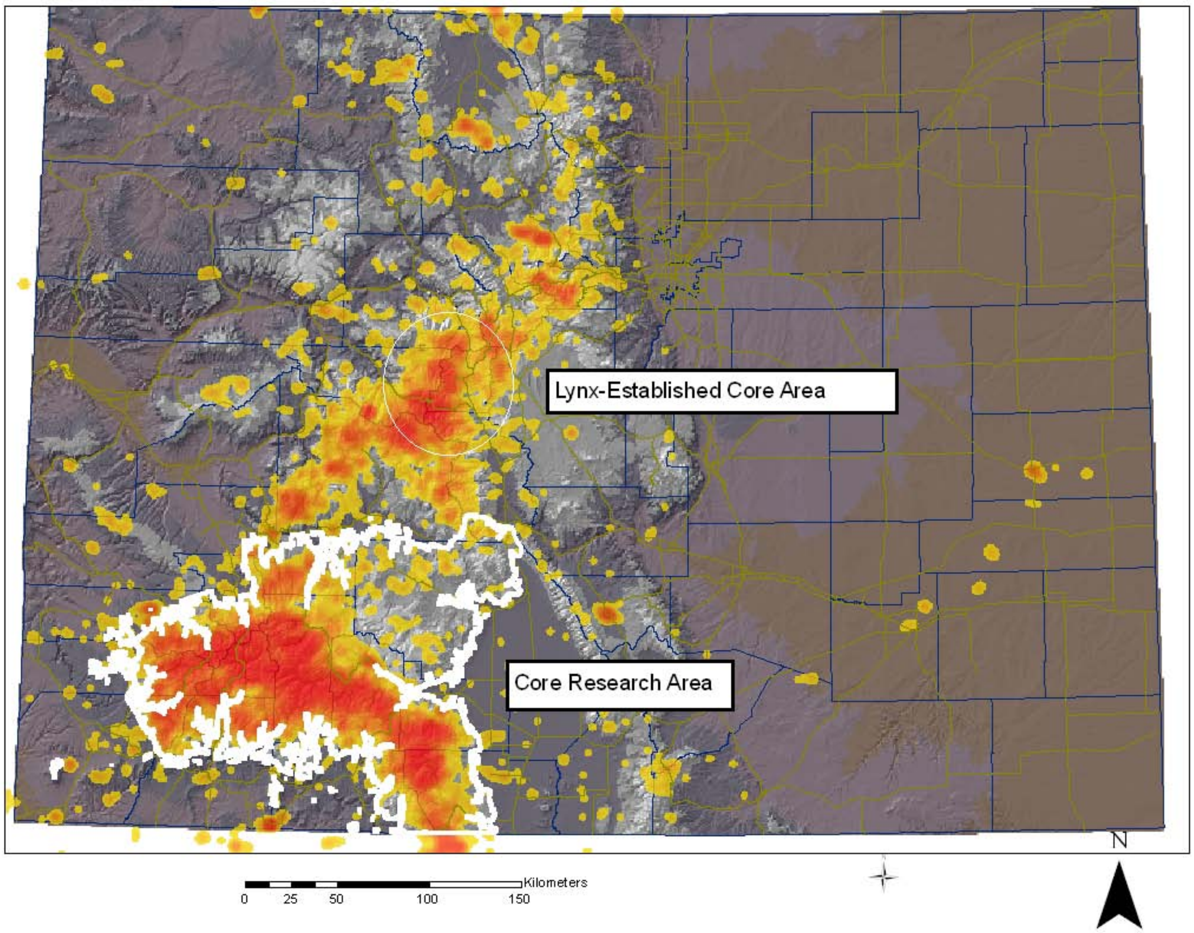

Figure 1. Study area depicting the Core Research Area, Lynx-established Core Area and relative lynx use (red is high intensity use, yellow is low intensity use).

APPENDIX III

Colorado Division of Wildlife
August 2009
WILDLIFE RESEARCH REPORT

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

Federal Aid Project: N/A **:**

Period Covered: July 1, 2009- June 30, 2010

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

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

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ABSTRACT

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

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

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

WILDIFE RESEARCH REPORT

DENSITY AND SURVIVAL OF SNOWSHOE HARES IN TAYLOR PARK AND PITKIN

JACOB S. IVAN

P. N. OBJECTIVE

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

SEGMENT OBJECTIVES

1. Complete mark-recapture work across all replicate stands during late summer (mid-July through mid-September) and winter (mid-January through March).

2. Obtain daily telemetry locations on radio-tagged hares for 10 days immediately after capture periods, as well as monthly between primary trapping sessions.

3. Locate, retrieve, and refurbish radio tags as mortalities occur.

SUMMARY

Snowshoe hares (*Lepus americanus*), their famous 10-year population cycle, and close association with Canada lynx (*Lynx canadensis*) have been well-studied in boreal Canada for decades. Snowshoe hare range, however, extends south into the Sierra Nevada, Southern Rockies, upper Lake States, and Appalachian Mountains. Ecology of snowshoe hares in these more southerly regions is not as well understood, though hare research in the U.S. Rocky Mountains has accelerated over the past decade. Through this recent work, biologists have identified stands of young, densely-stocked conifers and those of mature, uneven-aged conifers as primary hare habitat in the region. Both stand types are characterized by dense understory vegetation that provides both browse and protection from elements and predators.

From 1999 to 2006, Canada lynx were recently reintroduced into Colorado in an effort to restore a viable population to the southern portion of their former range. Snow tracking of released individuals and their progeny indicated that the majority of lynx winter diet in Colorado was comprised of snowshoe hares. Thus, long–term success of the lynx reintroduction effort hinges, at least partly, on maintaining adequate and widespread populations of snowshoe hares in the state.

To improve understanding of snowshoe hare ecology in the southern portion of their range, and enhance the ability of agency personnel to manage subalpine landscapes for snowshoe hares and lynx in Colorado, I conducted an observational study to evaluate purported primary hare habitat in the state. Specifically, I estimated snowshoe hare density, survival, recruitment, and movement indices in mature, uneven-aged spruce/fir and 2 classes of young, even-aged lodgepole pine: 1) "small" lodgepole stands, which were clear cut 20–25 years prior to this study and had regenerated into densely stocked stands trees 2.54–12.69 cm in diameter, and 2) "medium" lodgpole pine stands (tree diameter = 12.70–22.85 cm) which were clear cut 40-60 years prior to this study and pre-commercially thinned ~20 years prior. I used a combination of mark-recapture and radio telemetry to estimate parameters. I sampled during both summer and winter to cover the range of annual variation in parameters.

Animal density is one of the most common and fundamental parameters in wildlife ecology and was the first metric I used to evaluate the stand types. However, density can be difficult to estimate from mark-recapture data because animals can move on and off of a trapping grid during a sampling session (i.e., lack of geographic closure), which biases abundance estimates and makes them difficult convert to density. Before estimating snowshoe hare density, I developed a density estimator that uses ancillary radio telemetry locations, in addition to mark-recapture information, to account for lack of geographic closure resulting in relatively unbiased estimates of density. I derived the variance for this estimator, showed how individual covariates can be used to improve its performance, and provided an example using a subset of my snowshoe hare data.

Next, I completed a series of simulations to test the performance of this “telemetry” estimator over a range of sampling parameters (i.e., capture probabilities, sampling occasions, densities, and home range configurations) likely to be encountered in the field. I also compared the percent relative bias of the telemetry estimator to two other commonly used, contemporary estimators: spatial explicit capture-recapture (SECR), and mean maximum distance moved (MMDM). The telemetry estimator performed best over most combinations of sampling parameters tested, but was inferior to SECR at low capture probabilities. The telemetry estimator was unaffected by home range configuration, whereas performance of SECR and MMDM was dependent on home range shape.

Density is an important metric of habitat quality, but it can be misleading as some habitats with high animal density may function as population sinks. A complete assessment of habitat quality requires estimation of habitat-specific demographic rates in addition to density. I used the telemetry estimator to estimate snowshoe hare densities in each stand type during summer and winter, 2006-2009. I then combined mark-recapture and telemetry data to estimate survival via the Barker robust design model as implemented in Program MARK. Finally, I used age- and habitat-specific density and survival estimates to estimate recruitment in each stand type. Snowshoe hare densities were generally <1 hare/ha. During summer, hare densities were highest in small lodgepole pine, lowest in medium lodgepole pine, and intermediate in spruce/fir. During winter, densities became more similar between the 3 stand types. Annual survival of hares varied from 0.11 to 0.20. Survival tended to be higher during summer-winter intervals than during winter-summer, and higher in spruce/fir compared to the 2 lodgepole stands. Recruitment of juvenile hares occurred during all 3 summers in small lodgepole stands, 2 of 3 summers in spruce/fir stands, and in only 1 of 3 summers in medium lodgepole.

In addition to density and demography, movement is an informative aspect of animal ecology as well. Timing, extent, and frequency of movements can reflect predation pressure, food scarcity/abundance, availability of mates, or seasonal changes in any of these parameters. I used telemetry data to assess movement patterns of snowshoe hares at 3 scales (daily, within-season, between-season) in all 3 stand types. Hares in mature, uneven-aged spruce/fir stands made daily movements at the same scale as within-season and between-season movements in that habitat type, indicating they routinely traversed their entire home range over the course of a day. Conversely, hares in small and medium lodgepole stands appeared to use their home range in a more stepwise fashion (especially hares in medium stands), making smaller movements on a daily basis, but using larger areas over longer time frames. Additionally, hares in both lodgepole stands made large movements between seasons, possibly reflecting the patchy distribution of lodgepole landscapes in the study area and the variable value of patches as mediated by snow depth.

In summary, snowshoe hare density, survival, and recruitment were relatively low in medium lodgepole stands compared to spruce/fir or small lodgepole. Furthermore, hares in medium lodgepole stands made relatively large movements which may reflect poorer quality habitat. Thus, while hares occur in these stands, they do not appear to be capable self-sustaining hare populations and are probably less important than mature spruce/fir and small lodgepole. Management for snowshoe hares (and lynx) in central Colorado should focus on maintaining the latter. Given the permanent nature of spruce/fir compared to small lodgepole, and the fact that such stands cover considerably more area, mature spruce/fir may be the most valuable stand type for snowshoe hares the state.

Colorado Division of Wildlife
July 2009 – June 2010

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of Wildlife
Cost Center:	3420	:	Spatial analysis
Work Package:	0663	:	Deer Conservation
Task No.:	1	:	Mule Deer Body Condition model

Federal Aid
Project No. W-185-R

Period Covered: July 1, 2009 - June 30, 2010

Author: M.B. Rice and K. Searle

Personnel: C. Anderson, C. 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

Understanding the ways that resource heterogeneity shapes the performance of individuals and the dynamics of populations is a central challenge in contemporary ecology. Emerging evidence shows that herbivores track heterogeneity in nutritional quality of vegetation by responding to phenological differences in plants, differences that result from spatial and temporal variation in conditions favoring plant growth. The objective of this study will quantify the benefits mule deer accrue from accessing habitats with asynchronous plant phenology. To examine evidence for these hypotheses we used path analysis to examine links between variation in body condition (percent fat) of adult female mule deer in western Colorado and plant phenology indices and climate. Path analysis can be used to examine both the direct (physiological) and indirect (via plant phenology) effects of climate on ungulate body condition in this population, assuming linear relationships among predictor and response variables. We implemented the analysis within the hierarchical Bayesian framework, which allowed us to separate out and properly account for different sources of uncertainty in the data and process models. Significant effects of climate and topographical variables on the slope of vegetation green-up were found, although they were not consistent across years for some effects. The only year in which the slope of vegetation green-up had a significant, and negative, effect on mule deer percent bodyfat was 2008. Process variance was lower for the NDVI submodel than for the percent fat submodel, indicating that the percent fat path equation accounted for less of the important underlying processes. In conclusion, spring precipitation seems to play the greatest role in determining winter body condition of mule deer in this study area, having a positive effect on percent bodyfat that is mediated via its effect on plant phenology, acting to decrease the slope of the green-up in spring, thereby prolonging the period of availability of high quality forage. This finding does, however, need to be validated with more years of data with sufficient numbers of animals for analysis, and with direct assessments of spring precipitation on the quality of forage available to animals in different home ranges.

WILDLIFE RESEARCH REPORT

MULE DEER BODY CONDITION DATA

MINDY B. RICE, KATE SEARLE, CHUCK ANDERSON, AND CHAD BISHOP

P. N. OBJECTIVE

The objective of this study will quantify the benefits mule deer accrue from accessing habitats with asynchronous plant phenology. Using data on the winter body condition (percent fat) of adult mule deer in western Colorado and remotely-sensed plant phenology (normalized difference vegetation index, NDVI), we will evaluate the contribution of asynchronous pulses of forage emergence and growth on individual mule deer performance.

SEGMENT OBJECTIVES

The spatially and temporally explicit NDVI data will be used to derive indices of vegetation phenology in home ranges of individual mule deer. These indices will be used to predict observed variation in individual adult mule deer winter body condition. We hypothesize that:

1. Individuals inhabiting ranges with more asynchronous phenology will have prolonged access to high quality forage and have better winter body condition than individuals inhabiting ranges with more synchronous phenology.

2. Individuals inhabiting ranges with shorter 'green-up' periods will suffer from a compression in the time period over which high quality forage is available and have poorer body condition than individuals inhabiting ranges with more prolonged green-up periods. We also expect that mean winter body condition of all animals will be lower in years with shorter green-up periods than in years with longer green-up periods.

3. Winter body condition will be more strongly influenced by temporal variation in plant quality (coefficient of variation, *cv*, of the temporal trend in mean NDVI in an individual's home range) than by spatial variation in plant quality (*cv* of NDVI across an individual's home range at a single point in time). This is because greater temporal variation in plant quality (as indexed by NDVI) prolongs the time period over which individuals may maximize diet quality, which we expect to have a greater relative influence on body condition than spatial variation at a single point in time.

INTRODUCTION

Understanding the ways that resource heterogeneity shapes the performance of individuals and the dynamics of populations is a central challenge in contemporary ecology. Emerging evidence shows that herbivores track heterogeneity in nutritional quality of vegetation by responding to phenological differences in plants, differences that result from spatial and temporal variation in conditions favoring plant growth. The ability of landscapes to support herbivores is ultimately limited by the total amount of aboveground net-primary production (ANPP) available for consumption (Cebrian and Lartigue 2004; McNaughton et al. 1989). However, theory predicts that when spatial variation in temperature, nutrients, or moisture results in spatially asynchronous pulses of plant growth, herbivores are able to prolong the period during which they have access to forage of peak nutritional value. Emerging evidence suggests that limits set by ANPP can be modified by the spatial pattern and timing of plant growth. In particular, there is evidence that heterogeneity in plant communities expressed over space, particularly heterogeneity that induces variation in time by influencing plant phenology, offers fundamentally important nutritional benefits to foraging herbivores, benefits that enhance the performance of their populations. This finding means that access to heterogeneity can be a critically important feature of habitats for large, mobile herbivores (Fryxell et al. 2005; Hobbs et al. 2008; Owen-Smith 2004). The interactions between spatial and temporal heterogeneity and ungulate performance and population dynamics will mediate the response of Colorado ungulate populations to environmental change, such as land-use and climate change. Understanding the mechanisms underlying these interactions is, therefore, of great importance for prediction and management of Colorado ungulate populations in the face of environmental change.

Climate change is one of the dominant threats to ecosystems around the world. Large herbivores such as mule deer have profound impacts on ecosystem structure and function, and understanding the ways in which their behavior, individual performance and population dynamics are likely to change under future climate scenarios is crucial for effective management of Colorado ecosystems. By mechanistically linking changes in climate and variation in the spatial and temporal patterns of plant phenology across landscapes with the body condition of mule deer, we will be able to make some inferences as to climate change on this important species.

Secondly, as more oil and gas development occurs, there is a growing need to assess the effect of fragmentation on ungulate species. The intrusion of roads and drilling platforms in wildlife habitat has impacts on ungulate behavior. Sawyer et al. (2006) demonstrated that winter habitat selection in mule deer was altered by well pads and road development in western Wyoming; animals avoided areas up to 2.7-3.7km around well pads. Moreover, these changes in habitat use were immediate and did not decline over the 3 year study, rather mule deer selected for areas further away as development progressed (Sawyer et al. 2006). Rost & Bailey (1979) showed that mule deer avoided areas within 200m of a road. By applying an understanding of the likely implications of different development scenarios for ungulate movement and foraging patterns, we will be able to examine the effect of this development on mule deer body condition, as mediated by access to resource variation. By combining remotely accessed data such as NDVI with measurements of mule deer body condition, we will model changes in habitat quality over time and space relative to resource heterogeneity.

STUDY AREA AND DATA SOURCES

Initial deer body condition data is from research conducted in southwest Colorado on the southern half of the Uncompahgre Plateau and in the adjacent San Juan Mountains by Chad Bishop of the Colorado Division of Wildlife (Bishop et al. 2009). Methods outlined for the measurement of body fat is also given in Bishop et al. 2009. All deer that were supplemented in the Bishop et al. 2009 study were taken out of our analysis so we only used the control deer. The initial model will have 18 deer from 2002, 26 deer from 2003, and 30 deer from 2004 including 19 of those deer with multiple years of body condition data.

Extension of this data set would include body condition data that currently exists in the Piceance region of northwest Colorado from Chuck Anderson of the Colorado Division of Wildlife. There is additional individual deer body condition data from a study in the Uncompahgre Plateau by Eric Bergman that may be included in future model development. In addition, the use of Chuck Anderson’s data from body condition in the winter of 2009 can be used as a validation data set on the development models.

METHODS

To examine evidence for these hypotheses we used path analysis (Shipley 2002) to examine links between variation in body condition (percent fat) of adult female mule deer in western Colorado and plant phenology indices and climate. Path analysis can be used to examine both the direct (physiological) and indirect (via plant phenology) effects of climate on ungulate body condition in this population, assuming linear relationships among predictor and response variables. We implemented the analysis within the hierarchical Bayesian framework, which allowed us to separate out and properly account for different sources of uncertainty in the data and process models.

Quantifying these relationships will give insight into the likely impacts of future changes in climate on mule deer performance in this region of Colorado.

Data

Percent bodyfat and age

Percent body fat and age data were collected over 5 non-consecutive years (Table 1). To ensure independence of samples, individuals for which there were more than one year of measurement had the second year dropped from the analysis (n=5). Percent fat measurements were taken following the rLIVINDEX method (Cook et al.2007).

Home range calculations

All individual deer locations were grouped by individuals and the centroid of their locations were found in ArcMap. Distances moved by each individual deer were calculated and we determined that 21 km would encompass a buffer that would represent movements by each deer. The 21 km buffer was applied to each individual deer and variables were extracted for each deer.

Plant phenology

We used NDVI as a proxy for vegetation phenology (greenness), which has been used extensively as a surrogate for vegetation dynamics (Bellis et al. 2008, Boone et al. 2006, Morisette et al. 2006). Data were collected from the Global Land Cover Facility (GLCF) Moderate Resolution Imaging Spectroradiometer (MODIS) 16-day composite imagery (NASA 2000-2004). MODIS uses NASA's terra and aqua satellites with 16 day orbits, a 2330 km swath, and a 250 m resolution. The Normalized Difference Vegetation Index (NDVI) is a ratio of red and near infrared reflectance using bands 1 and 2 of the MODIS sensors (NDVI = (NIR – RED)/(NIR + RED) where NIR is the near infrared light reflected by vegetation, and RED is the red visible light reflected by vegetation). NDVI values range from -0.25 to 1 where negative values indicate sparse green vegetation.

We created several different indices from the satellite-derived NDVI measurements to test our hypotheses:

<u>Slope of NDVI during vegetation green-up ('slope'):</u> the slope between the mean NDVI values measured at defined dates for each individual's home range. The dates defining the start and end of the green-up period were determined visually from plots of mean NDVI curves for all individuals in each year (green-up period April 4^{th} to June 25^{th}, Figure 1). This is a measure of the speed of vegetation green-up in the Spring – i.e., how elongated or compressed is the phenological development of plants in each individual's home range. We predict that individuals inhabiting home ranges with shallower green-up slopes, therefore experiencing elongated green-up periods where the vegetation is at peak quality, will have higher body condition than those individuals inhabiting home ranges with steeper green-up slopes.

Onset of vegetation emergence: the mean value of NDVI for each individual's home range per year on April 4^{th}. This date was determined by visual inspection of mean NDVI curves for all individuals in each year to capture the start of the green-up period (Figure 1). We predict that individuals inhabiting home ranges with an earlier vegetation onset (i.e., a higher value of NDVI on April 4^{th}) will have higher body condition than individuals occupying home ranges with a later vegetation onset (i.e., a lower value of NDVI on April 4^{th}). This is because individuals in home ranges with earlier vegetation onset will have a prolonged period of access to forage at peak nutritional value.

Climate and topographic variables

Precipitation and temperature data were collected from the prism climate group using their parameter-elevation regressions on independent slopes (PRISM) precipitation, minimum temperature, and maximum temperature layers (Daly et al. 1997). The resolution for all climatic variables was 4 km. We converted the precipitation data from hundredths of mm to inches. We converted the temperature layers from hundredths of celsius to fahrenheit. Both precipitation and temperature data were obtained from the previous years of deer body condition data.

Using this data we calculated the sum of precipitation over the green-up period (beginning of April to end of June, hereafter referred to as 'spring precipitation'), and the sum of precipitation over the previous winter (beginning of January to end of March, hereafter referred to as 'winter precipitation'). We calculated the average minimum temperature over the current winter months (beginning of October to end of December).

Elevation and aspect were collected from the USGS Digital Elevation Model (DEM) with a 30 m resolution. Elevation units were in meters and aspect was in degree categories based on the following: North (0-22.5), Northeast (22.5-67.5), East (67.5-112.5), SE(112.5-157.5), South (157.5-202.5), Southwest (202.5-247.5), West (247.5-292.5), Northwest (292.5-337.5), and North (337.5-360).

All data were resampled in ArcGIS to the broadest resolution which corresponded to the climate variables at 4 km. Temperature, precipitation, elevation, slope, and NDVI were extracted using spatial analyst in Arc GIS to each individual deer's buffer.

Modeling approach

We used hierarchical Bayesian path analysis to examine the direct and indirect effects of environmental variables on mule deer body condition. Path analysis requires hypothesizing causal inferential paths and testing the significance of these paths both directly and indirectly through a mediating variable. When using standard statistical methods for path analysis, variables are treated as having normal distributions and paths are estimated using least squares regression equations. However, when data are non-normally distributed, and variables are observed with error, estimation can be very difficult. Moreover, ignoring measurement error can lead to biased estimates of the regression parameters. These difficulties can be handled by employing a fully Bayesian approach.

We developed a model quantifying the direct effects of plant phenology (defined by the NDVI indices outlined above) on mule deer body condition, the direct effects of climate on mule deer body condition, and the indirect effects of climate, via plant phenology, on mule deer body condition. Based on our understanding of the system, we surmised a mechanistic model for how climate and plant phenology affect individual body condition of mule deer (Figure 2). We specified relationships among environmental variables (climate, topography and NDVI metrics), animal characteristics (age at capture), and body condition (percent fat) of adult female mule deer across 5 separate years (2001, 2002, 2003, 2008, 2009). Linear models were used throughout. Plant phenology (NDVI indices) was assumed to be functions of climate and topographic variables, but uncertainties in these relationships were taken into account (Fig. 2).

To implement this model within a hierarchical Bayesian framework, we specified three separate model parts; the data model, process model, and prior distributions of parameters.

Data Model

The data model is the likelihood linking the data to the model parameters. We have two data models, one linking observations of NDVI indices to climatic and topographic variables, and one linking observations of percent body fat to plant phenology (NDVI indices) and animal characteristics (age at capture). Both NDVI indices and percent body fat were logit transformed, such that

$$\text{logit}(yNDVI_{i,t}) \sim \text{normal}(\mu NDVI_{i,t}, \sigma_{obs1})$$

and

$$\text{logit}(yPF_{i,t}) \sim \text{normal}(\mu PF_{i,t}, \sigma_{obs2})$$

where $yNDVI_{i,t}$ is the observation for the NDVI index for the *i*th deer in the *t*th year, $\mu NDVI_{i,t}$ is the model prediction for the NDVI index for the *i*th deer in the *t*th year, σ_{obs1} is the estimate of observation error across all NDVI index observations, $yPF_{i,t}$ is the observation for the percent fat for the *i*th deer in the *t*th year, $\mu PF_{i,t}$ is the model prediction for the percent fat for the *i*th deer in the *t*th year, and σ_{obs2} is the estimate of observation error across all measurements of percent fat. Observations of percent fat for individual deer are assumed to be independent in this analysis. Radio-collared deer sometimes foraged together in the same groups; however, group dynamics were highly variable, suggesting any violations to the independence assumption were minor.

Process Model

The process component of the model relates the model predictions for NDVI indices and percent fat to the parameters of the model. As such, it derives the probability of the model prediction for each NDVI index for the *i*th deer in the *n*th year, $\mu NDVI_{i,t}$, given the respective process model parameters, and the process variance estimate for unaccounted variation in the modeled NDVI process, σ_{proc1}:

$$P(\mu NDVI_{i,t} \mid a_t, b_{1_t}, b_{2_t}, b_{3_t}, b_{4_t}, \sigma_{proc1}),$$

and the probability of the model prediction for percent fat for the *i*th deer in the *n*th year, $\mu PF_{i,t}$, given the respective process model parameters, and the process variance estimate for unaccounted variation in the modeled percent fat process, σ_{proc2}:

$$P(\mu PF_{i,t} \mid c_t, d_{1_t}, d_{2_t}, d_{3_t}, d_{4_t}, \sigma_{proc2}).$$

These probabilities are defined by two path equations:

$$\mu NDVI = a + b_1 sppt + b_2 elev + b_3 aspect + b_4 wppt$$
$$\mu PF = c + b_1 \mu NDVI + b_2 wtemp + b_3 wppt + b_4 age$$

where *sppt* is spring precipitation, *elev* is elevation, *wppt* is winter precipitation, and *wtemp* is winter temperature.

Prior distributions

Because our analysis is fully Bayesian, we specify prior distributions for all model parameters in the hierarchy. For this model, because all input variables (climate, topography and age) were standardized for the path analysis, all prior distributions were assumed to be normally distributed and uninformative (all parameters ~normal(0, 1.0E-6)). Because the data for NDVI indices and percent fat were logit transformed, these were also assumed to be normally distributed, and uninformative uniform priors were used for process variance and observation error for both the NDVI data model and percent fat data model, $\sigma_{obs1}, \sigma_{obs2}, \sigma_{proc1}, \sigma_{proc1} \sim \text{uniform}(0,1)$.

All models were fit using WinBUGS (Spiegelhalter et al. 1999) software and a Marcov Chain Monte-Carlo (MCMC) procedure for each model run for 1,000,000 iterations after an intial burn-in of 500,000 iterations to ensure convergence of all model parameters. Convergence diagnostics and autocorrelation statistics were used to assess the mixing of three MCMC chains per model, and to assess the MCMC sampling quality for each parameter.

The resulting fully hierarchical Bayesian model is, therefore, specified by

$$P(\theta_{data}, \theta_{process}, \mu \mid y) \propto P(y \mid \theta_{data}, \mu) P(\mu \mid \theta_{process}) P(\theta_{data}) P(\theta_{process})$$

where:

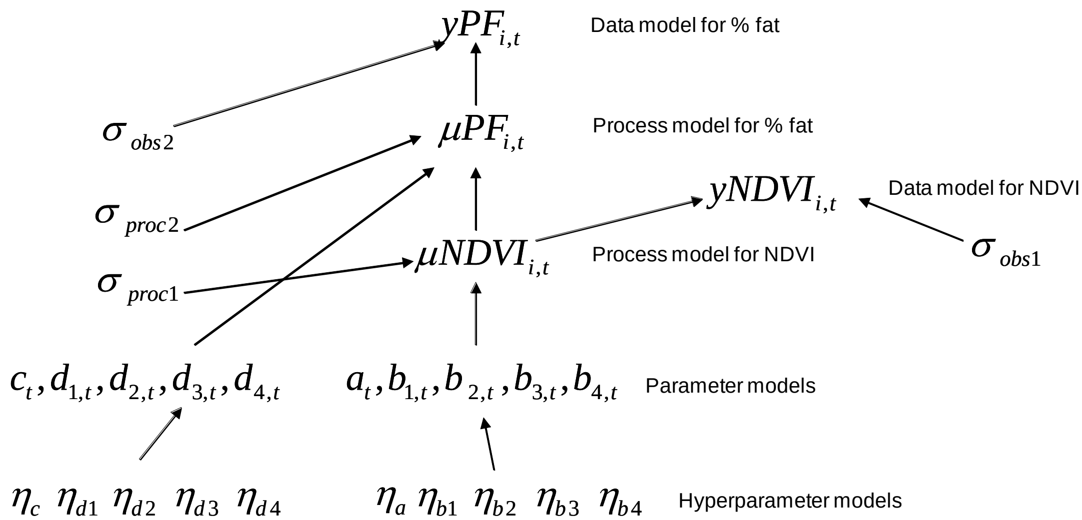
θ_{data} includes the parameters in the data model and parameters for observation error

$\theta_{process}$ includes the parameters in the process model and parameters for process variance

μ are the predictions of the process model

y are the data

Path Analysis Model, including random effect for year:



And the full model is specified as

$$P(\sigma_{obs1}, \sigma_{obs2}, \sigma_{proc1}, \sigma_{proc2}, a, b_1, b_2, b_3, b_4, c, d_1, d_2, d_3, d_4, \mu NDVI_i, \mu PF_i \mid yNDVI_i, yPF_i) \propto$$

$$\prod_{t=1}^{5} \prod_{i=1}^{n} P(yNDVI_{i,t} \mid \mu NDVI_{i,t}, \sigma_{obs1})$$

$$\prod_{t=1}^{5} \prod_{i=1}^{n} P(yPF_{i,t} \mid \mu PF_{i,t}, \sigma_{obs2})$$

$$\prod_{t=1}^{5} \prod_{i=1}^{n} P(\mu NDVI_{i,t} \mid a_t, b_{1_t}, b_{2_t}, b_{3_t}, b_{4_t}, \sigma_{proc1})$$

$$\prod_{t=1}^{5} \prod_{i=1}^{n} P(\mu PF_{i,t} \mid c_t, d_{1_t}, d_{2_t}, d_{3_t}, d_{4_t}, \sigma_{proc2})$$

$$\prod_{t=1}^{5} P(a_t) P(b_{1_t}) P(b_{2_t}) P(b_{3_t}) P(b_{4_t})$$

$$\prod_{t=1}^{5} P(c_t) P(d_{1_t}) P(d_{2_t}) P(d_{3_t}) P(d_{4_t})$$

$$P(\eta a) P(\eta b_1) P(\eta b_2) P(\eta b_3) P(\eta b_4)$$

$$P(\eta c) P(\eta d_1) P(\eta d_2) P(\eta d_3) P(\eta d_4)$$

$$P(\sigma_{obs1}) P(b\sigma_{obs2}) P(\sigma_{proc1}) P(\sigma_{proc2})$$

All climate, topographic and age variables were standardized prior to analysis. We used a logit transform on the observed values for each NDVI metric and percent fat.

Data simulation and initial model testing

Prior to running each developed model on actual data, models were tested on realistically simulated data to test their ability to converge on reasonable parameter estimates. All models performed well in simulations, converging on known parameter estimates such that 95% credible intervals for each parameter contained the true, known value.

RESULTS

Model convergence

Models converged satisfactorily on posterior distributions for model parameters (Tables 2 and 3). Model convergence for the 'slope' NDVI metric was good, producing a multivariate scale reduction factor of 1.12 (Gelman and Rubin 1992). Convergence for individual parameters was assessed and found to be satisfactory (all point estimates <1.20; 97.5% quantile <1.5 scale reduction factor; Table 4) for all parameters in all years. All posterior distributions were approximately normal, and autocorrelation in the MCMC chains was not a factor after the initial burn-in period.

Similarly, model convergence for the 'onset' NDVI metric was satisfactory, with a multivariate scale reduction factor of 1.35. Convergence for individual parameters was good; point estimates for all parameters were <1.1 with the exception of year 2002, in which point estimates for three parameters (NDVI model intercept, effect of spring precipitation on onset, and effect of elevation on onset) were approximately 1.5 (Table 3). Correspondingly, 97.5% quantiles for these three parameters in year 2002 were approximately 2. This was due to autocorrelation in the MCMC chain samples which persisted for >500,000 iterations. Autocorrelation for all other parameters in other years disappeared within the burn-in period. All posterior distributions were approximately normal.

Links between climate, plant phenology and mule deer percent bodyfat

Significant effects of climate and topographical variables on the slope of vegetation green-up were found (Table 2), although they were not consistent across years for some effects. For instance, spring precipitation had a negative effect on the slope of vegetation green-up in 2008, but a positive effect in 2009 (Table 2). Similarly, winter precipitation negatively affected the slope of vegetation green-up in three years (2003, 2004, 2009), but had a positive impact in 2008 (Table 2). Elevation (years 2002, 2008, 2009) and aspect (years 2003 and 2008) had positive effects on the slope of vegetation green-up.

The only year in which the slope of vegetation green-up had a significant, and negative, effect on mule deer percent bodyfat was 2008 (Table 2). Age and winter precipitation also had negative effects on percent bodyfat in 2008 (Table 2).

The onset of vegetation emergence was significantly influenced by several climatic and topographic variables. Again, these effects were not always consistent across years; for instance spring precipitation had a negative effect on vegetation onset in 2003 and 2008, but this effect was positive in 2009 (Table 3). Similarly, winter precipitation had a negative effect on vegetation onset in 2003 and 2004, but a positive effect in 2008 (Table 3). Aspect also produced contrasting effects in different years, having a negative effect on vegetation onset in 2003, and a positive effect in 2008. Elevation had a positive effect on vegetation onset in three years (2003, 2008 and 2009).

The only year in which vegetation onset had a significant, and negative, effect on mule deer percent bodyfat was 2008 (Table 3). Winter temperature (2003) and winter precipitation (2008) both had positive effects on percent bodyfat, while age had a negative effect on percent bodyfat in 2008 (Table 3).

Estimates of process variance and observation error were made for each path equation (NDVI and percent fat) across all years (Table 5). Process variance was lower for the NDVI submodel than for the percent fat submodel, indicating that the percent fat path equation accounted for less of the important underlying processes. However, observation error was lower for the percent fat submodel than for the NDVI submodel, which is to be expected given the quality of the percent fat measurements taken using the rLIVINDEX method (Cook et al. 2007).

Path analysis diagrams

We constructed path analysis diagrams for 2008, the only year for which we found significant effects of plant phenology – 'slope' (Fig. 3) and 'onset' (Fig. 4) - on mule deer percent bodyfat. Values are posterior means for each linear relationship.

DISCUSSION

Climate and topographic variables on plant phenology metrics

Although the models converged well on parameter estimates for each of the five years, we restrict our discussion to the year with the greatest number of individual deer sampled (2008, n=78). We feel that drawing conclusions from the other four years, in which the number of deer sampled ranged from 18-33, is difficult given the complexity of the final model.

Slope

Winter precipitation, elevation and aspect all contributed to make the slope during green-up steeper, while spring precipitation decreased the slope during green-up. Higher elevation and aspect with higher degrees associated with North and West slopes likely increase the slope during green-up because higher elevations and on North and West-facing aspects probably cause a compression in the window over which microclimatic conditions are favourable for plant growth. Winter precipitation likely increases the slope during green-up because there is more soil moisture when temperature conditions become favourable for plant growth, thus speeding up plant development.

Spring precipitation is likely to decrease the slope during green-up by providing additional inputs of moisture into the system, thus elongating the time window over which plant growth can occur.

We detected no significant effect of winter temperature on percent bodyfat, indicating that the direct, physiological impact of winter climate is less important than the indirect climatic effects on body condition mediated through plant phenology. Both of these study areas have relatively mild winters compared to certain other herds in the Intermountain West. If winter temperatures were to have an effect on percent body fat, it would be expected to occur in higher elevation, or more northerly, winter ranges typified by severe winter weather.

Winter precipitation had a positive effect on mule deer percent bodyfat in 2008; however we are reluctant to interpret this finding without reference to a longer time-series of data. In the other years for which we have data, this relationship was not significant, although this is likely related to the limited number of observations in other years. Age also had a negative effect on mule deer percent bodyfat, which is to be expected as body condition in ungulates often declines with age once a certain threshold is reached.

Effect of plant phenology on mule deer percent bodyfat

As predicted, the slope of the vegetation green-up period had a significant, negative correlation with mule deer percent body fat. This indicates that individuals inhabiting home ranges with more synchronous plant phenology performed less well than those individuals occupying home ranges with asynchronous phenology.

Rapid green-up of vegetation during spring has been negatively correlated with growth and survival of bighorn lambs (*Ovis canadensis*), growth of mountain goat kids (*Oreamnos americanus*) in Canada, and survival of Alpine ibex kids (*Capra ibex*) in northern Italy (Pettorelli et al. 2007).

Rapid changes in NDVI during vegetation green-up could translate to greater forage availability at a given point in time across a landscape. However, these rapid changes may also serve to compress the time window over which high quality forage is available to ungulates over a large spatial scale, such as the home range, potentially depressing diet quality over the longer-term (Pettorelli et al. 2007). The duration of the vegetation period was found to be predominantly constrained by spring weather in the Canadian study area (Pettorelli et al. 2005a). Warm temperatures in spring can override the effects of variable topography (Kudo 1991, Steltzer et al. 2009), reducing spatial heterogeneity in plant phenology over the landscape, and shortening the period over which ungulates have access to high quality forage (Pettorelli et al. 2007).

Overall effects

We can estimate the indirect effects of climate and topography through the mediating variable, plant phenology, on percent bodyfat by calculating the product of the standardized regression parameters for each pathway (Gajewski et al. 2005). For the slope index of plant phenology, summer precipitation had the greatest indirect influence on percent bodyfat, with a positive indirect effect of 0.85. Elevation had the strongest negative indirect effect on percent bodyfat with an indirect effect of -0.43, followed by winter precipitation (indirect effect -0.28) and aspect (indirect effect -0.15). However, because winter precipitation also had a direct effect on percent bodyfat of 0.22, its total influence on percent body fat is the sum of the direct and indirect effects (Gajewski et al. 2005), and is quite minimal (total effect of winter precipitation on mule deer percent bodyfat -0.058).

Onset

Onset had the opposite relationship to percent bodyfat than predicted, having a negative effect on percent bodyfat of mule deer. This is somewhat unexpected, because a higher mean NDVI value at the start of the green-up period is thought to be associated with an earlier start to the growing season, and elongated time period at which forage is at peak quality. However, a higher mean NDVI value at the start of the green-up period could also be indicative of a faster rate of green-up, which would compress the period of high quality forage for ungulates. Indeed, we suspect that this may be the case in this analysis, because of the close similarity between the parameter estimates for the independent variables for both the slope and onset models (Tables 2 and 3 and Figs 3 and 4).

Pettorelli et al. (2007) found no positive effect of early vegetation onset on juvenile growth or survival in three ungulate species in Canada and northen Italy, and suggest that there is a greater influence of the average duration of the period of access to high quality forage, rather than the measure of the average timing of vegetation onset.

SUMMARY

Studies in boreal forests with strong seasonality at northern latitudes have found summer fattening of ungulates linked to plant phenology to be a more important climatic factor for body condition in autumn than winter bodymass loss due to harsh conditions (snow depth and temperature) (Mysterud et al. 2008). While bodymass of yearling red deer (*Cervus elaphus*) in Norway was linked to winter snow and temperature, it was found that the magnitude of these effects was much smaller than the indirect effects of climate operating through plants. Similarly, in our study area, we detected no significant effect of winter temperature on percent bodyfat of mule deer, while several significant effects of spring climate on bodyfat, mediated through plant phenology, were found.

Pettorelli et al. (2007) detected an increase in the maximal increase in NDVI (slope) over time, suggesting a possible reflection of a warming trend, which could negatively affect alpine ungulates by compressing the period of high quality forage availability. In this study, we do not have enough years of data to reliably assess if a similar trend can be detected in this study area, but our findings do warrant increased attention to changes in climatic patterns, particularly spring precipitation, because any future decrease in spring precipitation may lead to decreases in the body condition of this important ungulate species.

In conclusion, spring precipitation seems to play the greatest role in determining winter body condition of mule deer in this study area, having a positive effect on percent bodyfat that is mediated via its effect on plant phenology, acting to decrease the slope of the green-up in spring, thereby prolonging the period of availability of high quality forage. This finding does, however, need to be validated with more years of data with sufficient numbers of animals for analysis, and with direct assessments of spring precipitation on the quality of forage available to animals in different home ranges.

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Prepared by _______________________

Mindy B. Rice, Spatial Ecologist

Table 1. Summary of data collected on mule deer percent bodyfat for 2002, 2003, 2004, 2008 and 2009. Age is mean of all individuals captured in that year, with associated minimum and maximum in parentheses.

Year	Number of individuals	Month of capture	Age
2002	18	February/March	4.5 (3.0-7.5)
2003	29	February/March	3.3 (1.5-8.5)
2004	24	March	3.4 (1.5-7.0)
2008	78	December	4.5 (1.5-10.5)
2009	33	March	4.5 (1.5-10.5)

Table 2. Results from the path analysis for how climate affects plant phenology and mule deer percent bodyfat in western Colorado (2002-2004, 2008, 2009). All variables except 'slope' were standardised.

Year	Metric	Metric	Posterior mean	95% credible interval
2002	a	NDVI intercept	-0.91	-1.65, -0.22
2009	a	NDVI intercept	-5.04	-5.54, -4.53
2008	b_1	Spring ppt	-0.61	-0.88, -0.35
2009	b_1	Spring ppt	8.48	7.49, 9.46
2002	b_2	Elevation	0.38	0.12, 0.64
2008	b_2	Elevation	0.31	0.021, 0.61
2009	b_2	Elevation	1.18	0.96, 1.39
2003	b_3	Aspect	0.058	0.012, 0.10
2008	b_3	Aspect	0.11	0.068, 0.15
2003	b_4	Winter ppt	-0.15	-0.23, -0.07
2004	b_4	Winter ppt	-0.12	-0.19, -0.05
2008	b_4	Winter ppt	0.20	0.021, 0.37
2009	b_4	Winter ppt	-0.39	-0.56, -0.21
2002	c	%Fat intercept	-2.59	-3.65, -1.58
2004	c	%Fat intercept	-2.43	-3.09, -1.78
2008	c	%Fat intercept	-2.95	-3.65, -2.27
2009	c	%Fat intercept	-2.21	-3.66, -0.78
2008	d_1	SLOPE	-1.39	-2.42, -0.39
2008	d_3	Winter ppt	0.22	0.00019, 0.44
2008	d_4	Age	-0.087	-0.16, -0.014

Table 3. Results from the path analysis for how climate affects plant phenology and mule deer percent bodyfat in western Colorado (2002-2004, 2008, 2009). All variables except 'onset' were standardised.

Year	Metric	Metric	Posterior mean	95% credible interval
2003	a	NDVI intercept	-3.27	-4.75, -1.06
2009	a	NDVI intercept	-1.41	-1.67, -1.13
2003	b_1	Spring ppt	-1.82	-2.70, -0.49
2008	b_1	Spring ppt	-0.37	-0.52, -0.22
2009	b_1	Spring ppt	2.76	2.21, 3.28
2003	b_2	Elevation	0.19	0.089, 0.26
2008	b_2	Elevation	0.28	0.12, 0.44
2009	b_2	Elevation	0.46	0.34, 0.59
2003	b_3	Aspect	-0.028	-0.053, -0.00098
2008	b_3	Aspect	0.11	0.087, 0.13
2003	b_4	Winter ppt	-0.089	-0.13, -0.044
2004	b_4	Winter ppt	-0.072	-0.11, -0.033
2008	b_4	Winter ppt	0.13	0.031, 0.22
2004	c	%Fat intercept	-2.23	-3.16, -1.32
2008	c	%Fat intercept	-2.78	-3.36, -2.22
2009	c	%Fat intercept	-2.18	-3.60, -0.74
2008	d_1	ONSET	-1.46	-2.56, -0.38
2003	d_2	Winter temp	0.41	0.14, 0.69
2008	d_4	Age	-0.088	-0.16, -0.014
2008	d_3	Winter ppt	0.23	0.014, 0.45

Table 4: Convergence statistics for all years and the scale reduction factors for slope and onset variables.

	SLOPE			ONSET		
Year	Parameter	Point Estimate	97.5% Quantile	Parameter	Point Estimate	97.5% Quantile
2002	a	1.01	1.01	a	1.00	1.01
2003	a	1.17	1.51	a	1.52	2.31
2004	a	1.01	1.02	a	1.03	1.11
2008	a	1.00	1.00	a	1.00	1.01
2009	a	1.01	1.03	a	1.01	1.05
2002	b1	1.00	1.01	b1	1.01	1.03
2003	b1	1.17	1.51	b1	1.52	2.31
2004	b1	1.01	1.02	b1	1.03	1.09
2008	b1	1.01	1.04	b1	1.00	1.01
2009	b1	1.01	1.02	b1	1.02	1.05
2002	b2	1.00	1.00	b2	1.00	1.02
2003	b2	1.13	1.37	b2	1.35	1.92
2004	b2	1.00	1.00	b2	1.03	1.09
2008	b2	1.01	1.02	b2	1.00	1.01
2009	b2	1.01	1.03	b2	1.00	1.01
2002	b3	1.00	1.01	b3	1.01	1.02
2003	b3	1.05	1.14	b3	1.12	1.35
2004	b3	1.00	1.01	b3	1.03	1.10
2008	b3	1.00	1.02	b3	1.00	1.01
2009	b3	1.01	1.02	b3	1.00	1.02
2002	b4	1.00	1.00	b4	1.00	1.01
2003	b4	1.03	1.10	b4	1.04	1.14
2004	b4	1.00	1.00	b4	1.00	1.02
2008	b4	1.01	1.03	b4	1.00	1.01
2009	b4	1.00	1.00	b4	1.00	1.00
2002	c	1.00	1.00	c	1.01	1.02
2003	c	1.03	1/09	c	1.03	1.09
2004	c	1.00	1.00	c	1.00	1.01
2008	c	1.00	1.00	c	1.00	1.00
2009	c	1.00	1.01	c	1.00	1.00
2002	d1	1.00	1.00	d1	1.01	1.02
2003	d1	1.03	1.09	d1	1.03	1.08
2004	d1	1.00	1.00	d1	1.00	1.01
2008	d1	1.00	1.00	d1	1.00	1.00
2009	d1	1.00	1.00	d1	1.00	1.00
2002	d2	1.00	1.00	d2	1.00	1.01
2003	d2	1.01	1.04	d2	1.01	1.02
2004	d2	1.00	1.00	d2	1.00	1.00
2008	d2	1.00	1.00	d2	1.00	1.00
2009	d2	1.00	1.01	d2	1.00	1.00
2002	d3	1.00	1.00	d3	1.00	1.01
2003	d3	1.03	1.09	d3	1.02	1.07
2004	d3	1.00	1.00	d3	1.00	1.00
2008	d3	1.00	1.00	d3	1.00	1.00
2009	d3	1.00	1.01	d3	1.00	1.00
2002	d4	1.00	1.00	d4	1.00	1.00
2003	d4	1.00	1.01	d4	1.00	1.00
2004	d4	1.00	1.00	d4	1.00	1.00
2008	d4	1.00	1.00	d4	1.00	1.00
2009	d4	1.00	1.00	d4	1.00	1.00

Table 5. Estimates for process variance and observation error for each of the two path equation submodels (NDVI and percent fat), for the 'slope' and 'onset' vegetation phenology indices. Estimates are posterior means and 95% credible intervals estimated across all years.

SLOPE	Posterior mean	2.5% credible interval	97.5% credible interval
Process variance (NDVI)	0.033	0.0017	0.056
Observation error (NDVI)	0.21	0.042	0.34
Process variance (percent fat)	0.24	0.077	0.35
Observation error (percent fat)	0.034	0.0018	0.056
ONSET			
Process variance (NDVI)	0.019	0.0013	0.031
Observation error (NDVI)	0.21	0.042	0.34
Process variance (percent fat)	0.24	0.077	0.35
Observation error (percent fat)	0.019	0.00084	0.031

Figure 1. Mean NDVI curves for each deer captured in 2004. The vegetation green-up period was determined to occur from dates 4 to 7, corresponding to April 4th to June 25th. The 'slope' NDVI index was calculated by finding the slope between mean NDVI values across each individual's home range from April 4th to June 25th (green dotted line). The 'onset' of vegetation green-up NDVI index was the mean NDVI value across each individual's home range on date 4, April 4th.

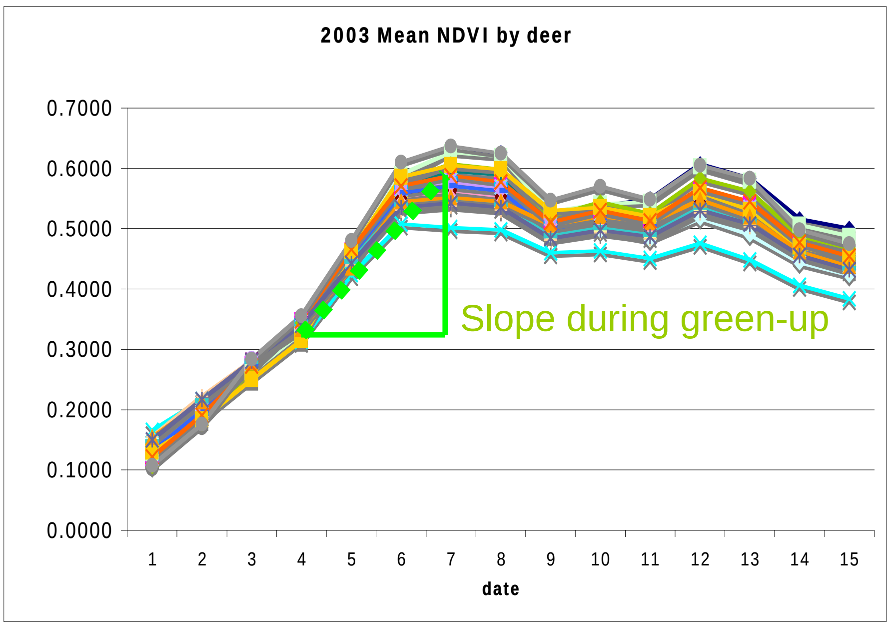


Figure 2. Path analysis diagram for how performance (percent body fat) of adult, female mule deer is affected directly and indirectly by climate and plant phenology in western Colorado. All lines in diagram represent a specific linear model.

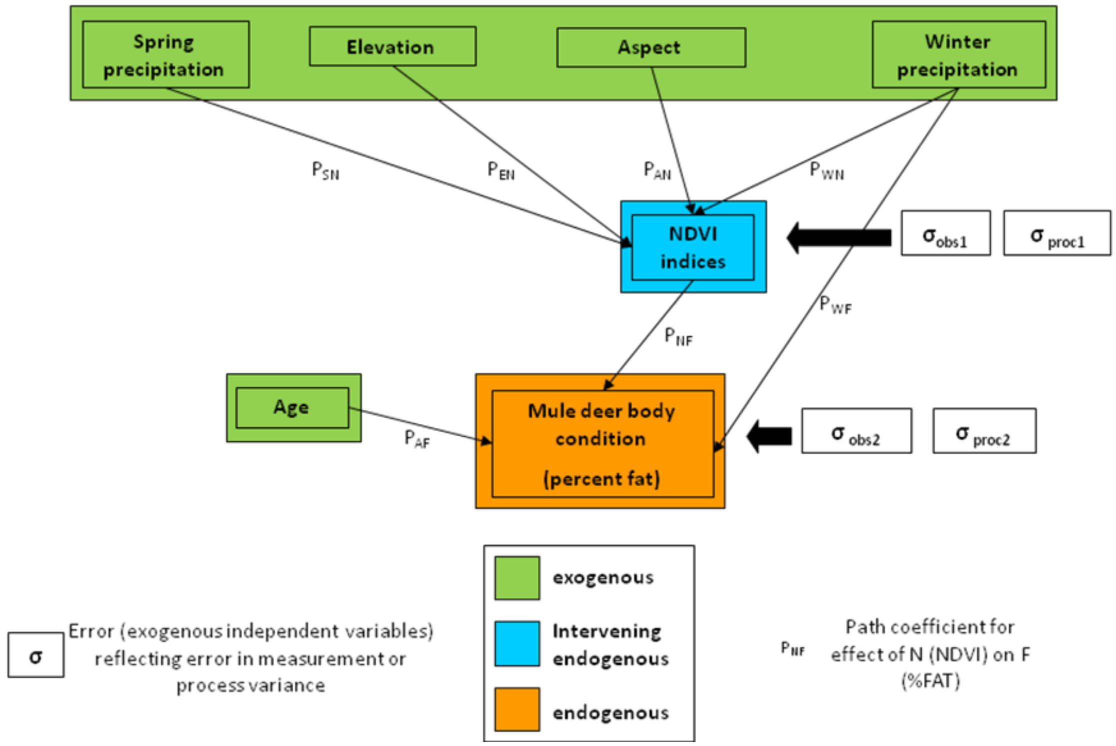
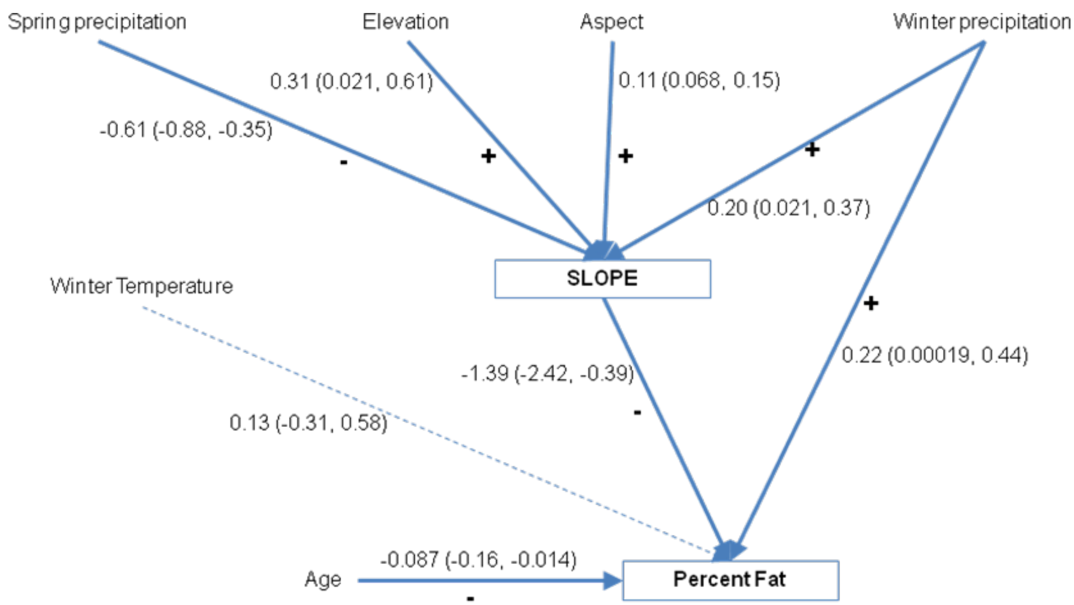
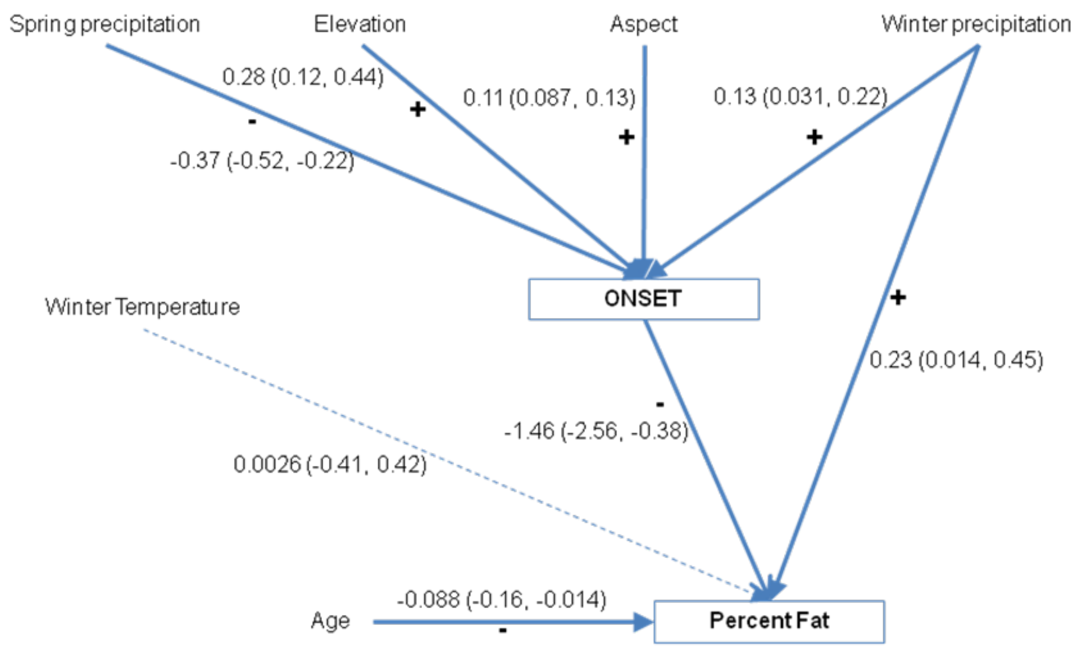


Figure 3: Path analysis diagram for how performance (percent fat) of adult, female mule deer is affected directly and indirectly by climate in western Colorado in 2008. Indirect linkages are manifested through a measure of the speed of vegetation green-up in the spring derived from NDVI measurements ('slope'). All lines in the diagram represent a specific linear model. Thick solid lines represent strong evidence for an effect (95% credible interval does not overlap zero). Dotted lines represent no clear effect. Regression coefficient estimates are given with 95% credible intervals. '+' predicted positive relationship, '-' predicted negative relationship.



2008: SLOPE

Figure 4: Path analysis diagram for how performance (percent fat) of adult, female mule deer is affected directly and indirectly by climate in western Colorado in 2008. Indirect linkages are manifested through a measure of the timing of vegetation green-up in the spring derived from NDVI measurements ('onset'). All lines in the diagram represent a specific linear model. Thick solid lines represent strong evidence for an effect (95% credible interval does not overlap zero). Dotted lines represent no clear effect. Regression coefficient estimates are given with 95% credible intervals. '+' predicted positive relationship, '-' predicted negative relationship.



2008: ONSET

Colorado Division of Wildlife
July 2009 – June 2010

WILDLIFE RESEARCH REPORT

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

Period Covered: July 1, 2009 – June 30, 2010

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ABSTRACT

We propose to experimentally evaluate habitat treatments that may improve the landscape to benefit mule deer (*Odocoileus hemionus*) and evaluate human-activity management alternatives to reduce the disturbance of energy development impacts on mule deer. The Piceance Basin of northwestern Colorado was selected as the project area due to ongoing natural gas development in one of the most extensive and important mule deer winter and transition range areas within the state. The data presented here represent the first 2 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 modified the previous study design to monitor 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 locations/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 attached 250 VHF collars (50—80/study area) to fawns and 80 VHF collars to does (20/study area) in early December 2009 and 100 GPS collars (25/study area) to adult female mule deer in early March 2010. Based on the data collected thus far, deer from all areas appear to

be in reasonably good condition and are exhibiting high survival rates. Mild winter conditions the past 2 years certainly contributed to the observed mule deer population parameters. It will be informative to note how the different wintering mule deer herd segments react following a severe winter. 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. We will continue to collect the various population and habitat use data across all study sites to evaluate the effectiveness of the habitat treatments scheduled to begin this fall. 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. We are also evaluating deer behavioral responses to varying levels of development activity and habitat mitigation treatments. This will allow us to assess the effectiveness of certain Best Management Practices (BMPs) and habitat manipulations for reducing disturbance to deer. The study is slated to run through at least 2015, and preferably 2018, to adequately measure 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 and/or transition range elicits behavioral responses, improves body condition, increases overwinter fawn survival, or ultimately, population density on mule deer winter ranges exposed to extensive energy development.

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

SEGMENT OBJECTIVES

1. Collect and reattach GPS collars (5 location attempts/day) 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. Develop cooperative agreements to initiate habitat treatments for assessing efficacy of habitat improvement projects to mitigate energy development disturbances to mule deer.

6. Summarize data and present information in an annual Job Progress Report.

INTRODUCTION

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

The Piceance Basin in northwest Colorado contains one of the largest migratory mule deer populations in North America and also exhibits some of the largest natural gas reserves in North America. Projected energy development throughout northwest Colorado within the next 20 years is 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 3 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 2-3 years and evaluated for another 5-6 years. We initially selected 5 winter range study areas representing varying levels of development to serve as treatment and control sites. The past 2 years, we also estimated winter fawn survival and annual adult female survival, early and 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 differences in deer behavior and changing energy development plans, which can directly affect experimental design. During the previous year, we refined our study design using our baseline deer data and current energy development plans of the major companies operating in Piceance Basin. We split 1 study area (Magnolia split into North and South Magnolia) based on differences in deer movement and behavior patterns from GPS data (Anderson 2009) and eliminated 2 other study sites (Story/Sprague and Yellow Creek) due to incompatible deer behavior patterns to adequately serve as control sites and to reduce the annual project budget to the minimum necessary to meet the original research objectives. This progress report describes the previous 2 years of addressing mule deer population performance during the pretreatment phase, which includes monitoring habitat selection and behavior patterns of adult female mule deer, overwinter fawn and adult female survival, estimates of adult female body condition during early and late winter, and abundance estimates on 4 winter range herd segments in relation to varying levels of natural gas development in control and treatment experimental areas prior to proposed experimental modifications in energy developmental practices and potential habitat improvement treatments.

STUDY AREAS

The Piceance Basin between the cities of Rangely, Meeker, and Rifle in northwest Colorado was selected as the project area due to its ecological importance as one of the largest migratory mule deer populations in North America and because it exhibits one of the highest natural gas reserves in North America (Fig. 1). Historically, mule deer numbers on winter range were estimated between 15,000-22,000 (Bartmann 1975), and the current number of well pads (Fig.1) and projected number of gas wells in the Piceance Basin over the next 20 years is about 250 and 15,000, respectively. Mule deer winter range in the Piceance Basin is predominantly characterized as a topographically diverse pinion pine (*Pinus edulis*)-Utah juniper (*Juniperus osteosperma*; pinion-juniper) shrubland complex ranging from 1675 m to 2285 m in elevation (Bartmann and Steinert 1981). Pinion-juniper are the dominant overstory species and major shrub species include Utah serviceberry (*Amelanchier utahensis*), mountain mahogany (*Cercocarpus montanus*), bitterbrush (*Purshia tridentata*), big sagebrush (*Artemisia tridentata*), Gamble's oak (*Quercus gambelii*), mountain snowberry *Symphoricarpos oreophilus*), and rabbitbrush (*Chrysothamnus* spp.; Bartmann et al. 1992). The Piceance Basin is segmented by numerous drainages characterized by stands of big sagebrush, saltbush (*Atriplex* spp.), and black greasewood (*Sarcobatus vermiculatus*), with the majority of the primary drainages having been converted to mixed-grass hay fields. Grasses and forbs common to the area consist of wheatgrass (*Agropyron* spp.), blue grama (*Bouteloua gracilis*), needle and thread (*Stipa comata*), Indian rice grass (*Oryzopsis hymenoides*), arrowleaf balsamroot (*Balsamorhiza sagittata*), broom snakeweed (*Gutierrezia sarothreae*), pinnate tansymustard (*Descurainia pinnata*), milkvetch (*Astragalus* spp.), Lewis flax (*Linum lewisii*), evening primrose (*Oenothera* spp.), skyrocket gilia (*Gilia aggregata*), buckwheat (*Erigonum* spp.), Indian paintbrush (*Castilleja* spp.), and penstemon (*Penstemon* spp.; Gibbs 1978). The climate of the Piceance Basin is characterized by warm dry summers and cold winters with most of the annual moisture resulting from spring snow melt.

Wintering mule deer population segments we investigated in the Piceance Basin include: North Ridge (57 km^2) just north of the Dry Fork of Piceance Creek including the White River in the northeastern portion of the Basin, Ryan Gulch (130 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 (0.13 pads & facilities/km^2), and relatively high development in the Ryan Gulch (0.64 pads & facilities/km^2) and South Magnolia (0.81 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 (Best Management Practices; BMPs) that may 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 fiscal year 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, and estimating mule deer abundance applying helicopter mark-resight surveys. We employed helicopter net-gunning techniques (Barrett et al. 1982, van Reenen 1982) to capture 50—80 fawns and 20 adult females during early December and 25 adult females during early March in each of the 4 study areas (250 fawns and 180 does total). Once netted, all deer were hobbled and blind folded. Fawns were weighed, radio-collared and released on site, and adult females were transported to localized handling sites for collection of body measurements and were fitted with VHF (20/area during December) or GPS collars (25/area during March; 5 fixes/day; G2110B, Advanced Telemetry Systems, Isanti, MN, USA) and released. To provide direct measures of decline in overwinter body condition, we attempted to capture the same adult females during the March capture that were captured in December. Fawn collars were spliced and fitted with 2 lengths of rubber surgical tubing to facilitate collar drop during mid-summer—early autumn, adult VHF collars were attached static, and GPS collars were supplied with timed drop-off mechanisms scheduled to release early April, 2011. All radio-collars were equipped with mortality sensing options (i.e., increased pulse rate following 4 hrs of inactivity).

Mule Deer Habitat Use and Movements

We downloaded and organized data from GPS collars deployed March 2009 following collar drop and retrieval in early April 2010. GPS collars redeployed early March 2010 maintained the same fix schedule of attempting fixes every 5 hours. We plotted deer locations and recorded timing and distance of spring and fall 2009 migrations for each study area. Mule deer winter concentration areas were created using composite GPS data (winter locations since January 2008 from all deer) 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 (habitat data layers should be available by 2011).

Mule Deer Survival

Mule deer mortality monitoring consisted of daily ground telemetry tracking and aerial monitoring approximately every 2 weeks from fixed-wing aircraft. Once a mortality signal was detected, deer were located and necropsied to assess cause of death. We estimated over-winter survival on a weekly basis using the staggered entry Kaplan-Meier procedure (Kaplan and Meier 1958, Pollock et al. 1989). Capture-related mortalities (any mortalities occurring within 10 days of capture) and collar failures were censored from survival rate estimates. We estimated survival rates 28 June 2009—26 June 2010 for adult females and 6 December 2009—27 March 2010 for fawns. Premature failure of surgical tubing integrity beginning late March inhibited our ability to reasonably estimate fawn survival beyond March 27, 2010.

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) and loin depth (longissimus dorsi muscle, mm). We estimated a body condition score (BCS) for each deer by palpating the rump (Cook et al. 2001). We combined ultrasound rump fat measurements with BCS to develop an index (rLIVINDEX; Cook et al. 2001, 2007) of the relative nutritional status of deer from each study area. We examined differences ($P < 0.05$) in nutritional status among study areas using a two-sample *t*-test. We considered differences in body condition meaningful when either mean rump fat or rLIVINDEX 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 5 (North Magnolia) or 4 (the remaining study areas) helicopter mark-resight surveys (2 observers and the pilot) during late March, 2010 to estimate deer abundance in each of the 4 study areas. We delineated each study area from GPS locations during the same period the previous year and aerial telemetry locations of radio-collared deer within 1 week of the first mark-resight survey. Aerial fixed-wing telemetry surveys were conducted during helicopter 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 number, symbol combinations and attached to each radio-collar to enhance mark-resight estimates. Each deer observed during surveys was recorded as mark ID#, unmarked, or unidentified mark.

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 DISSCUSSION

Deer Captures and Survival

The helicopter crew captured 253 fawns and 80 does in early December 2009 and 103 does in early March 2010. Seven fawn (ultimate cause = 4 cougar predation, 2 coyote predation, 1 drowning) and 2 doe mortalities (ultimate cause = tangled in fence and coyote predation) occurred within the 10 day myopathy period following the December capture and 3 doe mortalities occurred during the March capture (all direct capture myopathy).

Fawn survival during early-December 2009—late March 2010 was similar among study areas ($P > 0.05$) ranging from 0.872 (Ryan Gulch) to 0.945 (North Magnolia; Table 1, Fig. 2). Although mean fawn survival was higher than last year among 3 of 4 study areas (with the exception of Ryan Gulch; see Anderson 2009), differences were statistically insignificant. Annual adult female survival was also similar among study areas ($P > 0.05$) ranging from 0.863 (North Ridge) to 0.943 (North Magnolia; Table 1, Fig. 1) and were comparable to last year ($P > 0.05$; Anderson 2009). The relatively high fawn survival observed the past 2 winters is likely due to the mild winter conditions present through late March, and doe survival was consistent with other mule deer populations experiencing normal winter conditions in the western US (Unsworth et al. 1999).

Seasonal Movement Patterns

Migration patterns differed among areas with North Ridge and North Magnolia deer 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 40.1 km (North Ridge). Similar to seasonal ranges, most deer monitored exhibited strong fidelity to spring and fall migration routes (Fig. 3). Timing of mule deer migration during 2009 was similar among study areas with median spring migration dates occurring between 15 and 20 May and median fall migration dates occurring between 15 and 22 October. Migration dates were later compared to last year (Anderson 2009), occurring 8 to16 days later in the spring and 11 to 14 days later in the fall. Length of migration was relatively short among areas averaging 5 to 10 days in the spring and 4 to 7 days in the fall; these observations were comparable to last year. 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 including next year's migration data is scheduled to be completed by spring 2012.

Winter concentration areas identified from January 2008—May 2010 (Fig. 4) reasonably followed study area boundaries delineated from deer locations applied the first winter of the project (Anderson and Freddy 2009b). We noted more continuous distributions from Ryan Gulch and North Ridge deer, with South Magnolia deer exhibiting the most fragmented and concentrated distributions, which may be related to relative development densities within each study area. Future resource selection analyses will address these differences relative to habitat attributes within each area. Minor modifications to study area boundaries will be applied in the future to better address winter deer use within each study area (Fig. 4).

Mule Deer Body Condition

Body condition measurements of adult female mule deer suggested that North and South Magnolia deer returned from summer range (December 2009) in better condition than North Ridge deer ($P < 0.05$) and condition of Ryan Gulch deer was intermediate and not significantly different (P > 0.05) from the other areas (Table 2). North and South Magnolia deer maintained relatively high body condition over winter, but only North Magnolia deer were in significantly better condition than deer from North Ridge and Ryan Gulch ($P < 0.05$; March 2010, Table 2) by late winter. Paired comparisons of deer captured during December 2009 and March 2010 indicted that mean rump fat and % body fat declined 8.3 mm and 6.9% in North Magnolia ($n = 15$), 8.1 mm and 6.9 % in South Magnolia ($n = 16$), 3.1 mm and

4.0% in North Ridge (*n* = 16), and 6.3 mm and 6.6% in Ryan Gulch (*n* = 19). In comparing late winter body condition from 2009 to 2010, we noted significant improvement from North and South Magnolia deer and similar condition from North Ridge and Ryan Gulch deer. Pregnancy rates were expectedly high ranging from 84% in Ryan Gulch (*n* = 25) to 100% in South Magnolia (*n* = 25).

Early December fawn weights of males and females averaged 39.5 kg (*n* = 30, SD = 4.3) and 36.5 kg (*n* = 30, SD = 3.2) from North Magnolia, 38.5 kg (*n* = 42, SD = 3.8) and 35.1 (*n* = 18, SD = 4.0) from South Magnolia, 37.5 kg (*n* = 33, SD = 4.0) and 34.9 kg (*n* = 50, SD = 4.3) from North Ridge, and 37.1 kg (*n* = 23, SD = 3.3) and 34.5 kg (*n* = 27, SD = 3.4) from Ryan Gulch. Fawn weights were similar among areas except that male and female fawns from North Ridge were larger than Ryan Gulch fawns ($P < 0.05$). Because North and South Magnolia study areas were not split until December 2009 and fawn locations were not sufficiently monitored prior to that time, comparisons to 2008 fawn weights were only possible by combining data from North and South Magnolia in 2009. Both males and females from the combined Magnolia area were larger during December 2009 than December 2008. Fawn weights from the other study areas were similar between years expect for males from North Ridge, which were also larger in 2009 ($P = 0.047$).

Mule Deer Population Estimates

Mark-resight models that best predicted abundance estimates (lowest AICc; Burnham and Anderson 2002) exhibited homogenous individual sightability ($\sigma^2 = 0$) for all study areas and variable sightability (*P*) across surveys in 3 of the 4 study areas; sightability was consistent across surveys in North Magnolia. North Ridge exhibited the highest deer density (20.1/km^2) and comparably lower deer densities were observed in the other 3 areas (6.9—9.3/km^2; Table 3). Abundance estimates were similar to last year (Anderson 2009) except in Ryan Gulch where deer numbers were significantly higher this year. It is unlikely deer abundance increased from 825 (95% CI = 672—1,016) to 1,442 (95% CI = 1112—1878) in 1 year, and we suspect this difference may be partially due differences in sampling approach between years. The abundance estimate from 2009 was derived from subsampling 20 to 40% of the Ryan Gulch study area (Anderson 2009), whereas the 2010 estimate was based on complete sampling of the entire study area. It is plausible that subsampling the study area resulted in a negative bias and we are more comfortable with the 2010 estimate derived from complete coverage of the study area.

Abundance estimates from 2010 were similarly precise from 3 of the 4 study areas (mean CV = 0.16—0.18), with Ryan Gulch exhibiting a relatively wide CI (Table 3; mean CV = 0.27). Number of marked deer was lowest from Ryan Gulch (*n* = 87) and increasing sample size would improve future estimates, as would increasing the number of mark-resight surveys. Additionally, winter concentration information from the past 3 winters (Fig. 4) can be used to more efficiently focus sampling effort potentially increasing mule deer sightability. Our goal is to achieve CVs of ≤0.15 to allow detection of at least 30% population change. We will attempt to improve precision of future mark-resight abundance estimates by increasing sample size using VHF radiocollars and increasing the number of surveys when feasible; simulations suggest CVs can be improved by about 0.02 for each additional mark-resight survey (C. Anderson, unpublished data).

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 2 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 at least 5 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 high survival rates. Mild winter conditions the past 2 years certainly contribute to the observed mule deer population parameters. It will be informative to note how the different wintering mule deer herd segments react following a severe winter. Observed differences in winter concentration areas (Fig. 4) may indicate behavioral modifications to areas of 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 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 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 and habitat mitigation treatments. This will allow us to assess the effectiveness of certain BMPs and habitat manipulations for reducing disturbance to deer.

We recently developed a habitat improvement plan and intend to begin implementation this fall with completion by fall 2011 if feasible or fall 2012 in the Magnolia study areas. In addition, hay field improvements have begun and will continue in the North Magnolia area and we plan to begin discussions addressing hay field improvements in the South Magnolia study area. Recent collaboration agreements with ExxonMobil Development Co. and Colorado State University will provide graduate research opportunities to enhance data collection and inference about mule deer/energy development interactions. 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. 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 2015 and preferably through 2018). We optimistically anticipate the opportunity to work cooperatively toward developing solutions for allowing the nation's energy reserves to be developed in a manner that benefits wildlife and the people who value both the wildlife and energy resources of Colorado.

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Table 1. Survival rate estimates ($\hat{S}$) of fawn (6 Dec. 2009—27 Mar. 2010) and adult female (28 June 2009—26 June 2010) 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	47		0.872 (0.777—0.968)
South Magnolia	63		0.937 (0.876—0.997)
North Magnolia	55		0.945 (0.884—1.000)
North Ridge	80		0.912 (0.849—0.974)
Adult females			
Ryan Gulch	25	47	0.868 (0.757—0.979)
South Magnolia	12	38	0.873 (0.757—0.989)
North Magnolia	14	44	0.943 (0.866—1.000)
North Ridge	27	50	0.863 (0.748—0.978)

[a]Adult female sample size following capture and radio-collaring efforts early March, 2010.

Table 2. Mean rump fat (mm), Body Condition Score (BCS)[a], and an index of relative nutritional status (rLIVINDEX)[b] of adult female mule deer from 4 study areas in the Piceance Basin of northwest Colorado, March and December 2009 and March 2010. Values in parentheses = SD.

	March 2009			December 2009			March 2010		
Study Area	Rump fat	BCS	rLIVINDEX	Rump fat	BCS	rLIVINDEX	Rump fat	BCS	rLIVINDEX
Ryan Gulch	1.73 (1.78)	2.66 (0.55)	2.71 (0.68)	8.35 (6.36)	4.06 (1.13)	4.71 (1.63)	2.31 (1.44)	2.35 (0.48)	2.41 (0.57)
South Magnolia	1.47 (0.68)	2.50 (0.60)	2.51 (0.63)	10.05 (6.19)	4.07 (1.21)	4.87 (1.75)	3.12 (2.20)	2.64 (0.59)	2.78 (0.74)
North Magnolia	1.30 (0.79)	2.56 (0.68)	2.57 (0.70)	10.20 (5.48)	4.25 (0.96)	5.07 (1.42)	3.15 (2.34)	2.85 (0.53)	2.99 (0.70)
North Ridge	1.57 (1.22)	2.60 (0.56)	2.62 (0.60)	5.25 (5.65)	3.63 (1.11)	3.98 (1.59)	1.77 (1.11)	2.42 (0.49)	2.46 (0.54)

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

Table 3. Mark-resight abundance (*N*) and density estimates of mule deer from 4 winter range herd segments in the Piceance Basin, northwest Colorado, 22—31 March 2009. Data represent 5 resight surveys from North Magnolia and 4 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	125	11	1,442 (1,112—1,878)	9.3
South Magnolia	103	18	575 (481—692)	6.9
North Magnolia	102	14	595 (498—715)	7.5
North Ridge	231	23	1,145 (975—1,348)	20.1

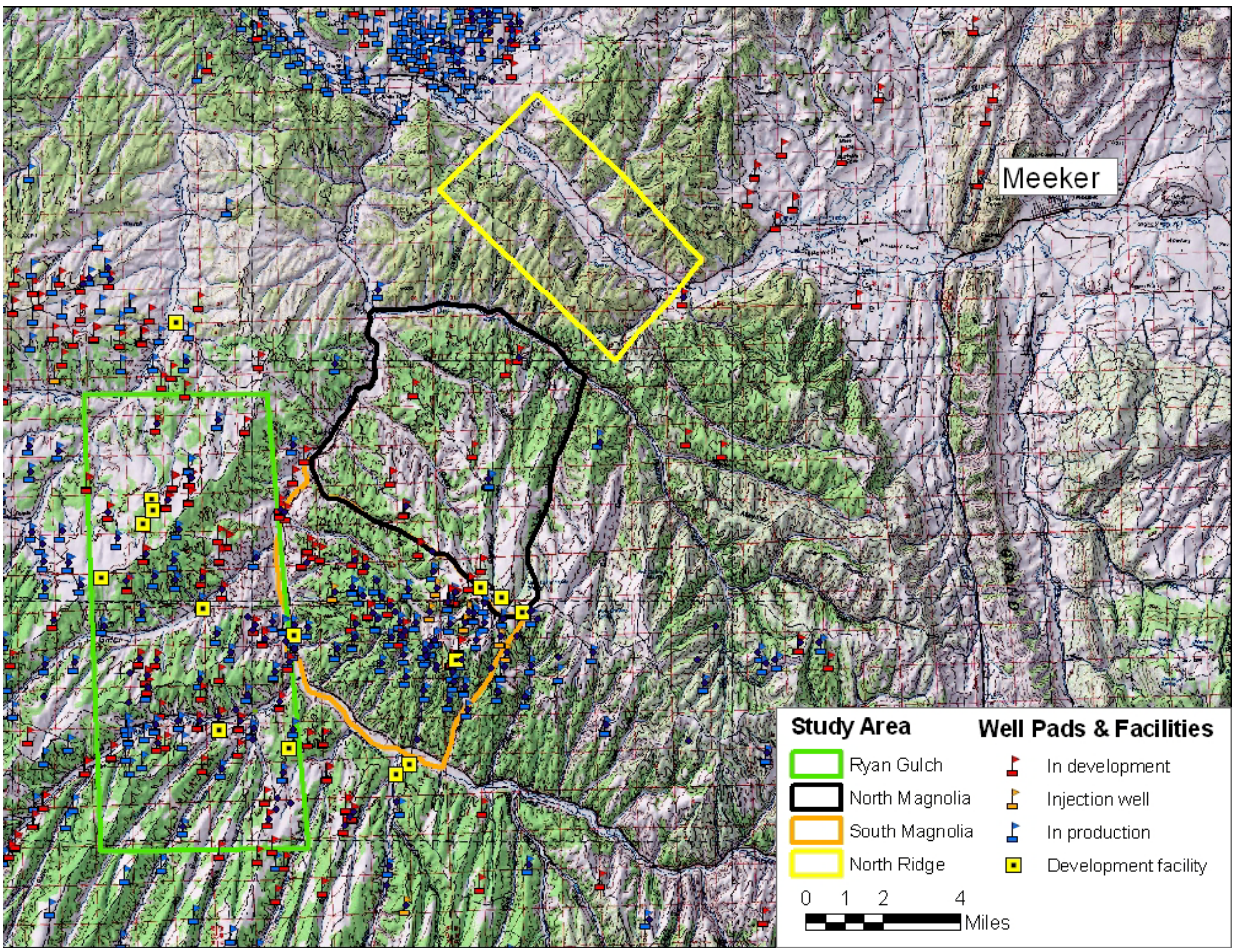
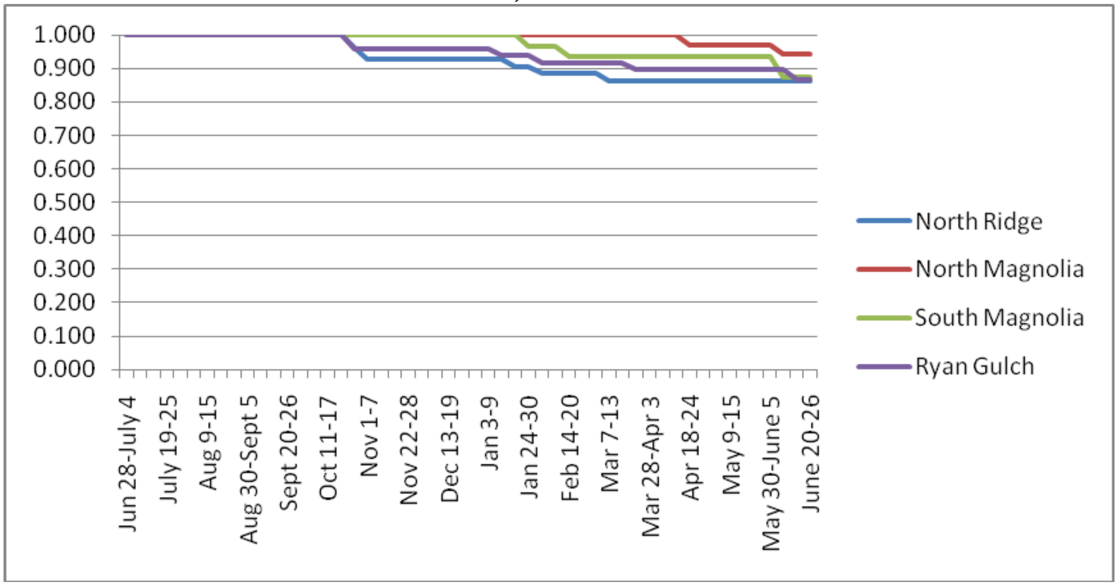


Figure 1. Mule deer winter range study areas relative to active natural gas well pads and energy development facilities in the Piceance Basin of northwest Colorado, summer 2010.

Adult Female Survival, 28 June 2009—26 June 2010



Fawn Survival, 6 December 2009—27 March 2010

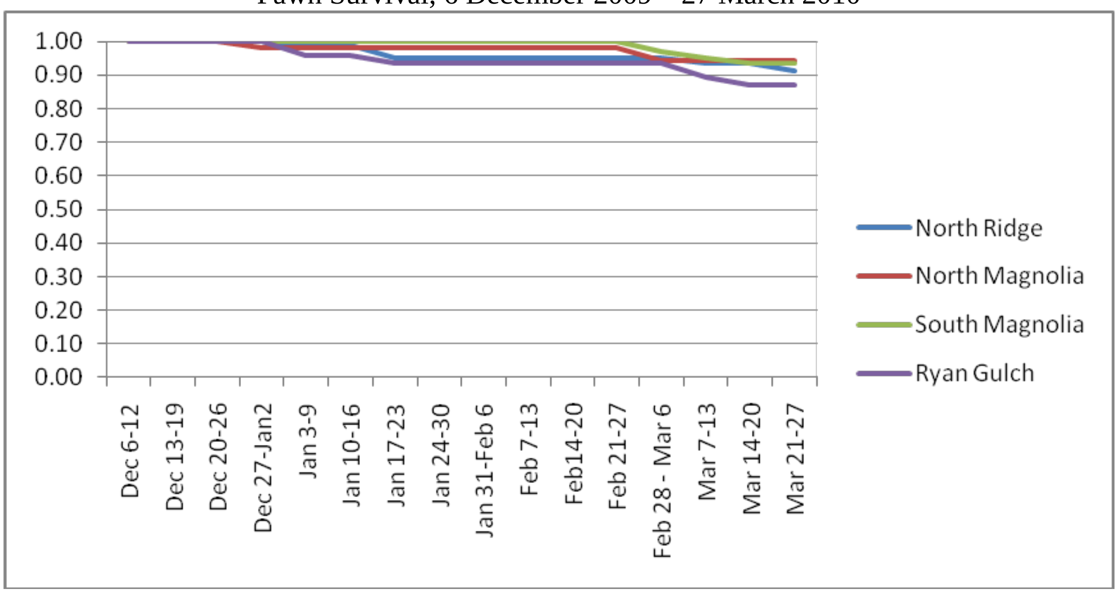


Figure 2. Annual and winter survival rates of adult female (28 June 2009—26 June 2010; top) and fawn (6 December, 2009—27 March, 2010; bottom) mule deer from 4 winter range study areas in the Piceance Basin of northwest Colorado. Survival rates among fawn and doe groups were statistically similar ($P >$ 0.05; Table 1).

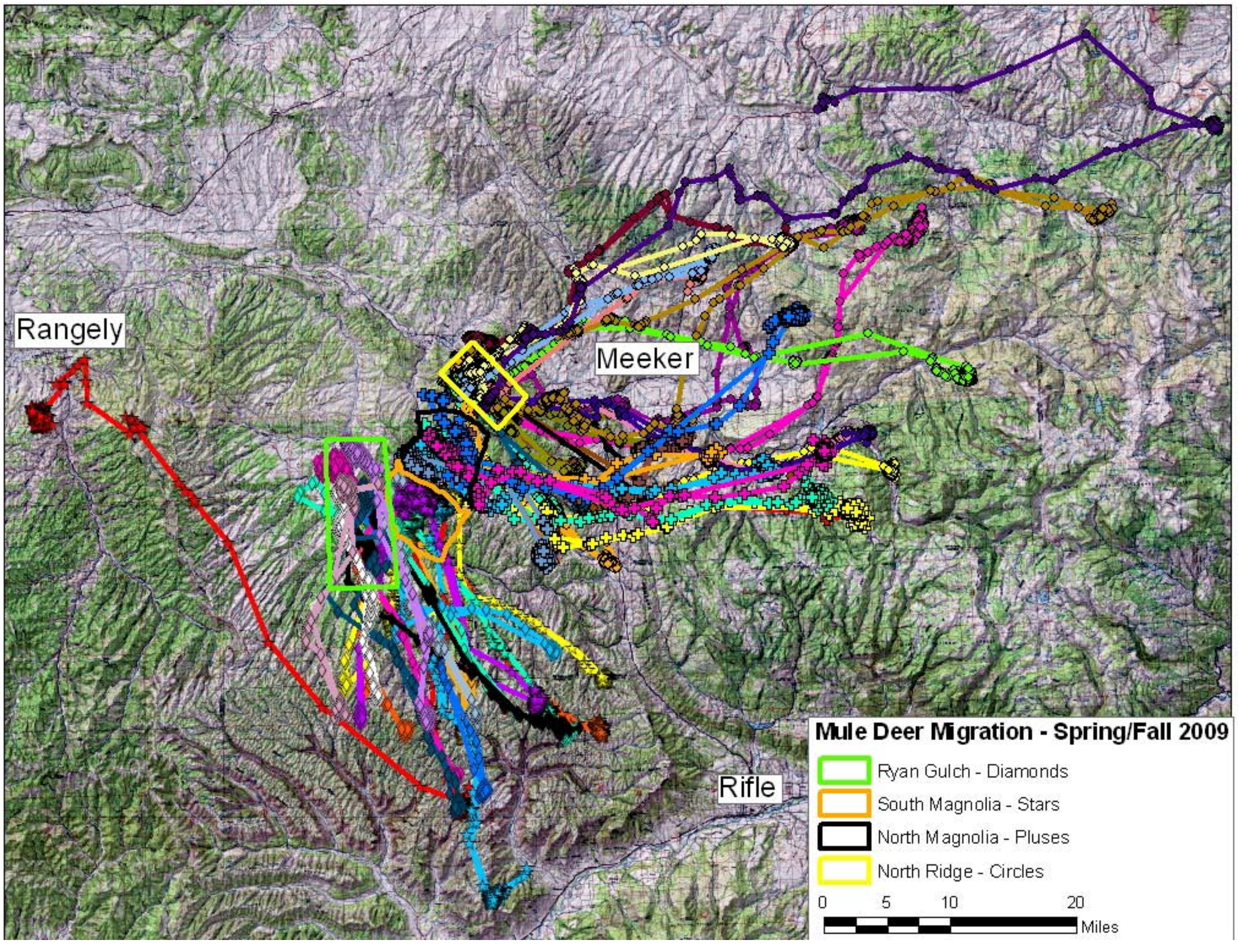


Figure 3. Mule deer migration routes from 4 winter range study areas in the Piceance Basin of northwest Colorado, spring and fall 2009.

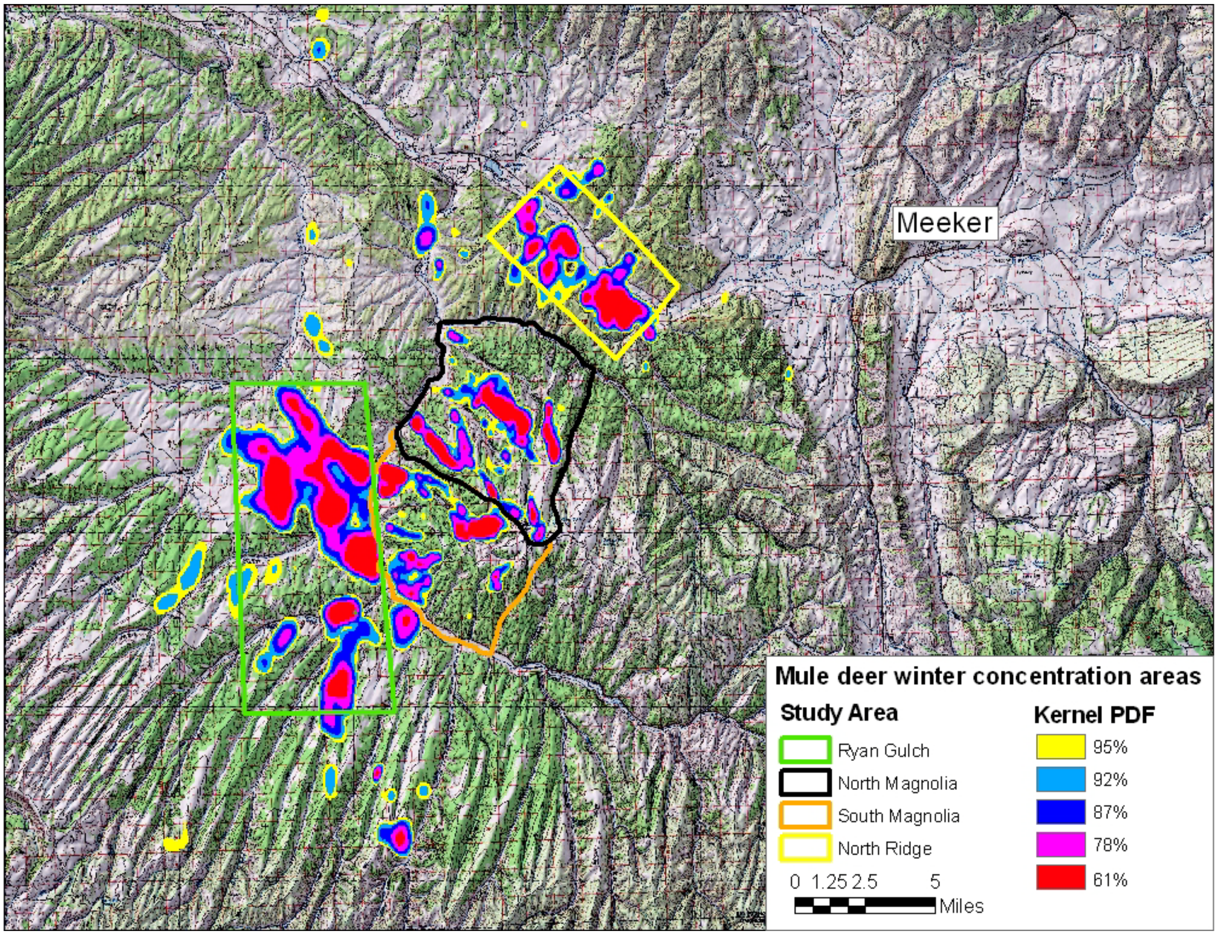


Figure 4. Mule deer winter concentration areas (composite kernel Probability Density Functions; PDF) from 4 study areas in the Piceance Basin of northwest Colorado, December 2008—May 2010. Data from composite GPS locations of adult female mule deer by study area (5 GPS location attempts/day).

Colorado Division of Wildlife
July 2009 – June 2010

WILDLIFE RESEARCH REPORT

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

Period Covered: July 1, 2009 – June 30, 2010

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

ABSTRACT

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 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.

WILDLIFE RESEARCH REPORT

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

CHAD J. BISHOP, CHUCK R. ANDERSON, DANIEL P. WALSH, 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

1. Evaluate rates of VIT retention to parturition and fawn capture success using the newly-designed wings in free-ranging mule deer.
2. 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.

To date, the wings used to retain VITs have been purchased from a company in New Zealand (Carter Holt Harvey Plastic Products, Hamilton, New Zealand) that originally produced them for an application in the livestock industry (Bowman and Jacobson 1998). The company manufactured 1 large wing and 1 small wing; the former has been used 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). These study units are part of a larger research study evaluating effects of natural gas development and mitigation on mule deer (Anderson and Freddy 2008). Winter range habitat comprised predominantly pinyon pine (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*) and secondarily big sagebrush (*Artemisia tridentata*), serviceberry (*Amelanchier utahensis*), mountain mahogany (*Cercocarpus montanus*), bitterbrush (*Purshia tridentata*), and rabbitbrush (*Chrysothamnus* spp.). Drainage bottoms were characterized by stands of big sagebrush, saltbush (*Atriplex* spp.), and black greasewood (*Sarcobatus vermiculatus*), with the majority of the primary drainage bottoms having been converted to irrigated, grass hay fields. Elevations ranged from 1,860 m at Piceance Creek in Ryan Gulch to 2,280 m in Yellow Creek and Story-Sprague study units. Our summer range study area comprised roughly 1,700 km^2 across the Roan Plateau and Piceance Basin (Fig. 1). Principal summer range habitat types included aspen (*Populus tremuloides*), mountain shrub, oakbrush (*Quercus gambellii*), big sagebrush, and pinyon-juniper. Serviceberry, snowberry (*Symphoricarpos* spp.), and chokecherry (*Prunus virginiana*) were common species in mountain shrub communities. Elevation ranged from 2,000 m in Piceance Creek at the mouth of Story Gulch to 2,600 m on Roan Plateau.

METHODS

We worked with ATS personnel to redesign the M3930 VIT presently manufactured by ATS. The existing M3930 has been described in detail elsewhere (Bowman and Jacobson 1998, Carstensen et al. 2003, Johnstone-Yellin et al. 2006, Bishop et al. 2007). Our redesign included changes to the retention wings and the means by which they are attached to the transmitter body (Fig. 2). Specifically, we modified dimensions of the retention wings by lengthening them from 57 mm to 68 mm and widening them from 9 mm to 13 mm. We also added ridges to the wing surface as means to increase probability of retention to parturition. The wings were made of flexible plastic encased in silicone. We initially produced a small number of the newly-designed wings using a relatively inexpensive prototype mold, which met our target specifications and therefore was deemed acceptable. We then manufactured a production mold, necessary to produce a large number of the wings. We incorporated ejector pins into the VIT design that allow wings to be attached to the VIT transmitter body in the field. In the original design, wings were permanently affixed to the transmitter body during the VIT assembly process. Although we only used one wing size in this study, field-attachment will allow researchers to use more than one wing size or style, without purchasing extra transmitters, if additional production molds are manufactured over time. For each wing design (i.e., production mold), extra wings could be inexpensively purchased and available in the field to affix to the fixed number of transmitter bodies. Researchers could then individually fit VITs to animals in the field much in the same way radiocollars are individually fitted.

During late February and early March, 2009, we captured 60 adult female deer utilizing helicopter net guns (Barrett et al. 1982, Krausman et al. 1985, White and Bartmann 1994) in conjunction with ongoing research addressing other objectives (Anderson and Freddy 2008). We captured 20 deer each in Ryan Gulch and Yellow Creek, and 10 deer each in South Magnolia and Story-Sprague study units (Fig. 1). Captured deer were hobbled, blind-folded, and ferried ≤5 km by helicopter to a central handling location. For each captured deer, we used transabdominal ultrasonography (SonoVet 2000, Universal Medical Systems, Bedford Hills, NY) to determine pregnancy status and number of fetuses (Stephenson et al. 1995, Bishop et al. 2007, Bishop et al. 2009). We also measured rump fat depth of each deer using ultrasonography and estimated a body condition score using palpation to estimate percent body fat (Stephenson et al. 2002, Cook et al. 2007). We measured mass by placing each deer on a stretcher and attaching the stretcher to a scale supported by a steel frame. We measured chest girth by placing a cloth tape around the chest immediately posterior to the front shoulders and recording measurement when deer exhaled. Last, we measured hind foot length of each deer and estimated age by evaluating tooth replacement and wear (Severinghaus 1949, Robinette et al. 1957). This aging technique is susceptible to measurement error (Hamlin et al. 2000). However, two trained observers, each with experience aging >1,000 deer in the field, estimated age of all deer in this study to minimize error and to insure that relative age differences across all deer in our sample were correctly captured in the data. We performed handling procedures in a wall-frame tent to create a dim environment for viewing ultrasound imagery.

We fitted each pregnant deer with a radiocollar and VIT. Collar transmitters were turned off on Saturdays and Mondays to extend battery life for meeting other research objectives (Anderson and Freddy 2008). Each collar was equipped with a mortality sensor and store-on-board global positioning system (GPS). Mortality sensors were programmed to switch signal transmission from 60 pulses to 120 pulses per minute after remaining motionless for 8 hours. Each VIT had a temperature-sensitive switch and a pre-cut antenna (6 cm in length) with antenna tip encapsulated in a resin bead to eliminate sharp edges. The temperature-sensitive switch caused the VIT to increase pulse rates from 40 pulses to 80 pulses per minute when the temperature dropped below 32° C, which was indicative of VIT expulsion. We sterilized VITs in a chlorhexidine solution prior to insertion in the field. We inserted VITs using a clear, plastic swine vaginoscope (Jorgensen Laboratories, Inc., Loveland, CO) and alligator forceps. The vaginoscope was 15.2 cm long with a 1.59 cm internal diameter and had a smoothed end to minimize vaginal trauma. We placed vaginoscopes and alligator forceps in cold sterilization containers with chlorhexidine solution between each use and used a new pair of surgical gloves to handle the vaginoscope and VIT for each deer, and we applied lidocaine topically to the deer's vagina to minimize irritation during VIT insertion. To insert a VIT, we folded the wings together and placed the VIT into the end of the vaginoscope. We liberally applied sterile KY Jelly® to the scope and inserted it into the vaginal canal until the tip of the VIT antenna was approximately flush with the vulva. We used previous field experience to guide insertion distance and antenna length (Bishop et al. 2007). We extended alligator forceps through the vaginoscope to firmly hold the VIT in place while the scope was pulled out from the vagina.

During winter and spring, we monitored live-dead status and general location of radiocollared adult females daily from the ground, except when collars were inactive, and biweekly from the air via fixed-wing aircraft. During June, we checked VIT signal status each morning of the week that radiocollars were active by aerially locating each radiocollared doe carrying a VIT. We began flights at approximately 0630 hours and completed them by 0900–1100 hours. Early flights were necessary to detect fast signals because temperature sensors of VITs expelled in open habitats and subject to sunlight often exceeded 32° C by mid-day, which caused VITs to switch back to a slow (i.e., prepartum) pulse (Newbolt and Ditchkoff 2009). When we detected a fast (i.e., postpartum) pulse rate, we ground-located the VIT and radiocollared doe in ≤3 hours using very high frequency (VHF) receivers and directional antennae. We attempted to observe behavior of the collared adult female, establish whether the VIT was shed at a birth site, and search for fawns in the vicinity of the adult female and expelled VIT. In cases where the dam moved away from the VIT (i.e., >200 m), we located the VIT to determine whether shedding occurred at a birth site and whether any stillborn fawns were present and subsequently located the collared dam to search for fawns at her location. We attempted to account for each dam's fetus(es) as live or stillborn. We typically worked in pairs, which allowed us to effectively partition effort across the study area while maintaining efficiency when searching for neonates (i.e., two people were more effective locating a hidden neonate than one person). We described effort associated with locating fawns by calculating the number of person-hours per fawn. We also quantified cost per fawn by considering all operating and personnel expenses, including capture and VIT costs for adult females. All deer capture and handling procedures and use of VITs were approved by Colorado Division of Wildlife's (CDOW) Institutional Animal Care and Use Committee (Project # 17-2008).

We assigned the fate of each VIT to one of 4 categories: 1) retained (i.e., VIT expelled during parturition), 2) nearly-retained (i.e., VIT expelled ≤3 days prepartum), 3) not retained (i.e., VIT expelled >3 days prepartum), or 4) censored. We considered a VIT to be retained if it was expelled at or near a birth site in conjunction with parturition. For 75% of retention events, we located the VIT at a birth site and located neonate(s) near the VIT or in close proximity to the dam. In other cases, the VIT was not at a birth site but we readily found the dam and her newborn fawn(s) nearby, sometimes at a birth site 10–100 m from the VIT. In these situations, we considered a VIT retained if we documented <1-day-old fawn(s) <24 hours after the VIT was expelled. Finally, on two occasions, we considered a VIT retained because it was located at an evident birth site even though we could not locate fawns. Birth sites appeared as atypically large deer beds with soil appearing damp and with forbs and grasses flattened and radiating outward, consistent with a deer licking the site clean. On some occasions, fawns and/or placental remains were still present at birth sites when we arrived, providing positive confirmation of birth site characteristics. We distinguished VITs expelled ≤3 days prepartum as nearly-retained because they provided useful information for locating fawns, consistent with Bishop et al. (2007). We documented such cases by locating a dam's neonate(s) one or more days after the VIT was expelled and comparing neonate age to VIT expulsion date. We estimated neonate age using hoof characteristics, condition of the umbilical cord, pelage, and behavior (Haugen and Speake 1958, Robinette et al. 1973, Sams et al. 1996, Pojar and Bowden 2004). We assumed a VIT was shed >3 days prepartum if the VIT was not at an evident birth site and we documented ≥2 of the following characteristics: 1) the adult female was located with other deer during repeated relocations for >3 days after the VIT was shed, 2) the adult female exhibited no behavioral cues indicating she had a fawn, 3) the adult female was noticeably still pregnant, and 4) we failed to locate a neonate following repeated searches for ≥1 week after the VIT was shed. We censored VITs from our retention analysis when adult females died prior to parturition or when adult females were located on private land that we did not have permission to access. In either case, we were unable to evaluate VIT retention to parturition. All females dying prior to parturition were still carrying the VITs upon death.

We modeled VIT retention probability using a generalized logits model (i.e., multinomial logistic regression) in PROC LOGISTIC in SAS (SAS Institute, Cary, NC). We evaluated goodness-of-fit of the global model (i.e., model containing each predictor variable) by dividing model deviance by its degrees of freedom. We considered 3 levels of retention consistent with our description above (i.e., retained, nearly-retained, not retained) and we removed all censors from the dataset prior to analysis. Our primary purpose for this analysis was to evaluate whether our VIT design modifications increased VIT retention probability in larger deer. Our design modifications were based on the observation by Bishop et al. (2007) that VIT retention probability declined as deer body size increased. We modeled VIT retention as a function of mass (kg), hind foot length (cm), chest girth (cm), adult female age (yr), and body fat (%). We considered only linear models because we lacked a rationale for evaluating higher-order polynomial functions. Several of the variables we considered in our analysis were likely correlated because they represented different ways of expressing deer body size. We did not expect models comprising each of these variables to receive more support than simpler models. Thus, we focused our candidate model set on models with one or two variables. We evaluated all single-variable models plus we evaluated two-variable models that included age with each other variable. Age partially related to deer body size but age also related to number of times a female had previously given birth and possibly to behavioral differences among deer, either of which could have influenced retention probability. Thus, age tested hypotheses about retention probability that were not just related to body size or condition. We also considered several models with ≥3 variables to determine whether there was any support for models with higher numbers of parameters. We evaluated 13 models in total and we selected among models using Akaike's Information Criterion adjusted for sample size (AIC_c; Burnham and Anderson 2002). We model-averaged beta parameter estimates to incorporate model selection uncertainty when evaluating whether VIT retention probability varied as a function of the variables in our analysis. We did not model-average real parameter estimates because each of our predictor variables was continuous.

We modeled fawn detection probability based on adult females that retained or nearly retained VITs. We planned to conduct separate analyses for singleton and twin litters, but we achieved perfect detection with singleton litters. We therefore modeled fawn detection probability considering only females with twin fetuses using a generalized logits model in SAS, and we evaluated goodness-of-fit by dividing model deviance by its degrees of freedom. We used 3 detection levels (0, 1, 2 fawns) and we modeled detection as a function of VIT retention status (retained vs. nearly-retained), VIT shed-day, adult female age, and vegetative cover at VIT expulsion site. Shed-day distinguished between VITs detected on fast pulse on Sundays and Tuesdays (dummy code = 1) and VITs detected on fast pulse during Wednesday–Friday (dummy code = 0). We used the shed-day variable to evaluate whether delayed response time, caused by our inability to monitor deer on Saturdays and Mondays, influenced our ability to detect fawns. We included adult female age in our analysis to evaluate if older females may have been more experienced at hiding fawns. Last, we used vegetative cover to evaluate if fawns were more difficult to detect in heavier cover. We expressed vegetative cover categorically as low, medium, or high based on a visual assessment at the site. Low cover class was characterized by limited understory and overstory vegetation with minimal visual obstruction at ground level (e.g., sparsely-vegetated grass, sagebrush, or mountain shrub slopes). Medium cover class was characterized by moderate to heavy vegetative cover within 1 m of the ground but limited cover above 1 m (e.g., typical sagebrush, mountain shrub sites). High cover class comprised moderate to heavy vegetative cover from ground level up to > 1 m with nearly complete visual obstruction (e.g., oakbrush, aspen-mountain shrub, dense serviceberry). We evaluated all single-variable models in addition to 4 models with ≥2 variables to determine whether there was any support for models with higher numbers of parameters. We evaluated 9 models in total and we selected among models using Akaike's Information Criterion adjusted for sample size (AIC_c; Burnham and Anderson 2002). We did not model-average parameter estimates because it would have resulted in 10 different estimates of each level of fawn detection probability for a total of 30 probability estimates. These differences were not supported by the model selection results.

We used our VIT retention and fawn detection probabilities to guide calculation of VIT sample sizes for planning future neonatal studies. We expressed the expected number of neonates to be encountered from a sample of VITs as:

$$\mathbf{E}[n_{Neo}] = n_{VITs} S_{AdF} R_{VIT} \left[T_{AdF}\left(p_{1|Twins} + 2p_{2|Twins}\right) + (1 - T_{AdF}) p_{1|Single}\right],$$

where

n_{Neo}	= neonate sample size.
n_{VITs}	= sample size of adult females with VITs.
S_{AdF}	= probability an adult female survives to parturition and is accessible.
R_{VIT}	= probability an adult female retains her VIT to within 3 days of parturition given she survives to parturition and is accessible (i.e., VIT is retained or nearly retained).
T_{AdF}	= probability adult female has twin fetuses.
$p_{1\|Twins}$	= probability 1 fawn is detected given an adult female retains her VIT and has twin fetuses.
$p_{2\|Twins}$	= probability 2 fawns are detected given an adult female retains her VIT and has twin fetuses.
$p_{1\|Single}$	= probability 1 fawn is detected given an adult female retains her VIT and has one fetus.

Since we had perfect detection with singleton litters and observed a high probability of detecting at least 1 fawn from twin litters, we simplified the above equation to:

$$\mathbf{E}[n_{Neo}] = n_{VITs} S_{AdF} R_{VIT} \left(p_{Fawn} + T_{AdF} p_{2|Twins}\right),$$

where p_{Fawn} is the probability of detecting at least 1 fawn, irrespective of litter size.

Thus, given a targeted sample size of neonates, the estimated number of VITs required can be calculated as:

$$n_{VITs} = \frac{\mathbf{E}[n_{Neo}]}{S_{AdF} R_{VIT} \left(p_{Fawn} + T_{AdF} p_{2|Twins}\right)}.$$

We incorporated our estimates into the above equation to provide guidance for planning future studies.

RESULTS AND DISCUSSION

A retention wing of 1 VIT snapped at its base when the wings were squeezed together for placement into a vaginoscope, prior to insertion into a deer. No other retention wings exhibited any cracking or weakness when squeezed together, even after VITs were recovered from animals during spring and summer. Thus, we found this to be an isolated incident, and our resulting sample size was 59 deer with VITs.

The probability that an adult female receiving a VIT in winter survived to parturition and was accessible (S_{AdF}) was 0.797 (SE = 0.0529). We observed 9 adult female mortalities during winter and spring, and there was no evidence to suggest VITs were related to the mortality events. Four of the mortalities occurred within 1 week of capture and were likely capture-related. We were unable to ground-monitor 2 other adult females during the fawning period because they were located on private land that we did not have permission to access. One other adult female was inadvertently deleted from the aerial monitoring list due to miscommunication. We censored these 12 deer from our analysis of VIT retention because they did not permit evaluation of VIT retention to parturition, resulting in a sample size of 47 deer.

Our global model of VIT retention probability (k = 12) adequately fit the data (deviance/df = 0.670, P = 0.991). The model of VIT retention probability with the lowest AIC_c included only the intercept (k = 2, ΔAIC_c = 0.00, w_i = 0.331), although the model with deer age received some support (k = 4, ΔAIC_c = 1.42, w_i = 0.163; Table 1). There was slight evidence that retention probability was lower in older deer ($\hat{\beta}_{age,not\ retained}$ = 0.169, SE = 0.256; Fig. 3). Also, there was slight evidence that retention probability was lower in larger deer ($\hat{\beta}_{hind\ foot,not\ retained}$ = 0.086, SE = 0.171; Table 1). Based on the intercept-only model, the probability of a VIT being expelled during parturition (i.e., retained) was 0.766 (SE = 0.0605) and the probability of a VIT being expelled ≤3 days prepartum (i.e., nearly-retained) was 0.128 (SE = 0.0477). Thus, the probability of a VIT being retained to within 3 days of parturition (R_{VIT}) was 0.894 (SE = 0.0441).

Our global model of fawn detection probability (k = 12) adequately fit the data (deviance/df = 0.846, P = 0.730). The model of fawn detection probability with the lowest AIC_c included only the intercept (k = 2, ΔAIC_c = 0.00, w_i = 0.600), whereas the model with the next lowest AIC_c included the VIT shed-day variable (k = 4, ΔAIC_c = 1.80, w_i = 0.244; Table 2). Thus, we observed some evidence that fawn detection probability was influenced by our inability to monitor deer 2 days of the week ($\hat{\beta}_{shed-day,singleton}$ = 0.537, SE = 0.738). The probability of detecting twins was 0.688 (SE = 0.114) when we located adult females <24 hours after their VITs switched to fast pulse, whereas twin detection probability was 0.500 (SE = 0.115) when our response time was delayed due to irregular monitoring. There was no evidence that probability of fawn detection was influenced by dam age or vegetative cover. Also, fawn detection probability did not meaningfully differ between females with retained and nearly-retained VITs. We detected 58 neonates and 2 stillborns from 42 adult females (1.4 neonates/female) that retained or nearly retained VITs. We detected a neonate from each adult female that had 1 fetus ($p_{1|Single} = 1.0$, n = 8). For adult females with twin fetuses (n = 34), based on the intercept-only model, the probability of detecting 1 neonate ($p_{1|Twins}$) was 0.353 (SE = 0.0803) and the probability of detecting twins ($p_{2|Twins}$) was 0.588 (SE = 0.0827). Combining litter sizes, the probability of detecting at least 1 neonate (p_{Fawn}) was 0.952 (SE = 0.0334). The probability of an adult female having twin fetuses (T_{AdF}) was 0.810 (SE = 0.0613).

On average, we located one neonate or stillborn per VIT in our initial sample (n_{Neo} = 60, n_{VITs} = 59). Thus, inputting our estimates into our sample size equation, we found that VIT sample size should roughly equal the targeted neonate sample size:

$$n_{VITs} = \frac{\mathbf{E}[n_{Neo}]}{(0.80)(0.89)[0.95 + (0.81)(0.59)]} = \frac{\mathbf{E}[n_{Neo}]}{1.02}\ .$$

We expended roughly 700 person-hours during the fawning period to locate 58 neonates and 2 stillborns, or approximately 12 person-hours per fawn located. This estimate includes hours spent searching for fawns from adult females that expelled VITs >3 days prepartum, although we were never successful in these attempts. We expended $31,000 to net-gun our sample of adult females, $15,000 on VITs, $10,000 on fixed wing monitoring, and $20,000 on personnel. Thus, we expended approximately $1,267 per neonate located. We did not include adult female radio collars in this cost estimate because we used GPS collars to meet other research objectives, yet VHF collars would have sufficed for locating neonates. Assuming VHF collars were used on adult females at a rate of $250 per collar, our cost estimate is approximately $1,520 per fawn.

Our wing modification increased VIT retention in adult female mule deer. Our results are consistent with Haskell et al. (2007), who observed 81% retention (17/21) in the final year of their study after lengthening VIT wings and preventing antennas from protruding >1 cm past the vulva. Our study expanded on Haskell et al. (2007) by incorporating VIT wing modifications into the manufacturing process and conducting a focused field evaluation of those modifications. Investigators using the original VIT wing design in mule deer observed much lower rates of retention than we observed (Johnstone-Yellin et al. 2006, Bishop et al. 2007, Haskell et al. 2007). Using the original design, Bishop et al. (2007) found that the probability of VIT expulsion during parturition was 0.447 (SE = 0.0468), and the probability of VIT expulsion during parturition or ≤3 days prepartum was 0.623 (SE = 0.0456). We employed the same methodology as Bishop et al. (2007), except for the wing modification. Our study area was 100 km north of where Bishop et al. (2007) conducted their study. Assuming the 2 studies are comparable, our wing modification increased VIT retention to parturition by 0.319 (SE = 0.0765) and VIT retention to within 3 days of parturition by 0.271 (SE = 0.0634).

The intercept-only model of VIT retention probability received the most Akaike weight, which is partly a reflection of our limited sample size. However, overall high rates of retention likely explain why we did not observe any strong relationships between VIT retention and deer body size. Bishop et al. (2007) found that larger deer were more likely to expel VITs prematurely, which was our basis for modifying VIT wings and conducting this study. Our results suggest the wing modifications effectively reduced premature expulsion, particularly in larger deer (Fig. 4).

We documented a high probability of detecting at least 1 fawn from adult females that retained or nearly retained VITs, regardless of litter size. When a VIT was shed and evidence suggested the adult female was near parturition or had already given birth, we conducted intense searches up to 1 hour in length for successive days until a fawn was found. Thus, irrespective of vegetative cover or other covariates we assessed, we usually found a fawn when a VIT was adequately retained because it focused our search effort. Our likelihood of detecting twins was somewhat lower, in part because of our irregular monitoring schedule. However, other factors explain why twin detection probability was lower. First, our search intensity decreased when searching for a second fawn. For example, if we had searched most of an hour before detecting the first fawn, we typically limited our search time for a second fawn to minimize our disturbance to the adult female. Second, we did not place radio collars on fawns, and therefore, we could not relocate radiocollared fawns to search for their siblings. The technique of relocating a radiocollared fawn to locate its sibling was found to be successful in a previous study in Colorado (Bishop et al. 2009). During this earlier study, when a dam was known to have twin fetuses yet only one fawn was located and radiocollared during the initial capture attempt, the sibling fawn was found 45% of the time (10/22) by relocating the initial radiocollared fawn 1–2 days post-capture (C. J. Bishop, CDOW, unpublished data). Based on this rate, we would expect our probability of detecting both fawns from twin litters to be roughly 0.77 had we radiocollared fawns during our study.

We found that our sample size of detected neonates roughly equaled our sample size of VITs, which provides a useful guide for planning future research using our modified wing design. However, this recommendation may overestimate VIT sample size because of our lower rate of twin detection and because adult female survival was lower than we anticipated. Fortunately, accessibility of adult females was higher than expected considering we lacked permission to access a large tract of land in the middle of summer range. Bishop et al. (2007) observed 0.97 survival of adult females to parturition and 0.99 were accessible during fawning (S_{AdF} = 0.95). Adult female survival and accessibility is specific to study area. Twinning probability may also vary regionally. We therefore recommend use of the following equation for planning VIT sample size that incorporates information specific to the study area or region of interest:

$$n_{VITs} = \frac{\mathbf{E}[n_{Neo}]}{S_{AdF}[(0.85) + T_{AdF}(0.53)]} .$$

Bishop et al. (2007) expended 7 person-hours per captured fawn from adult females with successful VITs, 16 person-hours per fawn from females with partially successful VITs, and 42 person-hours per fawn from females with failed VITs and females not receiving VITs. Given their observed VIT success rates, Bishop et al. (2007) would have required approximately 1,315 person-hours to locate 60 neonates, or 22 person-hours per fawn. Assuming these studies are comparable, increased VIT success associated with our modified wing design resulted in a 45% reduction in labor required to locate a fawn from a radiocollared adult female.

The VIT technique is effective but expensive to employ. Actual cost of the technique, however, depends on what costs are already incurred to meet other research objectives. For example, in Colorado and elsewhere, researchers have begun estimating late-winter deer body condition as a response variable to accompany survival estimates. In these cases, adult female capture and radio collar costs are already accounted for in the base study, and thus, incorporation of VITs to facilitate neonate capture becomes much more cost-effective. In our study, where adult female capture and collar costs were covered by ongoing research efforts, the added cost of incorporating VITs and neonate capture was $750 per fawn.

SUMMARY

Use of VITs in well-designed field studies 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.

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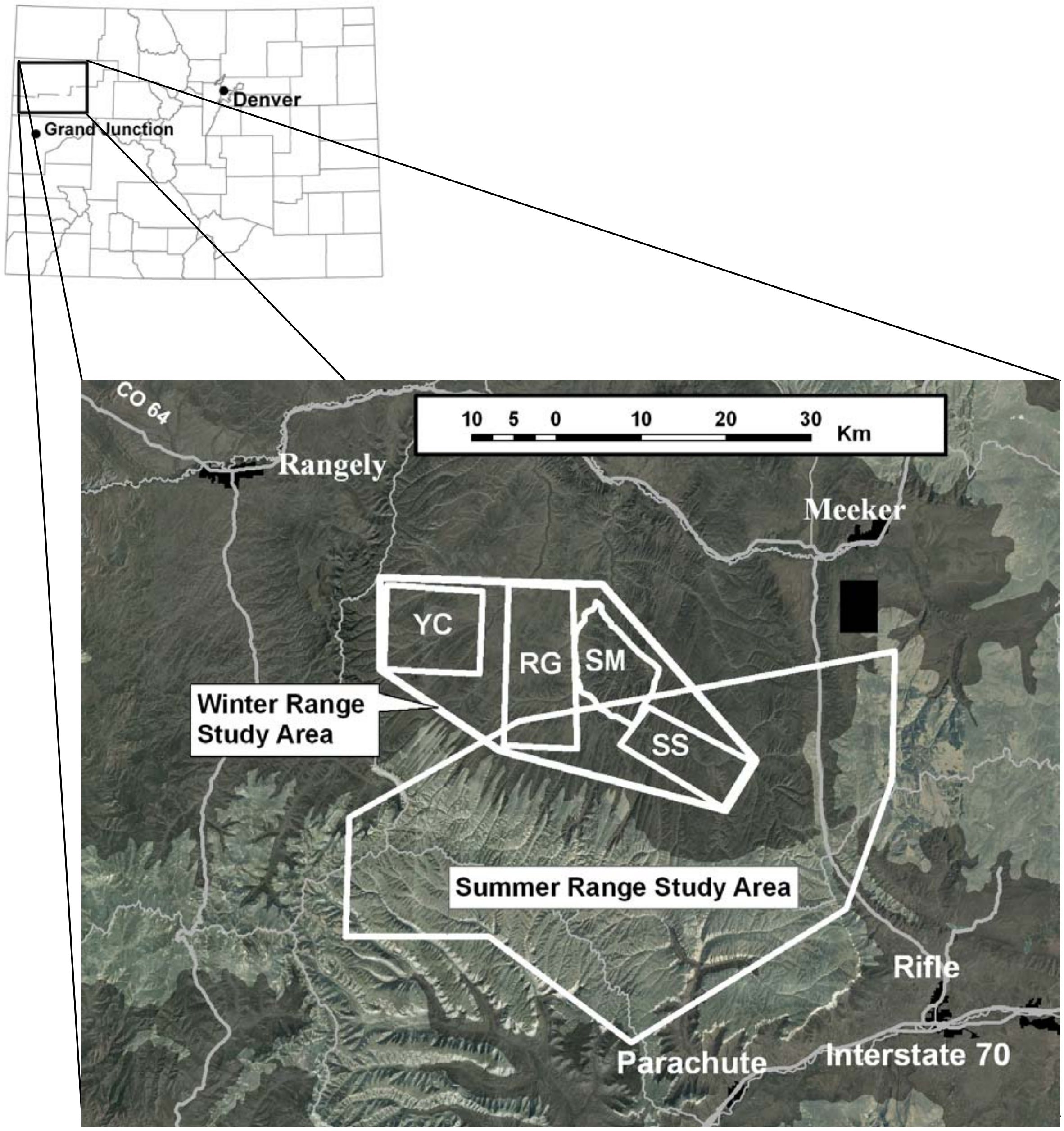
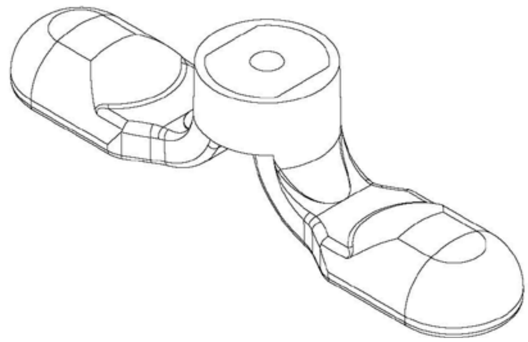


Figure 1. Location of winter and summer range study areas in Piceance Basin and Roan Plateau, northwest Colorado. Winter range study units where we captured and radio-marked mule deer are noted as: YC = Yellow Creek, RG = Ryan Gulch, SM = South Magnolia, and SS = Story-Sprague.

A



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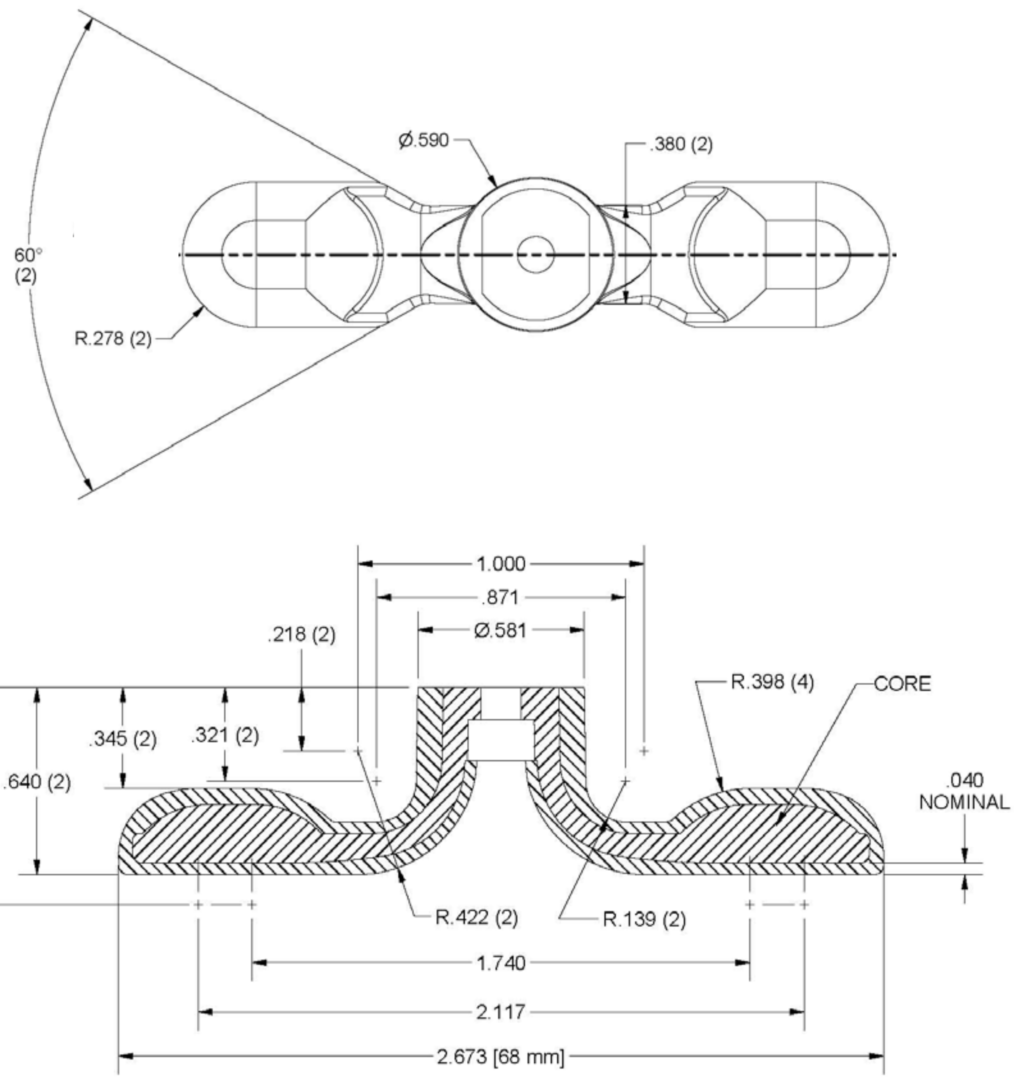

Figure 2. Three-dimensional view (A) and dimensions (B) of a modified retention wing used to retain vaginal implant transmitters in adult female mule deer. The displayed dimensions at bottom include a nylon core with an elastomeric overmold that protects deer from any sharp or rigid edges.

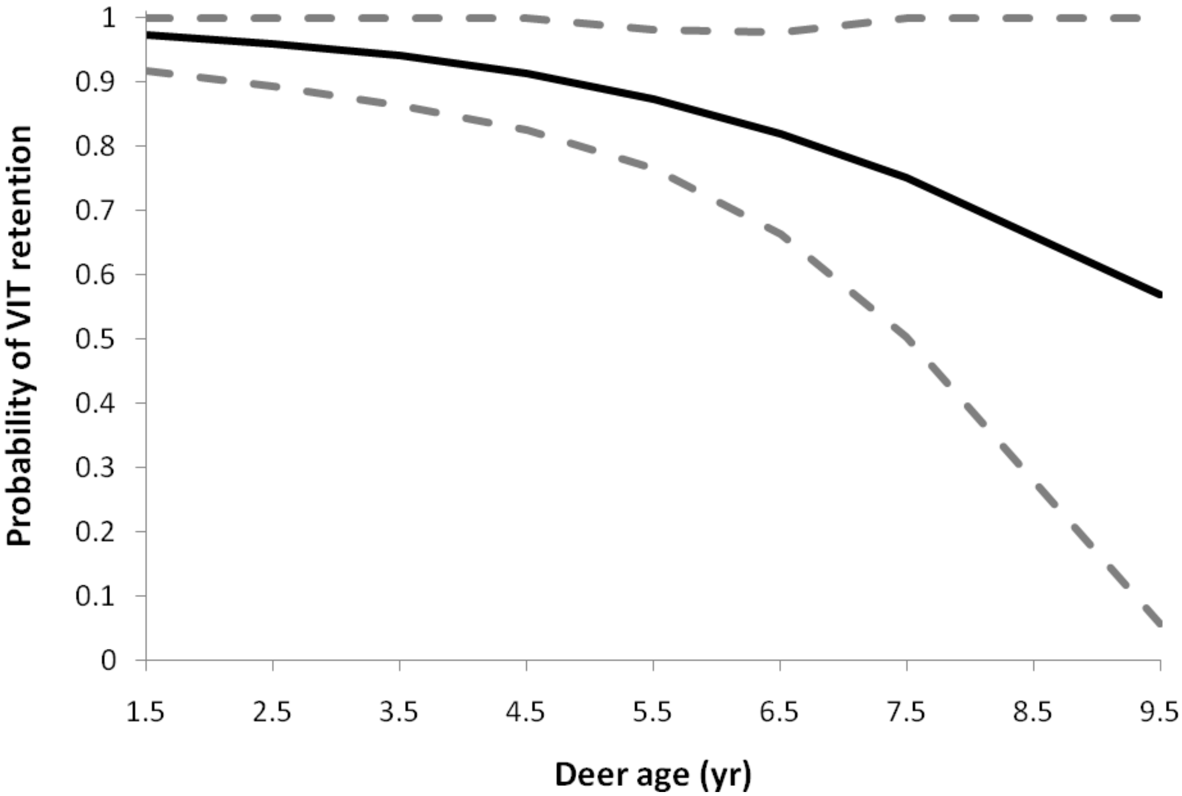

Figure 3. Estimated probability and 95% confidence interval of adult female mule deer retaining vaginal implant transmitters (VITs) to within 3 days of parturition as a function of deer age in northwest Colorado.

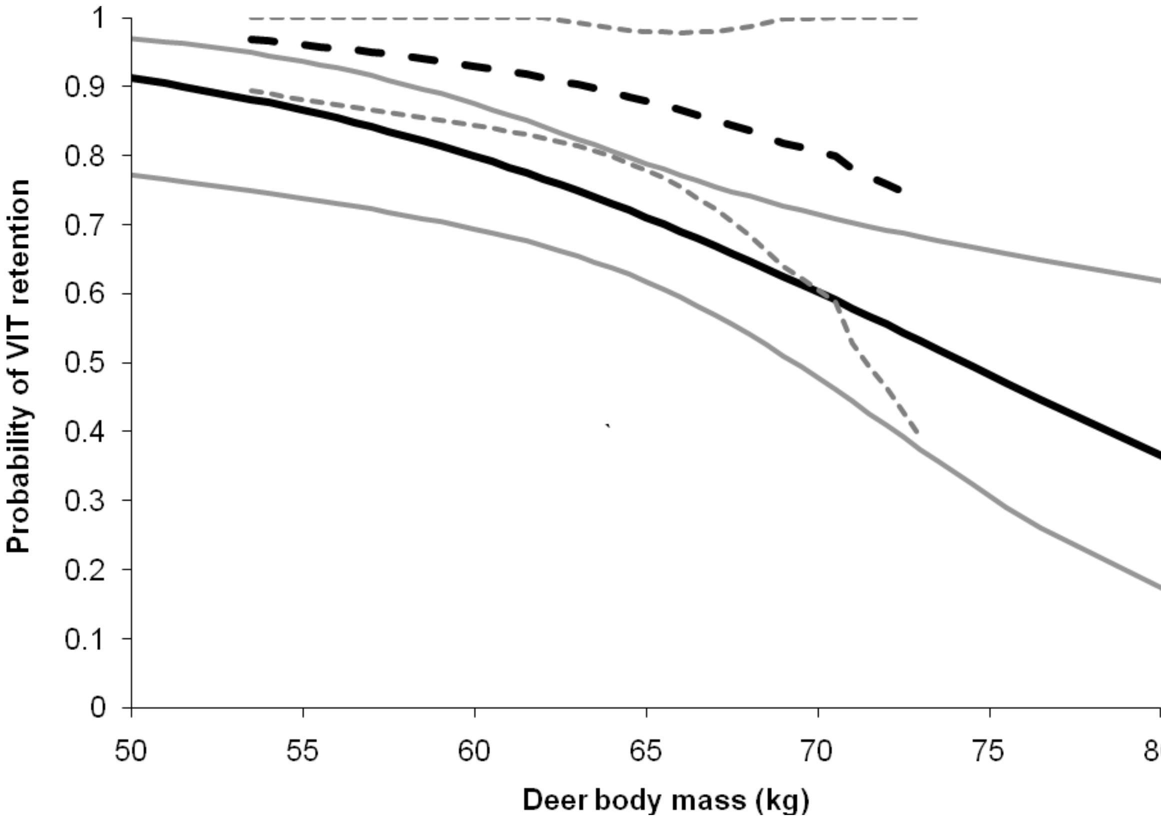

Figure 4. Estimated probabilities and 95% confidence intervals of adult female mule deer retaining vaginal implant transmitters (VITs) to within 3 days of parturition as a function of deer body mass in Colorado using original (solid line, Bishop et al. 2007) and modified (dashed line, this study) VIT retention wings.

Table 1. Model selection results, based on Akaike's Information Criterion with small sample size correction (AIC_c), from an analysis of vaginal implant transmitter (VIT) retention in adult female mule deer as a function of adult female age (yr), mass (kg), hind foot length (cm), chest girth (cm), and body fat (%) in northwest Colorado, USA, 2009.

Model	k	AIC_c	ΔAIC_c	w_i
Intercept only	2	70.58	0.00	0.331
Age	4	72.00	1.42	0.163
Foot length	4	72.88	2.30	0.105
Age, fat	6	72.96	2.39	0.100
Mass	4	73.57	2.99	0.074
Fat	4	73.66	3.08	0.071
Chest girth	4	73.79	3.21	0.066
Age, chest girth	6	75.10	4.52	0.035
Age, foot length	6	75.45	4.88	0.029
Age, mass	6	76.32	5.74	0.019
Age, foot length, chest girth	8	78.53	7.95	0.006

Table 2. Model selection results, based on Akaike's Information Criterion with small sample size correction (AIC_c), from an analysis of fawn detection probability associated with adult females that retained or nearly-retained vaginal implant transmitters (VITs) in northwest Colorado, 2009. We modeled detection probability as a function of VIT retention status (retained vs. nearly-retained), adult female age (yr), the day of the week VITs were shed (i.e., shed-day), and amount of vegetative cover at VIT shed sites. We evaluated detection probability relative to shed day because we were unable to monitor radio signals on Saturdays and Mondays.

Model	k	AIC_c	ΔAIC_c	w_i
Intercept only	2	61.94	0.00	0.600
Shed-day	4	63.74	1.80	0.244
Retention status	4	66.07	4.13	0.076
Age	4	66.26	4.32	0.069
Cover	6	70.46	8.52	0.008
Shed-day, cover	8	73.22	11.28	0.002
Shed-day, cover, retention status	10	79.53	17.59	0.000
Age, shed-day, cover	10	80.24	18.30	0.000

Colorado Division of Wildlife
July 2009 – June 2010

WILDLIFE RESEARCH REPORT

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

Period Covered: July 1, 2009 - June 30, 2010

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

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ABSTRACT

We completed 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 total deer density annually on 5 study areas. Four study areas were permanently located, whereas location of the fifth area varied each year to reflect the range of variability in habitat treatments across the southern half of the Uncompahgre Plateau. Additionally, on 2 of the study areas we estimated late winter body condition of does. Compared to results from other research throughout the West, as well as on the Uncompahgre Plateau, survival estimates for 6-month old mule deer fawns were highly variable between areas, and tended to be near published long term averages (mean survival rate of 0.59 (0.04 SE)). Preliminary 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. Point estimates of deer density on the study areas varied between winters, but in general density estimates did not show a trend between years. Major fluctuations within density estimates are likely attributable to animal movements. All final analyses will be completed during the fall of 2010 and submitted to 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 experimentally whether mechanical/chemical treatments of native habitat vegetation will increase over-winter mule deer fawn survival, adult doe body condition, and localized deer densities on the Uncompahgre Plateau in southwest Colorado and to conduct a simulation based optimization study to determine optimal foraging and movement strategies of deer under variable environmental and habitat conditions.

SEGMENT OBJECTIVES

1. Complete all field efforts associated with the assessment of mechanical/chemical treatments on survival and body condition of deer.
2. Complete first segment of academic dissertation requirements of PhD requirements through Colorado State University.
3. Initiate final analyses for survival, density and body condition components of the study.
4. Complete preliminary narrative for optimal foraging and movement strategy work.

INTRODUCTION

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

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

We designed and initiated a multi-year, multi-area study to assess the impacts of landscape level winter range treatments on mule deer population performance. 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).

Preliminary survival analyses were conducted on all years of data. In addition to including individual covariates (fawn sex and mass), we explored the role of habitat treatment history on survival. Due to the preliminary nature of these analyses and the ongoing status of the habitat treatment work, we did not attempt to rank individual study areas. Estimating survival for study areas was done in 5 different forms. The simplest form was constant survival where all study areas were pooled and survival was estimated using a single parameter (hereafter “constant”). The second simplest form was to estimate survival for each unique study area (i.e., 8 survival estimates were generated, hereafter “area”). The remaining 3 forms allowed study areas to be partitioned according to treatment history. The simplest of these forms was a comparison between treatment areas and reference study areas in which each study areas was partitioned into one of these two categories (i.e., two survival parameters, hereafter “treatment/reference”). The next simplest of these forms segregated study areas by treatment type. In this form, study areas were either reference areas (no treatment), management treatments (areas that received a typical management treatment at some point during the past 10 years), or repeated treatments (areas that received a typical management treatment but also received additional and repeated efforts in an attempt to force treatment effect). Thus, in this form (hereafter “treatment type”), the number of parameters dedicated to estimating survival rates across all study areas was 3. The final form followed the “treatment type” form, but further partitioned study areas according to a density/treatment gradient. A total of 5 parameters were used to estimate survival (high-density repeated treatment, high-density reference, management treatment, low-density super treatment and low-density reference, hereafter “treatment type by density”).

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

All preliminary abundance and density estimates were computed using program NOREMARK (White 1996). With the advancement of abundance theory and with improvements in software, abundance and density estimates will also be computed using Mark Resight models in program MARK (White and Burnham 1999).

RESULTS AND DISCUSSION

Preliminary survival models indicate that the individual parameter most influencing over-winter fawn survival was fawn mass (Table 1). Fawn sex did not appear to add much additional strength or support to any given model. Of particular interest to this study is that models incorporating study area treatment level were among the top performing models for the entire suite of models run, and the most supported model took treatment type by density into account. Closely competing with this model was one which estimated a constant survival rate, but thereby benefited by estimating 4 fewer parameters. The strongest model support for the model that estimated survival rates according to the treatment type by density structure lends credence to the study design and will likely become refined with a more complete analysis.

Late winter body condition estimates for adult females 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, but not in the T4 hormone (nmol/l) (Table 2). Pregnancy rates were surprisingly variable during this study (Table 2).

Density estimates were collected during March for all five study areas, during all years of the study. No major modifications were made to the field methodology, however, addition of new models into program MARK (White and Burnham 1999) allow for comparisons to occur with abundance/density estimates generated in program NOREMARK (White 1996). These analyses have not been completed. However, a summary of the 4 years of data include the observation that the variance surrounding abundance estimates of each study area are higher than expected. Enough data do not exist to isolate the variance components of these estimates. Overall, no major changes in abundance, in any of the study areas, are believed to have occurred.

Progress towards completion of the requirements for a PhD was also made during the 2009-2010 year. As of summer 2010, an additional 3 classes and a total of 14 credits are needed to complete the scholastic requirements. A draft study plan regarding the optimization of deer movement and foraging behavior was developed, but expansion of these ideas and simulation modeling techniques can be expected during the 2010-2011 year (Appendix I).

SUMMARY

Survival rates for mule deer fawns across our study areas averaged 59% with a measured high of 65% and measured low of 38%. Overall body condition parameter estimates for late-winter adult female deer were moderately low, which did not coincide with the milder winter conditions that were observed throughout deer winter range in Colorado. Pregnancy rates were slightly lower, but still within the long term range of observed data. Estimates of total deer density across our study areas continued to reflect historical estimates, but a dramatic early spring shift in movement was observed on one study area.

Overall, a consistent trend of higher survival of fawns was observed in treated study areas, indicating winter range treatments likely have a positive effect on survival. The magnitude and overall population effect of these impacts will be quantified during the next 12-18 months.

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

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

Table 2. 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
	% Body Fat	8.80% (2.02)	N.A.	9.81% (2.88)
2005-2006	T3*	1.12 (0.28)	N.A.	1.41 (0.51)
	T4	70.69 (20.94)	N.A.	79.97 (15.80)
	% Body Fat	7.61% (1.94)	7.03% (1.80)	N.A.
2006-2007	T3	1.55 (0.53)	1.42 (0.31)	N.A.
	T4	88.23 (19.53)	78.07 (22.34)	N.A.
	% Body Fat	8.09% (1.10)	7.20% (1.69)	N.A.
2007-2008	T3	1.17 (0.28)	1.17 (0.56)	N.A.
	T4*	94.30 (20.7)	56.20 (23.30)	N.A.
	% Body Fat	7.20% (1.85)	6.25% (1.63)	N.A.
2008-2009	T3	1.22 (0.32)	1.26 (0.35)	N.A.
	T4*	74.63 (14.61)	54.77 (19.34)	N.A.

APPENDIX I

Optimizing mule deer winter range treatments: allocating resources in highly dynamic and stochastic systems

Introduction

During the past three decades, wildlife and habitat managers have extensively worked to improve habitat for wildlife. With the development and incorporation of more sophisticated equipment into landscape management, the state of the art has progressed and evolved over the past three decades. However, two primary assumptions often underlying and justifying these efforts have been that landscape treatments benefit wildlife and that when delivered, landscape treatments are utilized by wildlife. The focus of this chapter will be to delve into the latter of these two assumptions and to explore the likelihood that when delivered, habitat treatments will be utilized.

This chapter will have two primary objectives. The first objective will utilize simulation and optimality modeling (Mangel and Clark 1989) to determine under what conditions mule deer would be most benefited by moving into a landscape that has been altered. As a case scenario, in western Colorado there is strong evidence that mule deer population performance is limited by winter range forage conditions. In cases where winter range forage is abundant and of high quality, there is circumstantial evidence that deer move down from summer and transition range regardless of habitat or weather conditions at higher elevations. In most of these cases, agricultural fields compose at least a nominal proportion of available winter range. Current dogma suggests that earlier movements by deer are directed at capitalizing on vestigial forage in these fields which is typically of high nutritional content. Of equal importance/concern to wildlife managers under this scenario is the movement of deer onto winter range when agricultural fields are absent. These are the areas where habitat improvement efforts are most commonly focused, in an effort to increase the local carrying capacity and to help stabilize populations. However, a largely unknown component to the effectiveness of landscape treatments pertains to the ability or willingness of deer to utilize treatment areas. An underlying assumption of deer movement and habitat selection behavior is that most individuals in a population make the best decision possible under the given circumstances. As such, deer in areas without high quality winter range can be expected to have made movement decisions based on the quality, abundance and availability of forage on summer and transition ranges. By modeling individual behavior (and its inherent variability), we hope to learn under what conditions a herd would most likely utilize and benefit from habitat improvements in areas that have not historically been used by deer.

In particular to the second objective of this study, we wish to use stochastic dynamic programming and simulation models to establish a decision-theoretic framework for landscape managers to apply in the *a priori* selection and delivery of winter range landscape treatments for mule deer (Williams et al. 2001). There are a great number of factors that determine the quality of a mule deer herd from a manager's perspective. Under most settings, wildlife managers' objectives are typically to increase herd productivity or to stabilize a declining herd. However, there are costs associated with all management decisions. In the case of landscape management for mule deer, the primary cost is financial. With finite monetary resources available for landscape management, a manager needs to know with as much certainty as possible if a landscape treatment will benefit deer. The opportunity cost of delivering a treatment to one herd is typically that a treatment cannot be delivered to another herd. But in light of environmental stochasticity, uncertainty remains high under the best of circumstances.

Methods

To address this optimal movement behavior question, I will use stochastic dynamic programming methods. I believe four key factors influence a deer's decision to move from summer and transition range onto winter range. Of these factors, the suitability of summer/transition range will be modeled purely as a stochastic variable. Availability of summer range is heavily dependent on weather conditions with harsh weather driving availability/suitability down and mild weather making range more accessible. Winter range forage quality, the second key factor, is also dynamic as a result of management efforts. Typically efforts to improve winter range quality are realized 1-2 years after an application as effectiveness is dependent on growing conditions. However, an element of stochasticity must also be present in this factor as during the most extreme winters, availability is further depressed. The third factor, number of competitors, is also dynamic but largely non-stochastic. Typically a trend of increase or decrease is observed in number of deer during consecutive winters. The fourth factor, cost of movement, is a merger of the other factors and is ultimately linked to an individual deer's body condition. While the most nebulous from a management standpoint, this is potentially the most influential factor that motivates a deer to either vacate or continue to occupy summer/transition range. For an overview of my thinking thus far, please see Figure A1.

To address the second objective of this work, I wish to identify a management structure for landscape enhancement from an adaptive standpoint. As understanding of deer movement behavior is pursued through an optimality modeling framework, circumstances conducive to deer use of winter range should be identified. From a management standpoint, an optimal decision framework for when and where landscape treatment efforts should be most useful would be beneficial. Ideally habitat treatment manipulations can be structured under an adaptive management framework in which resources for manipulating winter range can be optimally allocated based on expected mule deer population response.

To further these interests and to develop necessary skills, I hope to take classes on such modeling techniques during my studies.

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Figure A1. Conceptual diagram depicting four key factors that influence a deer's decision to move from summer/transitional range to winter range. The different levels and relative predictability of each factor are also depicted. Underlying assumptions to this conceptual diagram are that summer/transition range typically has higher quality and abundance of browse, winter range is always available and that deer can be expected to make the best decision given current resources and body condition.

Colorado Division of Wildlife
July 2009 – June 2010

WILDLIFE RESEARCH REPORT

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

Period Covered: July 1, 2009 – June 30, 2010

Authors: C. J. Bishop, D. P. Walsh, M. W. Alldredge, 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 will conduct an extensive field evaluation of the device with free-ranging mule deer during 2010-11.

WILDLIFE RESEARCH REPORT

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

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

P. N. OBJECTIVE

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

SEGMENT OBJECTIVES

1. Work with a professional engineering firm to produce a fully-functional prototype of an automated collaring device for ≥6-month-old mule deer fawns.

INTRODUCTION

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

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

A passive marking device would minimize animal stress associated with capture and should have virtually no potential to cause capture-related mortality. The large-mammal capture techniques described above place considerable, temporary stress on animals as part of netting and handling. Roughly 2-3% of animals typically die from capture-related injuries or stresses under routine capture conditions. Thus, successful development of a passive marking system would reduce CDOW's operating expenses and improve animal welfare. Therefore, our objective is to design, produce, and evaluate a fully-functional prototype of an automated collaring device for ≥6-month-old mule deer fawns.

STUDY AREA

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

METHODS

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

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 the course of the year. These meetings ensured that our device specifications were being satisfactorily met from both engineering and deer biology perspectives.

RESULTS AND DISCUSSION

We produced a fully-functional prototype device that met our design specifications as set forth in the contract. The prototype device comprises an aluminum cage attached to a bait compartment. 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. 1). 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 ready to fire 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. 2 and 3). 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 will evaluate effectiveness of the device in the field during 2010-11. Initially, we will only set the device with a collar when we are present and able to directly observe deer interactions with the device. After collaring 5-10 animals in this manner and troubleshooting any problems with the device, we will set the device to operate remotely without an observer on-site, which is how it is intended to be used.

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. The collaring device should significantly reduce stress that is typically associated with capture and handling and there should be no capture-related mortality. We also have designed the collaring device so that it should be relatively easy to adjust to target adult deer and other ungulate species. Last, the collaring device should have wide applicability for ungulate researchers and managers beyond Colorado. We will be evaluating the device in the field with free-ranging mule deer during the coming year and making additional modifications as necessary.

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Prepared by ________________________
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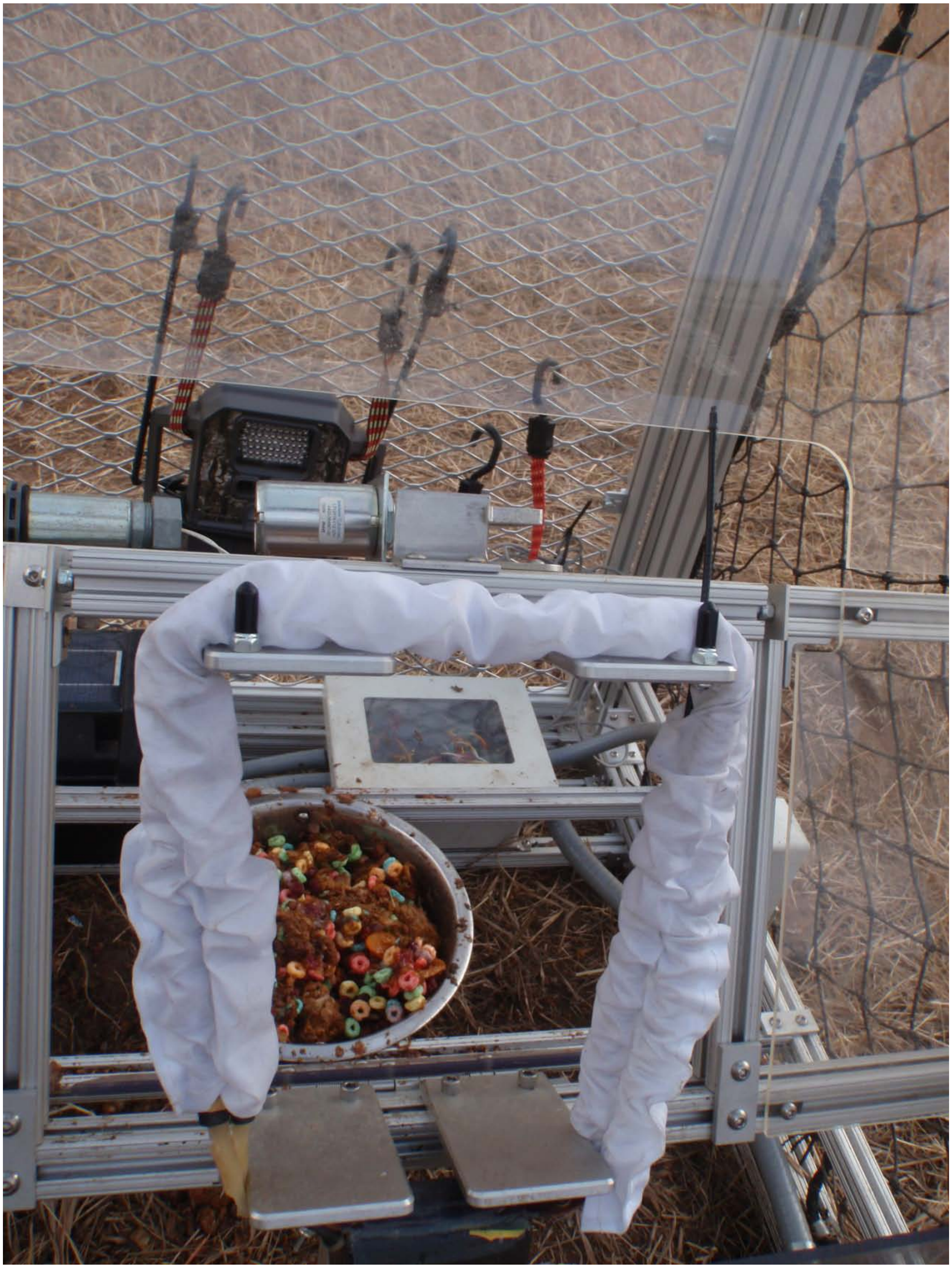

Figure 1. View of the radio collar and bait compartment of an automated collaring device for mule deer. To reach bait, deer must extend their head and neck through the expanded radio collar.

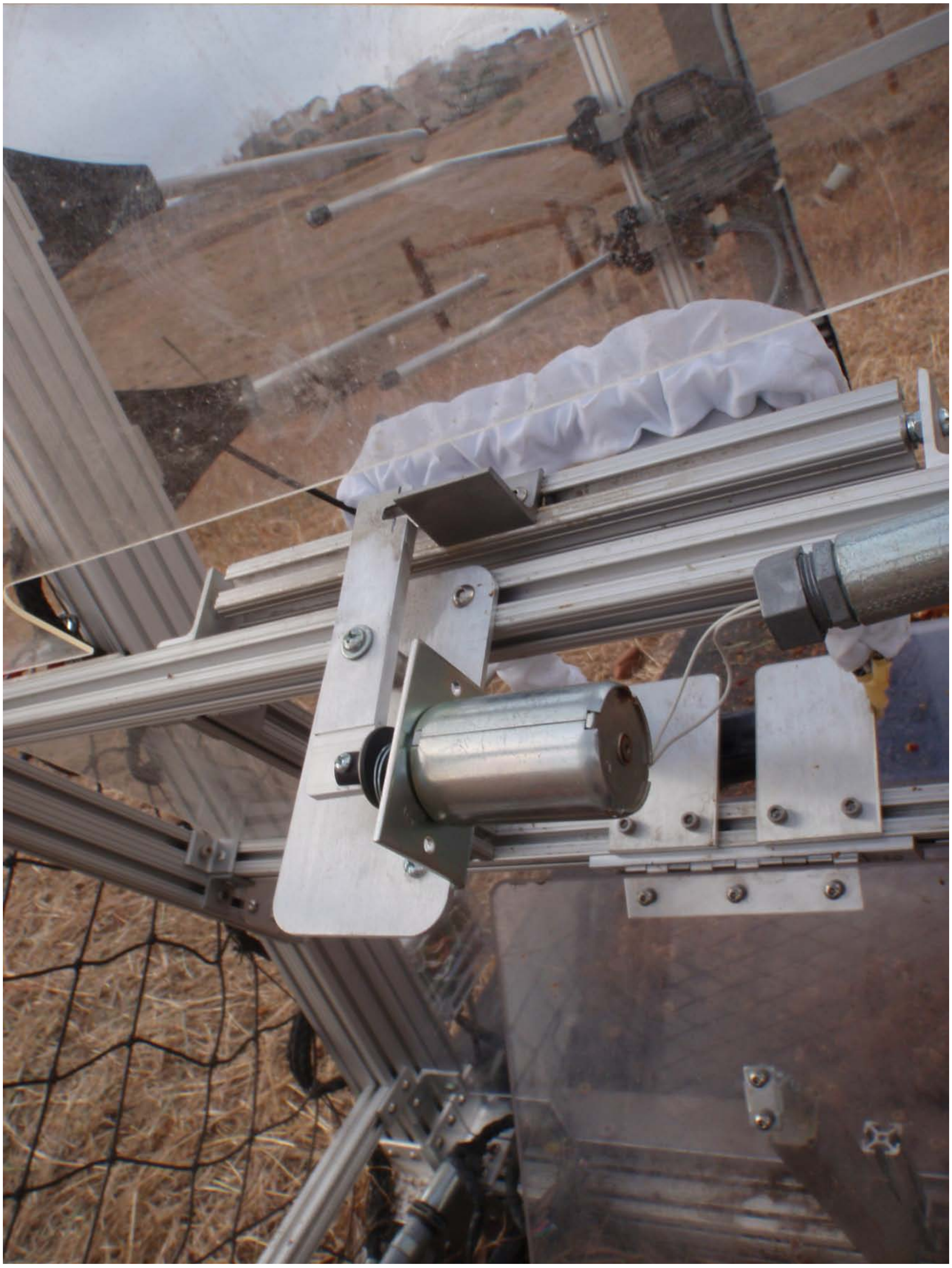

Figure 2. View of the collar release mechanism in an automated collaring device for mule deer.

Figure 3. Female mule deer fawn accessing bait by extending her head through an expanded radiocollar. The prototype device will be evaluated extensively in the field with free-ranging deer during 2010-11.

Colorado Division of Wildlife
July 2009 –July 2010

WILDLIFE RESEARCH REPORT

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

Period covered: July 31, 2009−July 31, 2010

Author: K. A. Logan.

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

ABSTRACT

The Colorado Division of Wildlife 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 Division of 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 first year of the *treatment period* (TY1), August 2009 through July 2010, on puma population characteristics and dynamics with hunting as a mortality factor. Puma sport-hunting opened November 16 and closed December 11, 2009 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 9 pumas were killed: 2 adult females, 1 subadult female, 5 adult males, and 1 dependent cub. The harvest of 8 independent pumas represented 15% of the expected (i.e., modeled) 53 independent pumas and 14.5% of the *minimum* number of 55 independent pumas counted 2009-10. Independent females and males comprised 37.5% and 62.5% of the harvest, respectively. Four other radio-collared pumas, 1 adult female and 3 adult male, in the study area population were killed in GMUs adjacent to the study area. The total harvest of 12 independent pumas represented 21.8% of the *minimum count* of independent pumas. Eight independent pumas will be the harvest quota for the 2010-11 hunting season (TY2). Seventy-nine hunters requested mandatory permits with an attached voluntary hunter survey in TY1. Seventy-one of the hunters provided responses to written (n = 43) or telephone call follow-up contact (n = 28). An estimated 67 hunters

actually hunted on the study area, of which 13% harvested pumas and 24% captured pumas (i.e., harvested plus treed and released). All hunters responded that they were selective hunters, and the capture and population data indicated that most successful hunters practiced selection. From August 2009 to July 2010 thirty-three individual pumas were captured 38 times. Two capture teams with dogs operated over 86 search days from December 2009 through April 2010 to find 266 puma tracks, pursue pumas 93 times, and capture 21 pumas 26 times. Capture efforts with cage traps resulted in the recapture of 2 adult pumas and 1 cub. Nine cubs were observed for the first time at nurseries. A total of 42 pumas were monitored by radiotelemetry. Search efforts also revealed the presence of at least 15 other independent pumas. Our *minimum count* of independent pumas from September 2009 to April 2010 was 55, including 31 females and 24 males. A preliminary *minimum* estimated density of independent pumas was 3.29/100 km^2. The proportion of radio-collared adult females giving birth in the August 2009 to July 2010 biological year was 0.42 (8/19). Seven litters that could be dated to month of birth were produced in June (4), July (2), and August (1). We monitored 19 female and 8 male adult radio-collared pumas for survival and agent-specific mortality. Survival rates in TY1 with hunting were generally lower than in the *reference period* without hunting. Causes of mortality were vehicle strikes and hunting. In addition, all 5 adult males with malfunctional radiocollars since the beginning of this study were harvested by hunters in TY1. Two radio-monitored subadult males died apparently due to natural causes. Of 19 cubs monitored with radiotelemetry, 5 died, all associated with infanticide. A non-marked adult male was also killed by a vehicle on the boundary of the study area. Puma harvest data also provided information on dispersals of 12 male and 1 female puma initially marked on the study area. Those pumas moved from about 60 to 370 km from initial capture sites. A pilot study on detection probabilities of pumas using a camera grid for a mark-recapture design was conducted in collaboration with Colorado State University Researchers J. Lewis and K. Crooks as they studied bobcats on the east slope of our study area. Two camera grids, Area 1 and Area 2, were on the east slope of the study area. Each grid was 80 square kilometers in size and contained 20 cells which were each 4 square kilometers. Cameras operated for 108 days from August 21 to December 7, 2009. Detection probabilities for 4 adult radio-collared pumas on Area 1 and 5 adult pumas on Area 2 were 0.75 and 0.80, respectively. Those pumas were photographed a total of 51 times: 17 times in Area 1 and 34 times in Area 2. Males were detected more frequently than females. Four other marked pumas without functioning collars were also detected 7 times. Non-marked pumas were photographed 31 times, representing 2 to 4 individuals in Area 1 and 3 to 5 individuals in Area 2. The next step in this collaboration is to conduct an intensive evaluation of pilot study data to model detection probability, estimate precision, and define the survey area for a camera grid design specifically for puma. Data are continued 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 Division of Wildlife (CDOW) puma management assumptions in the first year of a five-year *Treatment Period* of the Uncompahgre Plateau Puma Project— all to improve the CDOW model-based approach to managing pumas in Colorado.

SEGMENT OBJECTIVES

1. Execute the first year of the five-year *treatment period* by working with CDOW 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. Collaborate with Colorado State University (CSU) researchers on a pilot project to assess puma detection probability in a camera grid design.
7. Collaborate with other researchers involved with puma biology and ecology.

INTRODUCTION

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

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

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

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

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

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

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

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

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

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

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

While all projects cannot be addressed concurrently, understanding their relationships to one another is expected to help individual projects maximize their benefits to other projects that will assist the CDOW to achieve its strategic goal in puma management (Fig.1). 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 CDOW's model-based management approaches with Colorado-specific data from objectives 1—3. Consider other useful models.

Concurrently with the tasks associated with the objectives above, significant progress will be made toward a 5th objective, which will initially be subject to *pilot study*— develop methods that yield reliable estimates of puma population abundance.

A descriptive 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 CDOW assumes density ranges of 2.0−4.6 puma/100 km^2 (i.e., includes pumas of all age stages- adults, subadults, and cubs, J. Apker, CDOW Carnivore Biologist, person. commun. Nov. 19, 2003) to extrapolate to DAUs to guide the model-based quota-setting process. Likewise, managers assume that the population sex and age structure is similar to puma populations described in the intensive studies. Using intensive efforts to capture, mark, and estimate non-marked animals developed and refined during the study to estimate the puma population, the following will be tested:

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

2. Recreational puma hunting management in Colorado Data Analysis Units (DAUs) is guided by a model to estimate allowable harvest quotas to achieve one of two puma population objectives: 1) maintain puma population stability or growth, or 2) cause puma population decline (CDOW, Draft L-DAU Plans, 2004, CDOW 2007). Basic model parameters are: puma population density, sex and age structure, and annual population growth rate. Parameter estimates are currently chosen from literature on studies in western states that are judged to provide reliable information. Background material used in the model assumes a moderate annual rate of growth of 15% (*i.e.*,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 CDOW can manage puma population growth through recreational hunting on the basis that for a stable puma population hunting removes the annual increment of population growth (i.e., from current judgments on population density, structure, and $\tilde{\lambda}$). Puma harvest rate formulations for DAUs assumes that total mortality (i.e., harvest plus other detected deaths) in the range of 8 to 15% of the harvest-age population (i.e., independent pumas comprised of adults plus subadults) with the total mortality comprised of 35 to 45% females (i.e., adults and subadults) is acceptable to manage for a stable-to-increasing puma population (CDOW 2007).

H_3: Total mortality of an estimated 15% of the adults and subadults with no more than 45% of the total mortality comprised of females will not result in a 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 CDOW 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 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.

We want to examine the usefulness of this approach in Colorado. CDOW 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 CDOW managers, will help managers to biologically support and adapt puma management based on Colorado-specific estimated puma population characteristics, parameters, and dynamics.
3. Methods for assessing puma population dynamics will allow managers to evaluate modeled populations and estimate effects of management prescriptions designed to achieve specified puma population objectives in targeted areas of Colorado. Ascertaining puma numbers and densities during the project will allow assessment of monitoring techniques. Potential methods include use of harvest sex and age structure and photographic and DNA genotype capture-recapture. Study plans to develop and test feasible field and analytical methods will be developed 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 will be quantified, and management assumptions and hypotheses regarding population dynamics and effects of harvest will be tested. Contingent upon results of pilot studies, we will also assess enumeration methods for estimating puma population abundance.

The *reference period*, without recreational puma hunting as a major limiting factor, was consistent with the natural history of the current puma species in North America which evolved life history traits during the past 10,000 to 12,000 years (Culver et al. 2000) that enable pumas to survive and reproduce (Logan and Sweanor 2001). In contrast, puma hunting, with its modern intensity and ingenuity, might have influenced puma selection pressures in western North America for 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 CDOW's assumptions for its model-based approach to puma management. The *reference period* also facilitated other operational needs (because hunters did not kill the animals) including the marking of a large proportion of the puma population for parameter estimates and gathering movement data from GPS-collared pumas.

During the *treatment period*, years 6—10, recreational puma hunting will occur on the same study area using management prescriptions structured from information learned during previous years. Using recreational hunting for the treatment is consistent with the CDOW's objectives of manipulating natural tendencies of puma populations, particularly survival, to maintain either population stability or increase or suppression (CDOW, Draft L-DAU Plans, 2004). Theoretically, survival of independent pumas will be influenced mainly by recreational hunting, which will be quantified by agent-specific mortality rates of radio-collared pumas. Dynamics of the puma population will be manipulated to evaluate hypotheses that are related to effects of hunting (i.e.,: effects of harvest rates, relative vulnerability of puma sex and age classes to hunting, variations in puma population structure due to hunting). The killing of tagged and collared pumas during the *treatment period* 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 CDOW if they perceive that an individual puma may be a threat to public safety.

Field Methods

<u>Puma Capture</u>: 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 CDOW Animal Care and Use Committee (file #08-2004). All captured pumas were examined thoroughly to ascertain sex and describe physical condition and diagnostic markings. Ages of adult pumas were estimated initially by the gum-line recession method (Laundre et al. 2000) and dental characteristics of known-age puma (Logan and Sweanor, unpubl. data). Ages of subadult and cub pumas were estimated initially based on dental and physical characteristics of known-age pumas (Logan and Sweanor unpubl. data). Body measurements recorded for each puma included at a minimum: mass, pinna length, hind foot length, plantar pad dimensions. Tissue collections included: skin biopsy (from the pinna receiving the 6 mm biopsy punch for the ear-tags), and blood (30 ml from the saphenous or cephalic veins) for genotyping individuals, parentage and relatedness analyses, and disease screening; hair (from various body regions) 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, CDOW, attending veterinarian, pers. comm.). Immobilizing agent was delivered into the caudal thigh muscles via a Pneu-Dart® shot from a CO_2-powered pistol. Immediately, a 3m-by-3m square nylon net was deployed beneath the puma to catch it in case it fell from the tree. A researcher climbed the tree, fixed a Y-rope to two legs of the puma and lowered the cat to the ground with an attached climbing rope. Once the puma was on the ground, its head was covered, its legs tethered, and vital signs monitored (Logan et al. 1986). Normal signs include: pulse ~70 to 80 bpm, respiration ~20 bpm, capillary refill time ≤2 sec., rectal temperature ~101^{o}F average, range = 95 to 104^{o}F (Kreeger 1996). 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 puma was immobile for 3 to 24 hours so that dead pumas could be found to quantify survival rates and agent-specific mortality rates by gender and age. Locations of GPS- and VHF-collared pumas were fixed about once per week (as flight schedules and weather allowed) from light fixed-wing aircraft (e.g., Cessna 182) 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 are over 12 months old. Cubs were recaptured to replace collars as opportunities allowed. Monitoring radio-collared cubs allowed quantification of survival rates and agent-specific mortality rates (Logan and Sweanor 2001).

Analytical Methods

Population Characteristics: Population characteristics each year were tabulated with the number of individuals in each sex and age category. Age categories, as mentioned, include: adult (puma ≥24 months old, or younger breeders), subadults (young puma independent of mothers, <24 months old that do not breed), cubs (young dependent on mothers, also 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 2009 to July 2010, was the first year of the *treatment period* in this study of puma population dynamics on the Uncompahgre Plateau. Principal investigator K. Logan with CDOW biologists and managers developed a structure (i.e., officially approved by Wildlife Commission decision in September 2009) to manipulate the puma population with sport-hunting and to survey hunters. The hunting season on the study area began on November 16, 2009 and was scheduled to extend to January 31, 2010, 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 CDOW'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 quota of 8 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). We relied on the count data from 2007-08 because that was the last year in the *reference period* in which a fully staffed research team was able to adequately survey the study area in winter capture operations. The next year, 2008-09 (i.e., the last year of the *reference period*), a state government-mandated hiring freeze contributed to subpar winter capture operations, and thus, an inadequate minimum count effort.

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 CDOW 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 CDOW to monitor the number of hunters on the study area and to contact each hunter for survey information (see later).

All pumas harvested on the study area were examined by principal investigator K. Logan and sealed as mandated by Colorado statute. All successful hunters reported their puma kill and presented the puma carcass for inspection by CDOW within 48 hours of harvest. Upon inspection data was 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 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 16 to December 11, 2009, taking 26 days to fill the quota of 8 pumas. Nine pumas were killed, including: 2 adult females, 1 subadult female, 5 adult males, and 1 dependent male cub (Table 2). Three of the pumas were killed on the last day, resulting in the quota being exceeded by 1 puma. Of the harvested pumas, 3 were marked: dependent male cub M91 (offspring of F25), and 2 adult males M51 and M71. In addition to the pumas killed on the study area, 1 adult female (F110) and 3 adult males (M27, M29, M100) that had home ranges overlapping the study area were killed off the study area on adjoining GMUs (Table 3).

The harvest of 8 independent pumas on the study area was 14.5% (8/55*100) of the *minimum count* of 55 independent pumas, including 31 females and 24 males, estimated by the research team during September 2009 to April 2010 (Table 4). Independent females and males comprised 37.5% (3/8*100) and 62.5% (5/8*100) of the harvest, respectively. This harvest structure was 9.7% (3/31*100) of the independent females and 20.8% (5/24*100) of the independent males.

Considering the harvest of 4 other radio-collared adults (F110, M27, M29, M100) off the study area, which had home ranges overlapping on and off the study area, a harvest of 12 independent pumas was 21.8% (12/55*100) of the *minimum* number of independent pumas. The harvest composition of 4 females and 8 males was comprised of 33.3% (4/12*100) females and 66.7% (8/12*100) males. This harvest structure was 12.9% (4/31*100) of the independent females and 33.3% (8/24*100) of the independent males in the *minimum count*.

The *minimum count* of independent pumas in 2009-10 was highly consistent with the expected number and sex structure of independent pumas projected by the deterministic, discrete time model (see Tables 1 and 4. *Minimum count* 2009-10 = 55 independent pumas, including 31 females, 24 males. Model projected independent pumas = 53, including 31 females, 22 males). Therefore, we used the model to guide the decision to manipulate the puma population with a harvest of 8 independent pumas in the 2010-11 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 will probably be killed outside of the study area as in the 2009-10 hunting season (Fig. 3). The projected population trends are stable-to-increasing.

<u>*Hunter permits and survey:*</u> Mandatory permits with the voluntary survey attached were requested by 79 individual hunters. Thirty-three of the hunters requested a second permit after the first one expired after 14 days. Seventy-one hunters (90%) provided responses to the voluntary survey either by turning in the survey (i.e., n = 43) or providing information during follow-up telephone calls (i.e., n = 28) by principal investigator K. Logan. The remaining 8 hunters could not be contacted, because either they did not have working phone numbers or they did not return calls. Of the respondents, 11 hunters indicated that they did not hunt on the study area. As a proportion of the 71 respondents, the number that hunted extrapolated to the total of 79 hunters (60/71 = 0.845) indicated that about 67 hunters took to the field for pumas on the study area during the 26-day hunting season. Considering that 67 hunters were estimated to be afield, then 13% harvested pumas (9/67*100) and 24% of individual hunters captured pumas (16/67*100; see captured and released pumas below and in Table 5).

In response to the survey question, “Do you consider yourself a *selective* or *non-selective* hunter?” all the respondents that hunted on the study area indicated that they were selective hunters. (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.) Yet, *selective* hunter was indicated by the 3 hunters that killed a subadult female, a lactating female, and a dependent male cub, which may indicate that in fact not all the hunters are selective or some cannot distinguish types (i.e., sex, age stage) of pumas in the field to practice selection. On the other hand, hunter surveys 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 14 times, including 9 females and 5 males. All 9 females were described by the hunters as adult age; 2 males were described as adult age, and 3 males were described as subadults. Five of the treed pumas were marked, including adult female F8 treed twice, adult female F74, and 2 yellow ear-tagged subadult males (numbers could not be distinguished). Hunters gave various reasons for not wanting to kill the pumas, including reasons based on puma sex and size (Table 5). These preliminary survey and harvest data indicate independent females were probably captured slightly more frequently than independent males (i.e., ratio 12 females:10 males; females = 3 harvested + 9 captured and released; males = 5 harvested + 5 captured and released). This sex structure was consistent with the sex structure of the independent pumas in the *minimum count* (Table 4). Yet, the harvest was comprised of mostly males (3 females, 5 males).

This preliminary assessment from TY1 puma harvest and hunter survey data suggests that most hunters that captured pumas were selective and influenced harvest sex and age composition.

Segment Objective 2

After the design quota was filled, puma research teams immediately activated for capture operations with trained dogs. Two fully-staffed capture teams, one detailed on the east slope and one detailed on the west slope, systematically and thoroughly searched the study area to capture, sample, and GPS/VHF radiocollar pumas the remainder of winter and early spring 2009-10. 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 34 puma captures of 28 individuals from August 2009 to July 2010 (Tables 6-11). Twenty-one individual pumas were captured with dogs 26 times. Three pumas were captured in cage traps. Cubs were captured at nurseries 5 times. A total of 42 pumas were monitored with radiotelemetry from August 2009 to July 2010 (some of these had been collared in previous years). In addition, 2 cubs were monitored from birth to death at the nursery by monitoring the GPS and VHF data of their mother.

Trained dogs were used as our main method to capture, sample, and mark adult and subadult pumas from December 15, 2009 to April 30, 2010. Those efforts resulted in 86 search days, 266 puma tracks detected, 93 pursuits, and 26 puma captures (Table 6). Search days with dogs in this period was greater than our efforts in the 4 previous winters by 4 to 15 days (Table 12). In addition, this was the first year we deployed 2 fully-staffed hound capture teams. The frequency of tracks (tracks/day) encountered was higher than the previous 5 winters. The pursuits increased over all previous years by 18 to 58, with the lowest number of pursuits occurring in the first year of this study (2004-05). The capture rate was also the highest by 2 to 12 captures. Increased capture efforts and captures were probably the result of using 2 fully-staffed houndsmen teams even though the puma population had been reduced due to harvest just before our capture operations. Researchers also recorded instances when the first tracks $\leq$1 day old of independent pumas were encountered on each search route each day to represent encounters with puma tracks that could be pursued by houndsmen. The count was: 37 tracks of females, including 5 associated with cubs; 21 tracks of males; and 2 tracks of unspecified sex. The ratio of female to male tracks was consistent with the sex structure of independent pumas in our *minimum count* (Table 4).

Puma capture efforts using ungulate carcasses and cage traps extended from September 11, 2009 to May 17, 2010 (Table 10). We used 21 road-killed mule deer at 17 different sites, but did not capture any pumas. However, 2 adult pumas (M55, F94) were each recaptured in cage traps at mule deer kills they made. Pumas scavenged at 3 of 17 (17.65%) sites where ungulate carcasses were used for bait. A bobcat trapper inadvertently caught male cub M112 (offspring of F70) in a cage trap. The trapper notified us, and we sampled, tagged, radio-collared, and released the cub. The cub successfully rejoined his family.

We captured 5 cubs, all males for the first time (Table 11), and fit all with radio-collars (Appendix A). Two cubs of F3 were captured at nurseries, 2 were bayed by hounds (M115 of F28, M117 of F119), and 1 was caught in a bobcat cage trap (M112 of F70, see above). In addition, we found 2 male cubs (P1016, P1017) of F72 that were killed by male puma M32 on the day we investigated the nursery to sample and tag the cubs (see later). Two cubs of F93 were observed in the nursery at about 28 days old, but they could not be handled because the rock structure of the nursery afforded them complete protection from capture.

In addition to our direct puma captures with dogs December through April, we detected 16 pumas that we were able to identify with GPS or VHF telemetry 38 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. GPS data from pumas with functional GPS collars provided confirmatory information about movements of pumas. If GPS data indicated that the puma moved through the area at the time the tracks were made, then we ruled the data were confirmatory. This approach allowed us to more efficiently allocate our capture efforts toward pumas of unknown identity on the study area, particularly unmarked pumas or pumas with non-functioning GPS- or radiocollars.

Our search efforts throughout the study area also revealed the presence of at least 15 other independent pumas, we classified as 9 females and 6 males. Two of the males were treed by our hounds, but we could not handle the pumas because they climbed dangerous trees (Table 7). 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. Moreover, females in association with cubs of different numbers, sizes, and locations enabled us to separate 2 adult females followed by 2 to 3 medium-to-large-size cubs. The tracks we found of the other pumas were too old to pursue (i.e., probability of capture with the dogs was negligible). One of the adult females was likely F74, which was also treed and observed by a puma hunter on December 9, 2009. It is also possible that 1 of the adult females was previously marked animal F24 wearing non-functional GPS collar.

Our search and capture efforts during September 2009 through April 2010 enabled us to quantify a *minimum count* of 55 independent pumas detected on the Uncompahgre Plateau study area, including 31 independent females and 24 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 fresh puma tracks (i.e., ≤ 1 days old) observed by researchers that could not be attributed to pumas with functioning radiocollars. The estimated age structure of independent pumas in November 2009 at the beginning of the puma hunting season in Treatment Year 1 (TY1) on the Uncompahgre Plateau study area is depicted in Figure 4. In addition to the independent pumas, we also counted a minimum of 20 to 25 cubs. Of the 55 independent pumas, 34 to 35 (62-64%) were marked and 20 to 21 (36-38%) were assumed to be unmarked animals. Of the expected unmarked pumas, 10 to 11 were females and 10 were males. 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 28 independent pumas (17 females, 11 males). The west slope count included 27 independent pumas (14 females, 13 males). Considering the *minimum count* of 55 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 3.29 independent pumas/100 km^2.

<u>Segment Objective 3</u>

During the past 5.7 years of this work we compiled data on puma reproduction that was not previously available on pumas in Colorado. 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). We observed 6 litters born in June (3), July (2), and August (1) 2010, each with 1 to 3 cubs each, born to radio-collared females. We found sign (i.e., nurseries, tracks) of a fourth litter born in June to a GPS-collared female (F111); but, we could not catch the cubs before they developed well enough to escape us (about 6 weeks old). Data on reproduction observed in this first year of the *treatment period* were added to Table 13, but will not be summarized again until the end of the period. The proportion of radio-collared adult females giving birth from August 2009 to July 2010 biological year was 0.53 (8/15).

Considering our 32 total observed litters and 2 other litters confirmed by nurseries and nursling cub tracks with GPS-collared females, all with cubs 26 to 42 days old, the distribution of puma births by month indicate births extending from March into September, with 24 of 34 births (70.6%) occurring May through July (Fig. 5). Our data suggests that the large majority of puma breeding activity occurred February through April. In contrast, Anderson et al. (1992:47-48) found on the Uncompahgre Plateau that of 10 puma birth dates 7 were during July, August, and September, 2 in October, and 1 in December, with most breeding occurring April through June. Data on our 34 litters added to Anderson's data (Fig. 5), and indicated puma births on the Uncompahgre Plateau occurred in every month except January and November (so far).

Segment Objectives 4 & 5

From December 8, 2004 (capture and collaring of the first adult puma M1) to July 31, 2010, we radio-monitored 14 adult male and 26 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 indicated relatively high survival, with adult male survival generally higher than adult female survival (Table 15).

For this first year of the *treatment period*, we monitored 19 adult radio-collared females and 8 radio-collared adult males. The initial indication is that adult survival rates declined for adult females and males (Table 15). But, no conclusions should be drawn with only 1 year in the *treatment period* (TY1). The primary interest is the magnitude of reduction in survival, and the implications of those survival rates for population growth rate. This is what ultimately allows us to evaluate the effect of this harvest level for our population management assumptions when the goal is a stable to increasing population.

Causes of mortality for adult pumas with functioning radiocollars in TY1 were due to vehicle strikes on roadways (2 females, 1 male) and hunting (1 female, 1 male). In addition, all 5 adult males which developed non-functional radiocollars (M1, M27, M29, M51; Table 3) or shed a collar (M71) since the beginning of this study were harvested by hunters in TY1. Inclusion of those adult males in the survival estimate indicated a substantially lower adult male survival rate in TY1 (Table 15).

We have radio-monitored 11 pumas, 4 females and 7 males, in the subadult age-stage (independent pumas <24 months old) (Table 16). Three died before reaching adulthood, indicating a preliminary finite survival rate of 0.727. All 3 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 due to unknown causes; but, punctures in the skull suggested strife with another puma. 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. We need to increase our efforts to acquire larger samples of male and female radio-monitored subadult pumas to acquire reliable estimates of their survival.

Data from puma hunters provided additional information on fates of 13 pumas, 12 males and 1 female, initially captured and marked as cubs (10 males) or subadults (2 males, 1 female) on the Uncompahgre Plateau puma study area (Table 17). All 12 of the males were killed away from the study area by hunters at linear distances (i.e., from initial capture sites to kill sites) ranging from about 60 to 370 km. Two males with extreme moves were killed in the Snowy Range of southeastern Wyoming (369.6 km) and the Cimarron Range of north-central New Mexico (329.8 km). The female (F52) was treed and released by hunters in December 2008 and 2009 south of Powderhorn, Colorado, indicating that she probably established an adult home range there. These pumas represent dispersal moves from the

Uncompahgre Plateau. Eleven of the 13 pumas (except M68, 17 months old and M82, 19 months old) 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. In that summary 36 radio-collared cubs (16 males, 20 females) marked at nurseries when they were 26 to 42 days old were used for a Kaplan Meier procedure cub survival estimate of about 0.53 to one year of age. The major natural cause of death in cubs, where cause could be determined, was infanticide and cannibalism by other, especially male, pumas.

In this first year of the *treatment period*, we monitored the fates of 19 cubs (Appendix A). Five of the cubs were known to have died, all of them associated with infanticide. Two (M101, F103) were orphaned at 149 days old when their mother (F16) was hit by a vehicle on County Road 1 on September 11, 2009. The 2 cubs were killed and partially eaten by adult male puma M55 on September 17 and 19, 2009. Fate of their sibling M102 was unknown because of a failed radiocollar after September 4, 2009. But M102 probably would have died of starvation if he was not killed by M55. F72's 2 male cubs were killed, and 1 partially eaten, by adult male puma M32 at the nursery when the cubs were 39 days old on July 21, 2010. Mother F72 was about 2 km away from the nursery at the time the cubs met their fate. 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 2-year-old non-marked male puma was struck and killed by a vehicle on highway 62 in Leopard Creek on the south boundary of the study area on August 25, 2010. This mortality made the twelfth puma death recorded due to vehicle collision on the study area since 2004 (Table 18). Five of the 12 pumas were marked, including 3 adults with GPS/VHF collars. Those 3 adults died during the first year of the *treatment period*.

Segment Objective 6

We wanted to enhance this project with reliable estimates of puma abundance and density (see Objective 5, page 4). Because a majority of independent pumas were individually marked on the study area, we decided to explore the potential of using a camera grid mark-recapture structure to derive puma abundance estimates by first examining detection probabilities in a pilot effort. This effort is an attempt to develop puma population monitoring methods (Fig. 1). A camera grid mark-recapture approach is a method for counting pumas independent from our main method of capturing pumas with searches on snow-covered routes and dogs and thus has the potential of providing unbiased estimates. For this pilot project, we collaborated with Colorado State University Researchers Jesse Lewis (Ph.D. candidate) and Dr. Kevin Crooks (Dep. of Fish, Wildlife, and Conservation Biology) who studied bobcat distribution, abundance, and behaviors on the eastern slope of our Uncompahgre Plateau puma study area. Because those researchers used a camera grid design for bobcats where we also had GPS/VHF- collared pumas, this gave our project an opportunity to evaluate puma detection probability on a small scale. This was a first step in considering the usefulness of a camera grid design for puma abundance estimates.

We established 2 camera grids on the east slope of the study area (Fig. 6). Each grid was 80 square kilometers in size and contained 20 cells which were each 4 square kilometers. We searched each grid for potential camera sites with the intention to maximize the encounter of a puma or bobcat with a camera. We used our general knowledge about puma and bobcat behavior to place the cameras and did not use any GPS/VHF data on puma locations. Felid sign on the ground (i.e., tracks, feces, scrapes) helped to guide our camera placement. Initially we placed 1 Cuddeback Capture digital camera (Park Falls, WI) in each cell at the site we deemed best to intercept wild felids, and did not use scent or sight lures in an attempt to attract the felids. One alternate camera site was placed in Area 1 and 5 alternate camera sites were placed in Area 2 to increase the sample effort in canyon bottoms relative to canyon rims. All cameras were set at the highest design setting of 1 photo per 30 seconds if the passive infrared sensor were activated and serviced every 2 weeks to ensure operation and fresh batteries. Cameras operated for 108 days from August 21 to December 7, 2009.

During the period that the cameras operated, 4 adult (2 females, 2 males) GPS/VHF-collared pumas ranged on Area 1 and 5 adult (3 females, 2 males) GPS/VHF-collared pumas ranged on Area 2. Those pumas were photographed a total of 51 times: 17 times in Area 1 and 34 times in Area 2. Three of 4 adult pumas (probability 0.75) on Area 1 and 4 of 5 adult pumas (probability 0.80) were detected 2 to 19 times each in the 108 day period. Daily detection rates ranged from 0.02 to 0.18 (Table 19). Detection rates varied among individuals, and were the highest for adult males. Both adult pumas that were not detected were females. One, F16, died on September 11, so was available for 21 days. The other, F70, had a new litter of cubs on August 31 at a nursery in a canyon between the 2 camera grids where she focused her activities. Then on September 23 her GPS collar quit functioning and we were unaware of her movements.

In addition, 4 other marked pumas without functioning collars were detected by cameras a total of 7 times. Those pumas were: adult F3 (detected 3 times; non-functional GPS collar), adult M71 (detected twice; eartags, shed expandable VHF collar), a subadult female detected once (orange eartag right pinna), and a male cub detected once (yellow eartag left pinna).

Non-marked pumas were photographed 31 times on the camera grids. In Area 1 non-marked pumas were photographed 20 times at primary cameras and once at the alternate camera. We estimated the photos represented 2 to 4 individual independent pumas. In Area 2 non-marked pumas were photographed 8 times at primary cameras and twice by alternate cameras. We estimated the photos represented 3 to 5 independent pumas. Any of the non-marked pumas could have ranged on both camera grid areas.

Our next step in this collaborative process is to analyze the photographic data on the 2 grids, including modeling detection probabilities with landscape and puma covariates and to examine expected estimates of precision. We also will examine population closure and investigate methods for defining the survey area by using the GPS and VHF locations of pumas with functioning collars that used the camera grid areas. This information will be used to assess the feasibility of designing a camera grid specifically to obtain accurate and precise estimates of puma abundance and density on a portion of the Uncompahgre Plateau study area. This phase is expected to be completed by July 2011.

<u>Segment Objective 7</u>

Data from 28 (8 male, 20 female) GPS-collared pumas, totaling over 48 thousand GPS locations (Table 20) will be used to examine behaviors and social structure of the puma population on the Uncompahgre Plateau, including movements of pumas relative to Game and Data Analysis Unit boundaries and vulnerability to hunter detection. Those data will also be used in a set of collaborative projects, including: examination of puma behavior in relation to human development with Mammals Researcher Dr. Mat Alldredge, who is studying puma-human interactions on the Colorado Front Range and modeling and mapping puma habitat in Colorado and other western states with Dr. Kevin Crooks and Dr. Chris Burdett (Department of Fish, Wildlife and Conservation Biology, Colorado State University-DFWCB, CSU). Furthermore, puma population and genetic data from the Uncompahgre Plateau can be used in collaboration with Dr. Alldredge’s puma research efforts on the Front Range to examine similarities or differences in puma population dynamics and behaviors between the 2 environments.

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 5.7 years of effort 125 pumas have been captured, sampled, marked, and released. Of those animals, 107 were radio-monitored, allowing us to monitor fates of pumas in all sexes and age stages, including: 25 adult females, 13 adult males, 4 subadult females, 7 subadult males, 32 female cubs, 39 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 CDOW 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 CDOW wildlife biologists and managers for assessing puma harvest strategies. The first year of the 5-year *treatment period* was August 2009 to July 2010 in which sport-hunting is a mortality factor. The *treatment period* will be a population-wide test of CDOW puma management assumptions. The puma harvest quota for TY2 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 on life stages and sexes. Furthermore, we will continue collaboration efforts with colleagues on investigations of puma population parameter estimation, puma-human relations, puma habitat modeling and mapping, and individual puma detection rates in camera grid designs. All of these efforts should enhance the Colorado puma research and management programs.

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Table 1. 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 1 (TY1) on the Uncompahgre Plateau Study Area, Colorado, November 16 to December 11, 2009.

Puma sex/age/mark	Age (yr.)	Previous I.D.	Date of kill	Location/UTM	Hunter/status
M (cub of F25)	1.25	M91	11/17/2009	Pleasant Valley/ 13S,247640E,4228470N	Jack Flowers/ Resident
M	2-3		11/21/2009	Little Bucktail Creek/ 12S,726165E,4240290N	Ty Spangler/ Resident
F	4		12/9/2009	San Miguel Canyon/ 12S,732268E,4234711N	Larry McPeak/ Non-resident
F	1.5-2		12/9/2009	Pinyon Ridge/ 13S,256380E,4241740N	M. Ryan Hatter/ Resident
M	4	M71	12/9/2009	Spring Creek/ 12S,762033E,4248487N	Caleb Marquardt/ Resident
M	4		12/9/2009	Horsefly Canyon (E)/ 13S,249114E,4240143N	Darren Reed/ Resident
F (lactating)	2		12/11/2009	Roubideau Canyon/ 12S,746670E,4254762N	Brian Coe/ Non-resident
M	7	M51	12/11/2009	Shavano Valley/ 12S,761117E,4256800N	Darrel Moberly/ Resident
M	2-3		12/11/2009	Mailbox Park/ 12S, 726524E,4234984N	Donald Gambril/ Non-resident

Table 3. Five other independent pumas from the Uncompahgre Plateau Study Area killed by hunters off of the study area. Four adult pumas– F110, M27, M29, M100– were in the *minimum count* on the study area in winter 2009-10.[a] Adult male M1 probably no longer ranged on the study area.

Puma sex/age/mark	Date of kill	Place of kill/UTM	Hunter/status
M29/adult	11/16/2009	Beaver Creek (GMU70east) 12S,745500E,4219660N	Syver Bicknase/ Resident
M27/adult	12/9/2009	N. Fork Mesa Creek (GMU61north) 12S,693422E,4266607N	Kevin Thornton/ Non-resident
M1/adult	1/2/2010	West Bang's Canyon (GMU40) 12S,710656E,4314243N	Outfitter Steve Biggerstaff
M100/adult	1/16/2010	Naturita Canyon 12S,734604E,4216634N	Outfitter Wade Wilson
F110/adult	2/25/2010	Naturita Creek 12S,721010E,4230929N	Alex Sokolik/ Resident

[a]All five adult male pumas with non-functioning (4) or shed (1) radiocollars were killed during TY1 either on (M51, M71) or off (M1, M27, M29) of the UP Study Area.

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, Uncompahgre Plateau study area, Colorado.

Study Area region	Adults		Subadults		Cubs		
	Female	Male	Female	Male	Female	Male	Unknown sex
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							

*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 1 (TY1) on the Uncompahgre Plateau Study Area, Colorado, November 16 to December 11, 2009. Data are from puma hunter responses in 71 voluntary surveys, including: 43 original surveys on mandatory permits and 28 telephone contacts with hunters that did not return surveys on permits. Total response rate from 79 individual hunters was 90% (71/79 = 0.899*100).

Puma sex/age stage/mark	**Date of capture**	**Capture location**	**Hunter name**	**Reason for releasing the puma given by hunter**
F/adult/none	12/1/2009	N. Fork Cottonwood Creek	Preston Joseph	Did not want to kill a female puma.
F/adult/F8 collar & eartag	12/7/2009	N. Fork Cottonwood Creek	Ryan Weimer	Outfitter R. Weimer did not want hunter to kill a female puma.
M/subadult/ yellow eartags in both ears (numbers not distinguished)	12/8/2009	DeVinney Canyon	Gary Gleason	Did not want to kill a small male puma. Estimated ~125 lb.
F/adult/F74 orange eartags	12/9/2009	Cottonwood Creek	Larry McPeak, guided by Stan Garvey	Did not want to kill a female. L. McPeak later in same day killed another adult female puma.
F/adult/none	11/30 to 12/7/2009	Loghill Mesa, Fisher Creek area	Zachary Prock & Dustin Braiser	Hunters will not kill a female puma.*
F/adult/none	11/30 to 12/7/2009	Loghill Mesa, Fisher Creek area	Zachary Prock	Will not kill a female puma. *These 2 females treed ~4 days apart. One seemed younger than the other, so thought to be different females. But, could have been same puma.
M/subadult/none	12/11/2009	Big Bucktail Canyon	Brian Hibbert	Did not want to kill a small male puma. B. Hibbert estimated puma about 1.5 years old.
F/adult/F8 collar & eartag	11/23 to 12/11/2009	N. Fork Cottonwood Creek	Gerald Sickels, Jr.	Likes to look at the pumas and train his dogs. Does not want to kill a female puma.
F/adult/none	11/23 to 12/11/2009	East of Nucla	Gerald Sickels, Jr.	Likes to look at the pumas and train his dogs. Does not want to kill a female puma.
F/adult/none	11/23 to 12/11/2009	Pinyon, Cottonwood Creek	Gerald Sickels, Jr.	Likes to look at the pumas and train his dogs. Does not want to kill a female puma.
M/subadult/yellow eartag	11/23 to 12/11/2009	San Miguel Canyon below Pinyon	Gerald Sickels, Jr.	Likes to look at the pumas and train his dogs. Does not want to kill a small male. Wants to kill a big male puma.
M/adult/none	11/23 to 12/11/2009	Mailbox Park	Gerald Sickels, Jr.	Likes to look at the pumas and train his dogs. Does not want to kill an average male. Wants to kill a big male puma.
M/adult/none	11/23 to 12/11/2009	Dead Horse Mesa	Gerald Sickels, Jr.	Likes to look at the pumas and train his dogs. Does not want to kill an average male. Wants to kill a big male puma.
F/adult/none	Late 11/2009	Pinyon Ridge	Micah Brogden	Not interested in killing any puma. Likes to hunt pumas with dogs.

Table 6. Summary of puma capture efforts with dogs from December 15, 2009 to April 30, 2010, 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
December	10	27 tracks: 12 male, 15 female, 0 cub <u>Tracks ≤1 day old:</u> 5 male, 8 female, 0 cub	10 pursuits: 4 males, 6 females , 0 cubs	2 pumas captured 3 times: F3 recaptured (non-functioning GPS collar replaced). One adult male puma ~2-3 yr. old captured twice, but not handled due to dangerous trees. In addition, adult F93 associated once with tracks by VHF telemetry (no pursuit with hounds).
January	20	80 tracks: 24 male, 35 female, 21 cub <u>Tracks ≤1 day old:</u> 11 male, 15 female, 10 cub	23 pursuits: 7 males, 10 females, 6 cubs	6 pumas captured 9 times: M55 recaptured twice; F70 recaptured once; F111, F115, & F116 captured for first time. Then M115 & F116 recaptured. One adult male ~2-3 yr. old was captured, but not handled due to dangerous tree. In addition, 5 adult pumas were associated with tracks 6 times with VHF or GPS telemetry: M55 twice (VHF), F70 (GPS), F72 (GPS), F93 (VHF), F111 (GPS).
February	22	77 tracks: 19-20 male, 36-37 female, 20 cub; 1 unknown sex <u>Tracks ≤1 day old:</u> 11 male, 24 female, 12 cub	36 pursuits: 7 males, 17 females, 12 cubs	10 pumas captured 12 times: F23 recaptured 3 times, but in trees too dangerous for handling to replace her non-functional GPS collar. F28 recaptured in a tree too dangerous for handling to replace her non-functional GPS collar. M32 recaptured (VHF collar replaced). F72 recaptured (non-functional GPS collar replaced). Cubs F106, M107 & F108 recaptured (expandable radiocollars fitted on F106 & F108). M114, M117, F118 captured for the first time. In addition, 7 adult pumas were associated with tracks 9 times via VHF or GPS telemetry: M32 (VHF), F70 (GPS), F95 (VHF), F111 three times (GPS), F113 (VHF), F116 (VHF), F118 (VHF).
March	23	58 tracks: 16 male, 26 female, 16 cub <u>Tracks ≤1 day old:</u> 7 male, 14 female, 10 cub	18 pursuits: 4 males, 8 females, 6 cubs	3 pumas captured: F96 and M115 recaptured. F119 captured for first time. In addition, 8 pumas were associated with tracks 16 times via VHF telemetry and/or GPS: F3 three times (GPS, VHF & GPS, VHF), M6 twice (VHF), M55 four times (VHF, GPS, VHF & GPS twice), F70 three times (VHF, GPS twice), cub M112 once (VHF), F93 once (VHF), F96 once (GPS), and cub M115 (VHF).
April	19	24 tracks: 11-12 male, 12-13 female, 0 cub <u>Tracks ≤1 day old:</u> 3-4 male, 6-7 female, 0 cub	6 pursuits: 2-3 males, 3-4 females, 0 cubs	0 pumas captured physically, but F95 identified in one pursuit with VHF telemetry. In addition, 3 adult pumas associated with tracks with VHF telemetry: F93, F104, F118.
TOTALS	86	266 tracks: 82-84 male, 124-126 female, 57 cub, 1 unknown sex <u>Tracks ≤1 day old:</u> 37-38 male 67-68 female 32 cub	93 pursuits: 24-24 males, 44-45 females, 24 cubs	21 individual pumas were captured 26 times with aid of dogs. In addition, 16 radio-collared pumas were detected 38 times by tracks and identified with VHF and/or GPS telemetry.

[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: 37 tracks of females, including 5 associated with cubs; 21 tracks of males; and 2 tracks of unspecified sex.

Table 7. Adult and subadult pumas captured for the first time, sampled, tagged, and released from December 2009 to April 2010, Uncompahgre Plateau, Colorado.

Puma I.D.	Sex	Estimated Age (mo.)	Mass (kg)	Capture date	Capture method	Location
MA*	M	24-36	Unknown	12-16-09	Dogs	West Fork Dry Creek Basin
MB*	M	24-36	Unknown	01-03-10	Dogs	East Fork Dry Creek Basin
F111	F	24-27	35	01-01-10	Dogs	Cushman Canyon
M112	M	4.7	10	01/23/10	Cage trap	Horsefly Canyon (east slope)
F113	F	36	47	01/26/10	Cage trap	McKenzie Butte
M114	M	36	63	02-27-10	Dogs	McKenzie Butte
M115	M	14	39	01-13-10	Dogs	San Miguel Canyon
F116	F	36-48	49	01-20-10	Dogs	San Miguel Canyon
M117	M	6	12	02-05-10	Dogs	San Miguel Canyon
F118	F	18-24	38	02-25-10	Dogs	Big Bucktail Canyon
F119	F	60-72	46	03-25-10	Dogs	San Miguel Canyon

* Pumas MA and MB were adult males that could not be handled because they climbed dangerous trees.

Table 8. Pumas that were captured and observed with aid of dogs, or observed in association with another radio-collared puma, but were not handled at that time for safety reasons, December 2009 to April 2010, Uncompahgre Plateau, Colorado.

Puma sex & I.D.	Age stage or months	Capture date	Location	Comments
MA	24-36	12-16-09	West Fork Dry Creek Basin	Puma climbed dangerous tree, not handled. No noticeable marks.
MB	24-36	01-03-10	East Fork Dry Creek Basin	Puma climbed dangerous tree, not handled. This puma obviously larger than MA (above).
F23	72	02-23-10	San Miguel Canyon	F23 climbed dangerous tree, not handled to change non-functional GPS collar.
F23	72	02-24-10	Big Bucktail Creek	F23 climbed dangerous tree, not handled to change non-functional GPS collar.
F23	72	02-25-10	San Miguel Canyon	F23 climbed dangerous tree, not handled to change non-functional GPS collar.
F28	89	02-01-10	Tomcat Creek	F28 climbed dangerous tree, not handled to change non-functional GPS collar. F28 was in association with M115, apparently her offspring.

Table 9. Pumas recaptured with dogs, cage traps, or visually observed, November 2009 to May 2010, Uncompahgre Plateau, Colorado.

Puma I.D.	Recapture Date	Mass (kg)	Estimated Age (mo.)	Capture Method/ Location	Process
F3	12-23-09	Not weighed	101	Dogs/East Fork Dry Creek Basin	Non-functional GPS collar replaced.
M32	02-04-10	54	100	Dogs/Dry Creek Basin	M32's old VHF collar was replaced.
M55	11-06-09	70	66	Cage trap/Puma Canyon	M55's old GPS collar was replaced.
M55	01-07-10	Observed	68	Spring Creek Canyon	M55 was wearing a functional GPS collar. No need to handle.
M55	01-24-10	Observed	68	Linscott Canyon	M55 was wearing a functional GPS collar. No need to handle.
M67	02-24-10	73	31	Dogs/Tomcat Creek	M67 fitted with VHF collar. Offspring of F30, born July 17, 2007.
F70	01-19-10	Not weighed	63	Dogs/Horsefly Canyon (east slope)	Non-functional GPS collar replaced.
F72	02-09-10	Observed	47	Dogs/Loghill Mesa	F72 wore functional GPS collar, no need to handle.
F94	05-13-10	Not weighed	58	Cage trap/Pinyon Hills west of Happy Canyon	F94's VHF collar changed to GPS collar.
F96	03-11-10	43	50	Dogs/Happy Canyon	F96's old GPS collar was replaced.
F106	02-10-10	20	9	Dogs/Dry Park	F106 fitted with expandable VHF collar. Offspring of F75, born May 7, 2009.
M107	02-24-10	Observed	9	Dogs/Spring Creek Canyon	M107 captured with sibling F108, offspring of F94, born May 25, 2009.
F108	02-24-10	20	9	Dogs/Spring Creek Canyon	F108 captured with sibling M107, offspring of F94, born May 25, 2009. F108 fitted with expandable VHF collar.
M115	01-21-10	Observed	14	Dogs/San Miguel Canyon	Attempted to capture female puma with M115. Dogs got on M115's tracks.
M115	03-18-10	34	16	Dogs/North Fork Cottonwood Creek	M115 handled to examine draining wound to left foreleg that occurred about 1-2 weeks prior to this capture; cause unknown. Broken bone detected by palpation. Left ulna was broken (examined later at mortality 08/06/10).
F116	01/21/10	Observed	36-48	Dogs/San Miguel Canyon	F116 wore functional VHF collar, no need to handle.

Table 10. Summary of puma capture efforts with cage traps from September 11, 2009 to May 17, 2010, Uncompahgre Plateau, Colorado.*

Month	No. of Sites	Carnivore activity & capture effort results
September	2	Set cage trap with mule deer and predator call box on east rim Roubideau Canyon 09-11-09 to 09-15-09. Adult female puma with 2 large cubs visited 09-13-09; clawed at deer carcass, but did not feed; clawed at call box. Puma family did not return.
October	1	A non-collared puma (probably subadult or adult female) visited the fawn mule deer carcass 10-17-10, but did not feed (Reconyx camera photos). A black bear walked ~10 m from the carcass, but did not feed. Mule deer carcasses scavenged by bobcats and magpies.
November	2	Cage trap set with catnip oil and K-9 call scent bait and predator call box and stuffed toy rabbit 11-03-09 to 11-06-09. Cage trap closed due to proximity of puma F72 to trap. Puma M55 was recaptured at a mule deer buck he killed 11-06-09.
January	2	Set cage trap with mule deer buck killed by male puma 01-04 to 08-10. Male puma was treed by dogs on 01-03-10, but could not be safely handled in East Fork Dry Creek. Puma did not return to its deer kill and cage trap. Bobcat trapper inadvertently captured cub M112 in cage trap on west rim Horsefly Canyon 01-23-10. M112 offspring of F70.
February	2	A bobcat and Golden Eagle scavenged mule deer carcasses.
March	12	Puma F94 and cubs walked with 10 m of a mule deer carcass with predator call box, but did not feed 03-29-10. A male puma walked by mule deer carcass with predator call box, but did not feed 03-18-10. A male puma scraped 2 m from mule deer carcass, but did not feed 03-23-10. Puma F96 investigated a predator call box set about 10 m from a mule deer carcass and clawed the call box, but did not feed on the deer.
April	6	Puma F94 and cubs M107, F108 consumed a mule deer carcass 04-03 to 07-10. A male puma scavenged a mule deer carcass sometime during 04-05 to 13-10, possibly M55. M55 scavenged from another mule deer carcass on 04-05-10.
May	3	Cage trap set 05-13-10 with mule deer doe killed by a female puma in Pinyon Hills; recaptured F94. Tracks indicated a male puma walked ~15 m from 2 cage traps with call boxes and scent lures, but did not go to cage traps to investigate.

* We used 21 road-killed mule deer at 17 different sites. Of the road-killed deer baits, 3 of 17 (17.65%) were scavenged by pumas.

Table 11. Puma cubs sampled July 2009 to July 2010 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)
M112	M	August 31, 2009	145	10	F70	52
M115	M	November 2008	427	39	F28	68
M117	M	August 2009	183	12	F119	66
M120	M	June 28, 2010	30	2.5	F3	107
M121	M	June 28, 2010	30	2.2	F3	107
P1016[b]	M	June 12, 2010	39	2.1	F72	51
P1017[b]	M	June 12, 2010	39	half eaten	F72	51

[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] Cubs P1016 and P1017 were monitored from birth via F72's GPS data and visual of her nursery to the day of their death; but the cubs were not individually marked. Individual identification of non-marked pumas were designated with P one thousand series numbers (e.g., P1016). On the day we investigated F72's nursery, male adult puma M32 was at the nursery; he had killed both cubs and half-consumed one about 3 to 6 hours before our arrival.

Table 12. Summary of puma capture efforts with dogs, December 2004 to April 2010, 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

Table 13. Individual puma reproduction histories, Uncompahgre Plateau, Colorado, 2005-2010.

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
F16	32				09/22/05			4
F16	52				05/24/07	19.9		4
F16	75	M6	80	01/13-14/09	04/15/09	22.7	91-92	3
F23*	21				05/30/06			3
F23	45	M27 or M29[f]	78 107	02/19-25/08	05/23/08	23.8	87-93	3
F24	75	M29	92	04/12-15/07	06/14/07		90-93	4
F25	74				08/01/05			1
F25	94				04/16/07	20.5		1
F25	110				08/19/08	16.1		2
F28*	36				06/09/06			2
F28	48	M29	88	12/27-29/06	03/30/07	11.7	92-93	≥2 tracks
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
F104	110				07/08/10			1
F111*	32				06/16/10			≥1 tracks
F116[g]	36-48				2009			2
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, 2010, 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 07-31-10	Alive.
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	Alive.
M67	08-23-07 to 07-31-10	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 07-31-10	Alive.
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.
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 07-31-10	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 02-25-10	Lost radio contact after12-02-09. Recaptured F23 on the study area 02-25-10, but could not be handled to replace non-functional GPS collar.
F24	01-17-06 to 09-03-08	Lost radio contact after 09-03-08− failed GPS/VHF collar.
F25	02-08-06 to 09-04-09	Lost radio contact after 09-04-09– failed GPS/VHF collar.

Table 14 continued.

Puma I.D.	Monitoring span	Status: Alive/Lost contact/Dead; Cause of death
F28	03-23-06 to 02-01-10	Lost radio contact after 09-25-07− failed GPS/VHF collar. Recaptured on the study area 02-01-10, but could not be handled to replace non-functional GPS/VHF 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 07-31-10	Alive.
F72	02-12-08 to 07-31-10	Alive.
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 07-31-10	Alive.
F94	12-19-08 to 07-31-10	Alive.
F95	08-01-09 to 07-31-10	Alive.
F96	01-28-09 to 07-31-10	Alive.
F104	05-21-09 to 07-31-10	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 07-31-10	Alive.
F113	01-26-10 to 06-06-10	Dead. F113 died 06-06-10 of injuries consistent with being struck by a vehicle. GPS data indicated that F113 had crossed highway 550 and roads on Loghill Mesa north of Ridgway 24-30 hours before she died in McKenzie Creek. F113 was about 42 months old at death.
F116	01-20-10 to 07-31-10	Alive.
F118	02-25-10 to 07-31-10	Alive.
F119	03-25-10 to 07-31-10	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 1 year 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., 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.

Period of interest	**Females**			**Males**		
	S	**SE**	***n***	***S***	**SE**	***n***
Reference Annual 8/1/2005 to 7/31/2006	1.000	0.0000	10	0.667[a]	0.2222[a]	6[a]
Reference Annual 8/1/2006 to 7/31/2007	0.909	0.0867	11	1.000	0.0000	5
Reference Annual 8/1/2007 to 7/31/2008	0.831	0.0986	14	1.000	0.0000	7
Reference Annual 8/1/2008 to 7/31/2009	0.875	0.1031	13	1.000	0.0000	8
Treatment Annual 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]

[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 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.

Table 16. Summary of subadult puma survival and mortality, December 2004 to July 2010, Uncompahgre Plateau, Colorado.

Puma I.D.	Monitoring span	No. days	Status
M5	09-16-05 to 06-30-06	308	M5 was offspring of F3, born August 2004. Independent and dispersed from natal area at 13 months old. Established adult territory on northwest slope of Uncompahgre Plateau at the age of 24 months (protected from hunting mortality in buffer area) and ranged into the eastern edge of Utah (vulnerable to hunting). Killed by a puma hunter on 02-20-09 in Beaver Creek, Utah at about 54 months old.
M11	06-21-06 to 12-02-07	529	M11 was offspring of F2, born May 2005. Independent at 13 months old. Dispersed from natal area at 14 months old. Moved to Dolores River valley, CO, by 12-14-06. Killed by a puma hunter on 12-02-07 when about 30 months old.
F23	01-04-06 to 02-04-06	31	Alive. Captured on the study area when about 17 months old. Survived to adult stage; gave birth to first litter at about 21 months old.
M31	04-19-06 to 04-26-06	7	M31's estimated age at capture was 20 months. Dispersed to northern New Mexico and was killed by a puma hunter on 12-11-08 in Middle Ponil Creek, Cimarron Range. He was about 52 months old.
M49	03-26-07 to 10-01-07	189	M49 was offspring of F50, born July 2006. Orphaned at about 9 months old, when F50 died of natural causes. Dispersed from his natal area at about 10 months old and ranged on the northeast slope of the Uncompahgre Plateau. When M49 was about 15 months old, he shed his expandable radiocollar on about 10-01-07 at a yearling cow elk kill on the northeast slope of the Uncompahgre Plateau. He was killed by a puma hunter in Blue Creek in the protected buffer zone north of the study area on 01-24-09; he was about 29 months old, a young adult.
F52	01-10-07 to 05-15-07	125	F52 dispersed from study area as a subadult by Jan. 16, 2007. F52's last VHF aerial location was Crystal Creek, a tributary of the Gunnison River east of the Black Canyon 05-15-07. She was treed by puma hunters on 12-29-08 on east Huntsman Mesa, southeast of Powderhorn, CO. She was about 41-43 months old and could have been in her adult-stage home range. GPS collar nonfunctional.
F66	08-23-07 to 11-05-07 11-25-08 to 06-03-09	74 190	F66 was offspring of F30, born July 2007. Lost contact; her cub collar quit after 11-05-07. Recaptured as an independent subadult on her natal area 11-25-08 when 16 months old. F30 was killed by a puma when F66 was 12 months old, within the age range of normal independence. F66 died of injuries to internal organs that caused massive bleeding attributed to trampling by an elk or mule deer on about 05-28-09 when she was 23 months old. Her range partially overlapped her natal area.
M69	01-11-08 to 04-07-08	87	M69 was captured on the study area when about 14-18 months old. Emigrated from the study area as subadult by 03-19-08. Last VHF aerial location was southwest of Waterdog Peak, east side of Uncompahgre River Valley on 04-07-08. M69 was killed by a puma hunter on 11-06-08 in Pass Creek in the Snowy Range, WY when he was 24 to 28 months old.
F95	12-29-08 to 07-31-09	214	Alive. F95 is the offspring of F93, born about August 2007. She became an independent subadult by about 18 months old (02-11-09 aerial location) 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	M99 died on unknown causes; but, possibly killed by another puma (holes in skull) in Jan. 2010 when he was about 16 months old. His radiocollar quit after 54 days.

Table 16 continued.

Puma I.D.	**Monitoring span**	**No. days**	**Status**
M115	01-13-10 to 07-21-10	189	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 Mar. 18, 2010, he had previously suffered a broken left ulna. M115 was probably independent by July15, 2010 when he was located outside of his natal area on a probably dispersal move. M115 died on about July 21, 2010 apparently from complications of his broken left foreleg; possibly not allowing him to kill prey sufficiently for survival. M115 was about 20 months old at death.

Table 17. Records of pumas that dispersed from the Uncompahgre Plateau study area, December 2004 to July 2010.

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.
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.
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 U.S. Wildlife Service agent for depredation on llamas in the Little Dolores River on 11-07-09. M65 was 28 months old.
M68	08-23-07	13S,257371E, 4235231N→ 12S,711262E, 4198681N	80.7	M68 was offspring of F30, born July 2007. He was orphaned at 12 months old when his mother was killed by a puma. He was killed by a puma hunter in the Disappointment Valley in southwest CO on 12-30-08; he was 17 months old.

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
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 2008. 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.
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.

Table 17 continued.

*Estimated linear dispersal distance (km) from initial capture site on Uncompahgre Plateau study area to hunter kill or recapture 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 2010.

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	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

[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. GPS- and VHF-collared pumas with functioning collars using two camera grids (Area 1- Loghill, Area 2- Delores Creek to Spring Creek) during August 21 to December 7, 2009 (i.e., 108 days), Uncompahgre Plateau, Colorado.

Puma ID	Sex	Estimated Age (mo.) Aug.-Dec. 2009	Collar & data type	Number of detections by cameras in grid primary/alternate camera[a]	Capture rate per day for primary camera configuration (photo per puma/no. days)
Area 1- Loghill					
F16	female	79-83	GPS	0	0
F72	female	41-45	GPS	4/0	4/108 = 0.04
M6	male	90-94	VHF	6/0	6/108 = 0.06
M55	male	50-54	GPS	7/0	7/108 = 0.06
Area 2- Delores Creek to Spring Creek					
Puma ID	**Sex**	**Estimated Age (mo.) Aug.-Nov. 2009**	**Collar & data type**	**Number of detections by cameras in grid primary/alternate camera[b]**	**Capture rate per day for primary camera configuration (photo per puma/no. days)**
F70	female	52-56	GPS	0	0
F94	female	49-53	VHF	3/1	3/108 = 0.03
F96	female	43-49	GPS	2/0	2/108 = 0.02
M32	male	96-100	VHF	4/0	4/108 = 0.04
M55	male	50-54	GPS	19/5	19/108 = 0.18

[a]Aug. 21 to Nov. 2 (74 days) to detect 3 of 4 adult pumas with functioning collars for first time.
[b]Aug. 21 to Oct. 20 (61 days) to detect 4 of 5 adult pumas with functioning collars for first time. It took 88 days (Aug. 21 to Nov. 16) to also detect 2 adult pumas with non-functioning collars.

Table 20. Numbers of GPS locations and spans of monitoring for pumas captured on the Uncompahgre Plateau, Colorado, December 2004 to July 2010.

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 08-09-10	3,226
M100	M	adult	03-27-09 to 01-16-10	923
F2	F	adult	01-07-05 to 08-14-08	3,516
F3	F	adult	01-21-05 to 05-14-08	3,344
F7	F	adult	02-24-05 to 08-03-08	3,922
F8	F	adult	03-21-05 to 10-10-06	1,541
F16	F	adult	10-12-05 to 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 06-26-09	3,398
F28	F	adult	03-24-06 to 08-15-07	1,499
F30	F	adult	03-30-07 to 02-22-08	1,057
F50	F	adult	12-14-06 to 03-26-07	352
F52	F	subadult	01-10-07 to 05-08-07	383
F54	F	adult	01-12-07 to 08-18-08	723
F70	F	adult	01-14-08 to 07-01-10	2,429
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 08-08-10	1,061
F104	F	adult	05-29-09 to 08-09-10	1,349
F111	F	adult	01-01-10 to 08-02-10	488
F113	F	adult	01-27-10 to 06-06-10	445

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

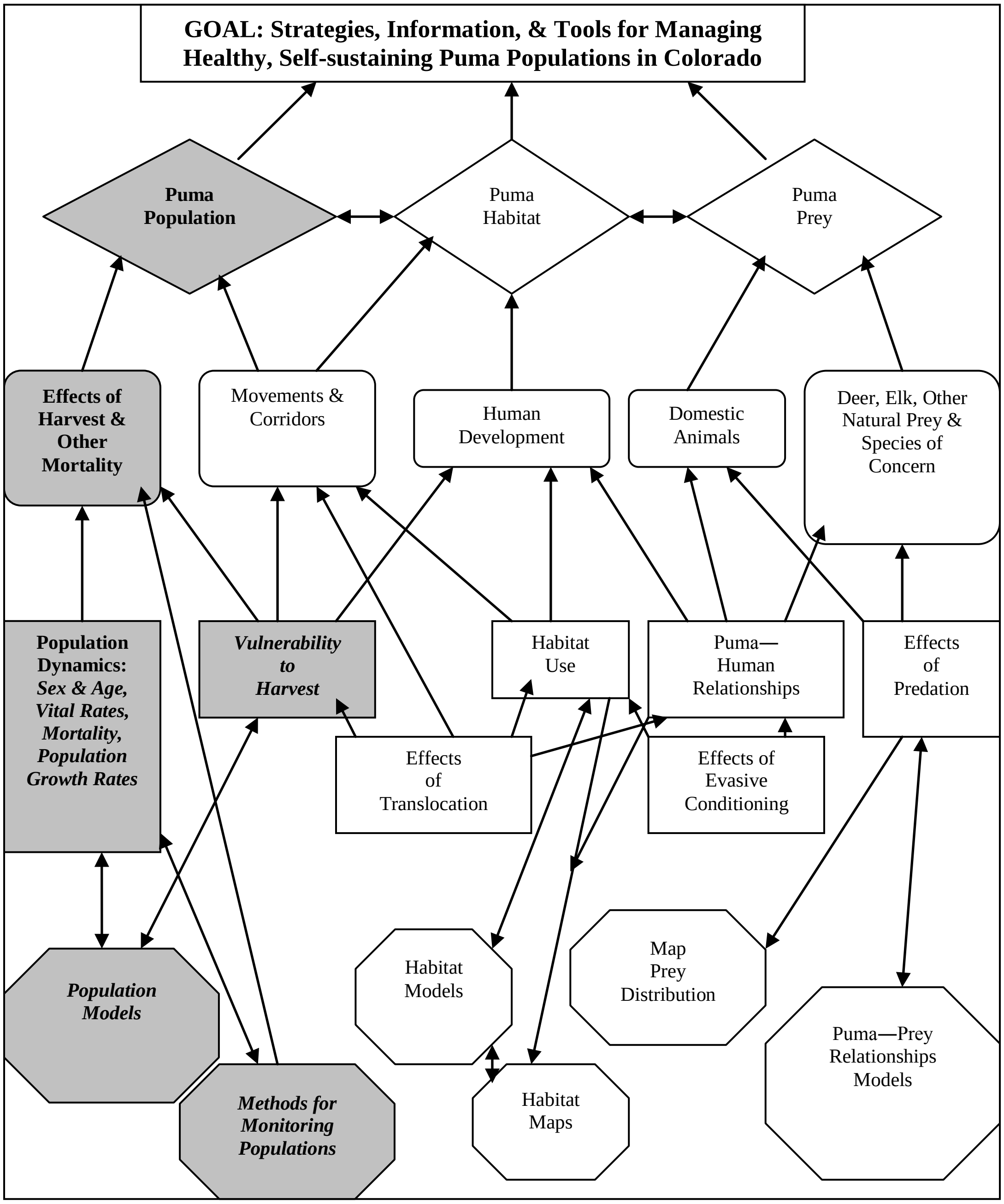

Figure. 1. An ecologically-based conceptual model of the Colorado Puma Research Program that provides the contextual framework for this and proposed puma research in Colorado. Gray-shaded shapes identify areas of research addressed by this puma research on the Uncompahgre Plateau for the puma management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

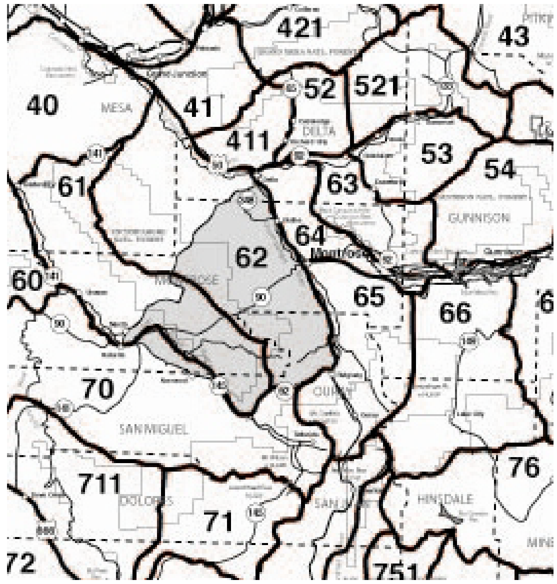

Figure 2. The puma study area on the southern half of the Uncompahgre Plateau, Colorado (shaded in gray) comprising the southern portions of Game Management Units (GMUs) 61 and 62 and a northern portion of GMU 70.

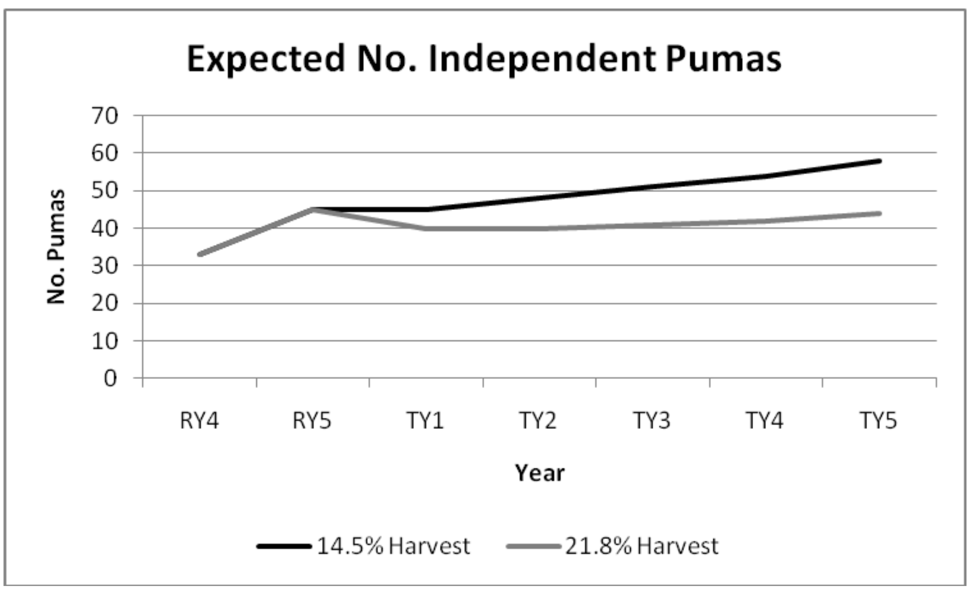

Figure 3. Expected (i.e., modeled) number of independent pumas on the Uncompahgre Plateau Study area after the harvest of 14.5% and 21.8% of independent pumas observed in the 2009-10 hunting season. The 14.5% harvest rate represents 8 independent pumas (3 females, 5 males) killed inside the study area. The 21.8% harvest represents 12 independent pumas (4 females, 8 males), including 4 pumas (1 female, 3 males) killed outside of the study area in addition to 8 killed inside the study area. The projected lines represent the expected population trends resulting from the observed harvest rates and sex structure.

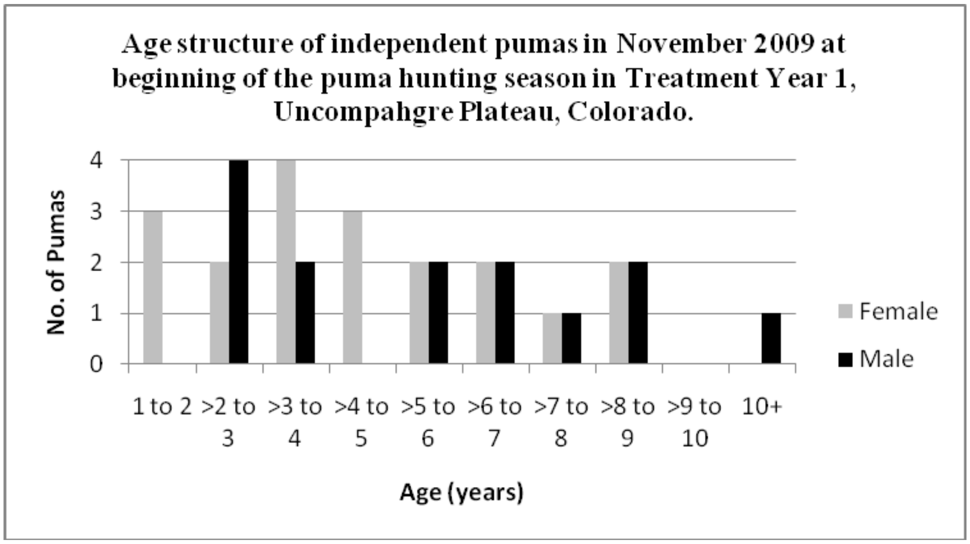

Figure 4. Estimated age structure of independent pumas in November 2009 at the beginning of the puma hunting season in Treatment Year 1 (TY1) on the Uncompahgre Plateau, Colorado. All these pumas were captured and sampled by researchers or harvested by hunters and examined by researchers. Mean ± *SD* of female and male ages, respectively: 4.55 ± 2.11 yr. (54.63 ± 25.29 mo.), $n = 19$; 5.48 ± 2.57 yr. (65.71 ± 30.88 mo.), $n = 14$.

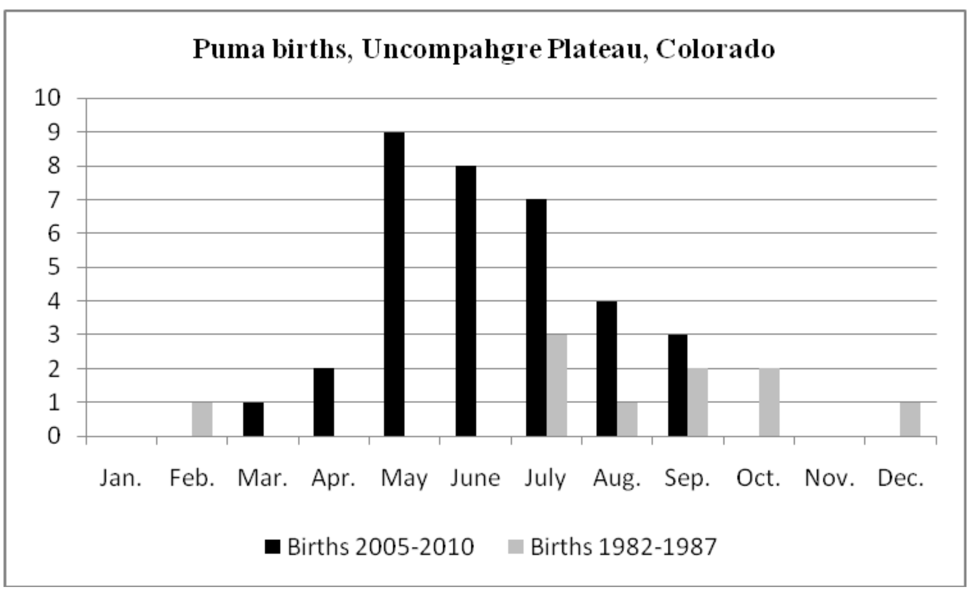

Figure 5. Puma births (black bars) detected by month during 2005 to 2010 ($n = 34$ litters of 17 females; 32 of the litters were examined at nurseries when cubs were 26-42 days old and 2 litters confirmed by tracks of ≥1 cubs following GPS-collared mothers F28 and F111 when cubs were ≤42 days old). Also shown (gray bars) are results of the earlier effort by Anderson et al. (1992:48; 1982 to 1987, $n = 10$ litters of 8 females, examined when cubs were <1 to 8 months old), Uncompahgre Plateau, Colorado.

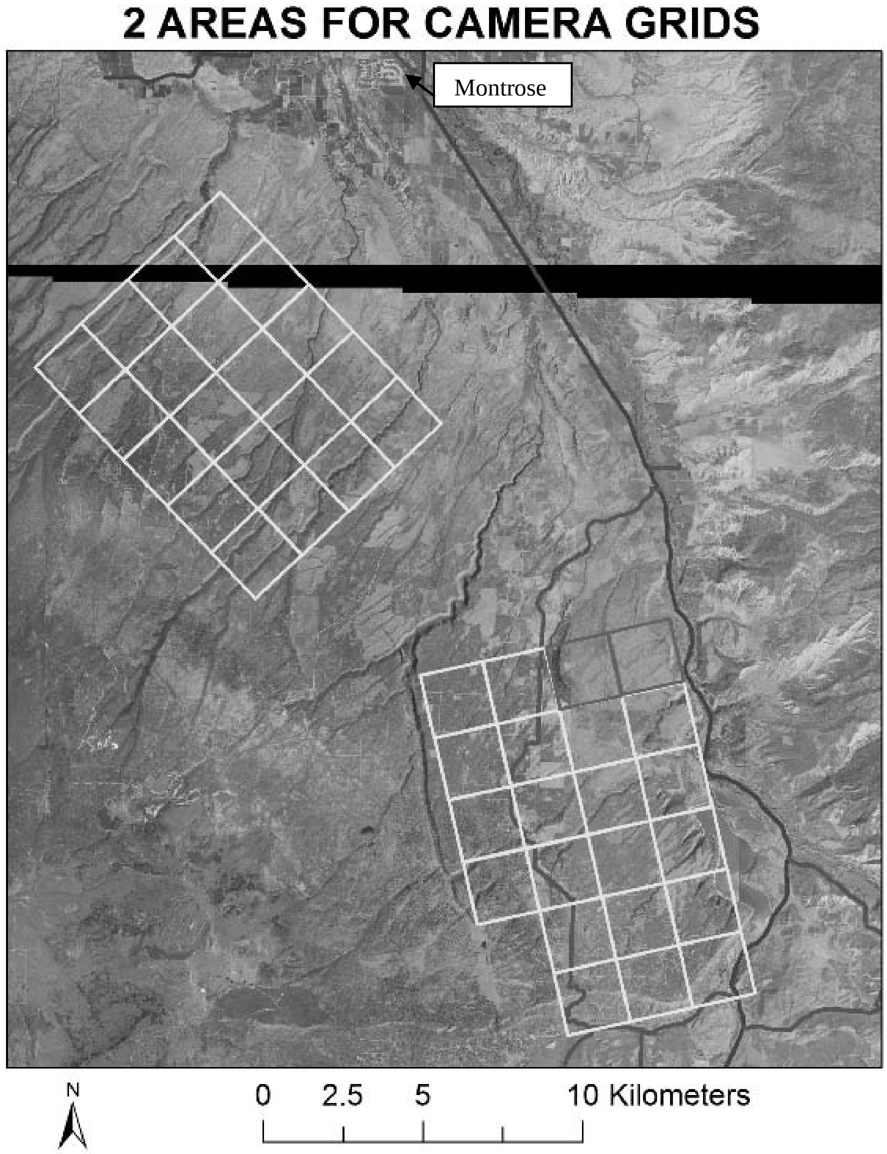

Figure 6. Layout of 2 camera grids on the east slope of the Uncompaghre Plateau Puma Study Area. Each grid was 80 square kilometers in size and contained 20 cells which were each 4 square kilometers. Area 1 was the south grid that covered Loghill Mesa to upper Horsefly Canyon. Area 2 was the north grid that covered from Dolores Canyon to Spring Creek Canyon.

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	Radio-collared. Lost contact; last location 11/5/07. No signals after that date. F66 was photographed with one male sibling, either M67 or M68, & F30 on 5/31-6/1/08. F66 was recaptured and radio-collared as a subadult on 11/25/08. She died from massive trauma & bleeding of internal organs possibly resulting from being trampled by an elk or mule deer on about 05-28-09 as an independent subadult 23 months old.	F30
M67	37	7-17-07	08-23-07		Not radio-collared. M67 or M68 was photographed with sibling F66 & mother F30 on 5/31-6/1/08.	F30
M68	37	7-17-07	08-23-07		Not radio-collared. M67 or M68 was photographed with sibling F66 & mother F30 on 05-31 to 06-01-08. 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
F80	40	5-23-08	07-02-08		Not radio-collared. Apparently died before 2-4-09; no tracks found in association with F23 & siblings F81 & F97.	F23

Appendix A continued

Puma I.D.	Estimated Age at capture (days)	Est. Birth date	Est. survival span from 1st capture to fate or last monitor date	Age to last monitor date alive or at death (days, birth to fate)	Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death	Mother I.D.
F81	40	5-23-08	07-02-08 to 07-29-09	424	Radio-collared. Last live location 7-29-09.	F23
F97	8 ½ mo.	5-23-08	02-04-09	354	Radio-collared. Lost contact after 05-12-09; shed collar at elk kill cache on Mailbox Park.	F23
M82	37	5-29-08	07-05-08 to 03-20-09 or 04-02-09	295-308	Radio-collared. 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		Not radio-collared.	F3
M88	28	7-3-08	07-31-08		Not radio-collared.	F3
F89	28	7-3-08	07-31-08		Radio-collared	F3
M90	36	7-9-08	08-14-08		Radio-collared	F72
Male 7A	28-35	7-10-08	~08-07-08 to 08-14-08	28 to 35	Not radio-collared. F7's cubs died from starvation after they were orphaned. F7 was shot on 8-3-08 for killing domestic sheep.	F7
Male 7B	28-35	7-10-08	~08-07-08 to 08-14-08	28 to 35	Not radio-collared. F7's cubs died from starvation after they were orphaned. F7 shot on 8-3-08 for killing domestic sheep.	F7
Female 7C	28-35	7-10-08	~08-07-08 to 08-14-08	28 to 35	Not radio-collared. F7's cubs died of starvation after orphaned. F7 shot on 8-3-08 for killing domestic sheep.	F7

Appendix A continued

Puma I.D.	Estimated Age at capture (days)	Est. Birth date	Est. survival span from 1st capture to fate or last monitor date	Age to last monitor date alive or at death (days, birth to fate)	Status: Alive/Survived to subadult stage/ Lost contact/Disappeared/ Dead; Cause of death	Mother I.D.
M91	35	8-19-08	09-29-08		Radio-collared.	F25
M92	35	8-19-08	09-29-08		Radio-collared.	F25
F95	16 mo.	June-07	12-29-08		Radio-collared. Survived to adult stage. Established adult home range overlapping 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. Cause of death unknown, possibly 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 03-16-10	275	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.	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
F108	34	5-25-09	06-28-09 to 03-05-10	250	Shed radiocollar at nursery; fastener failed. Recaptured and re-collared 2-24-10. Shed collar ~3-5-10.	F94
M109	34	5-25-09	06-28-09		Not radio-collared; too small.	F94
M112	145	8-31-09	05-04-10	246	Radio-collared. Lost contact after 5-4-10 (last live signal) possibly due to failed transmitter.	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

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.
M120	30	6-28-10	07-28-10		Radio-collared.	F3
M121	30	6-28-10	07-28-10		Radio-collared.	F3
M122	35	7-8-10	08-12-10		Radio-collared.	F104
F123	29	7-15-10	08-13-10		Radio-collared.	F94
F124	29	7-15-10	08-13-10		Radio-collared.	F94
M125	29	7-15-10	08-13-10		Radio-collared.	F94

[a] Cub F35 probably starved between 06-30-06 & 07-07-06 after the transmitter on the expandable collar got in its mouth.
[b] Cub M42 died after being captured by dogs, probably from stress of capture associated with severe infection of laceration under right foreleg caused by expandable radiocollar.
[c] Cub M56 was captured in association with F7 and her cubs M43 and M44. He may have been missed at the nursery when M43 and M44 were initially sampled and marked.
[d] Cub M60 died probably of starvation. The expandable radiocollar was around the neck and right shoulder, possibly restricting movement

Colorado Division of Wildlife
July 2009 - June 2010

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of Wildlife
Cost Center:	3430	:	Mammals Research
Work Package:	3003	:	Predatory Mammals Conservation
Task No.:	2	:	Cougar Demographics and Human Interactions
		:	Along the Urban-Exurban Front-range of
		:	Colorado
Federal Aid Project No.	N/A		

Period Covered: July 1, 2009 - June 30, 2010

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

ABSTRACT

Sampling cougar feces in the field may be a feasible non-invasive sampling method to estimate cougar populations. We continued analyzing cougar fecal samples collected from the 3 sibling cougars in captivity at the Foothills Wildlife Research Facility. Feces were stored at controlled temperatures after deposition and sub-sampled at monthly intervals. Genetic material has been found in samples up to 6 months post-deposition, but genotyping error rates have not yet been assessed. We are investigating 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. In addition to this, length relationships relative to genetic relatedness and individual stressors will give further insight into interpreting results from future data.

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 16 independent age cougars. Mortality remained high over the year exceeding 40% for independent age cougars (predominantly human related) and exceeding 50%

for cubs (predominantly starvation). Home-range patterns remained consistent to previous years. The effectiveness of aversive conditioning is still showing mixed results, which is likely a factor of the opportunistic nature of cougars using urban environments and a lack of habituation to them. 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
4. Evaluate the potential to develop a model for estimating age of bears and cougars based on telomere length.

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

SECTION A: GENETICS

INTRODUCTION

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

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

STUDY AREA

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

METHODS

Fecal samples were collected from the 3 sibling cougars located at the Foothills Wildlife Research Facility. During the year the entire remaining sample of 60 feces per cougar were collected and samples were placed at random into one of three treatment groups (-5 C, +5 C, and +15 C). Genetic samples were collected from these at the time of initial collection and at 2 weeks, and 1, 2, 3, 4, and 6 months post deposition. DNA was extracted and then stored at -20 C

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

PCR and DNA sequencing is being done at the Rocky Mountain Center for Conservation Genetics and Systematics laboratory. Individual cougars are screened and genotyped using 9 -12 nuclear microsatellite loci isolated from domestic cat (Menotti-Raymond and O'Brien 1995, Menotti-Raymond et al. 1999). Three recent studies have used sets of these primers successfully on mountain lions (Ernest et al. 2000, Sinclair et al. 2001, Anderson et al. 2004). We 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: TELOMERES

BY M. ALLDREDGE AND J. PAULI

INTRODUCTION

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

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

STUDY AREA

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

METHODS

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

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

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

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

RESULTS AND DISCUSSION

Amplification efficiencies were reasonable and consistent for both the single copy gene and telomere in the cougar samples. Standard curves obtained for cougars enabled a robust estimate of relative telomere length. However, there was considerable inconsistency in the standards used to quantify black bear telomere length and single copy gene. Estimated PCR efficiencies ranged from 51-263% and individual standards fluctuated even within a reaction. In general, inconsistent PCR amplifications prevent reliable estimation of telomere length and is often the consequence of poor sample quality. The DNA samples from black bears used quantify telomere length had low concentrations, and were potentially damaged during shipment to Laramie. Because of the limitation in these samples and resultant data, we did not calculate relative telomere length for black bears. Once age estimates have been obtained from the cougars for which we quantified telomere length, we will explore the relationship between age class and relative telomere length.

SECTION C: FRONT-RANGE COUGARS

BY M. ALLDREDGE AND K. BLECHA

INTRODUCTION

At the local scale, efforts have been made to continue the cougar/human interaction study on the Front-Range of Colorado. Given that cougars currently coexist with humans within urban/exurban areas along Colorado's Front-Range, varying levels of cougar-human interaction are inevitable. The CDOW is charged with the management of cougars, with management options ranging from minimal cougar population management, to dealing only with direct cougar-human incidents, to attempted extermination of cougars along the human/cougar spatial interface. Neither inaction 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 (CDOW, unpublished data).

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

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

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

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

STUDY AREA

The original pilot study was conducted in Boulder and Jefferson counties, in an area near Interstate 70 north to approximately Lyons, Colorado, which was also a likely area for addressing long-term research objectives (see Figure 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, 2009 and continuing through April, 2010, hounds were also used several times per week to capture cougars. Snares were used in situations where hounds could not be used and cougars would not enter cage traps. Captured cougars were anesthetized, monitored for vital signs, aged, measured, and ear-tagged. All independent cougars (> 18 months old) were fitted with GPS collars. All cubs greater than 15 kg (approximately 6 months or older) were ear-tagged with 22 g ear-tag transmitters. For detailed capture and handling procedures see the study plan APPENDIX I.

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

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

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

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

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

We evaluated cougar diet composition by using GPS location data to identify likely kill sites. Characteristics of clusters of GPS locations representing cougar-killed ungulate sites (Anderson and Lindzey 2003, Logan 2005) were used to develop a standard algorithm to group GPS points together, to provide a sound sampling frame from which statistical inference could be made about clusters that are not physically investigated. GPS collars collected locations 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. The clustering algorithm was written in Visual Basic and was designed to run within ARCGIS (Alldredge and Schuette, CDOW unpubl. data 2006). The widths of the spatial and temporal sampling windows were user specified, in order to meet multiple applications and research needs. This also enabled adjustment of the sampling frames to improve cluster specifications as needed.

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

RESULTS AND DISCUSSION

Collared cougars from the previous year were captured and re-collared to replace exhausted batteries throughout the year. An additional 16 independent age cougars were also captured and collared during the year (Table 1). Currently there are 18 independent age cougars in the study with functioning GPS collars, including a rehabilitation cougar that dispersed to New Mexico.

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

Mortalities of collared cougars were high with 7 new mortalities during the 2009-10 year (Table 1). Causes of death included vehicle collision, unknown sources, hunting, and management or landowner euthanasia.

Field investigations of GPS clusters have been conducted on 31 of the radio collared cougars in order to understand predation and feeding habits. From Aug 1, 2008 untill July 31, 2010, we have visited >1,402 clusters (S1-S5 types). However, only 1,100 of these clusters were considered to be random samples and thus inferences have only been drawn from this subset representative of the feeding habits of the cougars. Each cluster was classified by the probable behavior of the focal cougar. These sites averaged over the individuals were BED sites (12.8% ± 6.2%), UNKNOWN (63.8% ± 5.5%), and FEEDING sites (23.7% ±3.8%). Of the FEEDING sites, 21.5% ±3.8% were KILL sites and 2.2% ± 1.1% were SCAVENGING sites. UKNOWN sites were any site where no prey remains or cougar bedding sign was found, and is thus thought to represent travelling and/or hunting activities. When examining 477 random S1 clusters (clusters with at least 2 locations within 200m) we found a 46.4% ± 16.3% chance of being a probable FEEDING site. 622 of the clusters visited were of the S2, S3, S4, and S5 cluster types, and these showed to have a much lower probability of being a FEEDING site (6.3% ± 2.7%). Of particular interest was that the percentage of SCAVENGING cases represented 9.9% (± 5.7%) of known FEEDING sites. Of the known FEEDING sites, a vast majority (85.5%) were detected with the S1 cluster types, while a smaller percentage were detected with the S2-S5 cluster types (Figure 3).

For prey composition, we calculated the frequency (percentage) of occurrence of food items, averaged over the sample of collared cougars. Of the clusters with feeding activity, mule deer were the primary prey items (67.5% ± 11.9%), non-cervids were secondary (19.1% ± 10.7%), and elk the least used (13.3% ± 7.6%) found at clusters with confirmed feeding activity (Figure 4). Elk were found as prey items at clusters for male cougars (33.9%) much more frequently than female cougars (2.0% ± 1.9%). Females fed on deer (77.7% ± 13.3%) more frequently than males (49.1% ±19.6%) but differences are not yet substantiated to be significant. No significant differences were found between the frequencies of alternative prey items fed upon between females (20.3% ± 13.1%) and males (16.9% ± 19.3%) (Figure 5).

For this preliminary analysis, we also grouped prey items by relative size (Table 3). Female cougars killed a significantly higher proportion of Class 3 (i.e. coyote or fawn sized) prey compared to male cougars. Females also killed a much larger proportion of Class 2 prey compared to males. Males killed a significantly higher proportion of Class 5 and 6 prey compared to females (Figure 6). When pooling Class 1-3 into a small prey category, and Class 4-6 into a large prey category, we can speculate that males feed upon a higher proportion of large prey compared to females while females feed upon a higher proportion of small prey. A large difference does exist within males, as larger prey items (80.6% ± 14.1%) are fed upon much more frequently than smaller prey (19.4% ± 14.1%) (Figure 7).

GPS cluster locations are downloaded in monthly intervals, and then visited during the next monthly interval. Because our GPS cluster investigation sampling scheme utilizes a random representative sample of prey items from the entire time period a focal cougar is collared, a variable time lag exists between the day that a GPS cluster is made and when personnel can conduct a field visit to the actual site. This variable time lag may range between 1-60 days, and it is suspected that some prey items are missed as decomposition and scavengers can make it more difficult for field observers to verify the presence of prey remains. To investigate if a real bias may exist, we grouped each cluster by the time lag into 15 day intervals (1-15, 16-30, 31-45, 46-60). We then calculated the frequency of each probable action category (BED, FEEDING, UNKNOWN) occuring in each interval. To examine if a seasonal effect is possible, we classified clusters by the season that they were created in. October 1 – April 30 was considered winter, while May 1 – September 30 was considered summer. We found that the FEEDING actions decreased as the time lag increased. This was accompanied by an increase in the frequency of sites that were classified as UNKNOWN (Figure 8). This same pattern was observed when looking at the summer clusters (Figure 9), but not as apparent in the winter seasons (Figure 10).

SUMMARY

Genetic analysis for cougar feces revealed that DNA is still present in samples after feces have been in controlled temperature environments for up to 6 months. Genotyping error rates still need to be assessed. However, the presence of DNA in these samples suggests that field detection of cougar scats may be a viable non-invasive population sampling technique. We have added known-age samples collected from natural environments from known cougars marked in the front-range cougar project.

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

In addition to re-collaring previously collared cougars, an additional 16 independent age cougars were collared during the year. Mortality remained high over the year exceeding 40% for independent age cougars and exceeding 50% for cubs. Home-range patterns remained consistent to previous years. The effectiveness of aversive conditioning is still showing mixed results, which is likely a factor of the opportunistic nature of cougars using urban environments and a lack of habituation to them. Relocation of cougars as a management tool has had limited assessment, but given some success, still warrants further investigation. Mule deer are the predominant prey in cougar diets, although males also utilize elk regularly.

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

Cougar ID	Sex	Age	Date	Location	Occurrence	Capture	Release Loc	Conditioning	Status
AM02	M	1	6/14/07	Lacey Prop.	Baiting	Cage	On-site	NA	Alive
		1.5	1/10/08	White Ranch	Capture effort	Hounds	On-site	NA	Alive
		1.5	2/9/08	Coal Creek	Intraspecific mortality				Dead
AM04	M	7	7/14/07	White Ranch	Baiting	Cage	On-site	NA	Alive
		7	10/17/07	Eldorado Springs	Livestock depredation	Cage	White Ranch	Beanbag	Alive
		8	4/29/08	Magnolia/Flagstaff	Replace Collar	Hounds	On-site	NA	Alive
		8	5/5/08	South Boulder	Seen in town	Free-dart	Lindsey	Beanbag	Alive
		8	8/4/08	North Boulder	Killed deer in town	Cage	Centennial Cone	Beanbag	Alive
		9	2/24/09	Boulder Canyon	Punctured intestine				Dead
AM06	M	5	11/21/07	Heil Valley Ranch	Capture effort	Hounds	On-site	NA	Alive
		6	12/30/08	Heil Valley Ranch	Replace Collar	Hounds	On-site	NA	Alive
		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
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
AF11	F	1.5	3/5/08	South Table Mesa	Deer Kill	Cage	On-site	NA	Alive
			6/10/08	US-40/Empire	Roadkill				Dead
AM20	M	4	3/6/08	White Ranch	Capture effort	Hounds	On-site	NA	Alive

			5/18/08	West of White Ranch	Livestock Depredation	Shot			Dead
AF15	F	6	3/18/08	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
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
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
AM18	M	1.5	12/24/08	Evergreen	Deer kill	Cage	Mt. Evans SWA	None	Alive
			3/14/09	Evergreen	Livestock depredation	Cage	None	Euthanized	Dead
AF16	F	3	12/29/08	Evergreen	Deer Kill	Snare	Flying J Open Space	None	Alive
			3/20/09	Evergreen	Livestock depredation	Cage	Mt. Evans SWA	Beanbag	Alive
AF45	F	5	1/2/09	Gold Hill	Deer kill	Cage	On-site	NA	Alive
AF40	F	1.5	1/27/09	White Ranch	Capture effort	Hounds	On-site	NA	Alive
		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
AM46	M	2	11/13/09	Evergreen	Elk kill	Cage	On-site	None	Alive
				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
AM606	M	2	1/6/10	Boulder	Seen in town	Free-dart	MacGregor Ranch	None	Alive
AF54	F	4	1/14/10	White Ranch	Capture effort	Hounds	On-site	NA	Alive
AF52	F	4	1/28/10	Hall Ranch	Capture effort	Hounds	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
				Conifer	Pet Depredation	Cage	Euthanized		Dead
AM53	M	4	3/13/10	Genesee	Elk Kill	Cage	On-site	NA	Alive
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
AF62	F	5	4/13/10	Walker Ranch	Elk Kill	Cage	On-site	NA	Alive
AF59	F	5	4/22/10	Blue Jay/Jamestown	Deer Kill	Cage	On-site	NA	Alive
SW023	F	1	4/9/09		Rehab	Release	Pike forest	None	Alive
SW026	M	1	10/20/09		Rehab	Release	Hermit Park	NA	Alive
SW107	M	1	5/7/10		Rehab	Release	Radium	NA	Unkn

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

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

Table 3: Classification scheme for the most common prey items found at cluster sites. Other uncommon prey items were found including gray fox, corvids, bighorn sheep lamb.

PREY CLASS	PREY ITEM (example)	SIZE (small/large)
1	Squirrel, Bird, Rabbit	Small
2	Porcupine, Domestic Cat, Fox, Raccoon, Skunk	Small
3	Coyote, Fawn Deer, Domestic Dog	Small
4	Calf Elk, Yearling Deer	Large
4.5	Unknown Deer	Large
5	Yearling Elk, Adult Deer, Alpaca	Large
6	Adult Elk, Horse, Cattle	Large

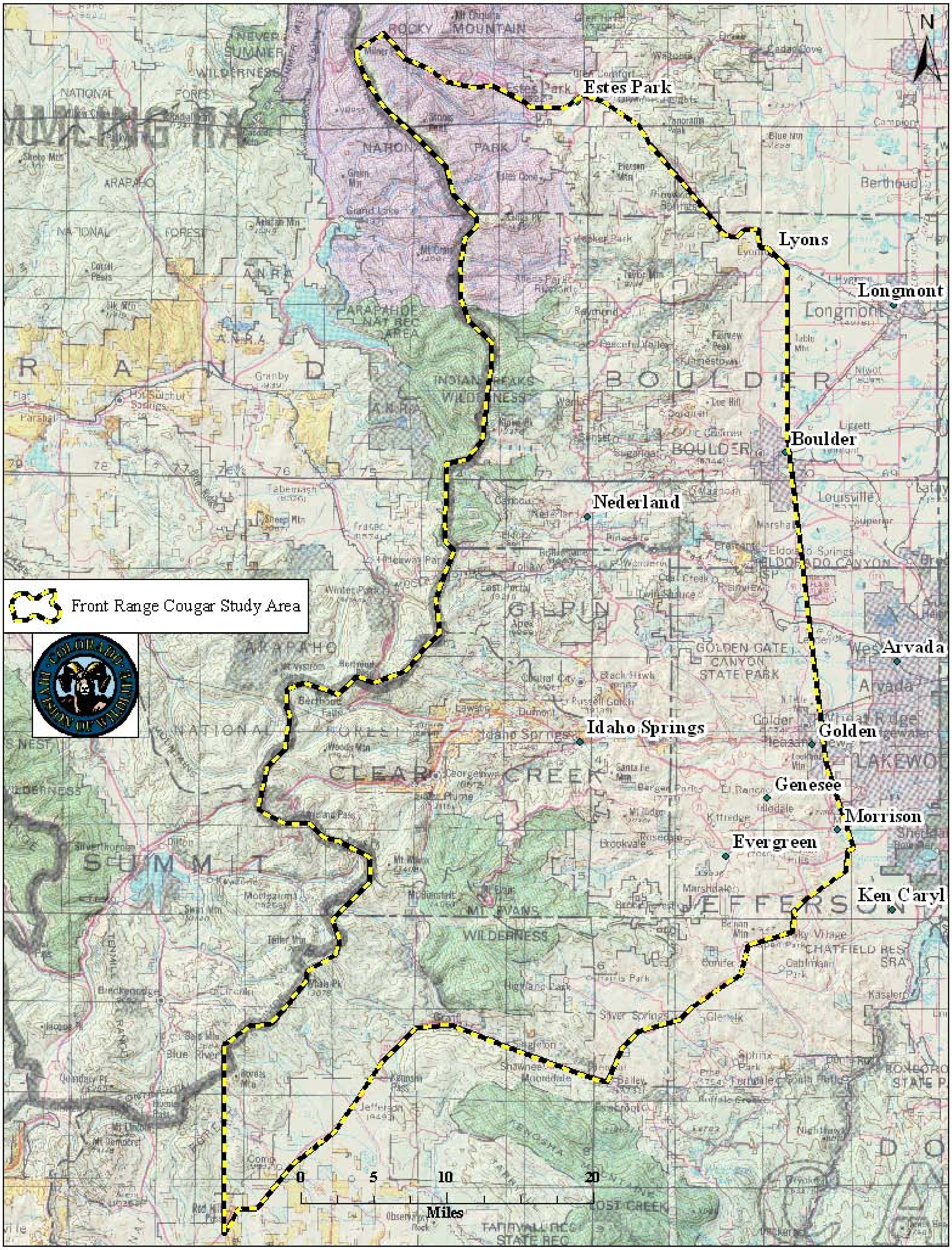

Figure 1: Study area boundary with the continental divide to the west, Highway 285 on the south, Highway 34 and 36 on the north, and the edge of the foothills on the east.

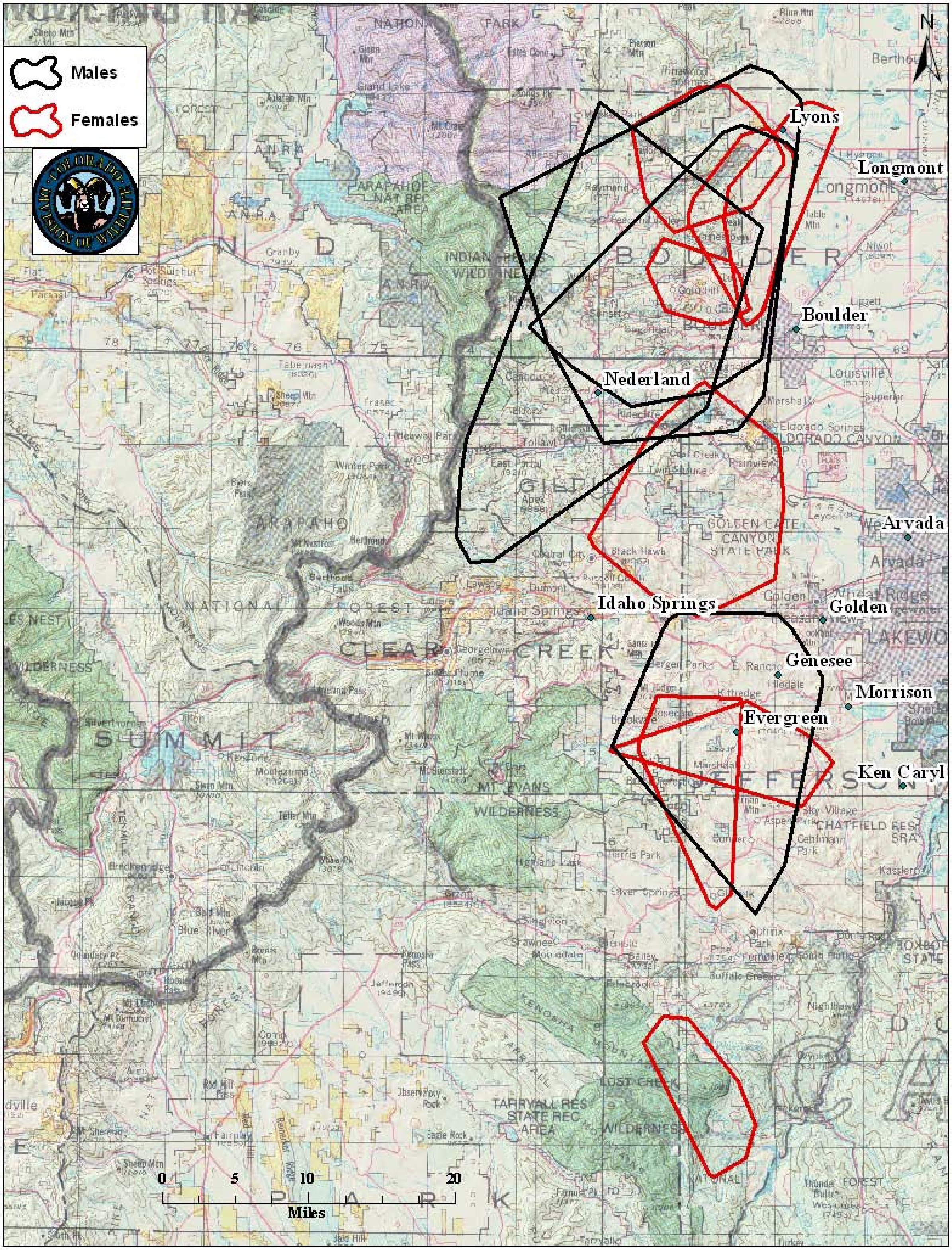

Figure 2: Male and female MCP homeranges for cougars with functioning GPS collars depicting the overlap in homeranges between males and females.

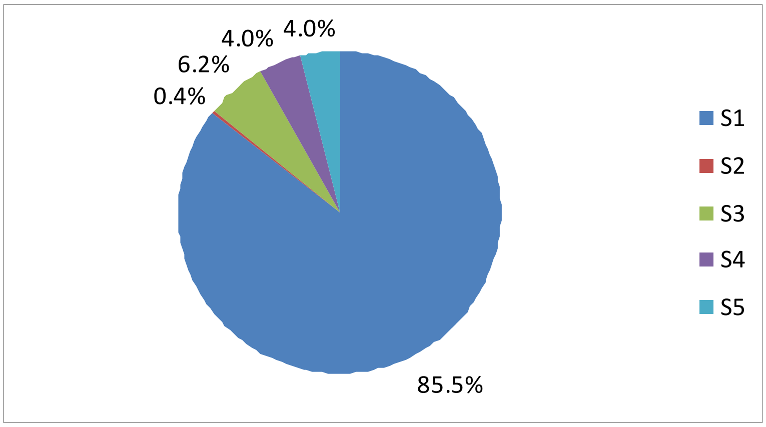

Figure 3: Percentage of feeding sites detected with S1, S2, S3, S4, and S5 cluster types.

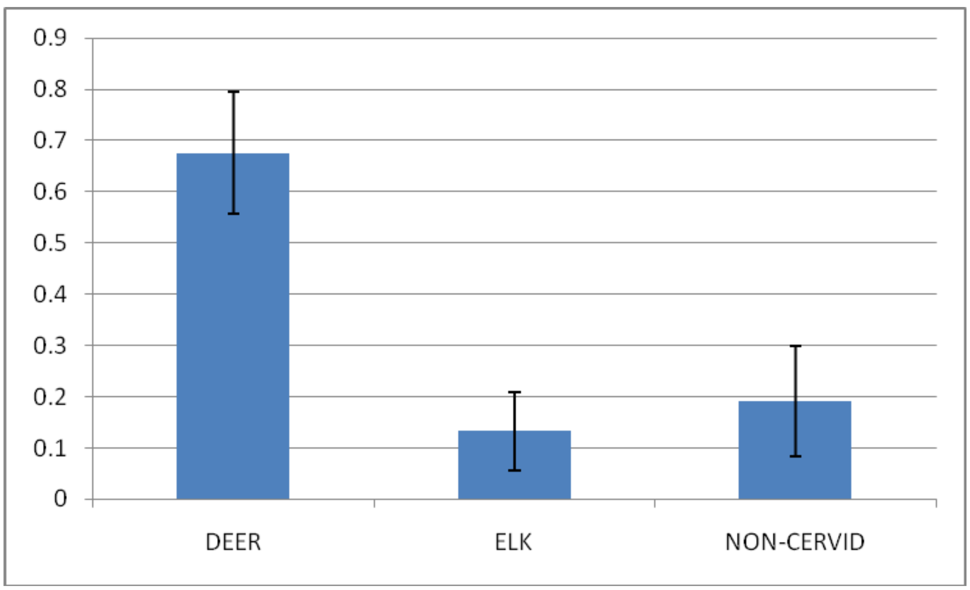

Figure 4: Mean proportion of Deer, Elk, and non-cervid prey remains found at feeding sites. Mean proportion drawn from the mean of 31 subject cougars (*n*=31).   Error bars represent 95% Confidence Limits with an assumed normal distribution.

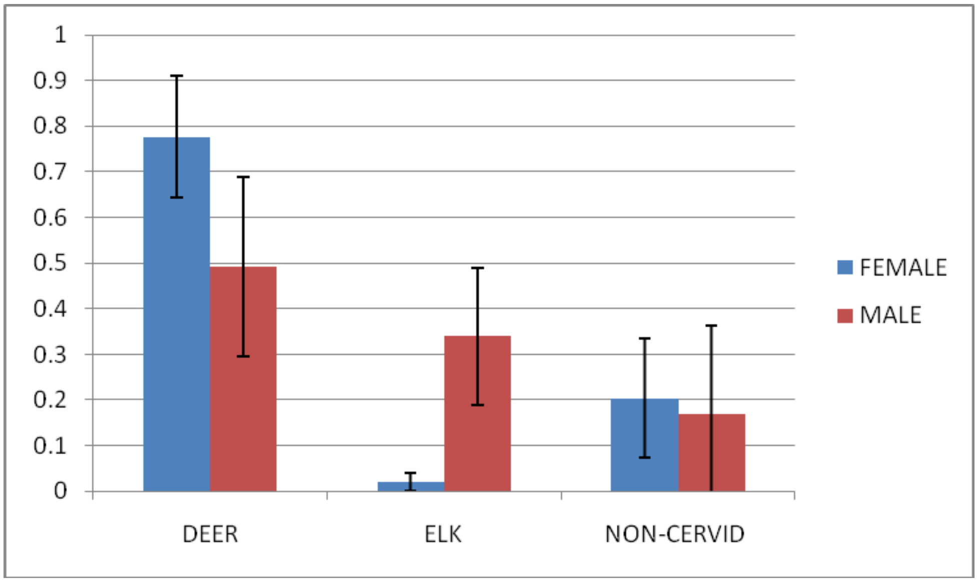

Figure 5: Mean proportion of Deer, Elk, and non-cervid prey remains found at feeding sites, classified by cougar sex. Averaged over female subject cougars and male subject cougars, (Female *n* = 20, Male *n*=11). Error bars represent 95% Confidence Limits with assumed normal distribution.

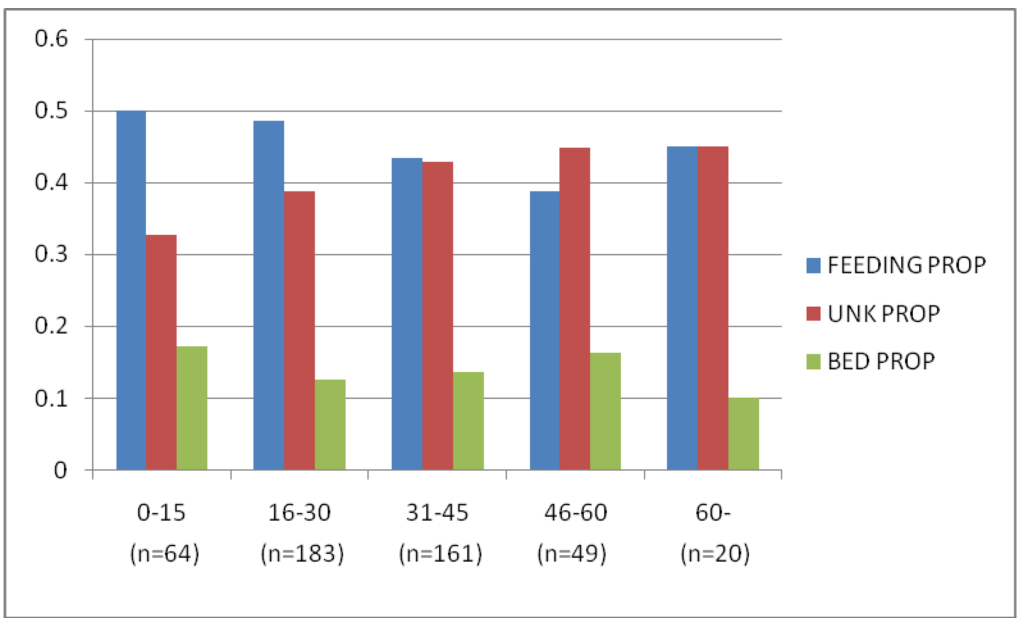

Figure 6: Mean proportion of sites with confirmed Class 1, 2, 3, 4, 4.5, 5 and 6 prey types for male and female subjects. (Female n = 20, Male n=11) Error bars represent 95% confidence intervals assuming a normal distribution. Female subject killed a significantly higher proportion of Class 3 prey over male subjects. Females also killed a much larger proportion of Class 2 prey over male subjects, but statistical significance is unknown. Males killed a significantly higher proportion of Class 6 prey over females. Males also killed a higher proportion of Class 5 prey over females, but statistical significance is unknown.

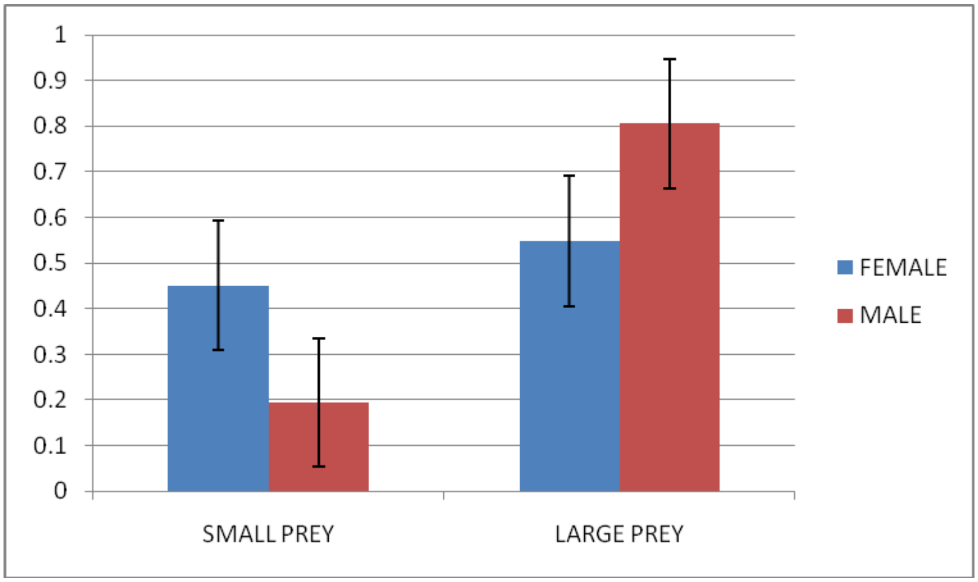

Figure 7: Frequency of large and small prey found at cougar feeding sites. Small prey consisted of Prey classes 1-3 (small mammals-Fawn deer). Large prey consisted of prey classes 4-6.

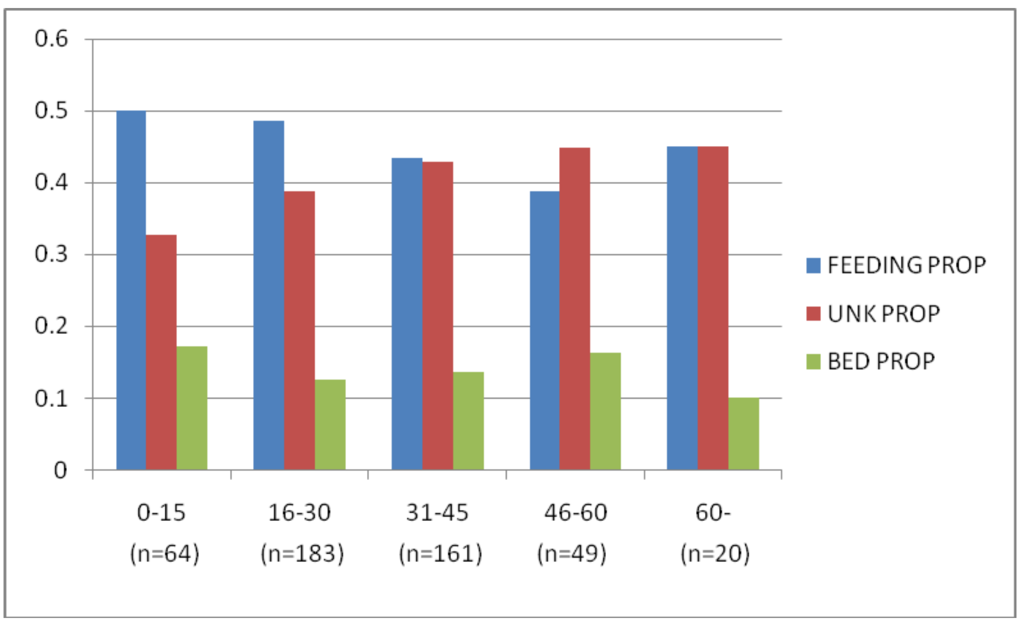

Figure 8: Frequency of occurance for the three primary actions at GPS cluster sites, categorized by time lag (i.e. 0-15 days) from when site was visited by the focal cougar to visitation by field personnel. Number of clusters in each time lag is represented by *n*. As time passes, chances of detecting feeding evidence decreases.

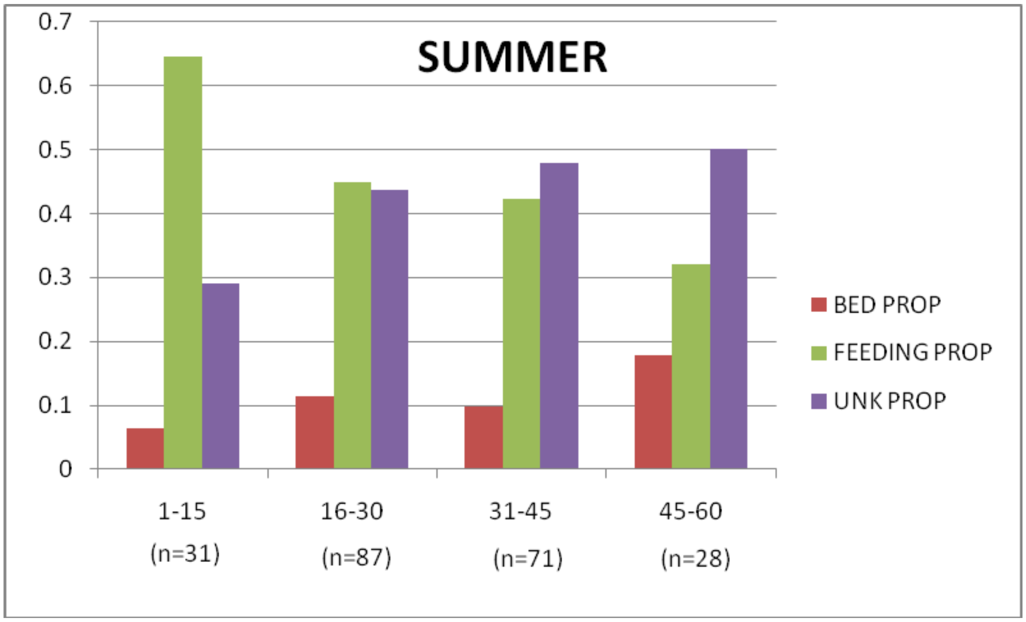

Figure 9: Frequency of occurance for the three primary actions at GPS cluster sites in the summer season, categorized by time lag (i.e. 0-15 days) from when site was visited by the focal cougar to visitation by field personnel. Number of clusters in each time lag is represented by *n*. As time passes, chances of detecting feeding evidence decreases.

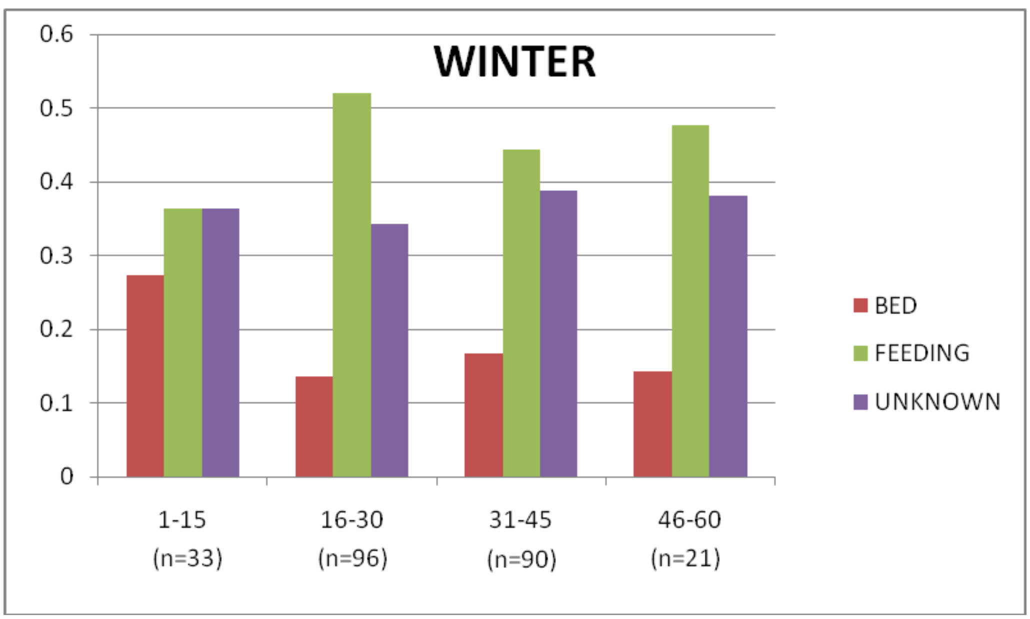

Figure 10: Frequency of occurance for the three primary actions at GPS cluster sites in the winter season, categorized by time lag (i.e. 0-15 days) from when site was visited by the focal cougar to visitation by field personnel. Number of clusters in each time lag is represented by *n*. Visitation time lag is not as strong as a predictor for the frequency of occurrence of feeding activity.

Colorado Division of Wildlife
July 2009 – June 2010

WILDLIFE RESEARCH REPORT

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

Period Covered: July 1, 2009 – June 30, 2010

Author: Kay Horton Knudsen

Personnel: Kay Horton Knudsen, Chad Bishop

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ABSTRACT

The Colorado Division of Wildlife Research Center Library has existed for several decades in the Ft. Collins office. A library housed in the Denver office was moved to Ft. Collins many years ago. Early librarians, Marian Hershcopf and Jackie Boss, can be credited with the physical organization of the Library including seven decades of Federal Aid reports, almost 50 years of Wildlife Commission reports and a unique book and journal collection.

Jackie Boss retired in April 2007 and the Library was temporarily closed to all services. Kay Horton Knudsen was hired as the new Research Center Librarian and began employment with CDOW 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 Colorado Division of Wildlife.

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 DIVISION OF WILDLIFE RESEARCH LIBRARY SERVICES

KAY HORTON KNUDSEN

P.N. OBJECTIVE

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

SEGMENT OBJECTIVES

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

SUMMARY OF LIBRARY SERVICES

When the Research Center Library reopened in August 2008, the librarian was charged with choosing and implementing a web-based Integrated Library System (ILS) and purchasing statewide access for Colorado Division of Wildlife staff to online research databases. Once those systems were available on a new Library website, training and outreach to staff should take place. Alongside these online efforts was the task of physical organization and cleaning of the Library offices, cataloging the backlog of purchased books and staff reprint articles, streamlining the periodical selection/purchase process and, with the help of work-study staff from Colorado State University, sorting through stacks of donated documents.

EOS International was chosen as 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) and delay other features until the system was up and running. The Library website was released to CDOW staff in March 2009. Full-text searchable PDFs of Division reports and staff reprints were added to the online catalog as they became available to the librarian. The next module purchased from EOS was Indexer – this feature allows for full-text searching of the linked PDFs and was implemented in December 2009.

In addition to the catalog of books and reports housed in the Ft. Collins Library, the Library website also gives all CDOW 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 SocIndex 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. CDOW staff are authenticated through WildNet (intranet) eliminating the need for individual usernames and passwords.

The next step was training of CDOW staff on the various features of the new Library website. Group and individual sessions were held in Ft. Collins and at CDOW offices in Glenwood Springs, Grand Junction, Durango, Montrose, Colorado Springs, Denver, Hot Sulphur Springs, and Gunnison during 2009 and 2010. Handouts were created to assist staff with basic website use and the specialized database features such as creating subject and table of contents alerts.

Other projects in the Library this year included: 1) reorganization of the book, reference and journal collections to make them more accessible to the library staff, 2) weeding and storing duplicate copies and updating the catalog records as part of the first project, 3) cataloging new material, 4) continued addition of PDF formats into the catalog's bibliographic file, 5) clean-up of old-style bibliographic barcodes in the Library database, 6) renewal of print journal subscriptions based on discussions with research managers and the cancellation of print journals when full-text was available electronically, 7) printing and cataloging of the Data Analysis Unit (DAU) reports to maintain a historic record in the Library collection, 8) discussion with vendors on adding a federated/integrated search capability to the Library catalog and 9) initial research and testing of equipment and options for digitization of CDOW documents; a printer/scanner was purchased.

A job duty of the librarian is to assist with CDOW research publications. *Sagebrush of Colorado* by Alma H. Winward was reprinted; the full-color brochure from 2004 is a popular state publication. Two Special Reports were recently issued: number 81, *Colorado bighorn sheep management plan, 2009-2019* and number 82, *A Compendium of crustacean zooplankton and Mysis diluviana collections from selected Colorado reservoirs and lakes, 1991-2009.*

The librarian attended the Colorado Association of Libraries conference in Denver in November 2009, and the international WebWise10 conference on digitization in libraries in Denver in March 2010. There was also the opportunity to participate in several online "webinars" sponsored by various vendors and library agencies to expand knowledge on trends in the library field.

With the introduction of the expanded library services and the training sessions, the number of requests for documents or research assistance has grown. Most questions received in the Library are from CDOW staff or from outside researchers (generally consultants and out-of-state natural resources employees). At this time the Library is not open on a walk-in basis to the general public but the librarian does assist the Help Desk at the Denver office with questions they receive. CDOW employees generally request journal articles or items from the Library collection; outside researchers most often want a copy of a CDOW publication. The chart below shows the number of reference questions and document requests handled by the librarian during the past 2 years. Please note that one request from a CDOW staff member may be for multiple journal or book titles.

	Reference Requests			Reference Requests
			July 2009	20
August 2008	15		August 2009	25
September 2008	21		September 2009	30
October 2008	33		October 2009	38
November 2008	14		November 2009	28
December 2008	28		December 2009	32
January 2009	33		January 2010	62
February 2009	30		February 2010	43
March 2009	35		March 2010	36
April 2009	24		April 2010	23
May 2009	13		May 2010	17
June 2009	20		June 2010	26

STATISTICS: The Research Center Library holds 18,390 titles and 23,912 items (these are the multiple copies of a title) and has 108 registered patrons (CDOW staff). There were 2,026 searches conducted in the Library catalog during the year. Usage statistics for the research databases are given in the chart below. For American Fisheries Society, 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.

	American Fisheries	BioOne	EBSCO searches	JSTOR
July 2009	27	172	1255	111
August 2009	20	49	261	190
September 2009	3	87	872	187
October 2009	81	103	442	166
November 2009	53	64	686	289
December 2009	81	105	647	249
January 2010	83	123	764	361
February 2010	152	113	652	238
March 2010	128	91	1448	322
April 2010	41	33	331	176
May 2010	56	35	381	116
June 2010	37	9	487	84
TOTAL	762	984	8226	2489

Prepared by ____________________________

Kay Horton Knudsen, Librarian