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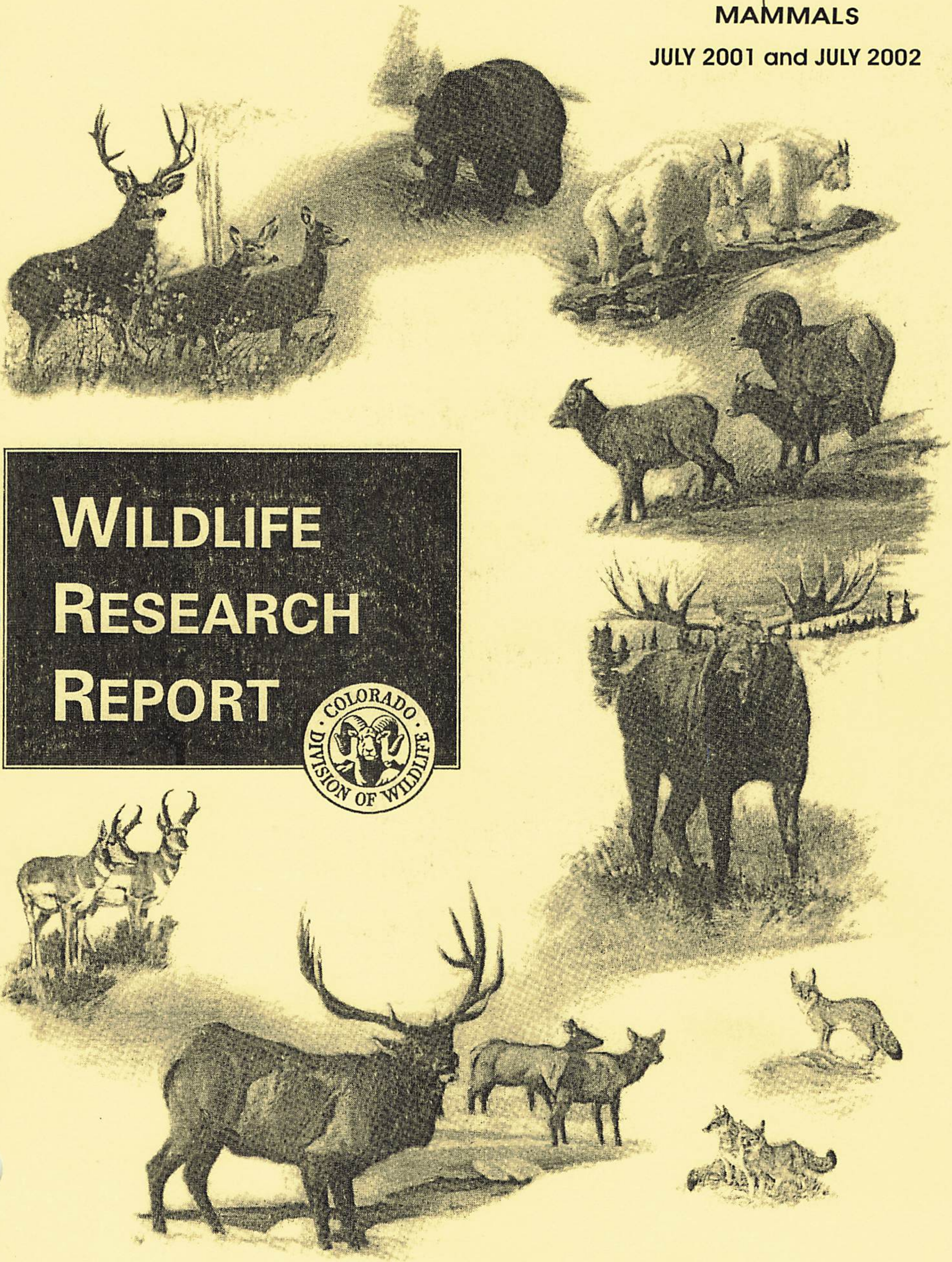
MAMMALS

JULY 2001 and JULY 2002



WILDLIFE RESEARCH REPORT

COLORADO DIVISION OF WILDLIFE

WILDLIFE RESEARCH REPORT

JULY 2001 and July 2002

Mammals Research Program

2004

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

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Colorado Division of Wildlife
Wildlife Research Report
July 2001 and July 2002

TABLE OF CONTENTS

MAMMALS RESEARCH PROGRESS REPORTS

PREBLE'S MEADOW JUMPING MOUSE CONSERVATION

LYNX CONSERVATION

DEER CONSERVATION

ELK CONSERVATION

CARNIVORE CONSERVATION

OTHER UNGULATE CONSERVATION

MULTISPECIES INVESTIGATIONS

Colorado Division of Wildlife
Wildlife Research Report
July 2001 and July 2002

JOB PROGRESS REPORT

State of Colorado : Division of Wildlife – Mammals Research

Work Package No. 0662 : Preble's Meadow Jumping Mouse Conservation

Task No. 2 : Effects of Resource Addition on Preble's Meadow Jumping Mouse (*Zapus hudsonius preblei*) Movement Patterns

Period Covered: July 1, 2000 – June 30, 2002

Author: Anne Trainor

Personnel: T. M. Shenk, G. C. White, K. Wilson

Interim Report – Preliminary Results

This work continues, and precise analysis of data has yet to be accomplished. Manipulation or interpretation of these data beyond that contained in this report should be labeled as such and is discouraged.

ABSTRACT

Preble's meadow jumping mouse (*Zapus hudsonius preblei*; PMJM) is federally listed as threatened under the Endangered Species Act (ESA). Habitat conservation plans (HCPs) as defined in Section 10 of the ESA, allow for 'take' of species and their habitat on private property. HCPs attempt to minimize take and provide for mitigation. Collection of reliable information and an increased understanding of PMJM habitat requirements are essential for the development of effective mitigation strategies for this species. Thus, our objectives are to (1) determine how the presence of resource additions influences the distribution of individual PMJM within a population, and (2) to quantify and compare microhabitat characteristics among areas PMJM used heavily to areas of no use. A manipulation experiment will be conducted in sections of riparian habitat and adjacent grasslands in Douglas County, Colorado in 2002 and 2003.

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Research Prospectus

Effects of Resource Addition on Preble's Meadow Jumping Mouse (*Zapus hudsonius preblei*) Movement Patterns

Anne Trainor, Tanya Shenk, and Kenneth Wilson

Problem: The U.S. Fish and Wildlife Service (USFWS) listed the Preble's meadow jumping mouse (*Zapus hudsonius preblei*; PMJM) as a threatened species in 1998 under the Endangered Species Act (USFWS 1999). Upon listing, little was known about the biology and habitat requirements of this subspecies within its range along the Front Range of Colorado and southeastern Wyoming. Since listing, a number of projects (e.g., long-term monitoring, surveying, and movement studies) have collected valuable information throughout Colorado (Schorr 2001, Meaney 2000, Shenk and Sivert 1999). However, information on specific habitat requirements and their relationship to the distribution, density, survival and reproduction of PMJM is still lacking.

The threatened status of PMJM requires management decisions be made despite our limited knowledge. In particular, the species and its habitat are subject to habitat conservation plans (HCPs). HCPs are written for endangered and threatened species to compensate for authorized "take" with mitigation practices (Bingham and Noon 1998). HCPs require the use of the "best available" science to determine the biological needs of target species (Harding et al. 2001). Collection of reliable information for the species will improve the mitigation practices developed for HCPs. Well-designed habitat manipulation experiments provide the strongest inference to determine cause and effect relationships. Understanding of the species habitat requirements will enable the development of effective mitigation strategies.

A manipulation experiment will be conducted in Douglas County, Colorado (Columbine Open Space) during 2002 and 2003 to advance our understanding of PMJM habitat requirements. We will manipulate sections of the riparian habitat and adjacent grassland within the 100-year flood plain. The site will be manipulated by adding patches (3 m x 2.43 m) of artificial resources (food and cover). Time limitations (2 field seasons are inadequate for vegetation to establish) and funding (cost of planting and sustaining vegetation) will restrict this manipulation experiment to simulating habitat with temporary structures and food supplementation. The treatments will be placed in areas of low use based on past monitoring studies conducted by the Colorado Division of Wildlife (CDOW) during 1998-2000 within 60 m of East Plum Creek. PMJM will be radio tracked before and after the manipulation to determine if PMJM locations can be altered through the addition of resources.

Research Objectives: We propose two primary objectives: 1) determine how the presence of resource additions influences the distribution of individual PMJM within a population, and 2) quantify habitat characteristics of PMJM on a microhabitat scale.

Desired outcome: We want to examine if the distribution of individual PMJM can be altered in response to the addition of resources (food and cover) and to quantify relevant microhabitat characteristics where PMJM have been detected.

Approach: A field experiment will be conducted during 2002-2003 (June-August) to test if PMJM can be attracted to areas where they have not previously been detected within the 100-year flood plain.

Study Site- Riparian habitat within the Columbine Open Space, owned by Douglas County Open Space managed by the CDOW and the adjacent grassland. Columbine Open Space was selected because PMJM were monitored for 3 years by the CDOW (1998-2000), providing site-specific information on PMJM locations before this manipulation experiment.

Methods- PMJM will be trapped using non-folding Sherman live traps (7.6 cm x 8.9 cm x 22.9 cm) placed 5 m apart along approximately 0.5 km transects adjacent to both sides of East Plum Creek for a minimum of 5 consecutive nights. Trapping procedures will be in accordance with the guidelines published by the USFWS (1999). Species other than PMJM will be recorded with trap location and immediately released. The following information will be recorded for captured PMJM: unique identification, trap location, weight, sex, age, and reproductive condition. PMJM will be scanned for a passive integrated transponder (PIT) tag. Newly captured individuals will have a unique PIT-tag injected and individuals $\geq$18 grams will be anesthetized with isoflurane to fit a 1-g radio transmitter (Holohil Systems Ltd Ontario, Canada). All methods were approved by the Animal Care and Use Committee of Colorado State University (Authorization Number A3572-01).

Radio telemetry will be used to monitor locations of individuals for a 21-day period, the battery life of the radio transmitters. Observers will attempt to stay approximately 3 m from the radio-tagged individual to avoid influencing PMJM movement. Observations taken 3 m or greater from PMJM did not influence movement (T. Shenk, CDOW personal comm.). The following information will be recorded at each relocation: individual identification, time, weather, and surrounding vegetation. All data will be combined into a geographical information system (GIS) database using ArcView®3.2 (Environmental Systems Research Institute, Redlands, California, U.S.A.).

The manipulation experiment will consist of 5 phases: 1) select areas of little or no previous use by PMJM based on CDOW location data (1998-2000) collected at Columbine Open Space, 2) record pre-treatment location data of radio-tagged individuals for 6 nights, 3) select placement of treatment plots based on pre-treatment and CDOW location data, 4) add resources to treatment plots, and 5) record post-treatment location data of radio-tagged individuals. Two sessions (June and July) of the manipulation experiment will be conducted each year.

A digital map with a grid cell size of 9 m x 9 m has been constructed for the entire study site with ArcView®3.2 (Environmental Systems Research Institute, Redlands, California, U.S.A.) software. CDOW location data was pooled into a single coverage over the grid to establish areas $\geq$ 1,000 m^2 containing only low use cells (<2 locations/cell based on CDOW location data) within the 100-year flood plain. Location of treatments will be selected with a stratified random design from a set of candidate cells meeting a criteria developed based on PMJM biology (sparse vegetation and little food source) within 60 m of East Plum Creek, and low historical use.

The artificial cover, simulating vertical complexity, will be constructed with wheat straw and tree branches distributed in a patch (3 m x 2.43 m). Burlap cloth will be suspended 30 cm over the tree branches and straw. Food supplements composed of an equal mixture of whole wheat, dehydrated alfalfa pellets and sweet feed will be placed on cardboard trays (0.16 m x 0.3 m) within the straw and branches as an attractant and a source of high protein. The dimensions of the treatments were selected to balance the manageability of construction and decrease the chance of inter and intra-species domination within a treatment.

Quantification of microhabitat variables in areas of high use will be examined by comparing a random sample of cells (9 m x 9 m) containing $\geq$ 99 % of PMJM locations for each session and a random sample of cells with no locations detected. Two line transects will be randomly placed in each selected cell with 6 quadrat frames (50 cm x 20 cm) evenly distributed per line transect (Daubenmire 1959). The variables measured in each cell will include percent bare ground, shrub, grass, and forb cover and vegetation composition.

Analysis- The location data will be analyzed with linear regression. The response variable will be the number of locations detected in a cell. A suite of candidate models will be developed as predictors of the response variable. Akaike's information criterion (AIC) will be applied to select the best "approximating" model (Burnham and Anderson 2002). The independent habitat variables of interest for the models include distance from the center of the cell to the nearest water, area and juxtaposition of nearest shrub, and presence of wetland grasses in the cell. Additional variables to be included in the models are period (pre- or post-treatment), sex, session, and year.

The microhabitat data collected from the Daubenmire plots will be analyzed with Proc GLM (SAS 2002) to test for differences in means among areas of high use and no use by PMJM.

Schedule:

Fall 2001................	Formation of committee and write study plan development
Spring 2002.............	Completion of study plan and preparation for field season
Summer 2002	Begin data collection
Fall 2002................	Begin data analysis
Spring 2003.............	Continue data analysis, begin thesis and complete comprehensive oral examination
Summer 2003	Complete data collection
Fall 2003...	Complete data analysis
Winter 2004.............	Complete thesis

Budget:

Fiscal Year 2001-02

Refurbished Holohil radio collars	$2,000
Technicians	1@$1,250/month for 3 months
Housing	$833/month for 3 months
Vehicles	1@$200/month for 3 months (including mileage)
Supplies	$700
Computer	$2,000
Tuition	$2,880
GRA	$1,300/month for 12 months
Faculty Support	$3,830.00
FY 2001-02 Total	**$33,779**

Fiscal Year 2002-03

Refurbished Holohil radio collars	$500
PIT tags	$1,000
Technicians	1@$1,250/month for 3 months
Technicians	1@$1,250/month for 2 months
Supplies	$500
Housing	$833/month for 3 months
Vehicles	1@$200/month for 3 months (including mileage)
Stipend	$1,300/month for 12 months
Tuition	$679.00
Faculty Support	$3830.00
FY 2002-03 Total	**$31,458**

Fiscal Year 2003-04	
Stipend	$1,300/month for 8 months
FY 2003-04 Total	**$10,400**
Project Total	**$75,637**

Potential cooperators: Funding is provided by the CDOW; Douglas County has given permission to use the Open Space; Colorado State University has provided office space, equipment, computers, and adviser.

Alternative and obstacles: Alternatives considered include modeling habitat utilization at a microhabitat and site specific scales. Potential obstacles include 1) low number of radio-tagged PMJM resulting in low power for the manipulation experiment, 2) other species deterring PMJM from using the additional resources, and 3) radio-tagged mice do not detect the additional resources. PMJM have demonstrated general site fidelity to daytime nesting sites and nighttime feeding sites (Shenk and Sivert 1999). It is possible PMJM have established use areas and do not easily alter their use patterns.

Literature Cited:

Bingham, B. B., and B. R. Noon. 1998. The use of core areas in comprehensive mitigation strategies. Conservation Biology 12:241-243.

Burnham K. P., and D. R. Anderson. 2002. Model selection and multimodel inference. Second edition. Springer, New York, New York, USA.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Science 33:43-64.

Harding, E., E. Crone, B. D. Elderd, J. M. Hoekstra, A. J. McKerrow, J. D. Perrine, J. Regetz, L. J. Rissler, A. G. Stanley, E. L. Walters and NCEAS Habitat Conservation Plan Working Group. 2001. The scientific foundations of habitat conservation plans: a quantitative assessment. Conservation Biology 15:488-500.

Meaney, C. A. 2000. Monitoring for Preble's meadow jumping mice along South Boulder Creek and Four Ditches. Boulder, Colorado, USA. Report prepared for the Colorado Division of Wildlife.

SAS Institute. 2002. SAS Version 8.2. SAS Institute, Cary, North Carolina, USA.

Schorr, R. 2001. Meadow jumping mice (*Zapus hudsonius preblei*) on the U.S. Air Force Academy, El Paso County, Colorado, USA.

Shenk, T. M., and M. Sivert. 1999. Movement patterns of Preble's meadow jumping mouse (*Zapus hudsonius preblei*) as they very across time and space. Annual Report to the Colorado Division of Wildlife. Fort Collins, Colorado, USA.

U. S. Fish and Wildlife Service. 1999. Interim Survey Guidelines for Preble's meadow jumping mouse. U.S. Fish and Wildlife Service. Denver, Colorado, USA.

Colorado Division of Wildlife
Wildlife Research Report
July 2001 and July 2002

PROGRESS REPORT

State of Colorado : Division of Wildlife – Mammals Research

Work Package No. 0670 : Lynx Conservation

Task No. 1 : Post-Release Monitoring of Lynx Reintroduced to Colorado

Period Covered: January 1, 2001 – December 31, 2001

Author: Tanya M. Shenk, Ph. D.

Personnel: A. B. Franklin, L. Gephert, R. Kahn, A. Keith, D. Kenvin, G. Miller, J. Olterman, M. Secor, C. Wagner, S. Wait, G. C. White, D. Younkin

Interim Report – Preliminary Results

This work continues, and precise analysis of data has yet to be accomplished. Manipulation or interpretation of these data beyond that contained in this report should be labeled as such and is discouraged.

ABSTRACT

In an effort to establish a viable population of lynx (*Lynx canadensis*) in Colorado 96 lynx were reintroduced into southwestern Colorado in 1999 and 2000. Release protocols were evaluated by monitoring released individuals through radiotelemetry. Numbers of mortalities and causes of death were documented and this information used to modify subsequent release protocols in an effort to attain the highest probability of survival for released lynx. In general, release protocols were modified by increasing length of time lynx were kept at the Colorado holding facility, delaying time of release to spring, and releasing non-pregnant females. Mortality due to starvation decreased as earlier protocols were modified. A suite of hypotheses was developed to model early survival and factors that may have influenced survival, including sex, age on capture, pregnancy, time spent in the Colorado holding facility, and release time. Models were evaluated using AICc model selection and model averaging used to estimate survival rates. There have been 39 confirmed deaths. Human-caused mortality factors such as gunshot and vehicle collision are the highest cause of death for lynx > 8 months post-release. Locations of each lynx were collected through aerial- or satellite-tracking to document movement patterns. Initial dispersal movement patterns and distances traveled by lynx released in 1999 were highly variable and more extreme than movements of lynx released in 2000. Movement patterns suggest lynx are pairing in March, but successful reproduction has not been documented to date. Snow-tracking results indicate the primary winter prey are snowshoe hare (*Lepus americanus*) and red squirrel (*Tamiasciurus hudsonicus*), with waterfowl and other mammals and birds forming a minor part of the winter diet. Site-scale habitat data collected from snow-tracking efforts indicate Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) are the most common forest stands used by lynx in southwestern Colorado. There is a seasonal trend in use of willows (*Salix* spp.) with use peaking in November and being at its lowest in May and June.

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Post-Release Monitoring of Lynx Reintroduced to Colorado

Annual Progress Report for the U. S. Fish and Wildlife Service
December 2001

Interim Report - Preliminary Results

This work continues, and precise analysis of data has yet to be accomplished. Manipulation or interpretation of these data beyond that contained in this report should be labeled as such, and is discouraged.

Tanya M. Shenk
Mammals Research
Colorado Division of Wildlife

Abstract

In an effort to establish a viable population of lynx (*Lynx canadensis*) in Colorado 96 lynx were reintroduced into southwestern Colorado in 1999 and 2000. Release protocols were evaluated by monitoring released individuals through radiotelemetry. Numbers of mortalities and causes of death were documented and this information used to modify subsequent release protocols in an effort to attain the highest probability of survival for released lynx. In general, release protocols were modified by increasing length of time lynx were kept at the Colorado holding facility, delaying time of release to spring, and releasing non-pregnant females. Mortality due to starvation decreased as earlier protocols were modified. A suite of hypotheses was developed to model early survival and factors that may have influenced survival, including sex, age on capture, pregnancy, time spent in the Colorado holding facility, and release time. Models were evaluated using AICc model selection and model averaging used to estimate survival rates. There have been 39 confirmed deaths. Human-caused mortality factors such as gunshot and vehicle collision are the highest cause of death for lynx >8 months post-release. Locations of each lynx were collected through aerial- or satellite-tracking to document movement patterns. Initial dispersal movement patterns and distances traveled by lynx released in 1999 were highly variable and more extreme than movements of lynx released in 2000. Movement patterns suggest lynx are pairing in March, but successful reproduction has not been documented to date. Snow-tracking results indicate the primary winter prey are snowshoe hare (*Lepus americanus*) and red squirrel (*Tamiasciurus hudsonicus*), with waterfowl and other mammals and birds forming a minor part of the winter diet. Site-scale habitat data collected from snow-tracking efforts indicate Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) are the most common forest stands used by lynx in southwestern Colorado. There is a seasonal trend in use of willows (*Salix* spp.) with use peaking in November and being at its lowest in May and June.

Introduction

In an effort to establish a viable population of lynx (*Lynx canadensis*) in Colorado (Seidel et al. 1998), 41 lynx were reintroduced into southwestern Colorado in the winter and spring of 1999 and an additional 55 lynx were released in April and May of 2000. Post-release monitoring of these lynx is crucial to evaluating the progress of this reintroduction effort. The monitoring program also provides information and data critical for improving release techniques to ensure the highest probability of survival for each individual lynx released in the Colorado effort, and perhaps in other reintroduction efforts.

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

Additional goals of the post-release monitoring program for lynx reintroduced to the southern Rocky Mountains include refining descriptions of habitat use and movement patterns, determining hunting habits, and obtaining information on reproduction. When the lynx establish home ranges that encompass their preferred habitat, more emphasis will be placed on refining descriptions of movement patterns and habitat use.

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). As a listed species, information specific to the ecology of the lynx in its southern range such as habitats used, movement patterns, mortality factors, survival, and reproduction in Colorado will be needed to develop recovery goals and conservation strategies for this species specific to its southern Rocky Mountain range. Thus, an additional objective of the post-release monitoring program is to develop conservation strategies relevant to lynx in Colorado

Objectives

The initial post-release monitoring of reintroduced lynx will emphasize five primary objectives:

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

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

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

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

Study Area

Five areas throughout Colorado were evaluated as potential lynx habitat (Byrne 1998). Criteria investigated in these 5 areas for comparison were (1) relative snowshoe hare densities (Reed at al., unpublished data), (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 release area for reintroducing lynx. Ten release sites within the San Juan Mountains were selected based on land ownership and accessability during time of release for the 41 animals released in 1999. Of the 55 lynx released in spring 2000, 45 were released at Rio Grande Reservoir and 10 lynx were released at 3 sites west of the Continental Divide. Based on current locations of the majority of the released lynx, the core research area remains in the southern San Juan Mountains.

Methods

Reintroduction Effort

A total of 96 lynx were released at selected areas in the San Juan Mountains of southwestern Colorado (Table 1). Estimated age, sex and body condition were ascertained and recorded for each lynx prior to release (see Wild 1999). Specific release sites were selected based on land ownership and accessibility during times of release. Lynx were transported from the holding facility to the release site in cages (usually1, occasionally 2 lynx per cage). Release site location was recorded in Universal

Transverse Mercator (UTM) coordinates and identification of all other lynx released at the same location, on the same day, was recorded. Behavior of the lynx on release and movement away from the release site were documented.

Assessment of Release Protocols

In 1999, lynx were released under 5 different release protocols (Table 2). Protocol 1 called for the immediate release of females once they passed veterinary inspection in Colorado. Males were to be held for a period of weeks until females established a territory, and then males were to be released near female territories. Four lynx were released under this protocol with poor survival. Protocol 2 was developed whereby lynx were held at the Colorado holding facility for a minimum of 3 weeks and fed high quality diets to encourage weight gain. Nine lynx were released under Protocol 2.

Table 1. Colorado lynx reintroduction effort.

Year	Females	Males	TOTAL
1999	22	19	41
2000	35	20	55
TOTAL	57	39	96

After a starvation death under Protocol 2, Protocol 3 was developed, requiring the 3-week minimum holding time and high-quality feeding of Protocol 2 plus a release date no earlier than May 1. A spring release would assure that lynx were released when prey was most abundant (i.e., young of the year would be most abundant and hibernating and migratory prey would be available). Twenty lynx were released under Protocol 3. Additionally, 6 females were released under Protocol 3 that were known to be pregnant (Protocol 3P) and 2 that were possibly pregnant (Protocol 3P?).

An assessment of the fates of each lynx under all 5 release protocols used in 1999 led to release protocols for lynx released in 2000. Release protocols 2 and 3 resulted in the fewest post-release (up to 8 months after release date) starvation mortalities. The common element in both protocols was increased captivity time in the Colorado holding facility. The single starvation mortality for lynx released under Protocol 2 in 1999 was also the only juvenile released under that protocol and the only animal released in February (the other 8 Protocol 2 lynx were released in March 1999). Thus, all lynx released in 2000 were released under either Protocol 2 or 3 but not before April 1. Because of the high percentage of starvation mortalities in females pregnant on release, we also attempted to avoid reintroducing lynx that were known to be pregnant. This was best accomplished by trying to have animals captured for the reintroduction effort in Canada prior to their breeding season.

Table 2. Release protocols for lynx released in southwestern Colorado in 1999 and 2000.

Protocol	Description
1	Release females as soon as they pass veterinary inspection in Colorado. Release males once females appear to have settled into an area.
2	Release males or females after they have been held in Colorado holding facility for a minimum of 3 weeks and fed a high quality diet.
3	Release males or females after they have been held in Colorado holding facility for a minimum of 3 weeks, fed a high quality diet, and released no earlier than May 1.
3P	Pregnant females released under Protocol 3.
3P?	Possibly pregnant females released under Protocol 3.

To evaluate the efficacy of the changes in release protocols we developed a series of *a priori* hypotheses concerning factors that affected lynx survival up to 8 months post-release. These factors included (1) the timing of release (winter vs spring), (2) age of lynx released (adults vs. kittens), (3) sex of lynx released, (4) whether or not females were released while pregnant and the interaction of pregnancy and age of the female (adult vs. kitten), and (5) the duration of holding time in the Colorado facility. A series of 11 models were developed using various combinations of these factors. We used

AICc (Burnham and Anderson 1998) as the model selection criterion to select the model that best explained the data.

Movement Patterns

To determine general movement patterns and habitats used by reintroduced lynx, regular locations of released lynx were collected through a combination of aerial, satellite and ground radio-tracking. Locations and general habitat descriptions at each location were recorded and mapped. Frequent flights (at least 2 times per week) were critical during the initial post-release periods because of the greater likelihood of dispersal and mortality in reintroduced carnivores during this period. Every effort was made to locate every lynx each flight during this period.

All 41 of the lynx released in the winter and spring of 1999 were fitted with Telonics™ VHF radio-collars, equipped with a mortality switch that activates if the collar remains motionless for 4 hours or more. Fifty-one of the 55 lynx released in the spring 2000 were fitted with Sirtrack™ dual satellite/VHF radio-collars (the other 4 lynx were fitted with Telonics™ VHF collars). These collars also had a mortality indicator switch that operated on both the satellite and VHF mode. The satellite component of each collar was programmed to be active for 12 hours per week. The 12-hour active periods were staggered throughout the week, with approximately 7 collars being active each day of the week. Signals from the collars allowed for locations of the animals to be made via Argos, NASA, and NOAA satellites. The location information was processed by ServiceArgos and distributed to the CDOW through e-mail messages.

Survival and Mortality Factors

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

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

Survival rates of lynx reintroduced to Colorado were estimated using the Kaplan-Meier method with staggered entries (Pollock et al. 1989) in Program MARK (White and Burnham 1999).

Recaptures

Recaptures were attempted on lynx that were either in poor body condition or need to have their radio collars replaced. Methods of recapture included trapping using a Tomahawk™ live trap baited with a rabbit, and darting lynx with Telazol (3 mg/kg) using a Dan-Inject CO_2 pistol (modified from Poole et al. 1993 as recommended by M.Wild, DVM). Hounds trained to pursue felids were also used to tree lynx for capture. Treed lynx were immobilized with Telazol or medetomidine (0.09mg/kg) and ketamine (3 mg/kg) administered intramuscularly (IM) with either an extendible pole-syringe or a pressurized syringe-dart fired from a Dan-Inject air pistol.

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

While immobilized, the lynx were fitted with a replacement VHF/satellite collar and blood and hair samples were collected. Once the animal was processed recovery was expedited by injecting the antagonist Antisedan IM if medetomodine/ketemine was used for immobilization. The lynx was monitored until it was sufficiently recovered to move safely on its own. No antagonist is available for Telezol so lynx anesthetized with this drug were monitored until the animal recovered on its own. If captured and in poor body condition the lynx was anesthetized with Telezol (2 mg/kg) and returned to the Colorado holding facility for rehabilitation.

Reproduction

Reproductive status of all female lynx was determined prior to release through radiographs. Pregnancy was confirmed through radiographs if the bones of the fetuses had begun to ossify. All females known to be pregnant or thought to possibly be pregnant on release were monitored closely from their release through the following August to determine reproductive success. Females remaining within a limited area immediately after release through August were located and observed to look for accompanying kittens or a den site. Females that had been released in 1999 and were alive in spring 2000 were monitored for proximity to males during breeding season and for site fidelity to a given area during the denning period of May and June 2000. Each female lynx from the 1999 releases was directly observed in summer 2000 over 3-5 different visits to look for accompanying kittens or evidence of denning. Each female alive in May 2001 that exhibited stationary movement patterns in June 2001 was observed in summer or fall 2001 to look for accompanying kittens. Females were also snow-tracked in winter months to look for accompanying kitten tracks.

Hunting Behavior

Snow-tracking of released lynx provided preliminary information on hunting behavior by documenting location of kills, food caches, chases, and diet composition estimated through scat analysis. Snow-tracking was conducted during February-May 1999 (Year 1), November 1999 – May 2000 (Year 2), and November 2000 - April 2001 (Year 3). Prey from failed and successful hunting attempts were identified by either tracks or remains. Scat analysis also provided information on foods consumed. Scat samples were collected wherever found and labeled with location and individual lynx identification. Only part of the scat was collected, the remainder was left where found so as not to interfere with the possibility that the scat was being used by the animal as a territory mark.

Habitat Use

Gross habitat use was documented by recording canopy vegetation at aerial locations. More refined descriptions of habitat use by reintroduced lynx were obtained through snow-tracking and site-scale habitat data collection. Specific objectives for the site-scale habitat data collection included:

1. Describe and quantify site-scale habitat use by lynx reintroduced to Colorado.
2. Compare site-scale habitat use among types of sites (e.g., kills vs. long-duration beds).
3. Compare site-scale habitat use between sexes.
4. Compare habitat use over years.
5. Develop methodology that will result in data that will be comparable to data collected in studies investigating the ecology of snowshoe hare in Colorado.

Snow-tracking

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

An attempt was made in Year 1 and Year 2 to track each lynx. In Year 3 we attempted to track all lynx within the Core Release Area. Ground crews were instructed to track lynx only where it was safe to travel. Restrictions to safe travel included avalanche danger and extremely rugged terrain. Ground crews worked in pairs and were fully equipped for winter back-country survival.

Data Collection

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

There were 4 levels of intensity of human activity recorded. They included:

1. None: track was not found off an existing snowmobile, ski, or snow shoe track. Distance to nearest human track is greater than 1.0 km
2. Low: track was found near low human activity (e.g., existing snowmobile or ski track)
3. Medium: track found near medium human activity (detected the presence of other people in the area during tracking effort).
4. High: track found near high human activity (e.g., detected presence of many people nearby, near major road, near housing).

There were 2 categories for recording detection of tracks of other species. They included “M” for tracks from multiple animals of the same species and “T” for detection of tracks of only a single animal of the species.

Once a track was located there were 2 types of 'sites' that were encountered. Site I areas needed documentation but either did not reflect areas lynx selected for specific habitat features, or sites that occurred too frequently to measure each in detail. Site II areas were places where lynx may have selected habitat features. At each of the 2 types of sites the date, lynx tracked, slope, aspect, forest structure class, UTM coordinates, and elevation was recorded. Forest structure classes included grass/forb, shrub/seedling, sapling/pole, mature, and old growth as defined in Table 3. For Site I areas, the only additional data that was collected was identification of what the site was used for (e.g., short-duration bed), and a brief description of the site. These sites included the start and end of the track being followed, the location of scat, and short-duration beds defined as being small in size (approximating an area a lynx would crouch), and with little ice formed in the bed indicating little time spent there.

The Site II areas included areas that might reflect specific habitat features lynx selected for. These sites required habitat sampling (see below) and included locations where the following were found: kills, start of chases, territory marks (e.g., spray sites, buried scat, scat placed on prominent locations), long-duration beds (encompasses an area where a lynx would have lain for an extended period, iced bottom), travel (if no other sites sampled in last hour), and road crossing (both sides of road).

Table 3. Definitions of forest structure classes used to describe habitat sites (Thomas 1979).

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

Description of the Habitat Plot

A habitat sampling plot was completed wherever a Site II was encountered. The habitat plot consisted of a 12 m x 12 m square defined by a series of 25 points placed in 5 rows of 5 with the center point being on the object that defined the site (e.g., a kill) (Figure 1). Each point was 3 m apart. The 12 m x 12 m sampling square exceeded the minimum requirement of 0.01 ha. Recommended by Curtis (1959) for sampling trees.

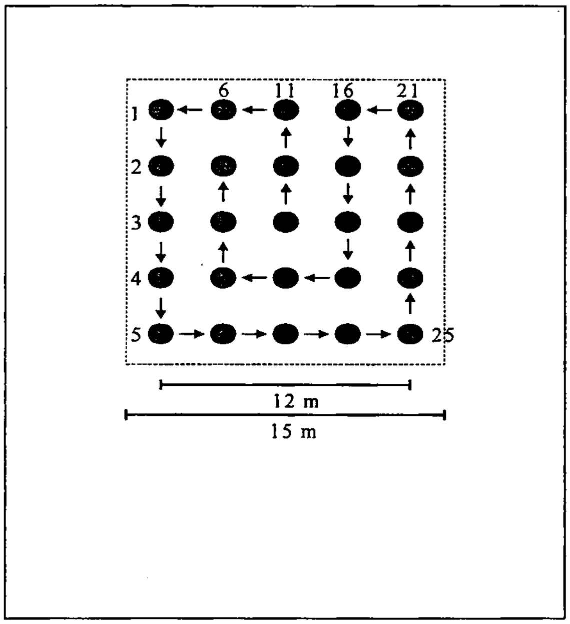

Figure 1. Design of site-scale habitat sampling plot. Each point was 3 m apart. The object that triggered the habitat sampling (e.g., a kill) was located at the center point.

Measurements taken at each of the 25 points included:

1. Snow depth - measured vertically by an avalanche probe marked in cm.

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

3. Overstory: measured at 150 cm above snow with a sighting tube. The tube was made of PVC pipe, with a curved viewing end and a crosshair made of wire on the opposite end. The sighting tube was attached to the avalanche probe used to measure snow depth. Species that hit the crosshair were recorded at each of the 25 points in the vegetation plot. Ganey and Block (1994) found this method of

measuring canopy cover (with ≥ 20 sample points per plot; Laymon 1988) provided greater precision among observers.

4. Species composition: all the different species of tree or shrub that hit the crosshair of the sighting tube at each of the 25 points were recorded.

Tree composition of the vegetation plot was recorded by species and diameter at breast height (DBH). Snow depth was used in conjunction with this recorded DBH to estimate true DBH. Within the 12 m x 12 m square all conifers and deciduous trees were recorded by DBH size class (A = 0-15 cm, B = 15.1-30 cm, C = 30.1-45 cm, D = 45.1-60 cm, E = »60 cm). Area for the tree composition analysis was 12 m x 12 m.

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

Results

Assessment of Release Protocols

A total of 41 lynx were released in Colorado in 1999 under 5 different release protocols (Table 2). Release protocols were modified as new information became available from monitoring the released lynx through radio-telemetry and snow-tracking. Each modification of the release protocols decreased the percent of animals dying from starvation (Table 4).

Three of the 4 animals released under Protocol 1 died of starvation within 6 weeks of their release and the fourth was recaptured and returned to the holding facility where she recovered and was later re-released. Reevaluation of the condition of animals released under the Protocol 1 suggested that these animals might not have been in optimal physical condition when released. Therefore, Protocol 2 was initiated. Most lynx gained considerable body weight while in captivity (Wild 1999). Nine lynx were released under this second protocol. Of these, 1 juvenile female died of starvation 7 weeks after release.

After the starvation death under Protocol 2, Protocol 3 was developed (3-week minimum holding time, high quality diet, no release prior to May 1). Twenty lynx were released under Protocol 3 with no starvation deaths of these animals occurring within 6 months post-release. Six females were released under Protocol 3P (known to be pregnant) and 2 under Protocol 3P? (possibly pregnant). Two of the 6 pregnant lynx released died of starvation within 6 months post-release.

An assessment of the fates of each lynx under all 5 release protocols used in 1999 led to release protocols for lynx released in 2000. Release Protocols 2 and 3 resulted in the fewest starvation mortalities up to 8 months after release date. The common element in both protocols 2 and 3 was increased captivity time in the Colorado holding facility. The single starvation mortality for lynx released under Protocol 2 in 1999 was also the only juvenile released under that protocol and the only animal released in February (the other 8 Protocol 2 lynx were released in March 1999). Thus, all lynx released in 2000 were released under either Protocol 2 or 3 but not before April 1. Because of the high percentage of starvation mortalities in females pregnant on release, we also attempted to avoid reintroducing lynx that were known to be pregnant. This was best accomplished by trying to have animals captured for the reintroduction effort in Canada prior to their breeding season.

A series of 11 models (Table 5) were developed using various combinations of the hypothesized factors that may have affected survival up to 8 months post-release: (1) whether the release was in winter or spring (Rel), (2) whether the released lynx was an adult or kitten (age), (3) sex of lynx released (sex), (4) whether or not females were released while pregnant (preg) and the interaction of pregnancy and age of the female (adult vs. kitten), and (5) the duration of holding time in the Colorado facility (DCF). Survival time and DCF were modeled with and without a log transformation (Ln) because of possible threshold effects over time. We used AICc as the model selection criterion to select the model that best explains the data (Table 5). The model that best fit the data was {S(age+preg+Rel+LnT+LnDCF}, which suggested pregnancy had a deleterious effect on survival of females, with the effect being stronger on kittens than adults (Figure 2). This model also indicated that winter releases led to higher mortality than spring releases for both non-pregnant kittens (Figure 3) and non-pregnant adults (Figure 4), with no sex effects on either age class. Lastly, long stays in the Colorado holding facility increased survival if the duration was at least 21 days with no significant decrease or increase in survival for stays longer than 21 days (Figures 2, 3, 4).

Table 4. Starvation mortalities and recaptures of poor body condition lynx reintroduced to Colorado under the 5 release protocols over 2 years.

Release Protocol	Year	Total Number Released	Number of. Starvation Mortalities [a]	% Mortality	Number of Recaptures in Poor Body Condition [a]	% Failure of Release Protocol
1	1999	4	3[b]	75	1	100
2	1999	9	1[c]	11	0	11
2	2000	41	1[c]	2	0	2
3	1999	20	0	0	0	0
3	2000	10	0	0	0	0
3P?	1999	2	0	0	0	0
3P?	2000	3	0	0	0	0
3P	1999	6	2[d]	33	0	33
3P	2000	1	0	0	0	0

[a] within 8 months of release.

[b] 1 juvenile, 2 adults.

[c] juvenile.

[d] adults.

Table 5. Model selection results of the *a priori* models concerning the effects of age, sex, pregnancy, season of release, and amount of time spent in the Colorado holding facility on survival of lynx 8 months post-release. Ranking based on AICc values.

Model	AICc	ΔAICc	AICc Weight	# Pars.	Deviance
{S(age+preg+Rel+LnT+LnDCF}	200.120	0	0.28305	6	188.036
{S(age*preg+Rel+LnT+LnDCF}	201.027	1.91	0.10908	7	187.914
{S(age+preg+Rel+T+LnDCF}	202.702	2.58	0.07784	6	190.618
{S(age+preg+Rel+T+T2+LnDCF}	203.225	3.10	0.05993	7	189.113
{S(age+Rel+preg+LnDCF}	203.266	3.15	0.05871	5	193.206
{S(age+preg+Rel+T'+T2'+LnDCF}	204.069	3.95	0.03930	7	189.957
{S(age+preg+Rel+T"+T2"+LnDCF}	204.936	4.82	0.02547	7	190.824
{S(age*preg +Rel+LnDCF}	205.265	5.14	0.02161	6	193.181
{S(age*Rel+preg+LnDCF}	205.289	5.17	0.02135	6	193.205
{S(age+Rel+preg+DCF}	205.609	5.49	0.01819	5	195.549
{S(age+Rel+preg+DCF+DCF2}	205.760	5.64	0.01687	6	193.676

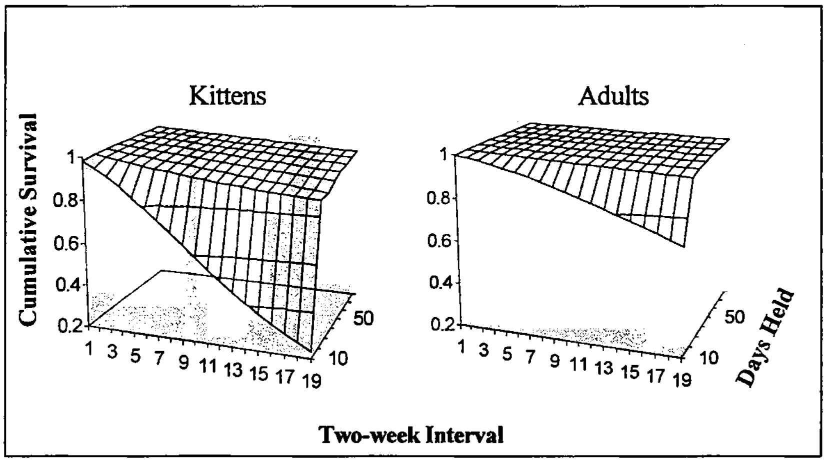

Figure 2. Effects of pregnancy and time spent in the Colorado holding facility on survival of pregnant kittens and adult females.

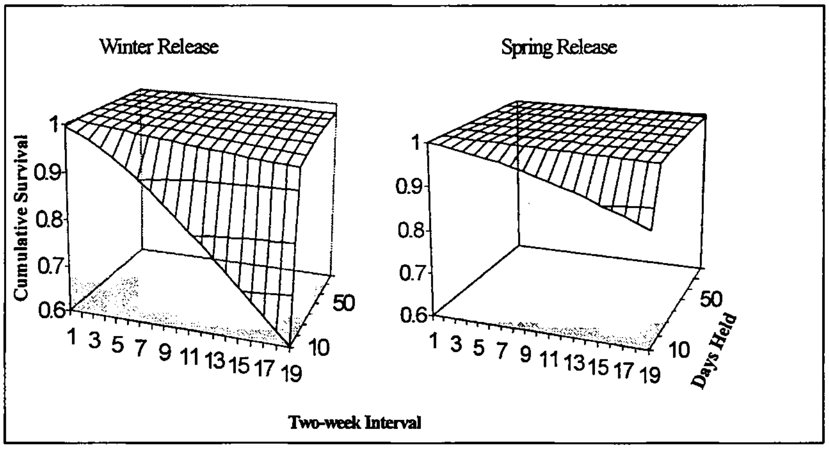

Figure 3. Effects of release season and time spent in the Colorado holding facility on survival of non-pregnant kittens.

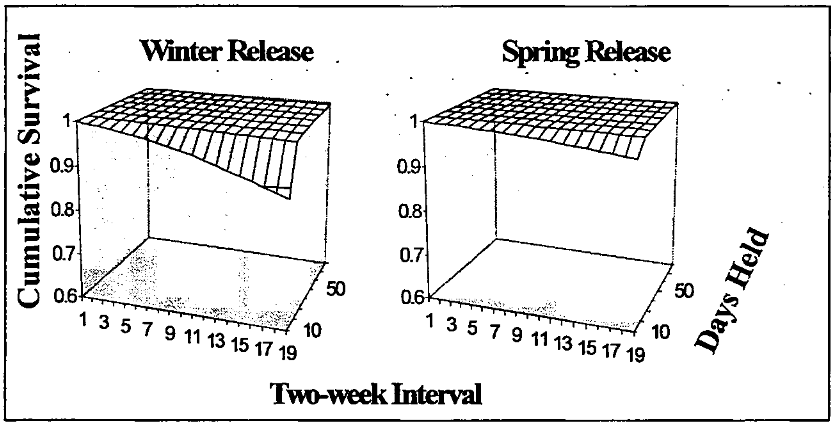

Figure 4. Effects of release season and time spent in the Colorado holding facility on survival of non-pregnant adults.

Movement Patterns

A total of 2,158 aerial VHF locations for all 96 reintroduced lynx have been collected to date (Figure 5, Figure 6). An additional 4,020 satellite locations (1,375 satellite locations if multiple locations for a single night were averaged and counted as only 1 location) for 49 of the 51 lynx fitted with dual collars have been collected. Two satellite collars never worked after the lynx were released.

The majority of movements in 1999 away from the an area encompassed by a100-km radius area centered on the release sites (Core Release Area) were to the north (Figure 5), although some movements occurred to the south into New Mexico and west into Utah as well. A single male from the 1999 releases traveled to Nebraska where he was shot in violation of Nebraska regulations. Initial dispersal habitats used by lynx released in 1999 were highly variable, from high elevation Engelmann spruce/subalpine fir to Nebraska agricultural lands.

Dispersal movement directions for lynx released in 2000 were similar to those of lynx released in 1999 (Figure 6). Most movements away from the Core Release Area were to the north. However, more animals remained within the Core Release Area. Numerous travel corridors have been used repeatedly by more than one lynx, possibly suggesting route selection based on olfactory cues. These travel corridors include the Cochetopa Hills area for northerly movements, the Rio Grande Reservoir-Silverton-Lizardhead Pass for movements to the west, and southerly movements down the east side of Wolf Creek Pass to the southeast through the Conejos River Valley. Lynx appear to remain faithful to an area during winter months, and exhibit more extensive movements away from these areas in the summer. Such movement patterns have also been documented by native lynx in Wyoming and Montana (Squires and Laurion 1999).

Most lynx currently being tracked are within the Core Release Area (Figure 7). Mortalities occurred throughout the areas through which lynx moved. However, mortalities occurred in New Mexico in higher proportion to all lynx locations in that area than elsewhere (Figure 8).

Survival and Mortality Factors

Of the 96 lynx released, 39 mortalities have been recorded to date. From the 1999 releases (41 animals) we have had 24 known mortalities (Table 6). From the 2000 releases (55 animals) we have 15 known mortalities (Table 6). Of the total 9 confirmed starvation deaths, 3 were associated with animals released in less than ideal body condition (released under Protocol 1) and 2 were lynx less than1-year old (Table 4). Fourteen of the mortalities died of unknown causes. In 4 of these cases starvation could be ruled out as cause of death by evidence of good body condition through examination of bone marrow. Pneumonic plague could be ruled out in all 14 cases. Delayed retrieval of carcasses resulted in advanced deterioration of the body, making determination of cause of death impossible.

Necropsy results for 3 female lynx released in 2000, indicate they died from pneumonic plague. Two of these lynx were in good condition, with abdominal fat, no muscle wasting, and fat in the bone marrow. The only gross lesions were an acute fibrinous pneumonia (i.e., lung infection of short duration). These lynx had probably only been sick a few days before they died. A third female was in poorer body condition when found. Plague was diagnosed by flourescent antibody tests and isolation of *Yersinia pestis* from lung and spleen samples. A fourth lynx was also diagnosed with plague after she was hit by a car. A male lynx, recaptured near Laramie, Wyoming, tested positive for plague titers but did not have active plague. Thus, he had been exposed to plague but either did not contract the disease or recovered from the disease.

Recaptures

Seven lynx have been recaptured and 6 subsequently re-released since their initial release. Lynx BC99F6 was released in 1999 under Protocol 1. Her behavior and incidental sightings by the public suggested the lynx was in poor condition. We trapped her using a Tomahawk™ live trap baited with rabbit. She was recaptured the first night (March 25, 1999) we set the trap. On capture, we found she was severely emaciated. We anesthetized her with Telezol (2 mg/kg) and returned her to the Colorado holding facility. She was rehabilitated through diet. The lynx gained weight steadily and was re-released on May

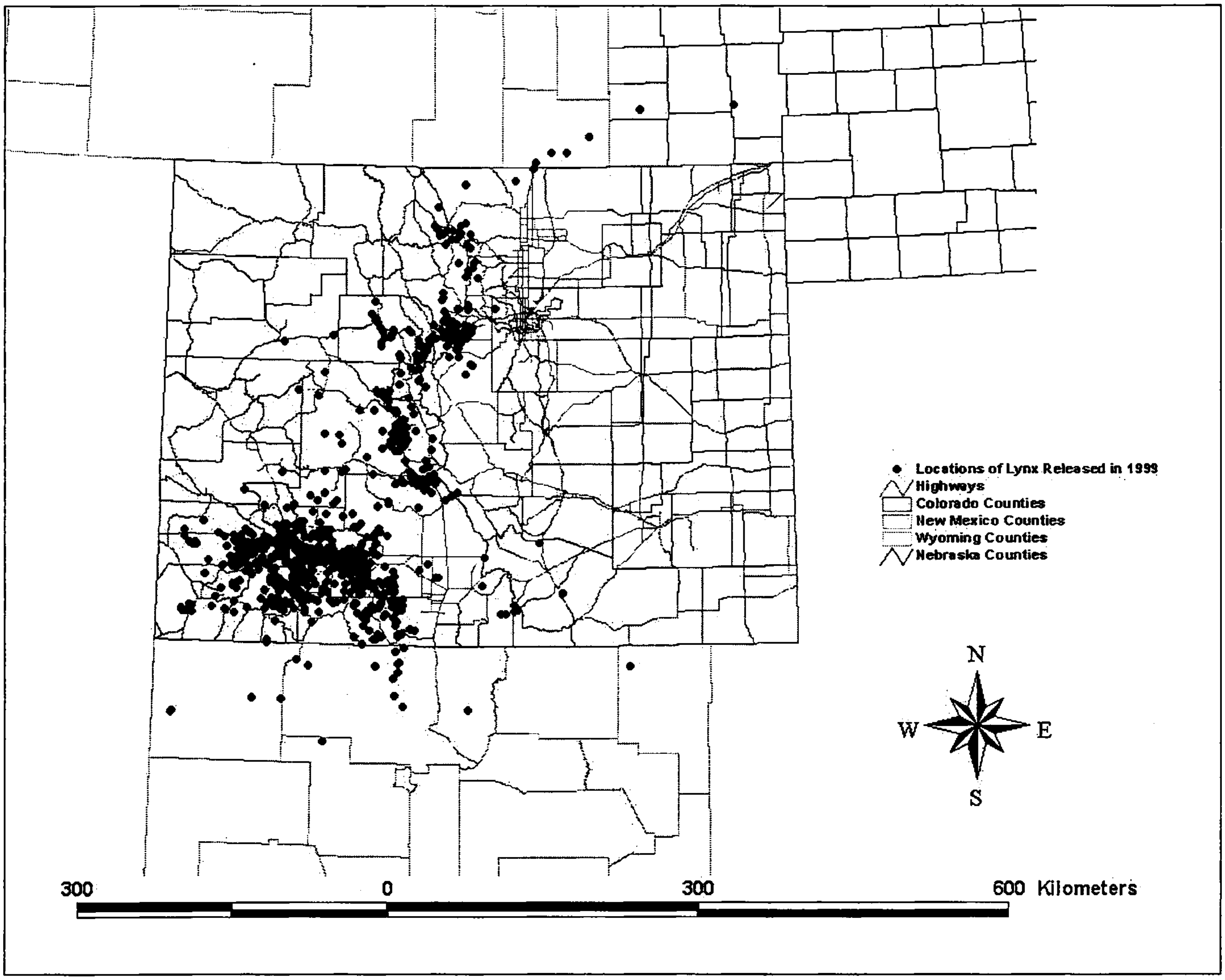

Figure 5. Locations of lynx released in 1999, obtained through aerial telemetry.

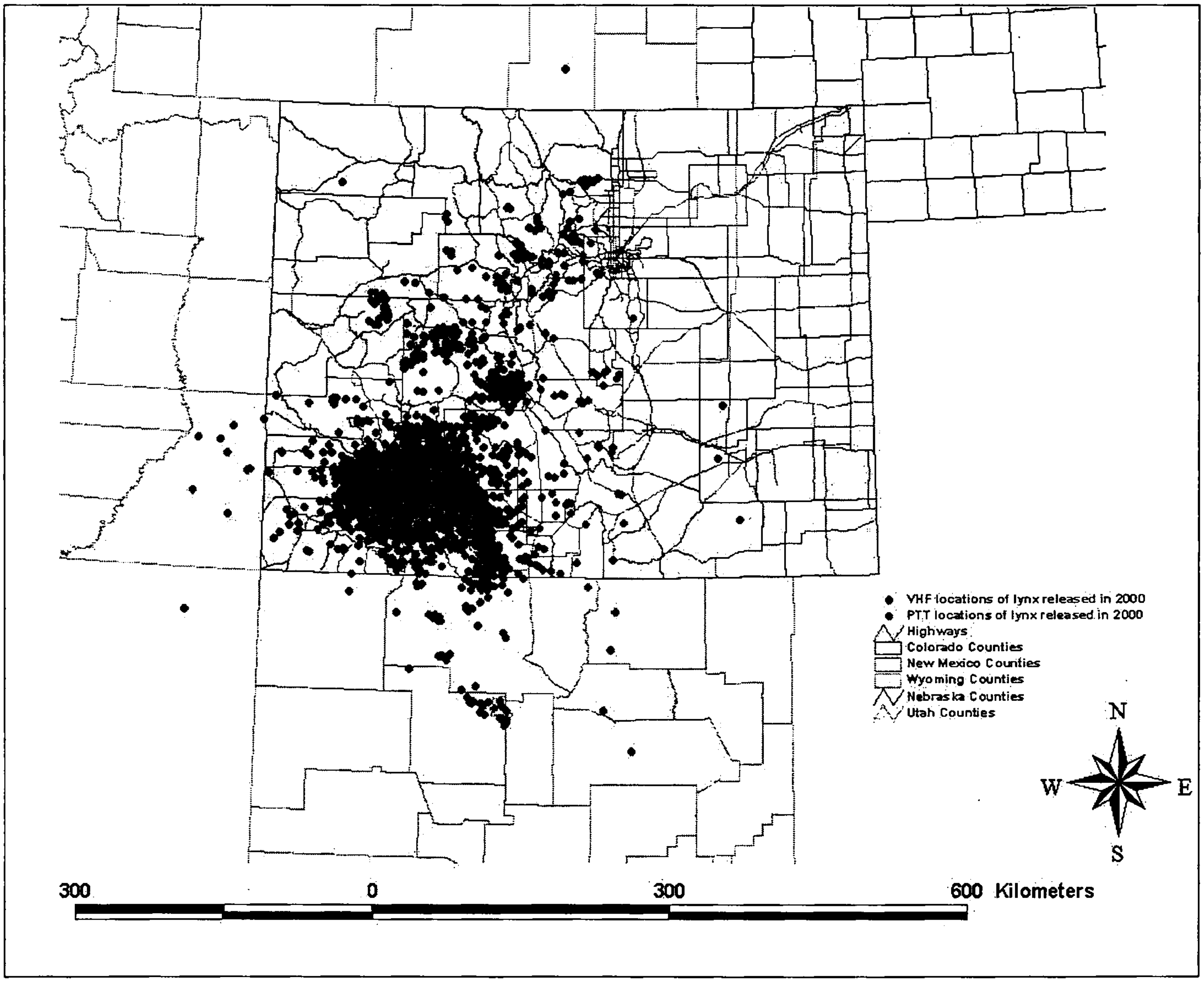

Figure 6. Locations of lynx released in 2000. Gray circles indicate locations obtained from satellite collars. Black circles are locations obtained through aerial telemetry.

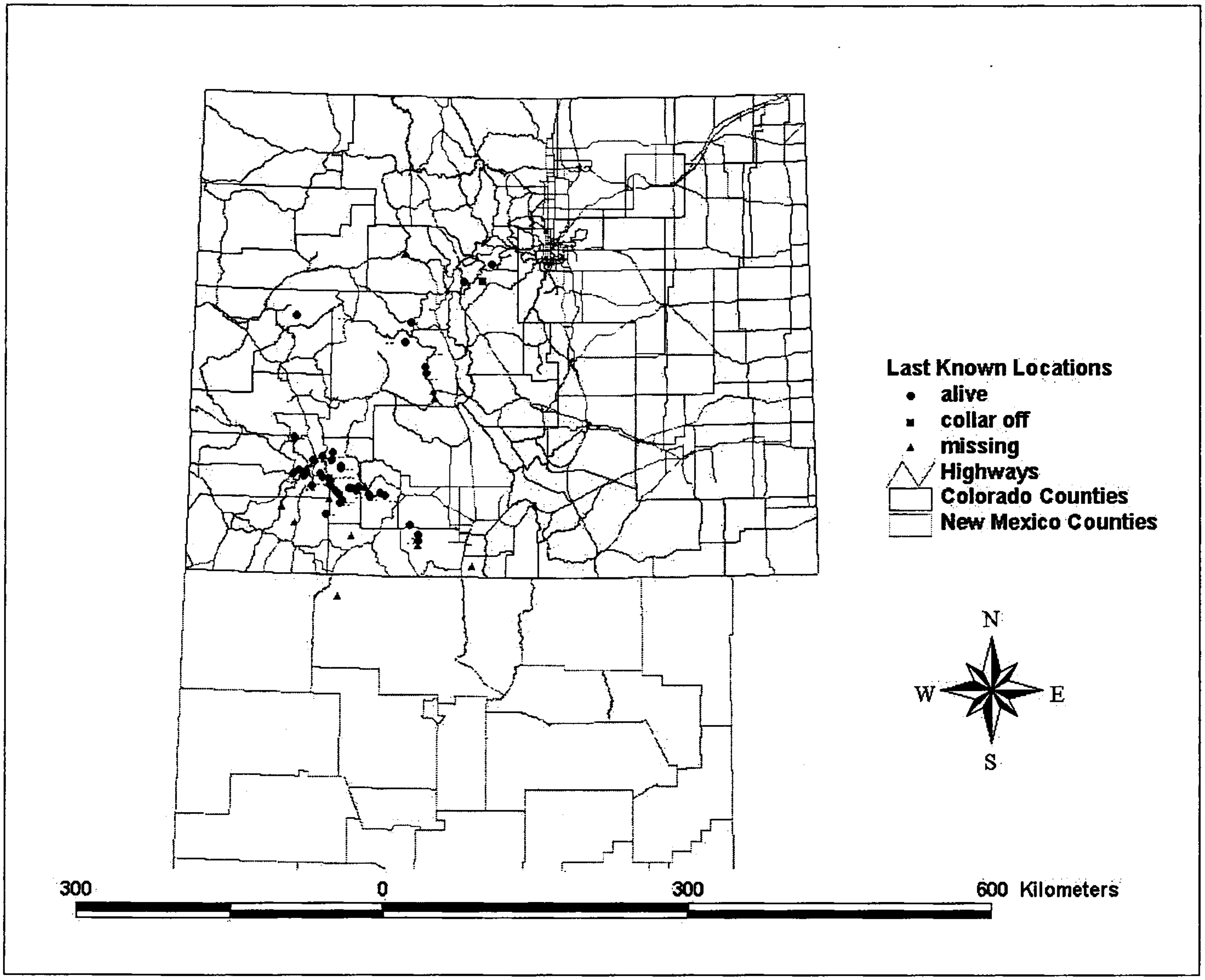

Figure 7. Last known locations of lynx. Circles depict locations of lynx currently being tracked. Triangles are last known locations of missing lynx.

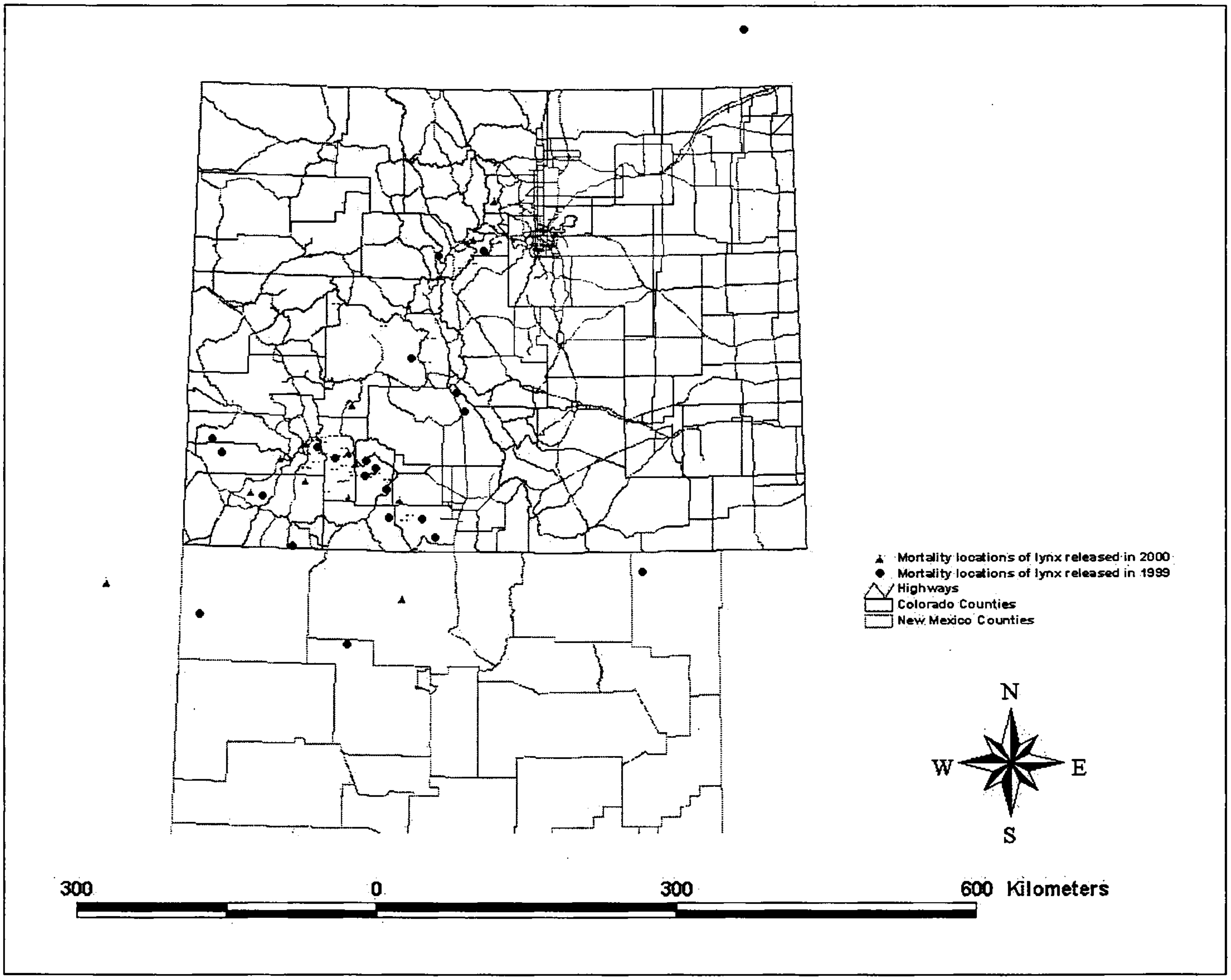

Figure 8. Locations of lynx mortalities. Circles depict mortalities of lynx released in 1999, triangles depict mortalities from lynx released in 2000.

Table 6. Causes of death for lynx released into southwestern Colorado in 1999 and 2000.

Cause	1999 Male	1999 Female	2000 Male	2000 Female	2000 Unknown	Total
Starvation	1	6	1	1		9
Road-kill		2		2	1	5
Shot	2	1	1	1		5
Human-caused [a]	1	1				2
Trauma - unknown cause		1				1
Possible predation		1				1
Plague				3		3
Unknown	2	3	2	2		9
Unknown – not starvation [b]	1	2		1		4
Total Mortalities	7	17	4	10	1	39

[a] Cut collar found, no carcass.

[b] Starvation ruled out by condition of bone marrow.

28, 1999. She was hit by a car on Interstate 70 on July 19, 1999. Necropsy results indicated she was in excellent body condition at her time of death.

Lynx AK99M9 was released on May 12, 1999 and recaptured on March 24, 2000. Field observations by the lynx monitoring crew suggested that the lynx was severely emaciated. Live-trapping the lynx failed, so the lynx was darted with Telazol (3 mg/kg) using a Dan-Inject CO_2 pistol. Physical examination revealed severe emaciation (6 kg). The lynx was returned to the Colorado holding facility and rehabilitated through diet. The lynx gained weight steadily and was re-released on May 3, 2000 but has not been located since and is listed as missing.

Lynx AK99F2 was released on May 7, 1999 and recaptured on April 18, 2000. Field observations by the lynx monitoring crew suggested that the lynx was emaciated. She was live-trapped with a Tomohawk™ live trap with one night's effort. On capture, we found she was emaciated. We anesthetized her with Telezol (2 mg/kg) and returned her to the Colorado holding facility. She was rehabilitated through diet. The lynx gained weight steadily and was re-released on May 22, 2000. This lynx is currently in the Core Release Area.

Lynx BC00F7 was released on April 2, 2000 and recaptured on February 11, 2001. She was severely emaciated and was captured by anesthetizing her with Telazol delivered IM by a jab-pole. She was returned to the Frisco Creek Wildlife Rehabilitation Center but died that night from emaciation and hypothermia.

Lynx BC00M13 was released on April 2, 2000 and recaptured on March 21, 2001 near Laramie, Wyoming. He had been observed by a homeowner on his porch. We recaptured the lynx because this type of behavior was not considered normal. On examination he was in good body condition. After a period of observation this lynx was re-released at the Rio Grande Reservoir on April 24, 2001. This lynx had previously been listed as one of our 15 missing lynx as he had not been located since Sept 2000. This lynx is currently in the Core Release Area

Lynx YK99F5 was recaptured on April19, 2001 to have her radio collar changed. She was captured in a live trap baited with one of her own kills. She was in very good body condition. We anesthetized her with Telazol (3mg/kg), processed and released her on the same site where she was captured. Only her cut collar was found on October 17, 2001, cause of death is assumed human-caused.

Lynx AK99F5 was treed by hounds and anesthetized with Telazol (3 mg/kg) on September 2, 2001. Her collar was exchanged, hair and blood samples were collected. She was in very good body condition and showed no evidence of lactation. She was re-released on the site she was recaptured once she recovered from the Telazol. This lynx remains in the same area as her recapture, within the Core Release Area.

Reproduction

Six lynx released in 1999 were known to be pregnant (Table 2, Release Protocol 3P), and 2 other females released may have been pregnant (Table 2, Release Protocol 3P?). Three of the 6 lynx known to have been pregnant on release in 1999 died within 2 months after release: 2 starved and 1 was killed on the road. Long-distance movements and lack of stationary movement patterns of the other 3 lynx known to have been pregnant on release in 1999 suggests these females did not have young with them by July 1999. Of the 2 females that might have been pregnant, movement patterns were not suggestive of a female rearing young. It is not known if any other females bred and/or had young once released, however no females snow-tracked in Year 2 had young with them.

Beginning in March 2000 both male and female lynx began to exhibit extensive movements (>100 km) away from areas they had used throughout the winter. For example, 1 male moved from the area near Frisco he used in the winter to the area west of Lizardhead Pass, a straight line distance of approximately 270 km (Figure 9). Such movements by both females and males put them in close (< 5 km) proximity to a lynx of the opposite sex. These extreme movements may have been related to breeding behavior. All 7 females alive in spring 2000 were documented in close (< 5 km) proximity to a male during the breeding season and could have bred. Two isolated males did not move during March or April and thus were not in close proximity to a known female during the breeding season. This was a male that had used the area in and adjacent to the northwest corner of Rocky Mountain National Park and a male that used the area around Cuchara, Colorado throughout the winter.

The 7 females in the wild during breeding season 2000 were monitored for site fidelity to a given area during the denning period of May and June. Each of these 7 females was directly observed in summer 2000 over 3-5 different visits to look for accompanying kittens. No kittens were found. The question of whether they successfully bred or had kittens at some point in 2000 is unknown. However, no kittens were found during the following winter through snow-tracking.

From radiographs taken of the 35 females released in 2000, after breeding season, 1 female was known to be pregnant and 3 were possibly pregnant. Movement patterns suggested none of these 4 females had kittens with them by July 2000.

Of the 49 lynx being tracked on a regular basis during the March 2001 breeding season, there were 29 females and 20 males. We documented movements that may have been related to breeding. The largest movement observed was a male that moved to Laramie, Wyoming and was subsequently recaptured, rehabilitated and re-released in the Core Release Area in Colorado after the breeding season. Other movements were of a much smaller scale, 10-30 km. These movements were primarily movements of males towards a female. We documented 10 potential 'pairs' where a pair was defined as a male and female within 5 km of each other and in the same drainage. More pairs could have occurred which we did not document from aerial- or ground-tracking because of the time delays between lynx locations. To date, no reproduction has been documented in 2001 from direct observations of females. Snow-tracking efforts this winter will focus initially on females in an attempt to document possible kittens through tracks.

Current Status

Of the total 96 lynx released we have 39 known mortalities (Table 7). We currently are listing 16 lynx as missing - 11 males, 5 females. We have not heard signals on 13 (11 males, 2 females) of these lynx since at least December 2000. The remaining 3 missing lynx are females that have been lost for less than 1 year. Possible reasons for not locating these missing lynx include (1) long distance dispersal, beyond the areas currently being searched, (2) radio failure, or (3) destruction of the radio (e.g., run over by car). We continue to search for all missing lynx during both aerial and ground searches. There have been 4 incidents where lynx missing for over a year have returned to the Core Release Area and are now once again being monitored on a regular basis. Thus, it is premature to consider missing lynx as lost to the Colorado lynx program. However, of the 16 missing lynx, 3 have collars whose battery life expired spring 2001 and will probably never be located through telemetry. At least 1 of the missing lynx is a mortality where we know a collar was found on a road kill but the collar was not returned to the

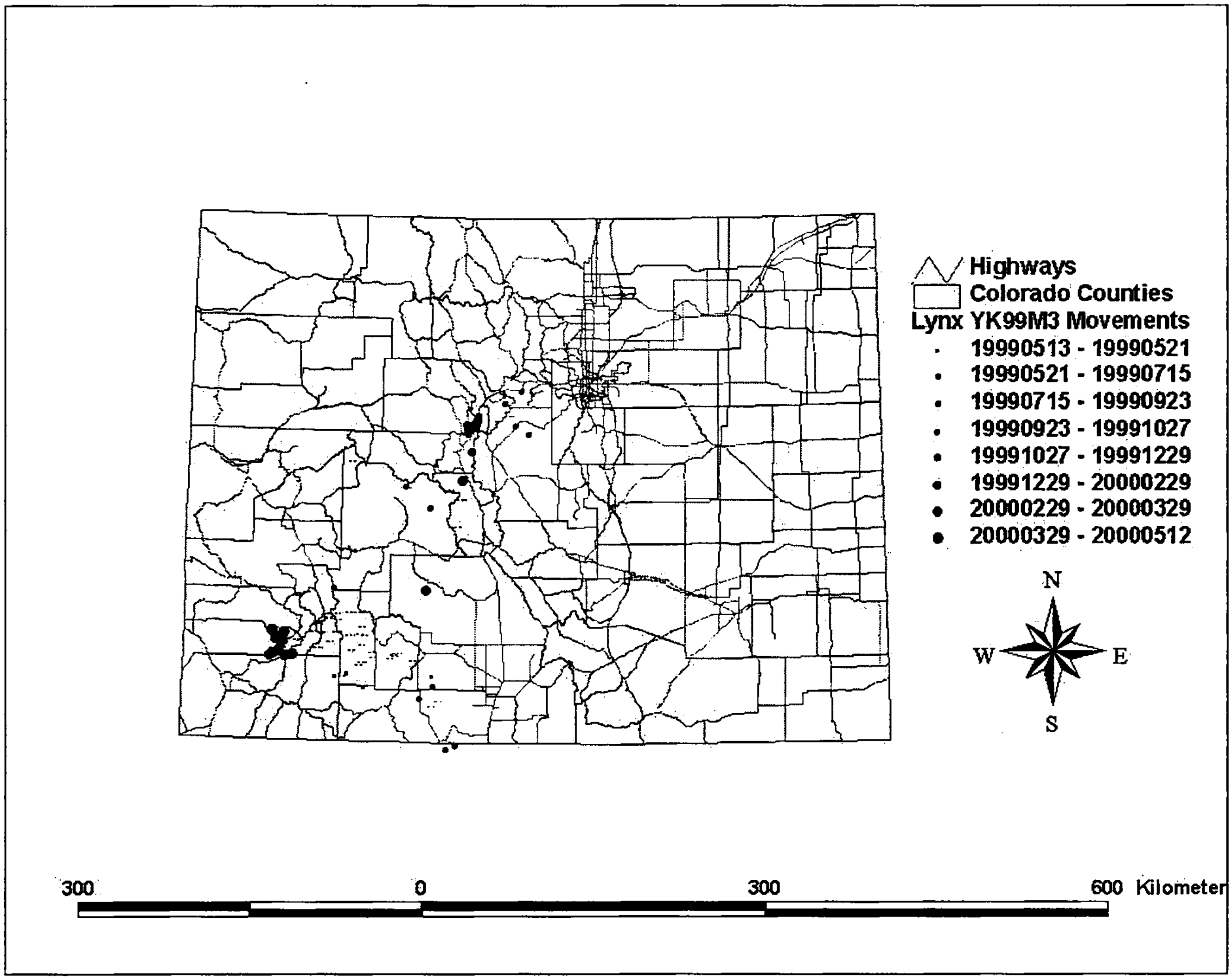

Figure 9. Movements of a male lynx in breeding season 2000. Straight-line distance from winter use area to the area used during breeding season in approximately 270 km. The larger the circle the more recent the date, up to May 2000

CDOW for identification. One female is known to have slipped her collar. Thus, we are currently tracking 41 lynx.

Table 7. Current status of lynx reintroduced to Colorado.

	Females	Males	Unknown	TOTAL
Released	57	39		96
Known Dead	27	11	1	39
Missing	5	11		16[a]
Slipped Collar	1			1
Tracking	24	17		41

[a] 1 is unknown mortality.

Hunting Behavior

Snow-tracking of released lynx provided preliminary information on hunting behavior by documenting location of kills, food caches, chases, and through scat analysis. Prey from failed and successful hunting attempts were identified by either tracks or remains. Scat analysis also provided information on foods consumed.

During Year 1 a total of 10 kills were located. All the snow-tracking effort was conducted on 9 lynx released under Protocols 1 and 2. Any lynx released under Protocol 3 were released too late to track. In Year 2, ground crews tracked 13 of the lynx released in 1999. Two other lynx were being located during this time but were not in areas covered by snow. We found 64 kills and collected 109 scat samples that will be analyzed for content. Lynx released in 2000 were released too late to snow track in Year 2. In Year 3, field crews snow-tracked 48 lynx, documented 86 kills and collected 189 scat samples.

Data collected on kills (Figure 10) suggests the reintroduced lynx are feeding on their preferred prey species, snowshoe hare (*Lepus americanus*) and pine (red) squirrel (*Tamiasciurus hudsonicus*) in similar proportions as those reported for northern lynx during lows in the snowshoe hare cycle (Aubry et al., 1999). Caution must be used in interpreting the proportion of identified kills. Such a proportion ignores other food items that are consumed in their entirety. For example, through snow-tracking we have some evidence that lynx are mousing and several of the fresh carcasses have yielded small mammals in the gut on necropsy.

However, the extent of small mammals in the diet are not accurately portrayed by information collected based on prey remains in snow. Nearly all the scat samples collected have been found through snow-tracking efforts and thus will be representative of winter diet only. The summer diet of lynx elsewhere has been documented to include less snowshoe hare and more alternative prey than in winter (Mowat et al. 1999).

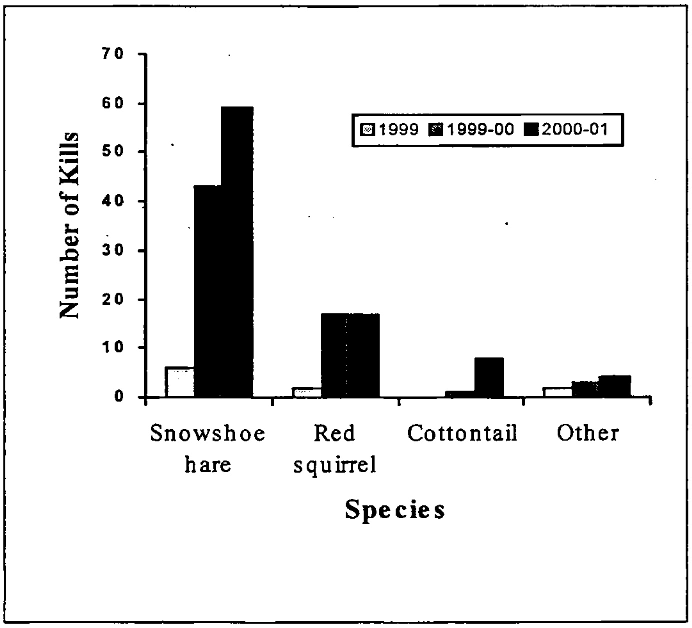

Figure 10. Winter diet of reintroduced lynx estimated from snow-tracking data.

Habitat Use

Gross habitat use was documented from 2441 aerial locations of lynx collected from February 1999 through December 2001. Throughout the year Engelmann spruce (*Picea engelmannii*) / subalpine fir (*Abies lasiocarpa*) (S/F) was the dominant cover used by lynx (Figure 11). A mix of Engelmann spruce, subalpine fir and aspen (*Populus tremuloides*) (S/F/A) was the second most common cover type used throughout the year. Various riparian and riparian mix areas was the third most common cover type where lynx were found during the daytime flights. Use of S/F and S/F/A was similar throughout the year. There was a trend in increased use of riparian areas beginning in July, peaking in November, and dropping off December through June.

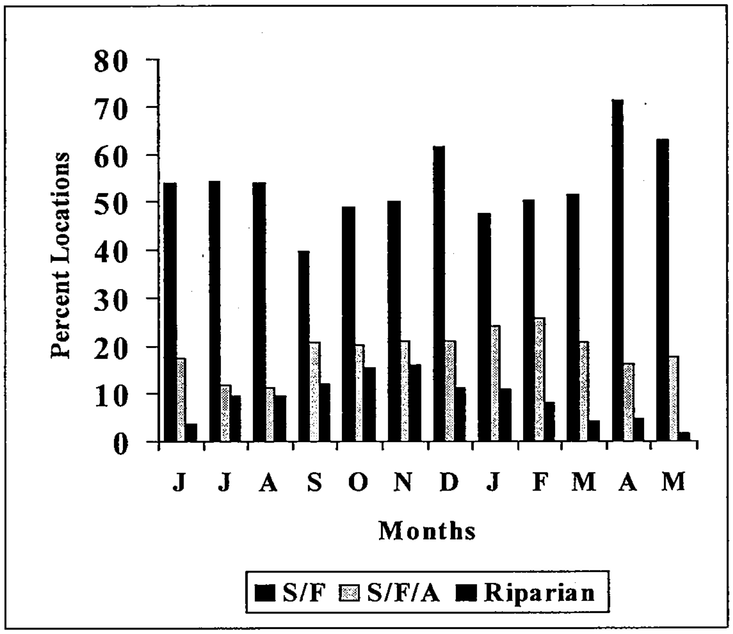

Figure 11. Percent aerial locations in Engelmann spruce - subalpine fir forests (S/F), Engelmann spruce- subalpine fir-aspen forests (S/F/A), and riparian areas by month.

A total of 473 site-scale habitat plots were completed in Year 3. The majority understory species at all 3 heights was Engelmann spruce, followed by subalpine fir, willow (*Salix* spp.) and aspen (Figure 12). Various other species such as Ponderosa pine (*Pinus ponderosa*), lodgepole pine (*Pinus contorta*), cottonwood (*Populus sargentii*), birch (*Betula* spp.) and others were also found in less than 5% of the habitat plots. Coarse woody debris was also present in 10-35% of plots. If present, willow provided the greatest percent cover within a plot (Figure 13) followed by Engelmann spruce, subalpine fir, aspen and coarse woody debris.

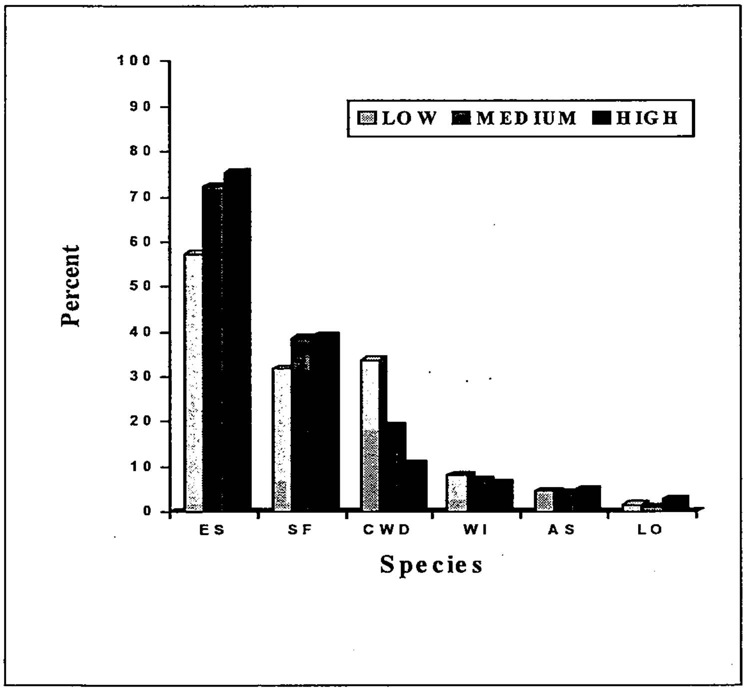

Figure 12. Mean percent cover of habitat plot by understory tree/shrub species Engelmann spruce (ES), subalpine fir (SF), willow (WI), aspen (AS), lodgepole pine (LO), and coarse woody debris (CWD) if species is present. Mean percent cover is estimated for 3 height levels above the snow (low = 0-0.5 m, medium = 0.51-1.0 m, high = 1.1-1.5 m).

Engelmann spruce provided a mean of 35.87 % overstory within 86.68% of the plots (Figure 14). Subalpine fir and aspen provided overstory for < 50% of the plots, but when present provided approximately the same mean percent cover as Engelmann spruce (Figure 14). Willow and lodgepole pine provided fewer than 10% of the plots with cover, but when present provided nearly the same percent cover as the other tree species (Figure 14).

The most common tree species in the habitat plots was Engelmann

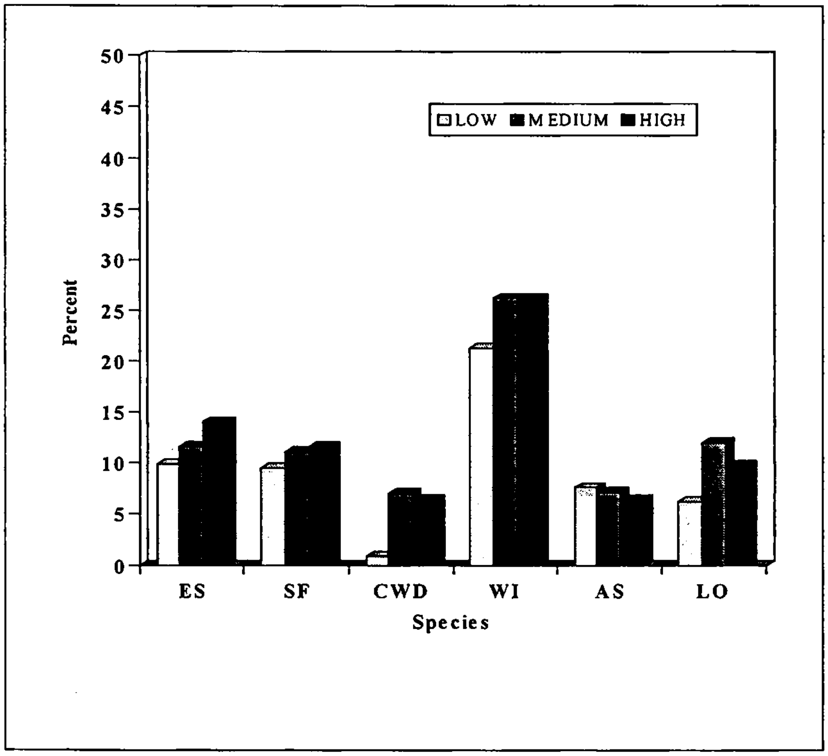

Figure 13. Mean percent cover of habitat plots by understory tree or shrub species Engelmann spruce (ES), subalpine fir (SF), willow (WI), aspen (AS), lodgepole pine (LO), and coarse woody debris (CWD) if species is present.

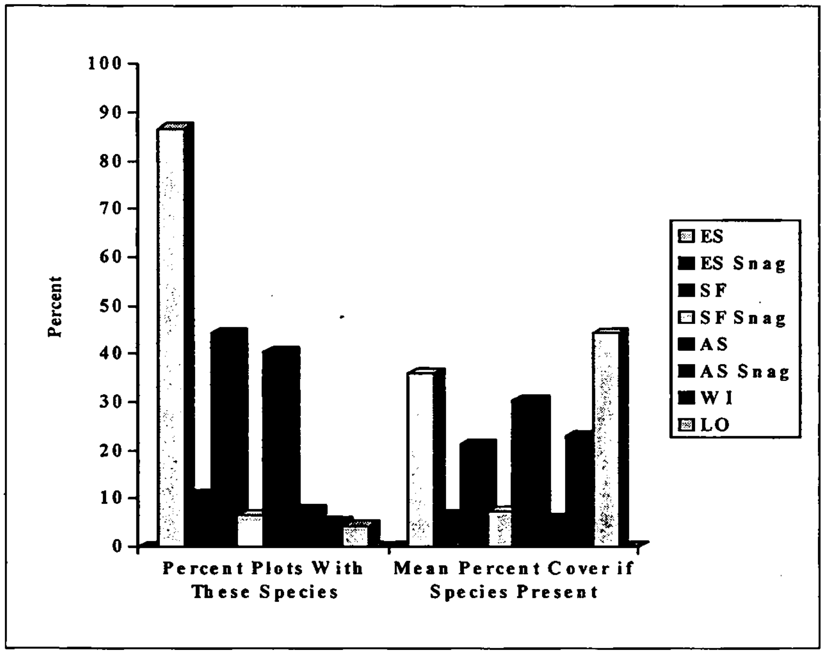

Figure 14. Percent plots with overstory tree species Engelmann spruce (ES), subalpine fir (SF), willow (WI), aspen (AS), lodgepole pine (LO), and coarse woody debris (CWD). Mean percent overstory cover if tree species present.

spruce (Figure 15). Subalpine fir and aspen were also present in > 35% of the plots. Most habitat plots were vegetated with trees of DBH < 6" (Figure 15). As DBH increased, percent occurrence decreased within the plot. The larger DBH trees (>18") within the plots were generally Engelmann spruce with fewer subalpine firs of that DBH class present in the habitat plots. No willow or aspen of DBH > 18" were present in any of the plots. Of the 5 most common tree species in the habitat plots, mean number of trees for each DBH size class ranged from 0.18 to 10.82 except for willow which averaged 74.83 plants per plot (Figure 16). Areas of willow used by lynx are typically dense willow thickets.

Discussion

Of the 96 lynx released in Colorado in 1999 and 2000 we are currently monitoring 41 lynx on a regular basis and an additional 16 lynx may still be alive, although not being monitored. We have 39 confirmed mortalities. Survival of lynx released in the second year has been higher than lynx released in the first year. Human-caused mortalities due to vehicle collision, gunshot, and the mortalities where only a cut collar was found comprise the greatest known cause of mortality for the reintroduced lynx (31%). Mortalities due to starvation (23%) were minimized with improved release protocols. Only 2 of the 55 lynx released in 2000 died of starvation and 1 of those died 8.5 months post-release. Three lynx died of plague, 1 road kill tested positive for plague, and 1 lynx had plague positive titers while healthy. Carnivores are most often exposed to plague by eating infected rodents or by being bitten by rodent fleas (Biggens and Kosoy 2001). Although it is known that felids are highly susceptible to plague (Aiello 1998), the 5 cases of plague in lynx reintroduced to Colorado are the first documented for this species.

Dispersal movement patterns for lynx released in 2000 were similar to those of lynx released in 1999. However, more animals remained within the Core Release Area. This increased site fidelity may be due to the presence of con-specifics in the area on release. Numerous travel corridors have been used repeatedly by more than 1 lynx, possibly suggesting route selection based on olfactory cues. These travel corridors include the Cochetopa Hills area for northerly movements, the Rio Grande Reservoir-Silverton-Lizardhead Pass for movements to the west, and southerly movements down the east side of Wolf Creek Pass to the southeast to the Conejos River Valley. Lynx appear to remain faithful to an area during winter months, and exhibit more extensive movements away from these areas in the summer. Most lynx currently being tracked are within the Core Release Area. During the summer of 2000 and 2001, several lynx that had been faithful to a

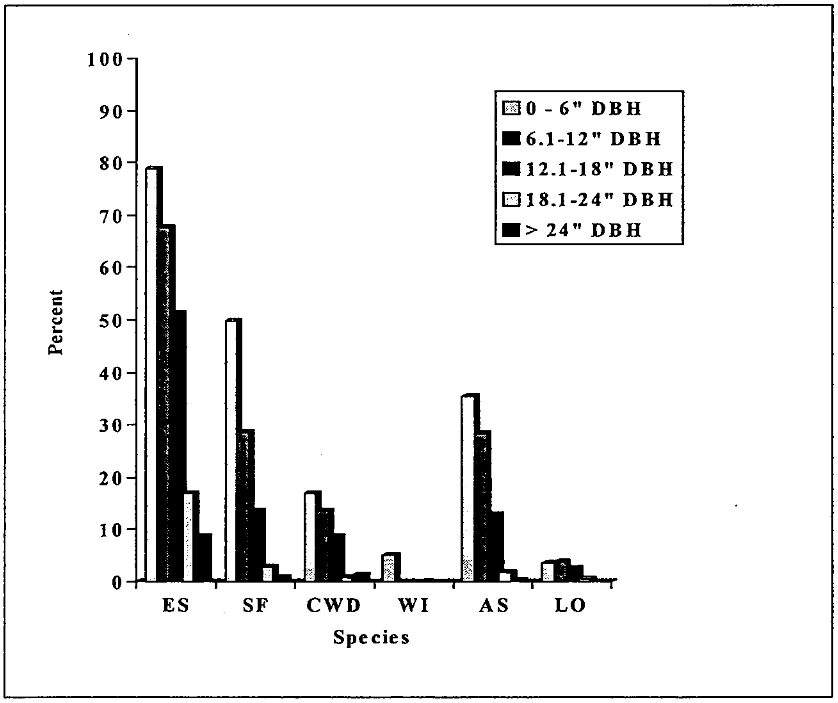

Figure 15. Percent of habitat plots with tree species Engelmann spruce (ES), subalpine fire (SF), willow (WI), aspen (AS), lodgepole pine (LO), and coarse woody debris (CWD) by diameter at breast height (DBH) size class.

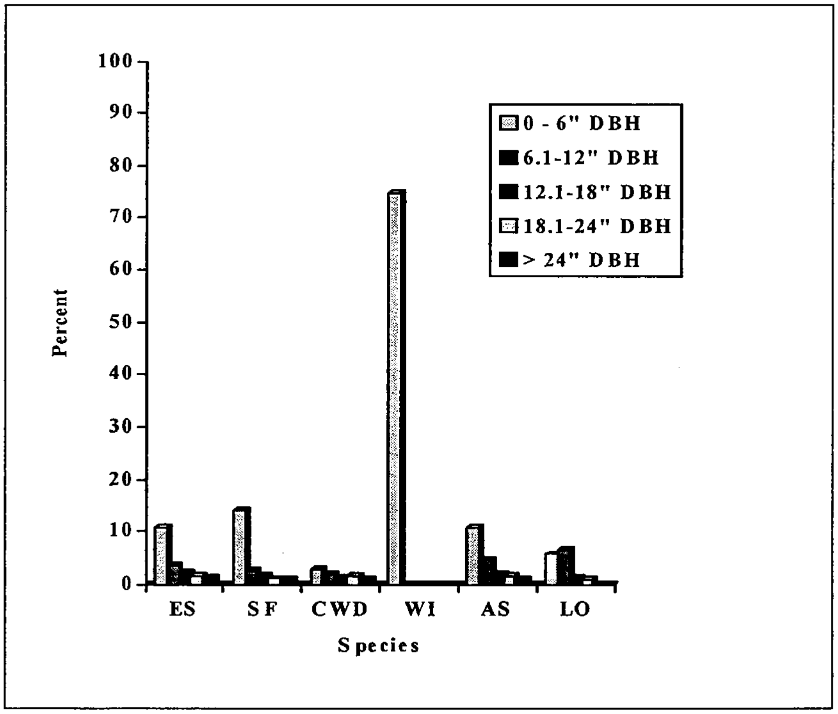

Figure 16. Mean number of trees or shrubs in habitat plots with tree species Engelmann spruce (ES), subalpine fire (SF), willow (WI), aspen (AS), lodgepole pine (LO), and coarse woody debris (CWD) by diameter at breast height (DBH) size class.

given area during the winter months made large movements away from their winter-use areas. Extensive summer movements away from areas used throughout the rest of the year have been documented in native lynx in Wyoming and Montana (Squires and Laurion 1999).

In winter, lynx reintroduced to Colorado appear to be feeding on their preferred prey species, snowshoe hare and red squirrel in similar proportions as those reported for northern lynx during lows in the snowshoe hare cycle (Aubry et al., 1999). Caution must be used in interpreting the proportion of identified kills. Such a proportion ignores other food items that are consumed in their entirety and thus are biased towards larger prey and may not accurately represent the proportion of smaller prey items, such as microtines, in lynx winter diet. Through snow-tracking we have evidence that lynx are mousing and several of the fresh carcasses have yielded small mammals in the gut on necropsy. Nearly all the scat samples collected have been found through snow-tracking efforts and thus are representative of winter diet only. However, the summer diet of lynx has been documented to include less snowshoe hare and more alternative prey than in winter (Mowat et al., 1999).

Reproduction is critical to achieving a self-sustaining viable population of lynx in Colorado. Although females have been monitored and observed during each denning season, no kittens have been found to date. Snow-tracking has also not provided evidence that any of the females tracked had kittens with them. However, the question of whether they successfully bred or had kittens at some point is unknown. With only 7 females from the 1999 releases in the wild in spring 2000 it was expected that there might not be successful reproduction in 2000. However, the extreme movements observed by both females and males in March and April 2000 may have been related to breeding behavior. March and April are the natural breeding periods for northern lynx (Tumlison 1987). From observations of the 29 females alive in summer 2001, we have not yet documented kittens. We may still find evidence of kittens through snow-tracking efforts in winter 2001-02.

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

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

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

Lynx also require sufficient denning habitat. Denning habitat has been described by Koehler (1990) and Mowat et al. (1999) as areas having dense downed trees, roots, or dense live vegetation. No den sites have been located as yet in Colorado for comparison.

Through extensive monitoring of released animals we were able to continuously evaluate and modify release protocols to improve survival of released lynx. The primary element in later, more successful release protocols was increased time in captivity at the Colorado holding facility. Increasing the amount of time lynx were held in the Colorado holding facility provided each lynx with an opportunity to increase body weight and acclimate to the climate, elevation, and local conditions of the environment they would be released into. Although most lynx were housed in individual pens, with a few sharing a pen with one other lynx, the holding facility also allowed the lynx to hear and smell each other throughout this acclimation period. Such contact may have provided time for social interactions to occur. Such social interactions may improve the likelihood these animals could form a breeding population.

If additional lynx are released in Colorado the following guidelines are recommended in establishing release protocols. Translocated animals should be adults and females should not be pregnant on release. Once lynx are moved from their place of origin they should be held a minimum of 3 weeks in a local holding facility to provide a high quality diet for gaining optimal body condition prior to release in the new area, acclimation time to adjust to local conditions, and possible social interactions. Animals should be released in the spring to ensure the highest prey abundance in the release area. These release protocol guidelines may also prove useful if other states attempt lynx reintroductions or augmentations.

Future Research

Future research will include the continued monitoring of lynx released in Colorado that have remained in the Core Release Area. Such monitoring will include continued data collection and analysis on survival and mortality factors, reproduction, habitat use, winter and summer diet, and movement patterns. If additional funding becomes available, reintroduced lynx that have moved beyond the Core Release Area should also be monitored, particularly those lynx using areas near the Interstate Highway 70 corridor. We will continue to attempt to recapture lynx to replace radio collars that are either malfunctioning or scheduled to stop functioning. Any Colorado born lynx will be radio collared once they reach a minimum of 10 months of age.

Studies have been initiated to refine mark-recapture techniques to estimate abundance of lynx from hair-snag data. Such an approach would provide a non-invasive technique for estimating abundance.

A snowshoe hare ecology study was initiated in 2001 to describe density of hares in various forest stands and which habitats and topographic features are most important to hare density and survival. From this research, management prescriptions may be designed to better manage forests for optimal hare populations. Maintaining abundant and widespread snowshoe hare populations is essential to establishing lynx in Colorado.

Through funding provided by Colorado Department of Transportation (CDOT) a detailed analysis of lynx movement patterns as they relate to highways has been initiated.

The feasibility of augmenting this reintroduction effort by releasing additional animals from Canada and Alaska is being considered by CDOW to improve the likelihood of establishing a viable population of lynx in Colorado.

Funding is being sought to develop protocols for collecting data on lynx summer diet by using dogs trained to locate lynx scat.

If viable, self-sustaining populations of lynx are established in Colorado, habitat manipulation studies will be needed to more fully understand how lynx respond to their habitat and how best to alter habitats to maintain and enhance lynx populations.

Acknowledgments

The lynx reintroduction program involved the efforts of literally hundreds of people across North America, in Canada and the U. S. Any attempt to properly acknowledge all the people who played a role in this effort is at risk of missing many people. The following list should be considered to be incomplete.

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Literature Cited

Aiello, S. E., editor 1998. The Merck Veterinary Manual. Eighth Edition. Merck & Co., Inc. Whitehorse Station, New Jersey.

Aubry, K. B., G. M. Koehler, J. R. Squires. 1999. Ecology of Canada lynx in southern boreal forests. Pages 373-396 *in* L. F. Ruggiero, K. B. Aubry, S. W. Buskirk, G. M. Koehler, C. J. Krebs, K. S McKelvey, and J. R. Squires, editors. Ecology and Conservation of Lynx in the United States. General Technical Report for U. S. D. A. Rocky Mountain Research Station. University of Colorado Press, Boulder, Colorado.

Biggins, D. E. and M. Y. Kosoy. 2001. Influences of introduced plague in North American mammals: implications from ecology of plague in Asia. Journal of Mammalogy 82: 906-916.

Burnham, K. P. and D. R. Anderson. 1998. Model Selection and Inference: A Practical Information-Theoretic Approach. Springer-Verlag, New York, New York.

Byrne, G. 1998. Core area release site selection and considerations for a Canada lynx reintroduction in Colorado. Report for the Colorado Division of Wildlife.

Curtis, J. T. 1959. The vegetation of Wisconsin. University of Wisconsin Pres, Madison.

Ganey, J. L. and W. M. Block. A comparison of two techniques for measuring canopy closure. Western Journal of Applied Forestry 9:1: 21-23.

Hodges, K. E. 1999. Ecology of snowshoe hares in southern boreal and montane forests. Pages 163-206 *in* L. F. Ruggiero, K. B. Aubry, S. W. Buskirk, G. M. Koehler, C. J. Krebs, K. S McKelvey, and J. R. Squires editors. Ecology and Conservation of Lynx in the United States. General Technical Report for U. S. D. A. Rocky Mountain Research Station. University of Colorado Press, Boulder, Colorado.

Koehler, G. M. 1990. Population and habitat characteristics of lynx and snowshoe hares in north central Washington. Canadian Journal of Zoology 68:845-851.

Laymon, S. A. 1988. The ecology of the spotted owl in the central Sierra Nevada, California. PhD Dissertation University of California, Berkeley, California.

Major, A. R. 1989. Lynx, *Lynx canadensis canadensis* (Kerr) predation patterns and habitat use in the Yukon Territory, Canada. M. S. Thesis, State University of New York, Syracuse.

Mowat, G., K. G. Poole, and M. O'Donoghue. 1999. Ecology of lynx in northern Canada and Alaska. Pages 265-306 *in* L. F. Ruggiero, K. B. Aubry, S. W. Buskirk, G. M. Koehler, C. J. Krebs, K. S McKelvey, and J. R. Squires, editors. Ecology and Conservation of Lynx in the United States. General Technical Report for U. S. D. A. Rocky Mountain Research Station. University of Colorado Press, Boulder, Colorado.

Pollock, K. H., S. R. Winterstein, C. M. Bunck, and P. D. Curtis. 1989. Survival analysis in telemetry studies: the staggered entry design. Journal of Wildlife Management 53: 7-15.

Poole, K. G., G. Mowat, and B. G. Slough. 1993. Chemical immobilization of lynx. Wildlife Society Bulletin 21:136-140.

Seidel, J., B. Andree, S. Berlinger, K. Buell, G. Byrne, B. Gill, D. Kenvin, and D. Reed. 1998. Draft strategy for the conservation and reestablishment of lynx and wolverine in the southern Rocky Mountains. Report for the Colorado Division of Wildlife.

Shenk, T. M. 1999. Program narrative: Post-release monitoring of reintroduced lynx (*Lynx canadensis*) to Colorado. Report for the Colorado Division of Wildlife.

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

Thomas, J. W. Ed. 1979. Wildlife habitats in managed forests - the Blue Mountains of Oregon and Washington. USDA Agricultural Handbook No. 553. U. S. Government Printing Office. Washington, D. C.

Tumlison, R. 1987. Mammalian Species: *Felis lynx*. American Society of Mammalogists.

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.

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

Wild, M. A. 1999. Lynx veterinary services and diagnostics. Job Progress Report for the Colorado Division of Wildlife. Fort Collins, Colorado.

Colorado Division of Wildlife
Wildlife Research Report
July 2001 and July 2002

JOB PROGRESS REPORT

State of Colorado : Division of Wildlife – Mammals Research

Work Package No. 0670 : Lynx Conservation

Task No. 2 : Ecology of Snowshoe Hares (*Lepus americanus*) in Colorado

Period Covered: July 1, 2000 – June 30, 2002

Author: Steven W. Buskirk and Jennifer L. Zahratka

Personnel: T. M. Shenk, Ph.D.

ABSTRACT

Despite what is known about Canada lynx (*Lynx canadensis)* and snowshoe hare (*Lepus americanus*) ecology in Canada and Alaska, a paucity of information exists in the contiguous United States. With the listing of the Canada lynx as threatened under the Endangered Species Act in 2000 the need for more knowledge about lynx and their prey become more pressing. The recent reintroduction of Canada lynx to southwestern Colorado (1999) by the state has furthered increased this need. The development of reliable knowledge about snowshoe hare ecology will be key to the recovery and delisting of lynx. Two habitat factors are generally considered overriding in their importance to the abundance and fitness of snowshoe hares: the density of small-diameter (generally < 5 mm) woody stems within reach of the snow surface for food, and the abundance of somewhat larger-diameter woody structure for overhead cover. This project focuses on two central conceptual issues. First, how do site conditions produce woody stems of suitable diameters and heights above the snow for food for snowshoe hares in late winter, and how do site conditions provide overhead cover suitable for hares? Second, do snowshoe hares in fact attain their highest densities in these presumptive high-quality habitats? Ecological information gained about snowshoe hares will be valuable not only to the recovery of Canada lynx in Colorado, but also throughout the range of lynx in the southern U.S.

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Ecology of Snowshoe Hares (*Lepus Americanus*) in Colorado

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Introduction

The snowshoe hare (*Lepus americanus*) is a widely distributed and well-studied leporid of North American boreal forests. Scientists have long been interested in the snowshoe hare and its cyclic relationship with the Canada lynx (*Lynx canadensis*). The snowshoe hare is the obligate primary prey item of the lynx, which was listed as threatened under the Endangered Species Act in 2000. Data dealing with the ecology, particularly the habitat ecology, of southern snowshoe hare populations is lacking, especially in the southern Rocky Mountains. Indeed, only a single study (Dolbeer and Clark 1975) described the habitat associations of hares in the southern Rocky Mountains, but only in the most cursory fashion. The reintroduction of Canada lynx to the southern Rocky Mountains in 1999-2000 has further stimulated the need for understanding the habitat requirements of snowshoe hare populations. Therefore, data from the southern Rocky Mountains is critical for understanding the ecology of snowshoe hares in their southern range.

The abundance and fitness of snowshoe hares depend on the protection afforded by plants as well as their suitability as foods for hares. Although food is an obvious requirement for snowshoe hare survival, snowshoe hares rarely starve to death. Instead, predation is the overwhelming proximate cause of death for snowshoe hares (Hodges 2000*b*) and food shortage only predisposes them to predation. The cover afforded by large-diameter woody structure provides horizontal and vertical protection from predators (Wolff 1980). Also, small-diameter (< 5-mm) (Grigal and Moody 1980) woody stems < 45 cm from the snow surface (Bider 1961) are an important food source (Hodges 2000*a*). Whereas large-diameter woody stems presumptively provide protection from predation, small-diameter woody stems presumptively provide nutrition. Therefore, we assume that woody structure in two different size classes meets the needs of snowshoe hares for habitat. Winter is a critical time of year for snowshoe hare survival because fewer woody stems of either size class are available in winter than in other seasons, and herbaceous plants are not available.

Understanding how the density of woody stems of different sizes, tree dominants, and successional stage affect densities of snowshoe hares is key to effective management of snowshoe hare habitats in the southern Rocky Mountains. Therefore, we investigated two conceptual issues relating to snowshoe hare habitat in late winter. First, how do site conditions produce woody stems of suitable diameters and heights above the snow surface for food and how do site conditions provide suitable protective cover for hares? Second, do snowshoe hares in fact attain their highest densities in these presumptive high-quality habitats?

Study Area

Location

The study area was a broad area of southwestern Colorado on the Gunnison and Rio Grande National Forests, which we studied during January – April 2002. Within our study area, we established two study sites: one was a 1963-km^2 area centered over Taylor Park Reservoir on the Gunnison National Forest (39° 50' N, 106° 34' W); the second was the Divide District (4,089 km^2) of the Rio Grande National Forest (37° 40' N, 106° 40' W) centered directly north of South Fork, Colorado.

The Gunnison study area represents the southernmost extent of naturally occurring lodgepole pine. In coniferous forests of the Rocky Mountains, lodgepole pine is an important habitat type for lynx and snowshoe hares. The Rio Grande study area is lower in elevation and contains ponderosa pine, also widely distributed in the Rocky Mountains, and therefore of interest in our study.

Topography

The landscape of southwestern Colorado is characterized by high, rugged mountains, wide plateaus, and gaping river valleys. Elevation of the Gunnison study site ranged from 2850 m to 3480 m. On the Rio Grande study site the elevation ranged from 2460 m to 2580 m. Our spruce-fir sites occurred at elevations of 3210 – 3480 m, our lodgepole pine sites occurred at 2850 – 3100 m, and our ponderosa pine sites occurred at 2460 – 2580 m.

Climate

Southwestern Colorado exhibits an arid and temperate climate; strong local variation responds to elevation and aspect. The mean temperature in Gunnison, Colorado from January - April is -7 °C. In South Fork, Colorado the mean temperature from January - April is 0 °C (National Weather Service, Gunnison, CO, unpublished data).

Unlike areas of the Western Slope where more precipitation falls as winter snow than as summer rain, the monsoon season in southwestern Colorado brings most yearly precipitation in late summer. The mean monthly precipitation in Gunnison, Colorado for January - April is 1.6 cm. In South Fork, Colorado the corresponding mean is 1.5 cm (National Weather Service, Gunnison, CO, unpublished data).

Methods

Trapping grid selection

Our study area comprised the Gunnison and Rio Grande National Forests, within which trapping grids were chosen using a GIS database of national forest lands with Common Vegetation Unit (CVU) coverage using the Integrated Resource Inventory protocol (IRI) made available by each of the forests. Two sets of criteria, applied sequentially, were used to select the site of the trapping grids. The first set of criteria was based upon the CVU coverages using GIS:

1. Species dominants represented were lodgepole pine, Engelmann spruce, ponderosa pine and riparian (*Salix* spp.).
2. For forests, structural stage considered was mature (structural stage 4).
3. Vegetation polygons were candidate if ≥30 m, but ≤1 km from an improved road.
4. Vegetation polygons were candidate if ≥25 ha.
5. Vegetation polygons were candidate if sufficient to admit a 330 m x 550 m (16.5-ha) trapping grid with a 50-m buffer between the edge of the trapping grid and the nearest edge of the polygon.

Fifteen of the candidate polygons were selected randomly. Within each of these random polygons a 330 m x 550 m rectangle was placed at a randomly generated orientation (0 - 180°).

All potential ponderosa pine sites on the Gunnison National Forest were excluded using these criteria. All potential riparian sites on the Rio Grande were excluded using these criteria and no lodgepole pine was available on the Rio Grande to evaluate by CVU layers. Potential sites were visited in random order, at which time we applied the second set of criteria:

1. Forested sites were excluded if ≥40% of the trapping grid was dominated by a cover type other than the nominal species dominant.
2. Candidate sites were excluded if inaccessible by snowmobile and snowshoes.
3. Candidate sites were excluded if they held any unmapped roads.
4. Candidate sites were excluded if logging or thinning had occurred within them.

5. Candidate sites were excluded if avalanche danger was present.
6. Candidate sites were excluded if trapping grids were <500 m from a grid that had already been included.

The first three from each species dominant to meet these criteria were included as trapping grids. Because of the availability of suitable sites, and for logistical reasons, all three spruce-fir trapping grids, all three lodgepole pine trapping grids and all three riparian trapping grids were selected on the Gunnison National Forest. Only the three ponderosa pine trapping grids were selected on the Rio Grande National Forest.

After visiting fourteen sites mapped as lodgepole pine on the Gunnison National Forest, three were found that met our criteria. Fifteen sites mapped as spruce-fir on the Gunnison National Forest were evaluated before three were found that met our criteria. Ten sites tentatively mapped as riparian on the Gunnison were visited, but none were found that met our criteria. Fifteen sites mapped as ponderosa pine-dominant on the Rio Grande National Forest were visited before three were found that met our criteria.

Trapping and handling

All methods related to trapping and handling were approved by the University of Wyoming Animal Care and Use Committee and by the Colorado Division of Wildlife Animal Care and Use Committee. Snowshoe hares were trapped using Tomahawk Model 204 live traps (18 cm x 18 cm x 51 cm) placed on trapping grids of 84 traps (7 lines of 12 traps each), with 50-m spacing for a trapping grid size of 16.5 ha (Fig. 1). Three replicates for each species dominant were sampled for 6 trap nights, which we assumed to be a closed population for the purposes of mark-recapture models. No reproduction occurred during our winter field season. The trapping grid size and method were developed by Scott Mills and Paul Griffin, University of Montana; we used these methods to maximize comparability between our study and theirs.

Upon visiting a suitable site, the trapping grid was flagged and numbered using the UTM coordinates generated by a GPS receiver and a compass bearing (Fig. 1). Traps were placed in suitable habitat within 2 m of the flagging and if necessary, covered with tree branches to provide cover for captured hares. Traps were baited with a mixture of pellets of Timothy grain, alfalfa, corn, and oats (TACO), alfalfa pellets and apples (P. Griffin, pers. comm.). Traps were checked as early as possible each morning and re-baited as needed.

Once a snowshoe hare was captured, a pillowcase with a drawstring was placed over the front door of the trap. The hare was persuaded into the bag by gently tipping the trap, blowing on the hare, or making noise. Once the hare was in the bag it was immediately weighed using a 2500-g Pesola spring scale. The hare was then carefully placed between the legs of a kneeling handler with the head facing towards the handler. The second handler marked the hare using a sterile passive-integrated transponder (PIT) tag. One tag was injected subcutaneously with a sterile needle between the shoulder blades. Both ears of the snowshoe hare were also marked using a permanent black marker for short-term identification. After the first day of any trapping session (i.e. on traps days 2-6) every snowshoe hare was scanned with a 125-kHz Mini-portable reader to determine whether the hare was a recapture or a new capture. In the event the snowshoe hare was preyed upon and partially ingested, the earmarks were checked. Each snowshoe hare was sexed by turning the hare on its dorsal side and protruding the genitalia. The forefinger and middle finger were used to apply slight pressure to the vent area just above the anus. Snowshoe hares were then released away from handlers.

Snowshoe hares that suffered severe trap or predation injuries were euthanized with a 1-ml intrathoracic injection of sodium pentobarbital. Each carcass was necropsied and the liver and kidneys preserved for metals analysis. After necropsy and tissue collection, euthanized animals were disposed of by cremation or deposited in a landfill. Any non-target species caught in traps were immediately released.

Diet

Within spruce-fir stands, where captures were expected to be more common, we marked trap bait in order to determine whether feces collected from traps contained any bait. TACO and alfalfa pellets were marked with a light dusting of fluorescent, non-toxic powder (DayGlo). Fecal pellets were then collected from the inside of each live-trap where a snowshoe hare was captured. Every fecal pellet within the trap was collected, placed in a brown paper bag and allowed to dry at room temperature. After collection the fecal pellets were placed under an ultraviolet light to show presence or absence of any fluorescent marker ingested by the hares. Samples will be submitted to the Wildlife Habitat and Nutrition Lab at Washington State University, Pullman, WA for analysis.

Measurement of fecal pellets

Each fecal pellet was measured to the nearest 0.1 mm using SPI dial calipers. The sizes of all fecal pellets were recorded, and the mean pellet size for each individual hare was calculated.

Vegetation measurements

Habitat attributes were estimated at two levels: at each trap site and at each trapping grid. Within each trapping grid, vegetation plots were sampled from 15 trap sites, similar to the design of S. Mills (Fig. 1). Methods developed by T. Shenk (Colorado Division of Wildlife) to monitor habitat use by reintroduced lynx to Colorado were followed, with some minor modifications (Fig. 2). Accordingly, a 12-m x 12-m square of 25 points was placed in 5 rows of 5 (3 m apart), centered over the trap location (Fig. 2). The measurements taken at each of the 25 points included:

1. Snow depth (cm), as measured by a calibrated avalanche probe.
2. Understory measured in a column of 3-cm radius around an avalanche probe.
    a. All live or dead stems and coarse woody debris (CWD) that fall within the 3-cm radius column using the standardized four-letter genus-species code at 3 height categories (0-0.5 m, 0.51-1.0 m, 1.01-1.5 m) above the snow surface.
    b. Each of the above stems classified in 3 different diameter categories (< 5 mm, 5.1-10 mm, 10.1-15 mm) measured at the point where the stem hit the avalanche probe.
3. Overstory was measured using a sighting tube ("moosehorn") attached to the avalanche probe.
    a. Species that hit the crosshairs inside the sighting tube were recorded. Multiple hits by the same species were only recorded once.
4. Every shrub within the plot along with its species and diameter at breast height was recorded (dbh).
5. Every tree within the plot along with its species and dbh was recorded.
6. Every snag within the plot along with its dbh was recorded.
7. Every sapling within the plot along with its species was counted.
8. All coarse woody debris (CWD) deemed usable by snowshoe hare for cover or food (i.e., available above the snow) was recorded along with its diameter.

At all of the 84 trap sites within the trapping grid, including the 15 trap sites sampled as described above, the following data were measured:

1. Snow depth (cm), as measured by a calibrated avalanche probe.
2. Species of, dbh of, and distance to the closest woody stem in two categories: ≥1.0 cm – 7.0 and ≥7.1 cm at the snow surface.
3. Canopy cover for the center of the trap site, as estimated by the use of a spherical densiometer, in the four cardinal quadrants (NW, NE, SE, SW).

The following rules were used for unusual events:

1. If a point in a vegetation plot lay within a tree bole, the tree species and the dbh was written on the data form.

2. A snag was defined as any dead tree bole >45° from the horizontal. Dead boles <45° vertical angle were considered CWD.
3. The mid-point diameter was measured of exposed CWD partially covered by snow.
4. If a leaning tree fell partially outside the 12 m x 12 m sampling plot it was included if >50% of the tree lay within the sampling plot.

Results

Captures of snowshoe hares by trapping grid and tree species dominant are summarized in Table 1. A total of 28 hares were captured in 4620 trap nights of effort. Mean dbh and density of trees, by species, for the nine trapping grids in three tree species dominant categories are summarized in Tables 2-3. Snow depths, and densities of various vegetative structures for the nine trapping grids (15-point protocol) in three tree species dominant categories are summarized in Table 4. Corresponding data for the 84-point protocol are summarized in Table 5.

Literature Cited

Bider, J. R. 1961. An ecological study of the hare *Lepus americanus*. Canadian Journal of Zoology 39:81-103.

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

Grigal, D. F., and N. R. Moody. 1980. Estimation of browse by size classes for snowshoe hare. Journal of Wildlife Management 44:34-40.

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

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

Hoover, R. L., and D. L. Wills. 1987. Managing forested lands for wildlife. Pages 455-477. Colorado Division of Wildlife, Eastwood Printing and Publishing, Denver, Colorado.

Wolff, J. O. 1980. The role of habitat patchiness in the population dynamics of snowshoe hares. Ecological Monographs 50:111-130.

Figure 1. Schematic of 300 m x 550 m trapping grid to be used for estimating population density of snowshoe hares in southern Colorado. Asterisks (*) indicate the location of the 15 vegetation plots centered on trapping points. Pound signs (#) indicate where the point-quarter method will be used on all other trap locations.

1#	2#	3#	4#	5#	6#	7#
8#	9*	10#	11*	12#	13*	14#
15#	16#	17#	18#	19#	20#	21#
22#	23*	24#	25*	26#	27*	28#
29#	30#	31#	32#	33#	34#	35#
36#	37*	38#	39*	40#	41*	42#
43#	44#	45#	46#	47#	48#	49#
50#	51*	52#	53*	54#	55*	56#
57#	58#	59#	60#	61#	62#	63#
64#	65*	66#	67*	68#	69*	70#
71#	72#	73#	74#	75#	76#	77#
78#	79#	80#	81#	82#	83#	84#

Figure 2. Schematic of 12 m x 12 m vegetation plot centered on each of the 15 trap sites (Fig. 1) used in measuring habitat variables for snowshoe hares in southwestern Colorado, late winter 2002. The trap location is at the center of the vegetation plot.

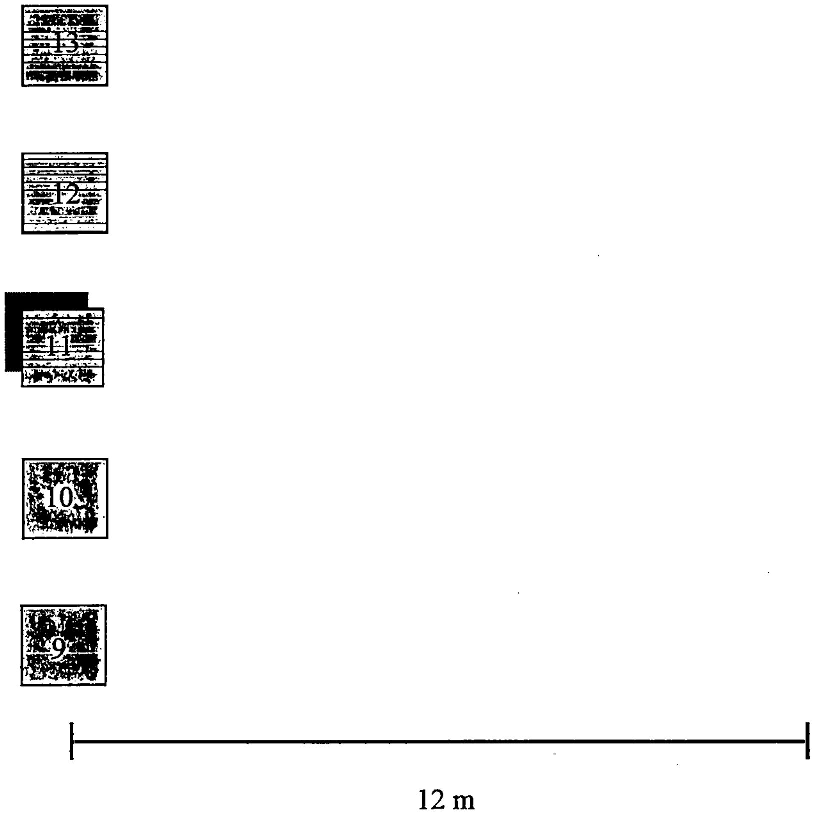

Table 1. The number of snowshoe hare captures (1st, 2nd, and 3rd), and total captures on nine trapping grids in three species dominant categories, and trapping effort (trap-nights), southwestern Colorado, late winter 2002.

Trapping grid number	Tree species dominant	1st capture	2nd capture	3rd capture	Total capture	Trap-nights
LP1	*Pinus contorta*	1	0	0	1	504
LP2	*Pinus contorta*	3	0	0	3	504
LP3	*Pinus contorta*	1	0	0	1	504
SF1	*Picea engelmannii, Abies lasiocarpa*	5	2	0	7	504
SF2	*Picea engelmannii, Abies lasiocarpa*	3	0	0	3	588
SF3	*Picea engelmannii, Abies lasiocarpa*	15	6	2	23	504
PP1	*Pinus ponderosa*	0	0	0	0	504
PP2	*Pinus ponderosa*	0	0	0	0	504
PP3	*Pinus ponderosa*	0	0	0	0	504

Table 2. Mean diameter at breast height (dbh) by tree species for 15 trap locations on nine trapping grids in three species dominant categories, southwestern Colorado, late winter 2002. All measurements are in cm ± SE (where n>1).

Trapping grid number	*Picea engelmannii*	*Abies lasiocarpa*	*Pinus contorta*	*Pinus ponderosa*	*Populus tremuloides*	*Psuedotsuga menziesii*	*Juniperus scopulorum*
LP1	NA	NA	14±1	NA	NA	NA	NA
LP2	NA	NA	14±1	NA	NA	NA	NA
LP3	NA	NA	15±1	NA	NA	NA	NA
SF1	23±3	13±2	NA	NA	NA	NA	NA
SF2	14±1	10±1	NA	NA	NA	NA	NA
SF3	20±2	11±2	NA	NA	NA	NA	NA
PP1	NA	NA	NA	27±3	11±1	21±2	9±2
PP2	NA	NA	NA	25±3	6	18±1	8
PP3	MA	NA	NA	21±2	3	20±3	NA

Table 3. Mean density by tree species for 15 trap locations on nine trapping grids in three species dominant categories, southwestern Colorado, late winter 2002. All measurements are in trees ha^{-1}.

Trapping grid number	*Picea engelmannii*	*Abies lasiocarpa*	*Pinus contorta*	*Pinus ponderosa*	*Populus tremuloides*	*Psuedotsuga menziesii*	*Juniperus scopulorum*
LP1	NA	NA	1273±171	NA	NA	NA	NA
LP2	NA	NA	1218±231	NA	NA	NA	NA
LP3	5±5	NA	1310±313	NA	NA	NA	NA
SF1	704±149	227±64	NA	NA	NA	NA	NA
SF2	1231±159	449±171	NA	NA	NA	NA	NA
SF3	1194±178	449±112	NA	NA	NA	NA	NA
PP1	NA	NA	NA	46±19	28±19	125±15	51±27
PP2	NA	NA	NA	93±24	5±5	14±7	5±5
PP3	MA	NA	NA	120±27	5±5	69±22	NA

Table 4. Mean snow depth, tree density, sapling density, shrub density, and snag density for 15 trap locations on Colorado, late winter, 2002. All measurements are in cm ± SE. Species dominant categories are listed in Table 1.

Trapping grid number	Snow depth at time of sampling ± SE	Tree density (ha^{-1})	Sapling density (ha^{-1})	Shrub density (ha^{-1})	Snag density (ha^{-1})
LP 1	37±1	1273±171	569±203	NA	620±139
LP 2	38±2	1218±231	333±148	NA	278±95
LP 3	32±1	1314±312	759±203	NA	431±98
SF 1	70±4	931±150	546±134	NA	162±50
SF 2	70±3	1680±215	749±254	NA	282±44
SF 3	75±3	1643±180	630±154	NA	417±108
PP 1	0	250±76	273±165	315±114	162±67
PP 2	0	116±28	481±161	722±305	379±125
PP 3	0	194±31	148±67	921±434	277±133

Table 5. Mean snow depth, mean canopy cover, mean diameter at breast height (dbh), and mean distances to nearest stem in two diameter categories for 84 trap locations on nine trapping grids in three species dominant categories, southwestern Colorado, late winter 2002. All measurements are in cm ± SE, except canopy cover, which is % ±SE.

Trapping grid number	Species dominant	Snow depth at time of sampling	Canopy cover	dbh of woody stems > 7 cm	Distance to nearest stem 1-7 cm dbh	Distance to nearest stem > 7 cm dbh
LP 1	*Pinus contorta*	40±1	73±2	15±1	352±35	116±7
LP 2	*Pinus contorta*	38±2	79±1	17±1	303±26	146±11
LP 3	*Pinus contorta*	40±1	69±2	18±1	351±52	163±14
SF 1	*Picea engelmannii, Abies lasiocarpa*	73±2	79±2	28±2	313±38	216±19
SF 2	*Picea engelmannii, Abies lasiocarpa*	66±1	75±2	24±1	238±21	165±16
SF 3	*Picea engelmannii, Abies lasiocarpa*	75±2	85±2	21±1	153±13	145±11
PP 1	*Pinus ponderosa*	0	37±4	27±1	490±41	422±37
PP 2	*Pinus ponderosa*	0	24±3	25±1	382±35	551±43
PP 3	*Pinus ponderosa*	0	48±3	26±1	479±46	291±32

Colorado Division of Wildlife
Wildlife Research Report
July 2001 and July 2002

PROGRESS REPORT

State of Colorado : Division of Wildlife – Mammals Research

Work Package No. 3001 : Deer Conservation

Task 1 : Mule Deer Life Cycle – Neonatal Fawn Survival

Federal Aid Project W-185-R : Research and Development

Period Covered: July 1, 2001 – June 30, 2002

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The following is an abstract and manuscript now in preparation for submission to the Journal of Wildlife Management describing the neonatal fawn survival study on the Uncompahgre Plateau. Because of requests by reviewers or editors some aspects of the presentation and analysis may be modified. Manipulation or interpretation of these data beyond that contained in this report should be labeled as such, and is discouraged.

Abstract: Declining mule deer (*Odocoileus hemionus)* populations resulting from apparent low recruitment brought management and political focus on neonatal fawn survival. Mule deer fawns on the Uncompahgre Plateau (5,957 km$^{2)}$ in west central Colorado were captured at mean age of 3 days (range from newborn to 6 days) and collared with mortality sensing drop-off radio collars. Two hundred thirty fawns were radioed with samples of 50, 88, and 92 during 1999, 2000, and 2001, respectively. Designated neonate survival period was from capture to 14 December. Survival was different among years ($X_2^2 = 6.160$, $P = 0.046$) with annual survival (Kaplan-Meier, 95% CL) of 0.321 (0.125-0.517); 0.589 (0.474-0.703), and 0.594 (0.472-0.716) for 1999, 2000, and 2001, respectively; the 3-year mean survival was 0.501. Combined 3-year cause-specific mortality (95% CL) was sick/starve 0.171 (0.116-0.226), Coyote 0.126 (0.078-0.174), bear 0.040 (0.012-0.068), feline 0.032 (0.006-0.057), trauma 0.043 (0.014-0.072), and unknown 0.047 (0.016-0.077). Neither all predation combined (coyote, bear, and feline) ($P = 0.379$) nor coyote predation alone ($P > 0.989$) differed among years. Mortality in the sick/starve category is the only source that approached significance among years ($P = 0.070$). The major difference was in 1999 with 0.318 mortality due to sick/starve compared to 0.115 and 0.148 in 2000 and 2001, respectively. Historic December (1990-99) fawns per 100 does ratios (f:d) were significantly correlated with the preceding June precipitation ($P = 0.004$) but not with June temperature ($P = 0.441$). June precipitation for 1999 was 3.66 cm and was 1.04 and 0.86 cm in 2000 and 2001, respectively, which

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may have contributed directly or indirectly to the differences in sick/starve mortality. Three-fourths of mortality from predation (75.0%) and sick/starve (73.7%) had taken place by 31 July with 76.3% of mortality from all sources occurring by 31 July. Mean fawn weights at capture were 4.35 kg, 4.50 kg, and 4.13 kg for 1999, 2000, 2001, respectively and were different among years ($P = 0.044$). There was also a difference in hind foot length among years ($P = 0.002$) with mean length of 26.14 cm, 26.62 cm, and 25.63 cm for 1999, 2000, and 2001, respectively. Weight and hind foot means were different between 2000 and 2001 ($P > 0.017$) with 1999 not different from either 2000 or 2001 ($P < 0.017$) using mean separation procedure controlled with Bonferonni significance level. Mean capture date was 19 June (4.83 days SD) and median capture date was 19 June (range 9 June to 6 July) with 94.78% of all captures occurring between 13-30 June. This implies that most does were bred during their first estrous cycle. Neonatal survival through 14 December does not completely account for observed low f:d ratios. Fetus mortality during late pregnancy or mortality of fawns at birth (before they could be detected for capture) is implicated as a potential cause of poor recruitment.

NEONATAL MULE DEER FAWN SURVIVAL AND CAUSE SPECIFIC MORTALITY

T. M. Pojar and D. C. Bowden

There is evidence that the mule deer populations in Colorado, as well as other western states, have declined during recent years due mostly to low fawn survival and subsequent low population recruitment (Unsworth et al. 1999). December f:d ratios on the Uncompahgre Plateau (5,957 km$^{2)}$ in west central Colorado have declined ($t = -3.41$, $P = 0.004$) by an average of 1.8 fawns:100 does per year from 1982-1998 where December ratios ranged from a high of 79f:100d in 1982 to a low of 32f:100d in 1997 (White et al. 2001). Declining deer densities and long-term decline in f:d ratios have resulted is much debate and concern among managers, sportsmen, administrators, and politicians. Gill et al. (2001) offers several potential causes for long-term decline in deer density: 1) habitat deterioration, 2) competition, 3) disease, 4) predation, and 5) hunting. Specifically, low December ratios could be the result of: 1) low pregnancy rate, 2) reduced fetal production, 3) prolonged breeding (fawning) season due to low buck to doe ratios, 4) late term mortality of fetuses and weak or stillborn fawns, or 5) low neonatal fawn survival through December. A popular perception is that predation especially by coyotes (*Canis latrans*), but also by black bear (*Ursus americanus*) and felines (*Felis concolor* and *F. rufus*), is a major contributing factor in apparent low neonatal fawn survival.

Pregnancy and fetal rates have been relatively constant for this species at population densities encountered during recent decades. During the 1960s and 1970s when deer populations were thriving in Colorado pregnancy rates in the following habitats were: 1) front-range foothills 92.0% (n=163) (Medin and Anderson 1979), 2) high mountain park 94.0% (n=134) (Gill 1971), and western slope pinyon-juniper 89.0% ($n = 47$) during 1973 and 82.0% ($n = 83$) during 1978 (Bartmann 1998). During 1963-71, a penned herd that was fed alfalfa hay ad libitum and a 16% protein supplement ranging from 0.23 to 0.90 kg per deer-day averaged 94.7% pregnancy (n=135) (Robinette et al. 1973). Fetal rates, as the other major component of reproductive rates, for adult does were 1.83 ($n = 41$) during 1961-1965 in front-range foothills habitat (Medin and Anderson 1979) and 1.82 ($n = 114$) in high mountain park habitat during 1969-1971 (Gill 1971) in Colorado. To determine if both pregnancy and fetal rates of adult does have not changed since the 1960s and 1970s and to have specific information from the Uncompahgre Plateau, a separate preliminary study examined these factors using transrectal ultrasound. A sample of 40 does was examined in February 1999. Pregnancy rate (93%) did not differ from the historic rate of 94%, (n = 328, $X_1^2 = 0.07$, $P = 0.791$) and the fetal rate (1.70) was not less than the historic rate of 1.87 (n = 307, $Z = 0.412$, $P = 0.681$) (Andelt, Pojar, and Johnson, unpublished data).

Density dependent effects of population growth follows the progression of reduced juvenile survival, increased age at first reproduction followed by a decline in reproductive rates of mature females late in the progression to carrying capacity and, finally, reduced adult survival (Eberhardt 1977). Juvenile survival is highly variable and sensitive to population density and stochastic environmental factors whereas, adult female survival is robust against most limiting factors (Gaillard et al. 1998, White and Bartmann 1998). Therefore, the most obvious area of investigation was to examine the survival and mortality sources of neonate fawns.

The primary objectives of this study were to estimate neonatal fawn survival from birth (time of capture) to 14 December and cause-specific mortality to determine the contribution of summer fawn mortality to December f:d ratios on the Uncompahgre Plateau. Timing of births (captures), as an index of fawning season compression was a secondary objective; this relates to cohort exposure to predation (predator swamping). Extent and timing of the various mortality sources are described.

STUDY AREA

The Uncompahgre Plateau was formed by a structural up-lift; it runs generally southeast to northwest with a crest, a break in the up-lift, roughly bisecting it forming drainages to the northeast and southwest. The small communities of Gateway and Ridgeway are on the northwest and southeast perimeter, respectively, with the larger communities of Montrose and Delta along the east boundary (Figure 1). The terrain slopes generally to the northwest along the crest with the highest point being Horsefly Peak at 3,147 m and the lowest, 1,389 m, near Gateway. Along the crest, the terrain slopes gently to the northeast where many tributaries to the Gunnison and Uncompahgre rivers have worn deep canyons; the Unaweep Canyon along the northwest boundary of the area averages 914 m deep (Young and Young 1984). Southwest of the crest terrain drops abruptly because the plateau cap lifted and tilted to the northeast giving a gentle slope to the northeast and a steep drop-off to the southwest (Marshall 1998) with drainages flowing to the San Miguel and Dolores rivers.

The latitude is from 38° 1.23' to 38° 59.05' and the longitude ranges from 107° 45.52' to 108° 58.80'. Normal annual precipitation (1971-2000 mean) is 29.11 cm with most precipitation in late summer and fall (July-October); the 30-year mean low temperature (-2.78° C) was in January and the high (22.86° C) was in July. These weather statistics were taken from 5 stations on the perimeter of the plateau and would best represent winter range; summer range is at higher elevations and would have lower temperatures and higher precipitation.

The study area includes Game Management Units 61 and 62 (5,957 km^2) and is designated as Data Analysis Unit D-19. Vegetation types are agricultural along the major river drainages and as elevation increases the following types are encountered: saltbrush-greaswood (*Atriplex canescens* and *Sarcobatus vermiculatus*), mature pinyon-juniper (*Pinus edulis* and *Juniperus osteosperma*) forest interspersed with big sagebrush (*Artimisia tridentata*) parks, Gambel oak (*Quercus gambelii*), ponderosa pine (*Pinus ponderosa*), and spruce-fir (*Picea-Abies*). The oak, pine, and spruce-fir communities are interspersed with aspen (*Populus tremuloides*) with some areas of pure aspen stands bordered by areas of mountain shrub and high mountain grass-forb meadows. There are vast stands of aspens on the rugged southwest slopes of the Uncompahgre. The oak, pine, spruce-fir, and aspen types are the major summer range and fawning habitat for mule deer and are generally above 2,438 m. Winter range can be from the oak-mountain shrub community (depending on winter severity) decreasing in elevation to the agricultural lands along major drainages (Figure 1).

Livestock grazing began in 1881 immediately after the Ute Tribe was expelled from the Uncompahgre Plateau (Anderson et al. 1992). Large herds of cattle were brought in from Texas, Kansas, and Mexico and within 20 years the town of Placerville (on the south end of the Uncompahgre Plateau) became "...the largest cattle-shipping point in the world" (Marshall 1998:59). Severe overuse by livestock continued for 70 plus years, at least until 1951, accompanied by extreme overpopulation of deer beginning in the 1940s until liberal harvests during the 1950s and 1960s reduced the deer population (Kufeld 1979). Range condition around 1900 was described as being eaten "...down to the nub" (Marshall 1998:59). Still, by about 1944 the range was described as appearing as having "...had a band of sheep "caked" on it" (anonymous, c.a. 1944:8). Sharp stocking rate declines began in 1948 and "...have remained relatively constant near their lowest rates from 1951 to the present" (Kufeld 1979:13). The overstocking of livestock from 1881 to 1948 and deer from the 1940s to the 1960s has been alleviated; however, reduction in grazing pressure does not necessarily result in range condition improvement because the range may stabilize at a lower successional state (Laycock1991).

Timber harvest has been a factor in the past and continues to the present. Roads and rural sub-developments are expanding especially in the southern area of the plateau. Summer and winter recreation, including sightseeing, camping, biking, hunting, all terrain vehicle, and snowmobiling and cross-country skiing are common human activities (Uncompahgre Plateau Partners 2002).

This study was approved by Colorado State University and Colorado Division of Wildlife animal care and use committees under Protocol Number 99-063A-01.

METHODS

The fawning area generally included the entire summer range of the plateau above 2,438 m. Mature does (*n* = 74) that had been radioed during the ultrasound reproductive study and during a separate survival study were tracked to more precisely identify fawning habitat during the first year of capture efforts. Fawns of radioed does were not necessarily targeted for capture. Searches for parturient does were from the ground, either on foot or by vehicle. Behavior and physical features were clues to identifying parturient does. Does that were alone, had udder development, and sunken flanks were prime candidates for initiating an intense search for bedded fawns within a 50± m radius of where the doe was first spotted. Searches were terminated if young were not found within about a half-hour.

Bedded fawns were approached from the rear, avoiding eye contact, quickly approaching for the last couple meters. Upon placing a hand (latex gloved) on it's back, the fawn would freeze. Immediately upon capture, it was blindfolded and hobbled; processing took ≤ 5 minutes and included weighing, hind foot measurement, and attaching the radio collar. Age of the fawn was estimated by condition of the umbilical cord, pelage, hoof condition, and behavior. Before release, the fawn was examined for signs of dehydration, sickness (diarrhea or respiratory discharge), or physical deformities. Attempts were made to leave the fawn at the same site where it was captured.

Radio collars (weighing < 110 g) were expandable from 22 cm to 33 cm and designed to drop off at approximately 6 months. Mortality sensor was set at 2 hours. Once radioed, each fawn was tracked to determine live status at least twice a day and sometimes as many as 6 times per day through 1 September and then once a day, excluding weekends, through 14 December. Determination of live status was done from distances (0.5-5.0+ km) sufficient to minimize disturbance to either the fawn or doe.

Mortality signals were investigated immediately upon detection. The site and evidence was surveyed and a determination of cause was assigned as best as evidence offered. If no carcass was present and evidence indicated predation or scavenging, criteria offered in the literature was used to help assign a specific predator (White 1973, Wade and Bowns 1984, Acorn and Dorrance 1990, and Andelt et al. 1998). Most of these, however, deal with adult or domestic animals (except White 1973) and other geographic areas but were used anyway to help evaluate on-site evidence. Ground cover and vegetation was too thick to find actual tracks so, in addition to the above, the following general criteria were used. Coyote kill/scavenge sites typically had only shards of bones, tufts of hair/hide, usually >1 feeding site within 30 m, and sometimes fawn parts buried in mineral soil. Bear sites were identified by one relatively large feeding site (1-5 m diameter) with the fawn hide nearby and usually intact and inverted (Schlegel 1976); bear usually defecate near their feeding site. The presence of hooves and small leg and cranial bones typify black bear kill sites (Bertram and Vivion 2002:751). Felines (Mt. Lion and bobcat) drag their prey from the kill site to a protected feeding area and cover any remains with litter and duff. Deaths due to vehicle collisions, entanglement in fences, accidents, or human caused (poaching) were categorized as trauma deaths. The unknown category included collars that were found with no carcass parts or other evidence of the fawn in the vicinity. It is possible the collar was carried from a kill site by an avian or terrestrial predator/scavenger. This category undoubtedly includes some collars that were slipped either by maternal grooming or a lucky stroke by a hind foot. Even if the collar had bite marks or blood on it, it was classified as unknown because assigning it to any of the 3 major terrestrial predators would be quite uncertain. Ballard et al. (1999) chose to construe this line of evidence as coyote predation because coyotes are known to prey on fawns in summer.

Whole carcasses that were found were examined for external evidence of sickness such as diarrhea or respiratory discharge or external injuries. Proximate site characteristics were described as with other mortalities. Whole carcasses were field classified as sick/starve but the mortality category was changed to trauma if necropsy revealed internal injury from trauma. During the first year, carcasses were frozen and transported to the necropsy laboratory within 5-7 days. Protocol for 2000 and 2001 provided for the carcass to be iced and transported to the laboratory within 2 hours of discovery. A trained pathologist did all necropsy and tissue collections. Details of laboratory procedures, tissue sample collection, diagnostic techniques and disease detection results are found in Myers (2001).

Thymus glands were not weighed during the first year of our study but the attending pathologist made a subjective judgment on the condition and size of the thymus at necropsy. During the last 2 years, thymus glands were weighed to the nearest hundredth of a gram.

Data in terms of survival time were censored if the radio dropped off before 14 December. If a radio was not heard and could not be accounted for, survival time data were censored on the last day the radio was heard. All survival time data associated with radios recovered and assigned to the "unknown" category were censored.

The key assumptions of a survival study are: 1) animals are sampled randomly, 2) experimental unit survival times are independent, 3) capture and carrying a radio package does not affect survival, 4) the censoring mechanism is random, and 5) emigration is zero (Pollock et al. 1989, Tsai et al. 1999). Because there is high probability of mortality soon after birth in mule deer and because the fawning season is temporally compressed (about 2 weeks), staggered entry of subjects was not used. The time origin for the nonparametric Kaplan-Meier (Kaplan and Meier 1958) survival estimator was the date when the first fawn was radioed. Staggered exits from mortalities and censoring were incorporated in the calculations of survival and confidence limits following Pollock et al. (1989). Large-sample Chi-square tests were used to compare yearly Kaplan-Meier estimates of survival rates. Fisher's Exact Test was used for tests of association and Log Rank statistic was used to compare mortality distributions among years (Cantor 1997). ANOVA and pair-wise mean comparisons were made following the Bonferroni inequality to compare fawn weight and hind foot measurements. The 0.05 significance level was used for all tests.

RESULTS

During 3 fawning seasons 230 fawns were radio collared with 50, 88, 92 captured during 1999, 2000, and 2001, respectively (Table 1). Mean capture date was 19 June (4.83 days SD) and median capture date was 19 June (range 9 June to 6 July) with 94.78% of all captures occurring between 13-30 June. Mean fawn weights at capture were 4.35 kg, 4.50 kg, and 4.13 kg for 1999, 2000, 2001, respectively and were different among years ($P = 0.044$). There was also a difference in hind foot length among years ($P = 0.002$) with mean length of 26.14 cm, 26.62 cm, and 25.63 cm for 1999, 2000, and 2001, respectively. Both weight and hind foot means were different between 2000 and 2001 ($P < 0.017$) with 1999 not different from either 2000 or 2001 ($P > 0.017$).

During the first year, the attending pathologist diagnosed 8 of 15 (53%) fawns in the sick/starve mortality category with "severe thymic atrophy". Mean thymus weight was 2.62 g (SD 2.90, $n = 10$) and 1.96 g (SD 2.40, $n = 10$) for 2000 and 2001, respectively. These means were not different ($P = 0.584$) and were combined for a 2-year mean of 2.29 g (SD 2.62, $n = 20$).

Mean June precipitation was 3.66 cm in 1999 and 1.04 and 0.86 in 2000 and 2001, respectively. June precipitation on the Uncompahgre Plateau during 1990-1999 was negatively correlated with subsequent December f:d ratios ($P = 0.004$) but was not correlated with June temperature ($P = 0.441$).

Survival was different ($X_2^2 = 6.160$, $P = 0.046$) among years with annual survival (95% CL) of 0.321 (0.125-0.517), 0.589 (0.474-0.703), and 0.594 (0.472-0.716) for 1999, 2000, and 2001, respectively. Sick/starve was the only cause-specific mortality that approached significance among years ($P = 0.070$) (Table 2). The major difference was in 1999 with 0.318 mortality due to sick/starve compared to 0.115 and 0.148 in 2000 and 2001, respectively. The 3-year combined mortality due to sick/starve was 0.171 (0.116-0.226). Coyote predation was 0.126 for combined 3-year data and was highly consistent ($P = 0.989$) among years. Likewise, bear and feline caused mortality was consistent among years (Table 2) and was 0.040 (0.012-0.068) and 0.032 (0.006-0.057), respectively. All predation combined did not differ among years ($P = 0.379$). Trauma, which included roads, fences, injury, etc. was 0.043 (0.014-0.072) and unknown causes accounted for 0.047 (0.016-0.077) of the 3-year mortalities. The temporal distribution of mortalities was consistent among years ($X_2^2 = 0.680$, $P = 0.712$) with 76.3% of all mortalities occurring by 31 July. This is the result of the major sources of mortality, sick/starve (73.7%) and predation (75.0%), taking place by 31 July.

DISCUSSION

Fawn capture effort was focused on the high elevation summer range generally above 2,438 m. How well the sample of fawns captured in this area represents the entire Uncompahgre Plateau population is of major importance. Mule deer tend to be seasonally migratory in the mountainous areas of Colorado (Garrott et al. 1987). However, in the Colorado eastern foothills the majority of the herd may remain at lower elevations yearlong (Kufeld et al. 1989). In Idaho, 26% of a herd that wintered in broad agricultural valleys and low elevation rangelands stayed on the wintering area yearlong (Brown 1992). Wintering area of the Uncompahgre Plateau herd includes some low elevation valleys but raises quickly into sagebrush and pinyon-juniper habitat (Figure 1).

To determine how representative the fawns captured at high elevations were of the entire population we used the elevations of winter-captured does ($n = 95$) during 1997-2000 and their subsequent aerial relocations during mid-May ($n = 64$) and late-May ($n = 144$). The mean elevations for capture, mid-May (May 18-21), and late-May (May 28-31) relocations were 1,927 m, 2,551 m, and 2,603 m, respectively with a highly significant difference ($P \leq 0.001$); mean of winter capture locations was different ($P < 0.05$) from the relocations. The 95% kernel home range of all does relocated during mid- or late-May closely matches the 95% kernel home range of all fawn capture sites (Figure 1). This indicates this population generally fits the near-total migratory pattern described by Garrott et al. (1987). Does had about 3 more weeks to complete their migration to summer/fawning areas, which would have reduced the May relocation home range size because does do not settle on their fawning area and reduce their individual home range until about 3-5 days of parturition (Haegel et al. 1985).

The aerial trapping operation did not attempt to capture does among farmsteads along the river bottoms and agricultural lands. These lands compose 6% of the total area (Figure 1).

During the 5 years prior to this study, the sex ratio of the Uncompahgre Plateau deer herd averaged 12.3 bucks per 100 does (Colorado Division of Wildlife data). Later mean parturition date, a less synchronized birthing pulse, and lower pregnancy rates resulting in reduced recruitment are some of the postulated consequences of low sex ratios (Squibb 1985, White et al. 2001). In a controlled experiment with elk, the calving season was later by 17 days and extended by 30 days when breeding was done by yearlings compared to 5-year-old bulls; pregnancy rate was 89% with yearlings and 97% with 5-year-olds (Noyes et al. 1996). In a free-ranging elk herd, bulls > 1 year old did 76% of the breeding with yearling bulls making an appreciable contribution to successful breeding in this herd and "...completely compensating for the absence of older bulls" (Squibb 1985:750). Low sex ratios could have a greater impact on deer compared to elk because deer have a tending-bond breeding system and elk form harems (Kie and Czech 2000). Examination of 20 years of sex ratio data and fawn to doe ratios provided no evidence to indicate that sex ratios observed across the state affected population productivity in Colorado mule deer (White et al. 2001). Our data support the contention that low sex ratios did not adversely affect herd productivity. Mean capture date was 19 June in this study, which is similar to the mean fawning date of 18 June (n=215) for a captive herd in Colorado (Robinette et al. 1973). Ninety-five percent of our captures were within a 2-week period, between 13 and 30 June, providing evidence that most does were bred during their first estrus. Estrous cycle is 23-29 days for mule deer and 97% conceive during their first cycle (Anderson and Wallmo 1984).

Survival of individual fawns is related to the interaction of nutrition, cover, and climate Picton (1979). On northern ranges, deer are frequently subjected to rigorous winters resulting in chronic malnutrition of does and subsequent stillbirths, weak fawns, and lactation failure (Verme 1969). Although the 3 winters encountered during this study were milder than normal, this population seems to fit the description of a herd that is stressed during winter. During our searches of fawning areas we discovered a total of 9 fawns that were stillborn or died within minutes/hours of birth. In addition, we found one doe that was so weakened from trying to deliver dead twin fetuses that she was captured, restrained, and the fetuses delivered; the doe apparently survived as she was not found in the vicinity the next day. Two mature does were killed or scavenged by bear; one was prime aged (3-4 years old) and the other was of unknown age. Both were found during the peak of fawning - 18 and 19 June. Bear are known to prey on both fawns and adult deer (Behrend and Sage 1974, Conger and Giusti 1992, Verspoor 1983) but bear rarely prey upon healthy adult deer (Verspoor 1983). The best speculation is that the does were in a difficult delivery, as the above mentioned doe, or had died from delivery complications and were scavenged.

During extended periods of damp cool weather fawns may have a higher incidence of exposure-related complications and deaths (Ginnett and Young 2000). Cool dry summer weather in the northern regions of mule deer range enhanced fawn survival (Picton 1979). Mortality due to sick/starve during 1999 was 0.312 compared to 0.115 and 0.148 for 2000 and 2001, respectively. In an attempt to discover possible causes for the higher sick/starve mortality in 1999 compared to 2000 and 2001, we examined June precipitation and temperature and fawn weights and skeletal development as gauged by hind foot length. We speculated that fawning-season weather might be a factor or that fawn robustness, as measured by fawn weights and skeletal development, might differ among years. Since the 1999 fawn size indicators were not different from the other 2 years when sick/starve mortalities were much lower, it cannot be concluded that fawn size affected the proportion of fawns dying of sickness or starvation.

Mean birth weight of fawns from a captive herd was 3.69 kg (n=172) (Robinette et al. 1973) and is less than means we observed. This is expected because these were nearly true birth weights and our measurements were taken at mean age of 3 days and fawns can gain 0.29 kg per day during their first 12 days (Robinette et al. 1973). Given these weight comparisons, there is no evidence to suggest that fawn weight was a factor in the difference in fawn mortality due to sick/starve among years.

Thymus gland development in cervids of similar size to mule deer (fallow deer (*Dama dama*) and sitka deer (*Cervus nippon*), follows a pattern of growth during fetal development then remains relatively constant from birth to puberty (Chapman and Twigg 1990). In mule deer (as in other cervids) it then declines into adulthood with seasonal peaks and troughs in summer and winter, respectively (Anderson et al. 1974). Measurements of thymus glands of fawn, yearling, and adult mule deer, Browman and Sears (1956) observed annual cycles of highs in summer and lows in winter with fawns having the highest values of the 3 ages. Thymic atrophy is generally the result of chronic stress and can be seasonal (related to photoperiod or climate) or due to immediate stress such as inanition and disease (Chapman and Twigg 1990). White-tailed deer (*O. virginianus*) on low energy diets had lower ($P < 0.05$) thymus weights than deer on high energy diets (Lawrence et al. 1986). Ozoga and Verme (1978) conclude that the thymus provides a reliable index to physiological status and Lawrence et al. (1986) suggest thymus weight of adult does could be used in management decisions.

Neonatal white-tailed fawns that were dying of disease or malnutrition had "extremely small" thymus glands averaging 1.3 g (range 0.5-3.0g, n = 14) compared to healthy fawns of similar age (X= 9.7 g, range 4.3-23.7 g, n = 7) (Ozoga and Verme 1978:794). Our combined 2-year mean thymus weight of 2.29 g (SD 2.62, n = 20) is similar to the mean of 1.3 g for fawns near death from disease or starvation observed by Ozoga and Verme (1978). In Colorado Anderson et al. (1974) collected 13 mule deer fawns (6 male and 7 female) from 1 to 5 months old; their mean thymus weight was 9.22 g (SD 2.88, n = 13) and was comparable to the healthy fawns sampled by Ozoga and Verme (1978). There were only 3 measurements in our sample of sick/starve fawns that approached the means observed by Anderson et al. (1974) or Ozoga and Verme (1978) for healthy fawns. In 2000 a fawn 68 days old died (6 September) of a hemorrhagic condition and had thymus weight of 8.00 g and a second fawn 69 days old died (8 August) of pneumonia with a thymus weight of 7.95 g. Both had fat reserves but were judged to be less than optimal. In 2001, a fawn 21 days old died (7 July) of a hemorrhagic condition and had a thymus weight of 8.28 g; it was judged to have poor fat reserves. Excluding these 3 values, the mean for fawn thymus weight in this study was 1.26 g (SD 0.85, n = 17).

The obvious reduced thymus size of fawns dying of sickness or starvation in this study should serve as a point of concern for managers. The reduced thymus size was probably initiated during the fetal stage of development and would indicate the stress factor was affecting the dam. Inanition has been shown to result in reduced thymus size in deer (Lawrence et al. 1986, Ozoga and Verme 1978) so the nutritional status of does during pregnancy, and especially during the last trimester, should be investigated. Fawns dying of sickness and starvation in 2000 and 2001 was nearly half the mortalities attributed to this cause in 1999. The weather during fawning seasons of 2000 and 2001 was warm and dry possibly allowing fawns that were not robust to stresses to survive.

This study was not designed as a manipulative study where some factor or factors were controlled or manipulated and the impact on fawn survival measured. Coyote predation on neonatal fawns was a popular theory and the opportunity arose to examine the effects of coyote control on a small portion of the study area. The area, 130 km (2% of the total area) included 3 sheep operations on private land. These ranches were used as lambing and summer ranges so coyotes were killed before the sheep were moved onto the area. Coyotes were killed from January trough September with most kills during winter and spring mostly by aerial gunning with a few kills from the ground. There was an active predator (coyotes and bear) control program during 1994 through 2001 on this area with a total of 187 coyotes and 17 bear killed (Animal and Plant Health Inspection Service, Wildlife Services records, Grand Junction, Colorado). During the 3 years of the fawn survival study there were 53 coyotes and 11 bear killed in the predator control area. Forty fawns were collared on this corresponding area allowing a comparison of fawn survival on and off the control area. Seven fawns were killed by predators inside the control area (4, coyote; 1, bear; and 2 feline) and 37 outside the area (24, coyote; 8 bear; and 5 feline). Comparison of predator kills inside and outside the area resulted in a Fisher's Exact Test result with $P = 0.830$; limiting the test to only coyote kills the results offered no evidence of an association between coyote control and fawn survival ($P = 0.794$).

For fawn survival study results to be comparable they should be similar in the following: 1) fawn age at capture, 2) equipment and handling procedures, 3) tracking frequency, 4) nutritional status of does, 5) vegetation and hiding cover, 6) predator density, and 4) mortality identification criteria. Although it is impossible to match all of the above for comparisons, generalizations may be useful to assess the possible impact of the various mortality sources, particularly predators, on neonatal fawns.

In Montana Hamlin et al. (1984) radioed 91 fawns over a 6-year period (1976-1981) and tracked them at 2-3-day intervals. Fawns up to 3 weeks old were included in their sample (Riley and Dood 1984). Mortalities were categorized as either "probable or known coyote involved deaths" or "other". They found no whole carcasses, which may be the result of tracking them on 2-3 day intervals allowing scavengers (including coyotes) time to find the carcass. Eighteen of 20 deaths (90%) were attributed to coyotes and 2 (2.2%) were listed as "other". Eighteen mortalities of 91 radioed fawns (19.8%) were assumed to be coyote-caused and total survival was 78.0%, which is higher than we observed. Their sample of fawns was most likely older than our sample. They used aerial observers to spot fawns indicating that the fawns were old enough to be trailing the does and ground crews used long-handled hoop nets to capture the fawns indicating the fawns were no longer in the hiding phase. A sample of older fawns would miss mortalities immediately after parturition and result in a higher survival rate compared to a sample of younger fawns such as ours.

A fawn survival study on a 51.8 km Steens Mountain study area in Oregon during 1971-74 had a sample of 106 neonate fawns aged 1-14 days old and were monitored every 3-4 days (Trainer 1975). Mortality attributed to coyotes was 10.3% and for all predators it was 15.1%. Disease and starvation mortality accounted for 9.4% of the total; survival was 72.6%.

Preliminary results of an Idaho study with a sample of 69 fawns during 1998-99 exhibited a loss to coyotes of 13% and total predators (coyotes and lions) of 32%. Overall survival was 44.9%. These results are not directly comparable to our study because coyotes and lions were controlled on a portion of the area.

Given the shortcomings of comparing results of studies where protocol is not similar, neonatal fawn mortality attributed to coyotes is in the range of 10-20% for the various studies. Survival is highly variable ranging from 44.9% to 78.0%; the range in survival is undoubtedly heavily influenced by differences in age of fawns at capture (beginning of monitoring).

Neonatal survival through 14 December does not account for observed low f:d ratios. In addition to pregnancy and fetal rates from the preliminary productivity study in February 1999, data available for this herd included random quadrat-based population size and herd structure estimates in December 1999. Survival estimates for bucks, does, and fawns during winter of 1999-2000 based on radioed animals

(Bruce Watkins, Colorado Division of Wildlife, Montrose, personal communication) were available. We used this information and incorporated our observed year 2000 summer fawn survival (0.5887) to calculate the expected f:d ratio for December 2000. Our calculations included 10% lower fetal rates of primaparous does (Robinette et al. 1973, Trainer et al. 1981) and a differential of viable neonates of 96% for multiparous does and 82% for primaparous does (Robinette et al. 1973). They did not have an estimate of fetal rate, but the birth rate of 1.92 fawns per doe is similar to the maximum fetal rate for mule deer (Jensen and Robinette 1955). Hamlin and Mackie (1989) estimated 80% viable neonates for all-age does; this estimate includes fetal and neonate mortality. Using differential viable rates of Robinette et al. (1973)(96% and 82%) the projected December f:d ratio was 75 and using all-age estimated viable rate of Hamlin and Mackie (1989) (80%) the projected December f:d ratio was 64. Both of these projections were higher than the observed f:d ratio of 51 as estimated by a random quadrat helicopter survey in December 2000. Our data are most comparable to those of Hamlin and Mackie (1989) because theirs was a wild population. The herd studied by Robinette et al. (1973) was a fed captive population but indicates that a proportion of fawns born are not viable for various reasons even in a well nourished herd.

Assuming the f:d ratio of 51 from the helicopter survey is unbiased, mortality of 37% from February when fetal rates via ultrasound were taken and June when fawns were captured would be necessary to match the observed f:d ratio. This indicates fetal or early neonate mortality that could be caused by inanition of the does, disease, or effects of poisonous plants.

The importance of nutrition in reproductive success and recruitment is well documented. However, in the study by Robinette et al. (1973) fawn weights did not vary with nutrition level of does. The fawn weights in our study were comparable to those of other studies (Robinette et al. 1973, Stieigers and Flinders 1980, Trainer et al. 1981, and others). Apparently, fawn weights do not provide a useful index of doe nutritional status. Although fawns are born at relatively uniform weights the nutritional status of the doe can affect fawn survival through indirect effects such as susceptibility to predation and disease. The dam can be directly affected by failure to conceive, resorption of fetuses, and inability to nourish offspring (Dietz and Nagy 1976).

What appears to be excessive fetal and neonate mortality from early pregnancy to a few days post-parturition and discovery of 9 under-sized ($X = 1.67$ kg, $n \equiv 7$) stillborn fawns may be indicative of an under nourished adult population. Increased loss to sickness and starvation during 1999 when June precipitation was higher that the other 2 years may also indicate that neonates are in a compromised condition and not robust to stresses.

Hemorrhagic diseases (HD), bluetongue (BT) and epizootic hemorrhagic disease (EHD), of the genus *Orbivirus* are present in the Uncompaghre Plateau mule deer herd (Myers 2001). These diseases are capable of causing significant mortality and Howerth et al. (2001) cite literature documenting many outbreaks in Western North America dating back to 1886. In temperate regions, mortalities from hemorrhagic disease usually occur in late summer, before first frost, and epidemics can develop when conditions are favorable to the vector, *Culicoides* spp. These outbreaks are usually sporadic (Howerth et al. 2001) and localized with total mortality estimated at < 1% for mule deer (Thorne et al. 1988). Infection with BT or EHD in mule deer may be asymptomatic, result in chronic disease, nonfatal infections, or sudden death (Howerth et al. 2001). Fever, internal bleeding, and shock resulting in death characterize hemorrhagic diseases (Shope 1967). Death may happen so suddenly that some animals may die "…while walking or running" while others struggle in lateral recumbency position (Thorne et al. 1988:115). Because this disease strikes quickly, animals in good physical condition may be found dead from HD (Chalmers et al. 1964).

Only 1 positive result based polymerase chain reaction (PCR) test was obtained for HD during our 3-year study. The low detection rate may be because these are RNA viruses and are very unstable in an open environment (Myers 2001). There may have been other deaths from HD based on the time of year, hemorrhagic condition, and the relatively good condition of the fawn at death indicating a sudden death. Five fawns that died between 18 August and 4 October satisfy the above criteria. An adult female found near (100 m) one of the fawns tested positive by PCR for EHD.

Hemorrhagic disease is present on the Uncompahgre Plateau but it is hard to assess the impact on the mule deer population. It is unlikely that an epidemic of HD occurred during this 3-year study. There were no reports of numerous dead deer as was the case in other epidemics (Chalmers et al. 1964, Thorne et al. 1988) and field personnel did not observe any abnormal concentrations of mortalities of either radioed fawns or unmarked deer during late summer.

Diseases that affect the reproductive capacity of a host population are most liable to have a noticeable impact on that population (Anderson and May 1979). Bovine viral diarrhea virus (BVDV) infections produce abortions, fetal malformations, stillbirths, weakened neonates, and immunosuppression in domestic livestock (Baker 1995, Van Campen et al. 2001*a*). There is a > 60% prevalence of BVDV titers in the adult population of deer on the Uncompahgre Plateau (Myers 2001). A mule deer population from northwestern Wyoming, USA, also had a 60% prevalence of BVDV titers (Van Campen et al 2001*a*), and a serological survey of 4 western national parks resulted in 59% prevalence in mule deer (Aguirre et al. 1995). Viral isolation (VI) is the most reliable method to determine exposure to BVDV and isolations from wild ruminants are rare (Van Campen et al. 2001a, Van Campen et al. 2001*b*). Isolates were obtained from 2 fawns in our study. These fawns died in the same general area (< 500 m apart) and within 2 days of each other, 17 and 19 July.

Diseases that have low mortality and produce immunity with exposure are self-limiting (Myers 2001). In closed herds with no previous exposure, introduction of BVDV can result in the loss of 75% of the first neonate cohort after exposure through abortions, stillbirths, and compromised immune response (Hana Van Campen, personal communication). With a high proportion of the Uncompahgre Plateau deer herd having titers, and presumed immunity to BVDV, this disease should not have a significant impact on the overall herd performance. However, its presence is certainly a depressant to some unknown degree. Other than the 2 fawns that provided VI of BVDV, there were 2 other fawns with symptoms of being exposed to BVDV in utero. One was hydrocephalic (1.90 kg) and the other had skeletal deformities (2.09 kg) both characteristic of BVDV exposure. BVDV was isolated from a stillborn fawn from northern New Mexico that had an atrophied thymus and weighed 2.3 kg (Hibler 1981).

The high prevalence of BVDV in the 2 above mentioned mule deer populations suggests that this virus circulates in these populations (Van Campen et al. 2001*b*) without exposure to outside sources such as cattle herds. High prevalence of titers to BVDV does not necessarily mean a population suffers significant consequences. In immunocompetent cattle the majority of infections (70-90%) are subclinical (Baker 1995). So unless the immune response of mule deer is compromised from some other cause, the impact of BVDV may not produce significant or detectable manifestations in population performance.

Ingestion of poisonous plants can impair reproductive functions of domestic livestock (Panter et al. 2002). Some of the plants poisonous to livestock are found on the Uncompahgre Plateau and could conceivably also affect the wild ruminants of the plateau. Lupines (*Lupinus* spp.) can cause skeletal defects through the effects of alkaloids that are toxic to fetuses (Panter et al. 2002). We found a stillborn fawn (2.09 kg) with "Multiple congenital skeletal defects, including flexion contraction, limbs, neck, and thoracic spine" (from lab report) with minimally deformed joints and normal limb bones; all of these symptoms fit lupine poisoning as described by (Panter et al. 2002). In the year following our study, another stillborn fawn with severe skeletal deformities was found (Chad Bishop, Colorado Division of Wildlife, Montrose, personal communication). Both of these fawns came from the same general area of the plateau where lupine is common. Livestock loses to poisonous plants is associated with range in poor condition (Ralphs 2002) and this area is heavily grazed. We have observed some possible pre-natal mortality from poisonous plants; it could be one of many mortality sources but it is unlikely this is a major factor in herd recruitment.

MANAGEMENT IMPLICATIONS

Conditions of Western ranges have changed dramatically from pristine times (Vale 1975) through an era of extensive overgrazing to the current level of management. The era of unsustainable livestock grazing promoted shrub and forb growth to the benefit of deer (Clements and Young 1997) and led to the eruption of mule deer populations (Gruell 1986). Subsequent management and wild fire control has resulted in over-mature shrubs and invasion of woody species into shrub communities reducing carrying capacity for deer (Gruell 1986). This trend continues. Nutrition is key to recruitment. It is a very common conclusion that although predators can cause a short-term effect on a deer population, alternate prey species abundance dictates the density of coyotes (Hamlin et al. 1984). Increases in vegetation production has a positive effect on abundance of alternate prey species (Hamlin et al. 1984) and may explain why Salwasser (1979) observed that coyote densities and fawn survival trend in unison. Most current land use patterns in the West are detrimental to deer and rather than control of hunting pressure or predators "...deer numbers are ultimately governed by quality and quantity of habitat" (Connolly 1981:238). Peek et al. (2002) and Salwasser et al. (1978) suggest that long-term decline of deer populations is not the result of predation but the result of deteriorating forage conditions. Given the high reproductive potential of mule deer, it seem reasonable that improving range conditions on the Uncompahgre Plateau and other mule deer ranges of the West would be the most fruitful for increased and long-lasting improved recruitment.

Ballard et al. (2001:112) state that "The relationship between predators and their prey is a very complex issue". They list numerous possible causes for deer declines including habitat loss (i.e. food and cover), disease, predation, competition, and others. The results of the Uncompahgre Plateau study do not provide evidence to suggest that predators are the cause of low recruitment in this particular herd. Coyote predation accounted for 0.126 of the neonatal mortality with bear and feline predation accounting for 0.040 and 0.032, respectively. Whether or not this degree of predation would warrant a control program would be a societal value judgment based on both the cost and the ethics of killing one species to favor another. Although there have been no studies that demonstrate predator reduction resulted in more mule deer in the possession of hunters (Ballard et al. 2001), that is obviously the ultimate objective of predator control. Predator control is a value judgment and has segments of the public sharply divided on the need or desirability for such a program. This study has provided information for a particular study area on the extent of fawn mortality from various causes that should be of assistance to the entities that make management decisions.

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LITERATURE CITED

Acorn, R. C., and M. J. Dorrance. 1990. Methods of investigating predation of livestock. Alberta Agriculture Protection Branch. Edmonton. Canada.

Aguirre, A. A., D. E. Hansen, E. E. Starkey, R. G. McLean. 1995. Serologic survey of wild cervids for potential disease agents in selected national parks in the United States. Preventive Veterinary Medicine 21:313-322.

Andelt, W. F., M. Bruscino, and C. Niemeyer. 1998. Interpreting the physical evidence of predation on big game animals and domestic livestock. Unpublished.

Anderson, A. E., D. C. Bowden, and D. M. Kattner. 1992. The puma on Uncompahgre Plateau, Colorado. Colorado Division of Wildlife Technical Publication No. 40. Fort Collins, Colorado, USA.

_____, D. E. Medin, and D. C. Bowden. 1974. Growth and morphometry of the carcass, selected bones, organs, and glands of mule deer. Wildlife Monographs Number 39.

_____, and O. C. Wallmo. 1984. Odocoileus hemionus. Mammalian Species No. 219. American Society of Mammalogists.

Anderson, R. M. and R. M. May. 1979. Population biology of infectious diseases: Part I. Nature 280:361-367.

Anonymous, c.a. 1944. Range management plan Escalante Unit, Ouray District, Colorado. Bureau of Land Management files, Delta, Colorado, USA.

Baker, J. C. 1995. The clinical manifestations of bovine viral diarrhea infection. Veterinary clinics of North America: Food animal practice 11:425-445.

Ballard, W. B., D. Lutz, T. W. Keegan, L. H. Carpenter, and J. C. deVos, Jr. 2001. Deer-predator relationships: a review of recent North American studies with emphasis on mule and black-tailed deer. Wildlife Society Bulletin 29:99-115.

_____, H. A. Whitlaw, S. J. Young, R. A. Jenkins, and G. J. Forbes. 1999. Predation and survival of white-tailed deer fawns in northcentral New Brunswick. Journal of Wildlife Management 63:574-479.

Bartmann, R. M. 1998. A prospectus on mule deer in Colorado. Colorado Division of Wildlife, Fort Collins, Colorado, Unpublished report.

Bertram, M. R. and M. T. Vivion. 2002. Moose mortality in eastern interior Alaska. Journal of Wildlife Management. 66:747-756.

Browman, L. G. and H. S. Sears. 1956. Cyclic variation in the mule deer thymus. Proceeding of the Society of Experimental Biological Medicine 93:161-162.

Brown, C. G. 1992. Movement and migration patterns of mule deer in southeastern Idaho. Journal of Wildlife Management 56:246-253.

Cantor, A. B. 1997. Extending SAS survival analysis techniques for medical research. SAS Institute, Cary, North Carolina, USA.

Chalmers, G. A., H. N. Vance, and G. J. Mitchell. 1964. An outbreak of epizootic hemorrhagic disease in wild ungulates in Alberta. Wildlife Diseases 42:1-6.

Chapman, N. and G. I. Twigg. 1990. Studies on the thymus gland of British cervidae, particularly muntjac, *Munticus reevesi*, and fallow, *Dama dama*, deer. Journal of the Zoological Society of London 222:653-675.

Clements, C. D. and J. A. Young. 1997. A viewpoint: Rangeland health and mule deer habitat. Journal of Range Management 50:129-138.

Connolly, G. E. 1981. Trends in populations and harvest. Pages 225-243 *in* O. C. Wallmo, editor. Mule and black-tailed deer of North America. University of Nebraska Press, Lincoln, Nebraska, USA.

Dietz, D. R. and J. G. Nagy. 1976. Mule deer nutrition and plant utilization. Pages 71-78 *in* G. W. Workman and J. B. Low, editors. Mule deer decline in the West a symposium. Utah State University, Logan.

Eberhardt, L. L. 1977. "Optimal" management policies for marine mammals. Wildlife Society Bulletin. 5:162-169.

Gaillard, J. M., M. Festa-Bianchet, and N. G. Yoccoz. 1998. Population dynamics of large herbivores: variable recruitment with constant adult survival. Trends in Ecology and Evolution 13:58-63.

Garrott, R. A., G. C. White, R. M. Bartmann, L. H. Carpenter, and A. W. Alldredge. 1987. Movements of female mule deer in northwest Colorado. Journal of Wildlife Management 51:634-643.

Gill, R. B., T. D. I. Beck, C. J. Bishop, D. J. Freddy, N. T. Hobbs, R. H. Kahn, M. W. Miller, T. M. Pojar, and G. C. White. 2001. Declining mule deer populations in Colorado: Reasons and responses. Colorado Division of Wildlife Special Report Number 77.

_____. 1971. Middle Park deer study - productivity and mortality. Colorado Division of Wildlife, Federal Aid in Wildlife Restoration Job Progress Report, Project W-38-R-25. July:189-207.

Ginnett, T. F. and E. L. Butch Young. 2000. Stochastic recruitment in white-tailed deer along an environmental gradient. Journal of Wildlife Management 64:713-720.

Gruell, G. E. 1986. Post-1900 mule deer irruptions in the Intermountain West: Principle cause and influences. General Technical Report INT-206. Ogden, Utah, U. S. Department of Agriculture, Forest Service, Intermountain Research Station.

Huegel, C. N., R. B. Dahlgren, and H. L. Gladfelter. 1985. Use of doe behavior to capture white-tailed deer fawns. Wildlife Society Bulletin 13:287-289.

Hamlin, K. L. and R. J. Mackie. 1989. Mule deer in the Missouri River breaks, Montana. Federal Aid Final Report, Project Number W-120-R-7-18. Montana Department of Fish, Wildlife and Parks.

_____, S. J. Riley, D. Pyrah, A. R. Dood, and R. J. Mackie. 1984. Relationships among mule deer fawn mortality, coyotes and alternate prey species during summer. Journal of Wildlife Management 48:489-499.

Hibler, C. P. 1981. Diseases. Pages 129-155 *in* O. C. Wallmo, editor. Mule and black-tailed deer of North America. University of Nebraska Press, Lincoln, Nebraska, USA.

Howerth, E. W., D. E. Stallknecht, and P. D. Kirkland. 2001. Bluetongue, epizootic hemorrhagic disease, and other orbivirus-related diseases. Pages 77-97, *in* E. S. Williams and I. K. Barker, editors. Infectious diseases of wild mammals. Iowa State University Press, Ames, Iowa, USA.

Jensen, W. and W. L. Robinette. 1955. A high reproductive rate for Rocky Mountain mule deer. Journal of Wildlife Management 19:503.

Kaplan, E. L. and P. Meier. 1958. Nonparametric estimation from incomplete observations. American Statistical Association Journal 53:457-481.

Kie, J. G. and B. Czech. 2000. Mule and black-tailed deer. Pages 629-657 *in* S. Demarais and P. R. Krausman, editors. Ecology and management of large mammals in North America. Prentice Hall, Upper Saddle River, New Jersey, USA.

Kufeld, R. C., D. C. Bowden, and D. L. Schrupp. 1989. Distribution and movements of female mule deer in the Rocky Mountain foothills. Journal of Wildlife Management 53:871-877.

_____. 1979. History and current status of the mule deer population on the east side of the Uncompahgre Plateau. Division Report No. 11. Colorado Division of Wildlife.

Lawrence, R. K., S. Demarias, R. D. Brown, M. Abbott. 1986. Nutritional effects on thyroids, ovaries, and thymuses in white-tailed deer. Proceedings of the Annual Conference of Southeast Association of Fish and Wildlife Agencies 40:416-423.

Laycock, W. A. 1991. Stable states and thresholds of range condition on North American rangelands: A viewpoint. Journal of Range Management 44:427-433.

Marshall, M. 1998. Uncompahgre. Western Reflections, Ouray, Colorado.

Medin, D. E., and A. E. Anderson. 1979. Modeling the dynamics of a Colorado mule deer population. Wildlife Monographs 68:1-77.

Myers, E. P. 2001. Assessing the role of selected infectious disease agents in neonatal mule deer fawn mortality on the Uncompahgre Plateau of Western Colorado. M. S. Thesis, Colorado State University, Fort Collins, Colorado, USA.

Noyes, J. H., B. K. Johnson, L. D. Bryant, S. L. Findholt, J. W. Thomas. 1996. Effects of bull age on conception dates and pregnancy rates of cow elk. Journal of Wildlife Management 60:508-517.

Ozoga, J. J. and L. J. Verme. 1978. The thymus gland as a nutritional status indicator in deer. Journal of Wildlife Management 42:791-798.

Panter, K. E., L. F. James, D. R. Gardner, M. H. Ralphs, J. A. Pfister, B. L. Stegelmeier, and S. T. Lee. 2002. Reproductive losses to poisonous plants: Influence of management strategies. Journal of Range Management 55:301-308.

Peek, J. M., B. Dennis, and T. Hershey. 2002. Predicting population trends of mule deer. Journal of Wildlife Management 66:729-736.

Picton, H. D. 1979. A climate index and mule deer fawn survival in Montana. International Journal of Biometerorology 23(2):115-122.

Pollock, K. H., S. R. Winterstein, C. M. Bunck, and P. D. Curtis. 1989. Survival analysis in telemetry studies: the staggered entry design. Journal of Wildlife Management 53:7-15.

Ralphs, M. H. 2002. Ecological relationships between poisonous plants and rangeland condition: A review. Journal of Range Management 55:285-290.

Riley, S. J. and A. R. Dood. 1984. Summer movements, home range, habitat use, and behavior of mule deer fawns. Journal of Wildlife Management 48:1302-1310.

Robinette, W. L., C. H. Baer, R. E. Pillmore, and C. E. Knittle. 1973. Effects of nutritional change on captive mule deer. Journal of Wildlife Management 37:312-326.

Salwasser, H. J. 1979. Ecology and management of the Devil's Garden Interstate deer herd and range. Dissertation, University of California, Berkeley, USA.

_____, S. A. Holl, and G. A. Ashcraft. 1978. Fawn production and survival in the North Kings River deer herd. California Fish and Game 64:38-52.

Schlegel, M. 1976. Factors affecting calf elk survival in north central Idaho: A progress report. Western Association of State Game and Fish Commissioners 56:342-355.

Squibb, R. C. 1985. Mating success of yearling and older bull elk. Journal of Wildlife Management. 49:744-750.

Thorne, E. T., E. S. Williams, T. R. Spraker, W. Helms, and T. Segerstrom. 1988. Bluetongue in free-ranging pronghorn antelope (*Antilocapra americana*) in Wyoming: 1976 and 1984. Journal of Wildlife Diseases 24:113-119.

Trainer, C. 1975. Direct causes of mortality in mule deer fawns during summer and winter periods on Steens Mountain, Oregon – a progress report. Western Association of State Game and Fish Commissioners 55:163-170.

Tsai, K., K. H. Pollock, and C. Brownie. 1999. Effects of violation of assumptions for survival analysis methods in radiotelemetry studies. Journal of Wildlife Management 63:1369-1375.

Uncompahgre Plateau Partners (BLM, CDOW, Public Lands Partnership, USFS). 2002. Uncompahge Plateau Project (UP) Plan: A collaborative approach to restore and maintain the ecosystem heath of the Uncompahgre Plateau in western Colorado. Available at the Colorado Division of Wildlife Service Center, Montrose, Colorado, USA.

Unsworth, J. W., D. F. Pac, G. C. White, and R. M. Bartmann. 1999. Mule deer survival in Colorado, Idaho, and Montana. Journal of Wildlife Management 63:315-326.

Vale, T. R. 1975. Presettlement vegetation in the sagebrush-grass area of the Intermountain West. Journal of Range Management 28:32-36.

Van Campen, H., K. Frolich, and M. Hofmann. 2001a. Pestivirus infections. Pages 232-244 *in* E. S. Williams and I. K. Barker, editors. Infectious diseases of wild mammals. Iowa State University Press, Ames, Iowa, USA.

_____, J. Ridpath, E. Williams, J. Cavender, J. Edwards, S. Smith, and H. Sawer. 2001b. Isolation of bovine viral diarrhea virus from a free-ranging mule deer in Wyoming. Journal of Wildlife Diseases 37:306-311.

Verme, L. J. 1969. Reproductive patterns of white-tailed deer related to nutritional planes. Journal of Wildlife Management 33:881-887.

Wade, D. A., and J. E. Bowns. 1984. Procedures for evaluating predation on livestock and wildlife. Texas Agricultural Experiment Station Bulletin B-1429, College Station.

White, G. C. and R. M. Bartmann. 1998. Mule deer management – What should be monitored? Pages 102-116 *in* J. C. De Vos, Jr., editor. Proceedings of the 1997 deer-elk workshop, Rio Rico, Arizona. Arizona Game and fish Department, phoenix, Arizona, USA.

_____, D. F. Freddy, R. B. Gill, and J. H. Ellenberger. 2001. Effect of adult sex ratio on mule deer and elk productivity in Colorado. Journal of Wildlife Management 65:543-551.

White, M. 1973. Description of remains of deer fawns killed by coyotes. Journal of Mammalogy 54:291-293.

Young, R. G. and J. W. Young. 1984. Colorado West land of geology and wildflowers. Artistic Printing, Salt Lake City, Utah, USA.

Table 1. Fate of neonatal mule deer fawns from capture (mean 3 days old) to 14 December, Uncompahgre Plateau, west central Colorado, USA, 1999-2001.

	1999	2000	2001	Total
Mortality Causes				
Sick/Starve	15	10	13	38
Coyote	6	11	11	28
Bear	3	3	3	9
Feline	4	2	1	7
Trauma	1	4	4	9
Unknown	2	5	3	10
Total mortality	31	35	35	101
Surviving	19	53	57	129
Total sample	50	88	92	230
Censored	12	11	20	43

Table 2. Chi-square comparison of mortality source proportion by year for mule deer neonates from capture (mean 3 days old) to 14 December on the Uncompahgre Plateau, west central Colorado, USA. Kaplan-Meier staggered exits to account for censored subjects were used.

Mortality Causes	1999	2000	2001	X^2	P
Sick/starve	0.318	0.115	0.148	5.330	0.070
Coyote	0.126	0.129	0.121	0.023	0.989
Bear	0.060	0.034	0.033	0.416	0.812
Feline	0.083	0.023	0.012	2.330	0.312
Trauma	0.025	0.048	0.047	0.568	0.753
Unknown	0.042	0.058	0.037	0.388	0.824

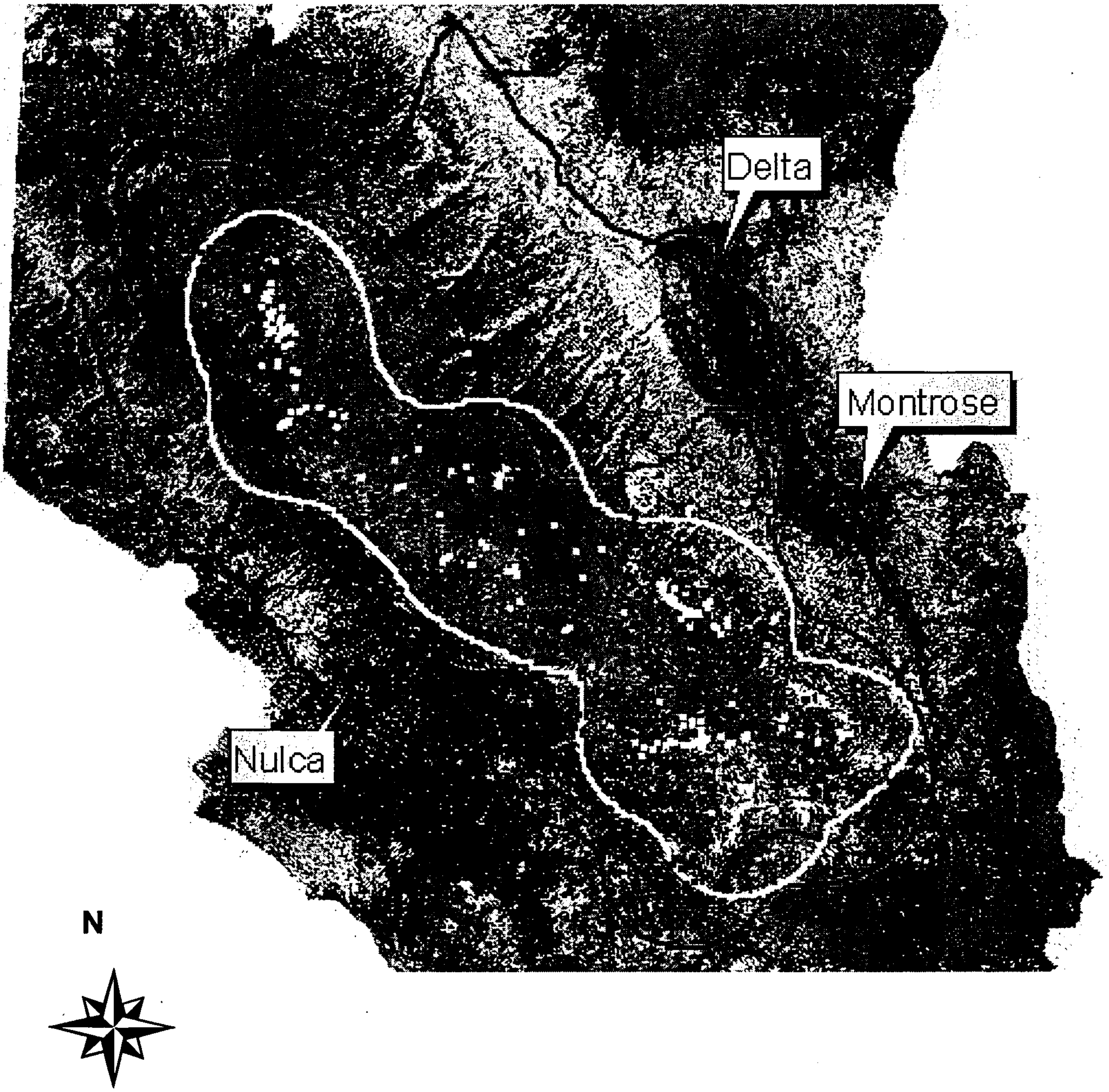

Figure 1. Uncompahgre Plateau mule deer Data Analysis Unit, D-19, is shown outlined in red. The 95% kernel home range for radioed does aerial located on May 18 and May 31 is outlined in black with black dots representing individual locations. Fawn capture locations are seen as white dots and the 95% kernel home range outlined in white. Blue shading shows pinyon-juniper type and higher elevation vegetative types (summer range) are shown in green, yellow, and brown. Agricultural land is in pink. See text for type descriptions.

Colorado Division of Wildlife
Wildlife Research Report
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JOB PROGRESS REPORT

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Work Package No. 3001 : Deer Conservation

Task No. 4 : Effect of Nutrition and Habitat Enhancements on Mule Deer Recruitment and Survival Rates

Project No. W-153-R : Research and Development

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ABSTRACT

To further understand the factors that caused deer numbers to decline in western Colorado during the 1990s, we designed and initiated a field experiment to measure deer population parameters in response to nutrition and habitat enhancement treatments. During November 2000 – March 2002, we captured and radio-collared 112 mule deer in a treatment unit and 109 mule deer in a paired control unit during winter on the Uncompahgre Plateau in southwest Colorado. We enhanced the nutrition of deer in the treatment unit by providing a safe, pelleted supplemental feed on a daily basis from December through April each winter. Early winter fawn:doe ratios were measured using helicopter and ground classification surveys the year following treatment delivery to determine whether fawn production and survival increased as a result of enhanced nutrition of adult females. Based on multiple age classification surveys, we concluded that the winter nutrition enhancement treatment did not cause an increase in neonatal production and survival during 2001. However, fawn production and summer-fall survival were atypically good during 2001, and not representative of most years during the past decade when the population declined. We also measured overwinter fawn survival rates in response to the treatment. The simplest model which effectively explained survival ($\chi^2_{51} = 51.87$, $P = 0.440$) included treatment ($\chi^2_1 = 9.95$, $P = 0.002$) and early winter fawn mass ($\chi^2_1 = 8.33$, $P = 0.004$). From December 1, 2001, through May 31, 2002, the survival rate of fawns was significantly greater ($\chi^2_1 = 13.216$, $P < 0.001$) in the treatment unit (0.865, SE = 0.056) than in the control unit (0.510, SE = 0.080); and fawns that survived the winter averaged 2.9 kg heavier than fawns that died ($F_1 = 6.11$, $P = 0.016$). Early winter fawn mass was not different among treatment and control fawns ($F_1 = 0.36$, $P = 0.550$), thus the effect of the treatment was not confounded with fawn mass. Simply, heavier fawns in both experimental units had higher survival probabilities. During winter 2001-02, which was a mild to average winter, the nutrition enhancement treatment clearly improved overwinter fawn survival, and thus yearling recruitment. We will continue this portion of the research for 2 more years. The results reported here are preliminary and should be treated as such.

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

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P. N. OBJECTIVES

1. To determine experimentally whether enhancing mule deer nutrition during winter and early spring by supplemental feeding increases December fawn:doe ratios and overwinter fawn survival.

2. To determine experimentally to what extent habitat treatments replicate the effect of enhanced nutrition from supplemental feeding.

SEGMENT OBJECTIVES

1. Capture and radio-collar target sample of adult female mule deer and 6-month-old fawns.

2. Deliver nutrition enhancement treatment to all deer occupying the treatment area.

3. Measure overwinter adult female and fawn survival rates and early winter fawn:doe ratios in the treatment and control areas.

INTRODUCTION

Mule deer numbers apparently declined during the 1990's throughout much of the West, and have clearly decreased since the peak population levels documented in the 1940's-60's (Gill et al. 1999, Unsworth et al. 1999). Biologists and sportsmen alike have concerns as to what factors may be responsible for declining population trends. Although previous and current research indicates that multiple interacting factors are responsible, habitat and predation have received the focus of attention. A number of studies have evaluated whether predator control increases deer survival, yet results are highly variable (Connolly 1981, Ballard et al. 2001). Together, predator control studies with adequate rigor indicate that predation effects on mule deer are variable as a result of time-specific and site-specific factors. Studies which have demonstrated deer population responses to predator control treatments have failed to determine whether predation is ultimately more limiting than habitat. Numerous research studies have evaluated mule deer habitat quality, but virtually no studies have documented population responses to habitat improvements. In many areas where declining deer numbers are of concern, predation is common yet habitat quality appears to have declined. The question remains as to whether predation, habitat, or some other factor is more limiting to mule deer in these situations, and whether habitat quality can be improved for the benefit of deer. It may also be that no single factor is any more or less important than another, and that a more comprehensive understanding of multi-factor interactions is paramount.

We designed a field experiment to measure deer population responses to nutrition and habitat enhancement treatments, to further understand the causative factors underlying observed deer population dynamics. We are conducting the study on the Uncompahgre Plateau, where several predator species (i.e. coyotes, mountain lions, and bears) are present in abundant numbers. In addition to predation, myriad diseases in combination proximately affect survival of the Uncompahgre deer population (Pojar 2000, B.E. Watkins, unpublished data). Predator numbers have not and will not be manipulated in any manner during the course of the study. All factors have been left constant with the exception of deer nutrition and habitat. Deer nutrition is being enhanced by providing supplemental feed to deer during the winter. If December fawn:doe ratios and overwinter fawn survival improve as a direct result of the nutrition enhancement treatment, then we can presume that deer nutrition is ultimately more limiting than predation or disease. The second phase of the field experiment will incorporate habitat manipulation treatments, which will consist of prescribed fire or mechanical techniques to set back succession of pinyon-juniper habitat in an effort to improve the vigor and quality of winter habitat for mule deer. Deer population responses will be measured in relation to the habitat manipulations in the same manner as the supplemental feed. Thus, the experiment allows us to determine whether nutritional quality of habitat is ultimately more limiting than other factors in a late-seral pinyon-juniper/sagebrush landscape, and if so, whether habitat can be effectively improved for mule deer. The results will also advance our current understanding of multi-factor interactions, with direct implications for mule deer management.

MATERIALS AND METHODS

Experimental Approach

Experimental Design and Study Area

We non-randomly selected four areas on the Uncompahgre Plateau to create 4 experimental units (A-D) (Fig. 1). Treatments were randomly assigned to the experimental units. The following criteria were used to select experimental units:

1.) Deer densities (~50-80 deer/mi^2): areas were selected where deer densities were sufficient to meet sample size requirements within the experimental unit, while simultaneously selecting areas that would require feeding less than ~500 animals during a normal winter
2.) Buffer zones: areas were selected such that experimental units would be separated by several miles of non-treatment area (buffers) to prevent deer from occupying more than one experimental unit
3.) Similarity: areas were selected that comprise relatively similar habitat complexes and deer densities that are representative of the overall area
4.) Elk populations: areas were selected to minimize the number of elk present during normal winters

Units A and B are receiving the nutrition enhancement treatment in a cross-over experimental design, and are being used to address P.N. Objective 1. Unit A served as the treatment unit, while Unit B served as the control, for the first 2 years of research (2000 – 2002). Beginning November 2002, Unit B will receive the treatment while Unit A will serve as the control. Upon completion of P.N. Objective 1, Units C and D will be used to conduct phase 2 of the research, or P.N. Objective 2. Habitat in one unit will be manipulated to set back plant succession (treatment), while habitat in the other unit will remain unchanged (control) throughout the experiment.

Year	Unit A	Unit B	Unit C	Unit D
2000-01	**Treatment**	Control		
2001-02	**Treatment**	Control		
2002-03	Control	**Treatment**		
2003-04	Control	**Treatment**		
2004-05			Control	Control
2005-06			Control	**Fire/Mechanical Treat.**
2006-07			Control	**Veg Response Yr 1**
2007-08			Control	**Veg Response Yr 2**
2008-09			Control	**Veg Response Yr 3**
2009-10			Control	**Veg Response Yr 4**

Figure 1. Schematic representation of experimental units and associated treatments. The nutrition enhancement cross-over design will encompass 4 years; monitoring in the habitat manipulation experimental unit and paired control area will encompass approximately 6 years.

The 2 experimental units (A and B) receiving the nutrition enhancement treatment are (Figs. 2 and 3):

(1) The Colona Tract of the Billy Creek State Wildlife Area

(2) Bureau of Land Management lands adjacent to Shavano Valley as defined by the following: Within Dry Creek Basin Quadrangle (USGS 7.5 Minute), includes Sections 6 and 7 in T. 48 N.-R. 10 W. and Sections 1, 2, 10, 11, 12, 13, 14, 15 in T. 48 N.-R. 11 W. This area roughly includes 38°25'00" – 38°27'30" Latitude and 108°00'00" – 108°04'30" Longitude.

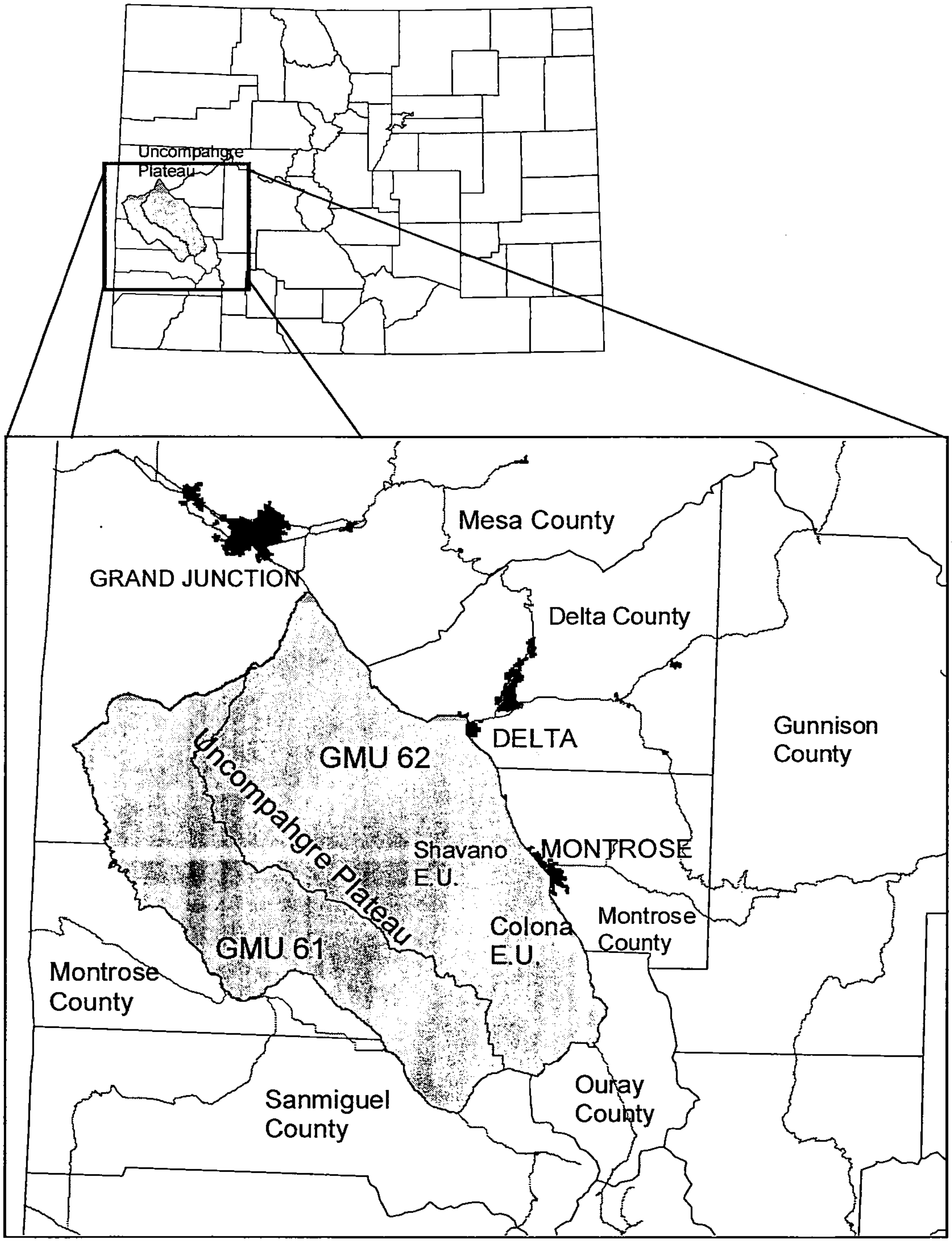

Figure 2. Location of Colona and Shavano (Units A and B) experimental units in Game Management Unit 62 on the Uncompahgre Plateau, southwest Colorado.

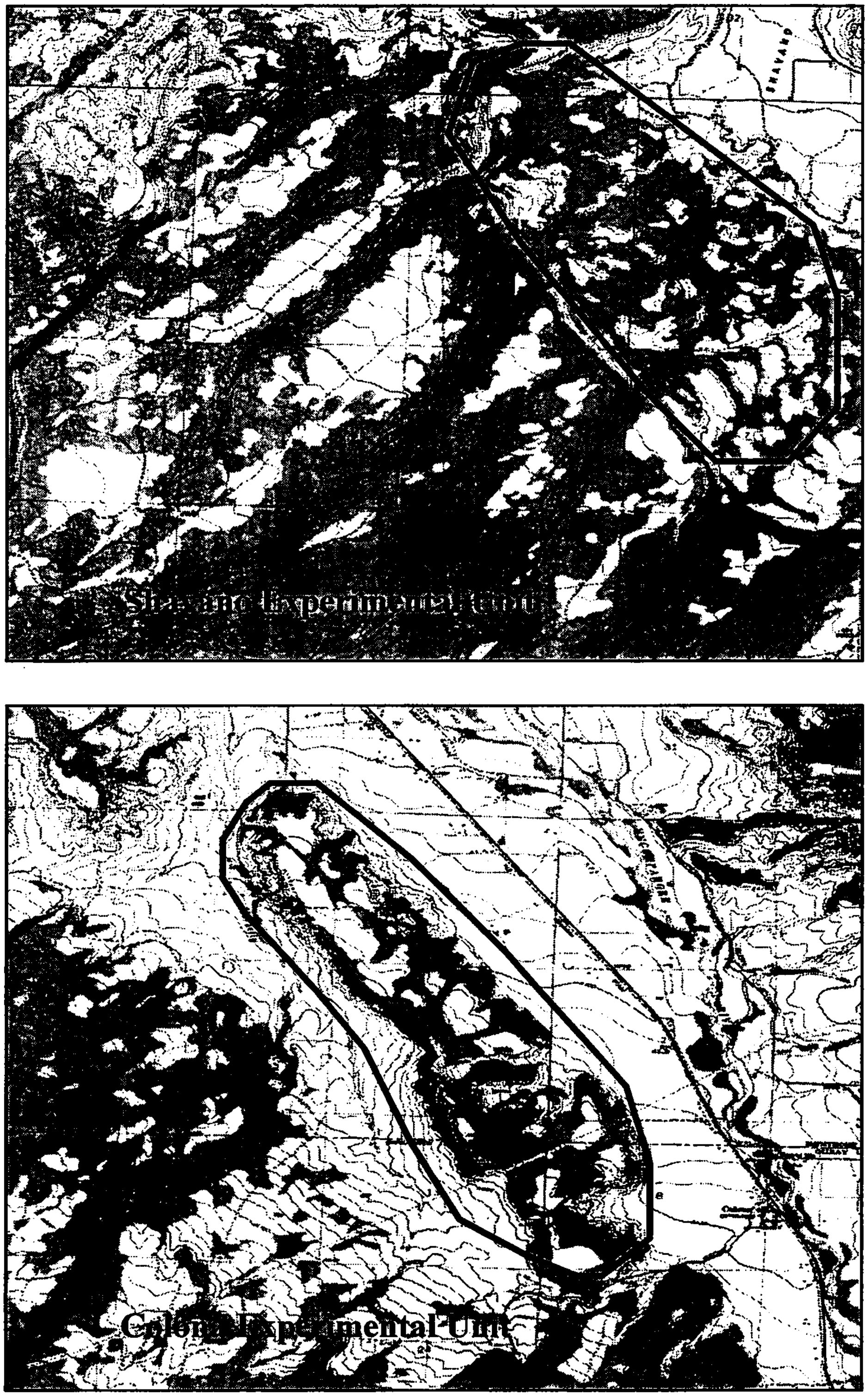

Figure 3. Colona and Shavano experimental units (Units A and B), located in Game Management Unit 62 on the Uncompahgre Plateau, southwest Colorado. Polygons represent the nucleus of each experimental unit, which is where animals have been collared and the nutrition enhancement treatment delivered.

Response Variables

The primary response variable is fawn:doe ratios measured during December and January following the previous winter's treatments. The fawns counted during early winter age classification were born the summer following the winter treatments, and classified when they were 6 months of age. Thus, we are measuring the effect of enhanced adult doe nutrition during winter on subsequent fawn production and survival. Fawn:doe ratios are currently being measured in Units A and B corresponding to P.N. Objective 1. The second response variable is overwinter fawn survival, measured from radio-collared fawns during the winter in direct response to the enhanced winter nutrition treatment. We are also measuring overwinter and annual survival of adult does as a function of enhanced winter nutrition.

Sample Size

The primary response variable is the mean fawn:doe ratios of the radio-collared does wintering on the experimental unit of interest. We desired to detect an effect size, i.e., an increase in fawn:doe ratios in response to the treatments, in the range of 15 to 20 fawns per 100 does. These values were based on simple population models with overwinter fawn survival of 0.444, adult female survival of 0.853, and December fawn:doe ratios of 66 fawns per 100 does to obtain a stationary population (Unsworth et al. 1999). Based on surveys of DAU D-19 from 1992-96, the standard deviation of the fawn:doe ratio for groups with at least one adult female was 57, with a mean of 41. Using an expected standard deviation of 57, the standard error of the mean fawn:doe ratio for 40 radio-collared does is $57/(40^{1/2}) = 9.0$, which is the expected standard deviation of measured fawn:doe ratios on each of the experimental units. We assessed power of the proposed experiment using SAS Analyst®. We used a two-sample *t*-test with a sample size of 4, representing the years of the study where treatment effects will be measured. The power of the design to detect an increase of 20 fawns per 100 does is about 0.87.

A sample size of 40 fawns per experimental unit per year provides a power of 0.81 to detect a difference of 0.15 in survival between 2 experimental units if survival on the control unit is 0.40. We expected to see an increase in fawn survival (effect size) of approximately 0.15, because this was the difference measured in the density reduction experiment conducted by White and Bartmann (1998).

Capture Methods

Deer were captured using baited drop nets (Ramsey 1968, Schmidt et al. 1978) and helicopter net guns (Barrett et al. 1982, van Reenen 1982). Drop nets were baited with certified weed-free alfalfa hay and apple pulp. Drop nets were used as the principal capture technique during a 3-week capture period; helicopter net-gunning was used at the end of the capture period to secure the remainder of deer needed to meet our target sample sizes. All deer were hobbled and blind-folded after being captured. All deer captured via drop nets were carried away from the net to an adjacent handling site using stretchers. Deer were fitted with leather radio collars equipped with mortality sensors, which cause an increase in pulse rate after remaining motionless for 4 hours. Permanent collars were placed on adult females, while temporary collars were placed on fawns. To make collars temporary, one end of the collar was cut in half and reattached using rubber surgical tubing; fawns shed the collars ≥6 months post-capture. A rectangular piece of flexible plastic (Ritchey® neck band material) engraved with a unique identifier was stitched to the side of each collar. The unique identifier consisted of 2 symbols for adult females, and only 1 symbol on 2 different colors of plastic for fawns. The identifiers were necessary to visually identify deer from the ground. This has allowed us to effectively document use of the treatment, measure fawn:doe ratios from the ground, and assess experimental unit population size via mark-resight estimators. We recorded the weight, hind foot length and chest girth of each deer, and collected blood samples from most does and fawns to evaluate disease prevalence.

Measurement of Fawn:Doe Ratios and Overwinter Survival

Each winter we used the radio-collared does to measure fawn:doe ratios in each experimental unit. The resulting fawn:doe ratio is a measurement of the previous year's treatment effect. We measured fawn:doe ratios using 2 techniques: (1) We located the sample of radio-collared does in each experimental unit from a fixed-wing airplane, and used the set of locations to define boundaries for the experimental unit. Shortly after (i.e. 1-2 days), we used a helicopter to systematically fly the defined unit and classify all deer groups encountered. For each group, we documented whether a radio-collared doe was present. (2) We located each radio-collared doe by radio telemetry from the ground. The group of deer with the collared doe was counted and classified by age and sex. Both methods have been employed to gather as much information as possible to determine whether there was a treatment effect. The "true" value cannot be measured perfectly because of the inherent biases and potential sources of error associated with each technique. Thus, by employing both techniques, we have a greater chance of fully understanding whether the treatment caused an effect.

We measured survival by radio-monitoring collared deer to determine fate (live/mortality). We also attempted to determine the cause of each mortality, with a primary goal of distinguishing between predation and non-predation mortality causes. Deer were radio-monitored on a daily basis during the winter, which typically allowed us to arrive at mortality sites within 24 hours.

Treatment Delivery

Deer nutrition was enhanced in the treatment area by providing a safe, pelleted supplemental feed. The supplemental feed was developed through extensive testing with both captive and wild deer (Baker and Hobbs 1985, Baker et al. 1998), and has been safely used in both applied research and management projects. Pellets were distributed daily using 4wd pickup trucks and ATVs on primitive roads throughout the experimental unit to provide a food source for the entire deer population in the treatment unit. Each 50lb. bag of pellets was carried ≤200m from the truck/ATV and distributed by hand in approximately 20-30 small piles of feed in a linear fashion. Numerous bags were distributed in successive order allowing us to create a line of feed that spanned most of the treatment area, which prevented animals from concentrating in any single location. This feeding technique also prevented dominant animals from restricting access to the food supply because of the large area over which pellets were distributed. We attempted to supply pellets ad libitum such that a small residual remained when the next day's ration was provided. Collared deer were closely monitored to ensure that treatment deer remained in the experimental unit and actually consumed the feed, and to make sure that non-treatment deer remained in the control unit, which they did. Treatment deer that did not regularly consume the feed were withdrawn from the sample for purposes of measuring treatment effects.

The pelleted ration was commercially produced in the form of 2×1×0.5-cm wafers (Baker and Hobbs 1985). Feed constituents (i.e. digestibility, protein, gross energy etc.) vastly exceeded those of typical winter range deer diets; exact constituent values are provided by Baker et al. (1998). When provided ad libitum, the feed should have allowed deer to meet or exceed nutritional requirements for growth and maintenance (Ullrey et al. 1967, Verme and Ullrey 1972, Thompson et al. 1973, Smith et al. 1975, Baker et al. 1979, Holter et al. 1979). The basis for feeding such high quality pellets was to ensure that the treatment (enhanced nutrition) was effectively delivered to the deer. Our intent was not to determine the exact level of nutrition necessary to increase fawn recruitment, but rather to determine if nutrition is a limiting factor to recruitment. If nutrition is in fact limiting, we will rely on the habitat manipulation treatment to evaluate what exactly can be done via management to increase fawn survival and recruitment.

Habitat Manipulations

In order to accomplish P.N. Objective 2, habitat will be manipulated in experimental unit D through collaboration with the Uncompahgre Ecosystem Restoration Project (UP), which comprises personnel from the Division of Wildlife, U.S. Forest Service, Bureau of Land Management, Public Lands Partnership, and a variety of other public and private stakeholders. The UP committee is using an experimental landscape approach to manipulate various habitats in a mosaic pattern throughout the Uncompahgre Plateau. We will focus our intensive deer monitoring on one of these habitat manipulations that will be conducted in experimental unit D. This portion of the research has not yet been initiated. A complete description of our planned protocols to accomplish P.N. Objective 2 is provided in the Program Narrative (Bishop and White 2000).

Statistical Methods

Once data collection is completed for the full study, we will test for differences in fawn:doe ratios between experimental units and years using the following statistical model:

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

where y_{ijk} = fawn:doe ratio for the ith deer group in treatment combination jk; $i = 1, 2, \ldots, n_{jk}$ (deer groups); $j = 1, 2, 3, 4$ experimental units (control, supplemental feed, habitat manipulation); $k = 1, 2, 3, 4$ (6) years; $\alpha\beta_{jk}$ = interactions among experimental units and years; and $e_{i(jk)}$ = random error associated with y_{ijk}. A similar model will be used to analyze overwinter fawn survival, but a logit-link function will be used in place of the identity link function in the above general linear model. A similar model will also be used to test for differences in fawn weights, except the response variable will be fawn mass, and sex and fate (i.e. lived or died) will be included in the model as independent variables.

For this progress report, a preliminary fawn:doe ratio analysis was completed using PROC MIXED in SAS (SAS Institute 1997). We used a reduced model with experimental unit as the lone independent variable, and considered experimental unit as a fixed effect and radio-collared does within an experimental unit as random effects. Survival rates were calculated using a Kaplan-Meier survival analysis (Kaplan and Meier 1958, Pollock et al. 1989), and contrasted among experimental units and sexes using a chi-square analysis. We modeled winter fawn survival with a product multinomial model (Grizzle et al. 1969) using PROC CATMOD in SAS (SAS Institute 1989*a*). Survival was modeled as a function of experimental unit, sex, and capture mass. We used a general linear model in PROC GLM in SAS (SAS Institute 1989*b*) to test for differences in fawn mass between experimental units, sexes, and fates (i.e. lived or died). Other results in this report are presented as data summaries incorporating means and standard errors, or in some cases, raw data values. These results are incomplete and preliminary in nature, and should be treated as such.

RESULTS AND DISCUSSION

Deer Capture

During November-December 2000, we captured and radio-collared 73 adult female mule deer: 37 in the treatment unit and 36 in the control unit. Due to budgeting constraints, we were unable to capture and radio-collar fawns. During November-December 2001, we captured and radio-collared an additional 32 adult females to replace mortalities from the previous year and to buffer our sample size, resulting in a total of 45 radio-collared does in each experimental unit. We also captured and radio-collared 80 fawns: 40 in each experimental unit. During February 28 – March 1, 2002, we captured an additional 36 does (18 in each experimental unit) as part of a related research project (Bishop et al. 2002). In total, we radio-monitored 221 mule deer (141 adult does and 80 fawns) during November 2000-June 2002.

Treatment Delivery

2000-01

From December 15, 2000, through April 19, 2001, we distributed 88 tons of the pelleted ration. For most of the winter and spring, on average, we distributed 0.85 tons of feed each day throughout 22 feeding sites across the 2.3 mi^2 treatment unit. Deer were fed ad libitum because there was always residual feed remaining the next day during the feeding routine. Each sack was distributed in approximately 20-30 distinct, small piles, resulting in >1000 small piles of feed throughout the treatment unit. This effort allowed deer to effectively access the feed in small groups, and no aggression was ever observed among deer seeking access to the feed. By distributing the feed in this manner, we were able to avoid the negative aspects associated with large-scale feeding operations. Deer adapted to the pelleted supplement right away and utilized it extensively throughout the winter. We continually monitored deer use of the feed from ground observation points, where we obtained 440 visual observations of radio-collared does consuming the feed. These observations, coupled with daily radio-monitoring and periodic aerial relocations, indicate 32 of the 37 radio-collared treatment does spent the entire winter and spring within the boundaries of the treatment unit and received the supplement on a daily basis.

Mark-resight population estimates from March helicopter (489 deer, SE = 62) and ground (494 deer, SE = 81) surveys, coupled with feed consumption, indicate we fed roughly 450 to 500 deer during most of the winter and spring. Feed consumption declined coincident with spring green-up, although deer continued to use the feed through mid-late April, at which point they began migrating to summer range. We also fed approximately 25 to 30 elk, but the elk did not affect deer access to the feed. Deer in the control experimental unit did not receive feed or any other treatment. Based on helicopter mark-resight surveys, the deer density in the treatment unit in December was 120 deer/mi^2 (SE = 9), but increased shortly after and was 213 deer/mi^2 (SE = 27) in March. Deer densities in the control unit changed little from 83 deer/mi^2 (SE = 12) in December to 101 deer/mi^2 (SE = 14) in March.

2001-02

From December 15, 2001, through April 25, 2002, we distributed 194 tons of the supplement throughout the treatment unit. For most of the winter and spring, we distributed 2.0-2.1 tons of feed each day. The dramatic increase in supplement distribution from the previous year occurred because a large number of elk descended into the Uncompahgre Valley during mid-late fall/early winter. Elk arrived in unusually large numbers throughout much of the valley prior to the onset of treatment delivery. Once feeding was initiated, approximately 300-500 elk adapted to the feed and remained in or around the 2.3 mi^2 treatment unit throughout most of the winter.

Given myriad logistical and budgetary constraints, 2.1 tons was the maximum amount of feed we could routinely deliver on a daily basis. Feed was not delivered ad libitum to all deer and elk in the treatment unit throughout the winter because residual feed was rarely observed during the next day's distribution. However, daily field observations indicate most deer approached ad libitum consumption of the supplement. In contrast to the previous winter, deer were waiting for the daily supplement to arrive each morning. Deer then consumed the supplement immediately after it was distributed. Elk were rarely observed utilizing the feed until late morning or afternoon, and elk continued to forage in fields below the treatment unit, whereas deer did not. We observed numerous radio-collared deer consuming the pelleted supplement each day; not all of these observations were recorded because of time constraints with distributing the feed. Given this time limitation, we still recorded 818 observations of radio-collared deer consuming the supplemental feed (497 collared doe observations and 321 collared fawn observations). Most days, >100 and sometimes 200-300 deer were observed utilizing the pellets during the course of distributing the supplement. These observations rarely included elk; thus, deer-elk competition was minimized because of temporal differences in feeding, and deer clearly had first access to the feed.

Fawn:Doe Ratios

In December 2000, at the beginning of the study and prior to the first year's treatment delivery, fawn:doe ratios were similar in the 2 experimental units. Pre-treatment fawn:doe ratios were 52.6 fawns:100 does (SE = 5.3) in the treatment unit, and 51.6 fawns:100 does (SE = 5.0) in the control unit. In late December 2001 and early January 2002, following the first year's treatment, we conducted 2 age classification helicopter surveys in the treatment and control units. On 12/23/01, we observed 52.8 fawns:100 does (SE = 6.7) in the treatment unit, and 36.7 fawns:100 does (SE = 3.8) in the control unit. On 1/8/02, we observed 54.7 fawns:100 does (SE = 6.6) in the treatment unit, and 50.5 fawns:100 does (SE = 6.0) in the control unit. During December 2001 – February 2002, we obtained fawn:doe ratio estimates from ground observations of radio-collared deer groups for both treatment and control deer. This survey resulted in 61.2 fawns:100 does (SE = 7.8) in the treatment unit, and 74.5 fawns:100 does (SE = 8.5) in the control unit, although the result was not statistically significant ($t_{74} = 1.16$, $P = 0.249$).
The fawn:doe ratio results are conflicting, and clearly do not provide evidence that there was any treatment effect. In short, we conclude that the nutrition enhancement treatment did not cause an increase in neonatal production and survival during 2001. However, our results, in conjunction with a December estimate of 64 fawns:100 does for the entire Uncompahgre deer population (B.E. Watkins, unpublished), indicate fawn production and survival was good during 2001. The observed fawn:doe ratios coupled with overwinter fawn survival and annual adult survival rates indicate the deer population is growing. Considering the past 1-2 decades, this was an atypically good year for the Uncompahgre deer population. It would appear that whatever set of environmental conditions have led to a declining deer population were not present during 2001 in the same manner as in the past. Our main interest lies in observing the effect of the treatment on the deer population in a year where fawn:doe ratios are lower for the population as a whole, similar to what they have been much of the past 15 years.

Our results point out the inherent difficulties and biases associated with precisely measuring fawn:doe ratios, particularly in this research study. Ratios obtained from helicopter surveys were based on 2 short-duration flights over small spatial units. Helicopter surveys were complicated by high deer densities in heavy cover, making both deer detection and fawn:doe classifications a considerable challenge. There is a variety of potential biases that may have affected the helicopter surveys, including differential sightability of does and fawns, and incorrectly classifying yearling bucks as adult does. These biases are likely real considering the higher ratios measured during the ground classifications based on the radio-collared does. Ground fawn:doe ratio observations of radio-collared doe groups were made using spotting scopes and field glasses, where we commonly studied the deer for some time. Incorrect classifications during these surveys were likely minimal. For example, small-antlered yearling bucks (e.g. 3 – 6" spikes) were detected from the ground, whereas they were clearly missed on occasion during helicopter surveys. The ground classifications were also preferable to the helicopter surveys in that we obtained repeated observations. We recorded as many as 5 separate ratio observations per radio-collared doe. Overall, we believe the ground fawn:doe ratio estimates, based on individual radio-collared does, provided less biased measurements.

Given the inherent difficulties of measuring fawn:doe ratios, and the lack of a clear indication as to the effectiveness of the treatment, we initiated a second study using vaginal implant transmitters in order to capture and radio collar newborn fawns from the radio-collared treatment and control does (Bishop et al. 2002). This new aspect of the research will allow us to gain better estimates of the treatment effect on subsequent fawn production and survival, evaluate cause-specific mortality of treatment/control neonates, and simultaneously provide a greater understanding as to the mechanisms affecting the deer population.

Survival

Adult Females

During winter 2000-01 (Dec 1, 2000 – May 31, 2001), the adult doe survival rate of deer in the treatment unit (0.968, SE = 0.032) was greater ($\chi^2_1 = 2.649$, $P = 0.104$) than the survival rate of deer in the control unit (0.861, SE = 0.058). However, annual adult doe survival rates (Dec 1, 2000 – Nov 30, 2001) were similar among the treatment and control deer (Trt: S(*t*) = 0.839, SE = 0.066; Control: S(*t*) = 0.833, SE = 0.062; $\chi^2_1 = 0.004$, $P = 0.947$). Thus, mortalities of control deer occurred primarily during the winter months, while treatment does died primarily during the summer and fall months.

During winter 2001-02 (Dec 1, 2001 – May 31, 2002), the adult doe survival rate of deer in the treatment unit (0.942, SE = 0.030) was once again greater ($\chi^2_1 = 3.116$, $P = 0.078$) than the survival rate of deer in the control unit (0.848, SE = 0.044).

At this preliminary stage in the research, the nutrition enhancement treatment has apparently increased survival of adult females during the winter, but the overall annual survival among treatment and control does has not varied. The annual survival rate of does measured thus far aligns with expected survival based on other studies (Unsworth et al. 1999, B.E. Watkins, unpublished).

Fawns

During winter 2001-02 (Dec 1, 2001 – May 31, 2002), the survival rate of fawns was significantly greater ($\chi^2_1 = 13.216$, $P < 0.001$) in the treatment unit (0.865, SE = 0.056) than in the control unit (0.510, SE = 0.080) (Fig. 4). The simplest model which effectively explained survival ($\chi^2_{51} = 51.87$, $P = 0.440$) included treatment ($\chi^2_1 = 9.95$, $P = 0.002$) and early winter mass ($\chi^2_1 = 8.33$, $P = 0.004$). Fawns receiving the nutrition enhancement treatment, and heavier fawns, had higher survival probabilities. During winter 2001-02, which was a mild to average winter, the nutrition enhancement treatment clearly improved overwinter fawn survival, and thus yearling recruitment.

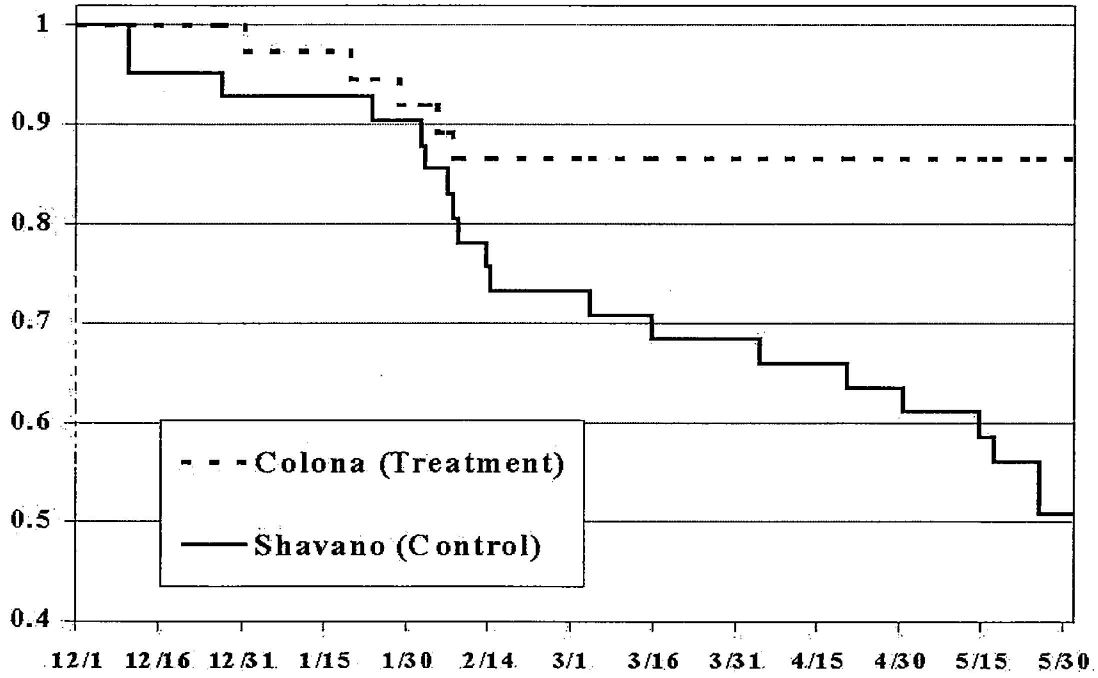

Figure 4. Overwinter fawn survival (Dec 1, 2001 – May 31, 2002) in a nutrition enhancement treatment unit (S(*t*) = 0.865, SE = 0.056) and a control unit (S(*t*) = 0.510, SE = 0.080), Uncompahgre Plateau, southwest Colorado.

Causes of Mortality

Adult Females

During winter 2000-01, only one adult doe from the treatment unit died, which was road-killed in early May. During June – August, 2001, an additional 4 treatment deer died: 2 from unknown causes that were not predator-related, 1 from a prolapsed uterus, and 1 unknown. In contrast, 5 adult does from the control area died during winter 2000-01: 3 from malnutrition, 1 from mountain lion predation, and 1 was road-killed. One additional deer from the control area died during August 2001 from an unknown cause that was not predator-related.

During winter 2001-02, 3 adult does from the treatment unit died: 1 from secondary causes related to chronic arthritis, 1 from predation, and 1 road-killed. The predation and road kill mortalities occurred in mid-late May after deer had left the treatment unit. In June, 2 more treatment adult does died during the fawning period. One doe died while giving birth, and the second doe died from an unknown cause seemingly related to birthing. This second doe, based on a field necropsy, had considerable fat and seemed otherwise healthy. On March 1, 2002, we measured 2 fetuses in utero (Bishop et al. 2002), yet the doe had only 1 fetus in utero when she died. Given her good condition, it is unlikely the second fetus was reabsorbed, which indicates she had already passed the first fetus and died prior to giving birth to the second. During winter 2001-02, 7 adult does from the control unit died: 4 died from mountain lion predation, 1 from entanglement in a fence, 1 from an unknown, non-predator mortality, and 1 unknown. No additional control does died during the month of June.

Fawns

Five fawns in the treatment unit died during winter 2001-02: 2 from malnutrition/sickness and 3 from disease. Of the 2 fawn mortalities caused by malnutrition/sickness, 1 was a result of basic malnutrition and occurred on December 31, 2001. The other fawn had a combination of heavy parasite loads, scours, and general poor condition. Each of the 3 fawns that died from disease had adequate fat stores. At least one of these fawns died as a result of pneumonia. In the control unit, 19 fawns died during the winter: 5 from malnutrition, 6 from mountain lion/bobcat predation, 4 from coyote/canine predation, 3 unknown predation mortalities, and 1 unknown. A majority of the fawns killed by predators had virtually no femur marrow fat remaining, indicating the predation was likely compensatory in nature.

Fawn Mass

During winter 2001-02, the early winter mass of radio-collared fawns varied significantly between sexes ($F_1 = 15.32, P < 0.001$) and fates ($F_1 = 6.11, P = 0.016$). Males averaged 3.6 kg heavier than females, and fawns that survived the winter averaged 2.9 kg heavier than fawns that died. Early winter mass was not different among experimental units ($F_1 = 0.36, P = 0.550$), thus the effect of the treatment was not confounded with fawn mass. The interaction of experimental unit × sex × fate was also significant ($F_1 = 5.80, P = 0.019$), while all other 2-way interactions were not significant. The 3-way interaction occurred because in the control experimental unit, female fawns that survived were not heavier than female fawns that died (Survived: $\bar{x} = 31.0$ kg, SE = 1.77; Died: $\bar{x} = 31.5$ kg, SE = 1.03); whereas male fawns that survived were considerably heavier than male fawns that died (Survived: $\bar{x} = 38.0$ kg, SE = 0.83; Died: $\bar{x} = 32.7$ kg, SE = 1.35). In contrast, in the treatment experimental unit, weight differences were more pronounced between surviving and non-surviving females (Survived: $\bar{x} = 33.1$ kg, SE = 1.00; Died: $\bar{x} = 28.2$ kg, SE = 2.75) than between surviving and non-surviving males (Survived: $\bar{x} = 35.0$ kg, SE = 0.87; Died: $\bar{x} = 34.5$ kg, SE = 1.21).

The importance of early winter fawn mass as a predictor of overwinter survival has been documented previously (White et al. 1987, Bishop 1998, White and Bartmann 1998, Unsworth et al. 1999).

LITERATURE CITED

Baker, D. L., and N. T. Hobbs. 1985. Emergency feeding of mule deer during winter: tests of a supplemental ration. Journal of Wildlife Management 49:934-942.

Baker, D. L., D. E. Johnson, L. H. Carpenter, O. C. Wallmo, and R. B. Gill. 1979. Energy requirements of mule deer fawns in winter. Journal of Wildlife Management 43:162-169.

Baker, D. L., G. W. Stout, and M. W. Miller. 1998. A diet supplement for captive wild ruminants. Journal of Zoo and Wildlife Medicine 29:150-156.

Ballard, W. B, D. Lutz, T. W. Keegan, L. H. Carpenter, and J. C. deVos, Jr. 2001. Deer-predator relationships: a review of recent North American studies with emphasis on mule and black-tailed deer. Wildlife Society Bulletin 29:99-115.

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

Bishop, C. J. 1998. Mule deer fawn mortality and habitat use, and the nutritional quality of bitterbrush and cheatgrass in southwest Idaho. Thesis, University of Idaho, Moscow, Idaho, USA.

Bishop, C. J., D. J. Freddy, and G. C. White. 2002. Effects of enhanced nutrition of adult female mule deer on fetal and neonatal survival rates. Colorado Division of Wildlife, Wildlife Research Report, Federal Aid in Wildlife Restoration Project W-153-R, Progress Report. Fort Collins, CO USA.

Bishop, C. J., and G. C. White. 2000. Effects of habitat enrichment on mule deer recruitment and survival rates. Colorado Division of Wildlife, Wildlife Research Report, Federal Aid in Wildlife Restoration Project W-153-R-13, Progress Report. Fort Collins, CO, USA.

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

Gill, R. B., T. D. I. Beck, C. J. Bishop, D. J. Freddy, N. T. Hobbs, R. H. Kahn, M. W. Miller, T. M. Pojar, and G. C. White. 1999. Declining mule deer populations in Colorado: reasons and responses. A report to the Colorado Legislature. Colorado Division of Wildlife, Denver, Colorado, USA.

Grizzle, J. E., C. F. Starmer, and G. G. Koch. 1969. Analysis of categorical data by linear models. Biometrics 25:489-504.

Holter, J. B., H. H. Hayes, and S. H. Smith. 1979. Protein requirement of yearling white-tailed deer. Journal of Wildlife Management 43:872-879.

Kaplan, E. L., and P. Meier. 1958. Nonparametric estimation from incomplete observations. Journal of the American Statistical Association 53:457-481.

Pojar, T. M. 2000. Investigating factors contributing to declining mule deer numbers. Colorado Division of Wildlife, Wildlife Research Report, Federal Aid in Wildlife Restoration Project W-153-R-13, Progress Report. Fort Collins, CO, USA.

Pollock, K. H., S. R. Winterstein, C. M. Bunck, and P. D. Curtis. 1989. Survival analysis in telemetry studies: the staggered entry design. Journal of Wildlife Management 53:7-15.

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

SAS Institute. 1989*a*. SAS/STAT® user's guide, version 6, fourth edition. Volume 1. SAS Institute, Cary, North Carolina, USA.

SAS Institute. 1989*b*. SAS/STAT® user's guide, version 6, fourth edition. Volume 2. SAS Institute, Cary, North Carolina, USA.

SAS Institute. 1997. SAS/STAT® Software: Changes and Enhancements through Release 6.12. SAS Institute, Cary, North Carolina, USA.

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

Smith, S. H., J. B. Holter, H. H. Hayes, and H. Silver. 1975. Protein requirement of white-tailed deer fawns. Journal of Wildlife Management 39:582-589.

Thompson, C. B., J. B. Holter, H. H. Hayes, H. Silver, and W. E. Urban, Jr. 1973. Nutrition of white-tailed deer. I. Energy requirements of fawns. Journal of Wildlife Management 37:301-311.

Ullrey, D. E., W. G. Youatt, H. E. Johnson, L. D. Fay, and B. L. Bradley. 1967. Protein requirement of white-tailed deer fawns. Journal of Wildlife Management 31:679-685.

Unsworth, J. W., D. F. Pac, G. C. White, and R. M. Bartmann. 1999. Mule deer survival in Colorado, Idaho, and Montana. Journal of Wildlife Management 63:315-326.

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

Verme, L. J., and D. E. Ullrey. 1972. Feeding and nutrition of deer. Pages 275-291 *in* D. C. Church, editor. Digestive physiology and nutrition of ruminants. Volume 3 – Practical Nutrition. D. C. Church, Corvallis, Oregon, USA.

White, G. C., and R. M. Bartmann. 1998. Effect of density reduction on overwinter survival of free-ranging mule deer fawns. Journal of Wildlife Management 62:214-225.

White, G. C., R. A. Garrott, R. M. Bartmann, L. H. Carpenter, and A. W. Alldredge. 1987. Survival of mule deer in northwest Colorado. Journal of Wildlife Management 51:852-859.

Colorado Division of Wildlife
Wildlife Research Report
July 2001 and July 2002

FINAL REPORT

State of Colorado : Division of Wildlife – Mammals Research

Work Package No. 3001 : Deer Conservation

Task No. 4 : Pilot Study – Use of Ultrasound and Vaginal Implants

Federal Aid Project W-185-R : Research and Development

Period Covered: July 1, 2001 — June 30, 2002

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ABSTRACT

Field research of mule deer could be greatly enhanced if newborn fawns could be captured from specific adult females from which data has already been collected. We evaluated the logistical feasibility and effectiveness of using vaginal implant transmitters (VITs) to determine the location and timing of birth of specific, radio-collared adult female mule deer. The VITs were manufactured by Advanced Telemetry Systems, Inc. (Isanti, MN). We placed VITs in 36 adult female deer on February 28 and March 1, 2002. At this time, we recorded data such as fetal rate, body condition, body mass, and serology from a blood sample. In June 2002, we intensively radio-monitored the VITs to determine when they were expelled from the deer. When a VIT was shed, we immediately located it to determine whether a birth site was present and to locate/capture neonates. The proportion of VITs that were expelled at or near the birth site with the transmitter functioning correctly was 0.33 (SD = 0.083). Of 36 VIT trials, 3 were censored, 7 were shed prematurely, 15 had battery failures, and 11 were successful (9 of which led to birth sites and subsequent fawn captures). In spite of the high VIT failure rate, we captured and radio-collared a total of 54 fawns from 38 adult does during June 11 – July 1, 2002. Twenty-six fawns were captured from 17 of the 36 VIT does and 28 fawns were captured from 21 radio-collared does that did not have VITs. Contrary to our own expectations, we successfully captured fawns from radio-collared does by relocating the does on a routine basis. However, this technique was inefficient and required a total capture effort of 1700 man-hours (212 man-days) during a 22-day period, or roughly 4 man-days/fawn. The VIT battery failures were clearly the main problem we experienced, which can be corrected. The amount of time and effort saved by the 11 successful VITs justifies their use, particularly with continued refinement of the VIT design.

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EFFECTS OF ENHANCED WINTER NUTRITION OF ADULT FEMALE MULE DEER ON FETAL AND NEONATAL SURVIVAL RATES: A PILOT STUDY TO ADDRESS FEASIBILITY

C. J. Bishop, D. J. Freddy, and G. C. White

PROJECT OBJECTIVE

1. To evaluate the feasibility of utilizing ultrasound techniques and vaginal implant transmitters in adult female mule deer to measure stillborn fetus mortality and to locate and capture specific neonate fawns.

SEGMENT OBJECTIVES

1. Prepare a Program Narrative for a 1-year pilot study.

2. Conduct the 1-year pilot study to evaluate logistical feasibility of field techniques, collect data necessary for subsequent sample size calculations, and to obtain preliminary biological data.

3. Prepare a Job Final Report for the 1-year pilot study.

INTRODUCTION

Background

The Colorado Division of Wildlife initiated 2 studies on the Uncompahgre Plateau in response to chronically low December fawn:doe ratios throughout the 1990's and an overall decline in total deer numbers. In 1997, an ongoing survival study was initiated to quantify overwinter fawn survival and annual adult survival rates, and to identify mortality agents (B.E. Watkins, Colorado Division of Wildlife, unpublished data). In 1999, another study began to quantify pregnancy/fetal rates and to measure survival rates and cause-specific mortality of neonate fawns (Pojar and Andelt 1999, Pojar 2000). These studies have provided several significant findings to date. First, overwinter survival rates of fawns, and annual survival rates of does and bucks, are above average when compared to measurements obtained elsewhere (Unsworth et al. 1999). Second, adult doe pregnancy rates (93%) and fetal rates (1.7 fawns/doe) in February are normal (Pojar and Andelt 1999). Third, summer fawn survival has been relatively low overall, with malnutrition/sickness and predation being the primary causes of mortality (Pojar 2000). Based on these findings, *in utero* fetus survival/summer fawn survival is clearly the limiting factor to population growth on the Plateau. Summer fawn survival has been measured directly, while the extent of *in utero* fetus mortality from February to birth has been back-calculated utilizing expected versus observed December fawn:doe ratios based on the observed summer fawn survival. Although this fetus mortality has not been measured directly, there is considerable evidence that some portion of viable fetuses in February are not surviving to birth.

Given the magnitude of malnutrition/sickness observed in newborn fawns, the question of prepartum adult doe nutrition is paramount. Summer range habitat quality on the Uncompahgre Plateau is seemingly good, and arguably better than many other deer summer ranges throughout the intermountain West. However, lower transitional and winter range habitat quality appears to be limited in terms of forage diversity and quality. We understand the inherent limits in nutritional quality of winter range forage, but hypothesize that winter range habitat quality on the Plateau may not be meeting the minimum nutritional requirements of pregnant adult does.

In 2000, we initiated a research study on the Uncompahgre Plateau to evaluate the effects of enhanced nutrition of mule deer during winter on fawn production and survival (Bishop and White 2000, Bishop and White 2002). The objectives of this research are twofold: 1) to determine experimentally whether enhancing the nutrition of deer during winter and early spring by supplemental feeding increases overwinter fawn survival and/or December fawn:doe ratios the following December; and 2) to determine experimentally to what extent habitat treatments replicate the effect of enhanced nutrition from supplemental feeding. We are addressing these objectives by radio-collaring adult does and 6-month old fawns in a treatment experimental unit and a control experimental unit. The current phase of the experiment uses supplemental feed as a nutrition enhancement treatment, while the second phase will use habitat manipulations (e.g. prescribed fire, mechanical) as the treatment. The main focus of this research is to determine whether a decline in winter range habitat quality has been a causative factor of poor December fawn recruitment on the Uncompahgre Plateau during the past decade. More specifically, we are determining whether nutrition enhancements and/or habitat treatments on winter range cause an increase in fawn:doe ratios the following December. Our primary response variable is December fawn:doe ratios measured from radio-collared does in the treatment and control units.

December fawn:doe ratios represent a combined approximation of fawn production (# fetuses produced and successfully brought to term) and survival (% of newborn fawns surviving from birth to December). Fawn:doe ratios are influenced by the number of yearling females in the population, the proportion of small yearling bucks that may be misidentified as does, doe harvests etc. Irrespective of these inherent biases, low December fawn:doe ratios typically indicate either poor fawn production, low summer fawn survival, or a combination of both.

To improve our current study design evaluating the importance of habitat/nutrition, we initiated a 1-year pilot study in an attempt to obtain separate, direct measurements of *in utero* fetus survival and summer fawn survival for treatment and control does. These direct measurements, if obtainable, would be preferable to December fawn:doe ratios, and would provide a better understanding of the effect, if any, of the nutrition enhancement treatment on the deer population. The purpose of the pilot study was to evaluate the logistical feasibility of field techniques necessary to accomplish the research, and to collect data for subsequent sample size calculations assuming the research progressed into a full-scale study.

In order to directly measure *in utero* fetus survival and summer fawn survival of radio-collared does from the treatment and control areas, we needed to record winter fetal rates of the collared does, and then locate and capture the collared does' fawns the following June. Winter fetal rates can be measured using established ultrasound techniques. However, there are no established techniques for locating and capturing a large sample of newborn fawns from specific, individual does. Previous attempts to capture neonates from radio-collared does in forest-shrub habitats have been largely unsuccessful (M. A. Hurley, Idaho Dept. of Fish and Game, pers. comm.; T. M. Pojar, Colorado Division of Wildlife, pers. comm.). There are 2 major problems: 1) there is no effective way to determine when any given doe will give birth to her fawn(s); and 2) it is often very difficult to find a fawn simply based on locating the doe, because the fawns are often bedded in heavy cover some distance from the doe (e.g. 50-100 yards). To overcome these problems, we conducted a 1-year research study to evaluate the use of vaginal implant transmitters in adult does as a technique to determine both the timing and location of birthing.

Vaginal Implant Transmitters

For some time, radio-transmitter implants in the vaginas of deer have been considered as a technique for locating and capturing newborn fawns from radio-collared does immediately following parturition. Early attempts to employ this technique were largely unsuccessful in terms of both effectiveness and animal welfare concerns (Garrott and Bartmann 1984, Giessman and Dalton 1984, Nelson 1984). This early technique used sutures to partially close the vulva in order to retain the transmitter in the vagina. More recently, Bowman and Jacobsen (1998) developed and employed a modified vaginal implant transmitter (VIT) for white-tailed deer, which met better success. This transmitter had plastic wings to retain the transmitter in the vagina until parturition; thus, no sutures were used. They found no indications that animals were negatively impacted by the newly designed VIT; however, retention rate of implants to parturition was only 75%, and sample sizes were small. Within the last 2 years, several studies have been initiated using (modified) VITs to study white-tailed deer (M. Carstenson and G. D. Delguidice, University of Minnesota, pers. comm.), black-tailed deer (N. Pamplin and D. Jackson, Oregon State University and Oregon Dept. of Fish and Wildlife, pers. comm.), and elk (J. Noyes and B. Johnson, Oregon Dept. of Fish and Wildlife, pers. comm.; J. Vore, Montana Fish, Wildlife, and Parks, pers. comm.) These ongoing studies have found greater success with VITs in terms of retention to parturition, and have not documented any detrimental effects to the animals. Given the success at finding birth sites and fawns, these studies do not indicate that vaginal implants cause major problems with *in utero* fetus survival or birthing.

MATERIALS AND METHODS

Experimental Design and Study Area

This research was conducted in conjunction with our ongoing research study evaluating the effects of enhanced winter nutrition on overwinter mule deer fawn survival and early winter fawn:doe ratios. The research is being conducted in 2 experimental units on winter range on the Uncompahgre Plateau. The 2 units are receiving a nutrition enhancement treatment in a cross-over experimental design. Unit A served as the treatment unit, and Unit B served as the control, for the first 2 years of research (2000 – 2002). Beginning November 2002, Unit B will receive the treatment while Unit A will serve as the control. Bishop and White (2002) provide a complete description of the experimental design and study area.

The 2 experimental units (A and B) receiving the nutrition enhancement treatment are (Fig. 1):
(1) The Colona Tract of the Billy Creek State Wildlife Area
(2) Bureau of Land Management lands adjacent to Shavano Valley as defined by the following:

Within Dry Creek Basin Quadrangle (USGS 7.5 Minute), includes Sections 6 and 7 in T. 48 N.-R. 10 W. and Sections 1, 2, 10, 11, 12, 13, 14, 15 in T. 48 N.-R. 11 W. This area roughly includes 38°25’00” – 38°27’30” Latitude and 108°00’00” – 108°04’30” Longitude.

In late April and May, prior to fawning, deer from the winter range experimental units migrate to summer range. The summer range study area encompasses 800 mi^2 covering the southern portion of the Uncompahgre Plateau and adjacent San Juan Mountains to the south and east (Fig. 1).

Winter range elevations range from 1830 m (6000 ft) in Shavano Valley to 2318 m (7600 ft) adjacent to the Dry Creek Rim above Shavano Valley. Winter range habitat is dominated by pinyon-juniper with interspersed sagebrush adjacent to agricultural fields in the Shavano and Uncompahgre Valleys. Summer range elevations occupied by deer range from 1891 m (6200 ft) in the Uncompahgre Valley to 3538 m (11,600 ft) in Imogene Basin southwest of Ouray, CO. Summer range habitats are dominated by spruce-fir, aspen, ponderosa pine, Gambel oak, and to a lesser extent, sagebrush and pinyon-juniper at lower elevations.

Sample Size

The main objective of the pilot study was to assess "success/failure" of VITs from an equipment functionality and field logistics standpoint. Our first definition of success/failure was the proportion of vaginal implant transmitters that were expelled at the birth site with the heat sensor functioning correctly (transmitter success rate). We set our sample size based on an initial assumption that 0.90 of the transmitters would function correctly, which necessitated 36 radio-collared does to estimate the transmitter success rate with a 95% confidence interval of +/- 0.10.

Our second definition of success/failure was the proportion of successful fawn captures that occurred from the sample of 36 does (fawn capture success rate). We defined a successful fawn capture as locating and capturing at least 1 fawn from a doe equipped with a vaginal implant. Prior to the study, we assumed a 0.80 rate of finding at least 1 fawn/radio-collared doe. With 36 radio-collared does, this would allow us to measure a fawn capture success rate with a 95% confidence interval of +/- 0.13. This level of precision was sufficient for us to evaluate the overall success/failure of vaginal implant transmitters as a field technique for locating and capturing newborn fawns from specific radio-collared does.

Capture and Handling Techniques

On February 28 and March 1, 2002, we captured a total of 36 adult female deer utilizing helicopter net guns (Barrett et al. 1982, van Reenen 1982). Eighteen deer were captured in the nutrition enhancement treatment unit, and 18 in the control unit. Captured deer were ferried by the helicopter to a central processing location. Most deer captured in each experimental unit were chemically immobilized using a combination of ketamine and xylazine to facilitate the ultrasound and VIT insertion procedures. Ketamine and xylazine were mixed in a 5:1 ratio (200:40 mg/ml), and administered intravenously at a dosage rate of approximately 1.5-2.0 ml/45 kg animal body mass. Immediately prior to release, drug effects were (partially) reversed with an intravenous injection of yohimbine at a rate of ~12 mg/45 kg animal body mass. Each deer was aged based on tooth replacement and wear, and only deer ≥2.5 years old were retained. For each captured deer, we used ultrasonography to measure pregnancy status, fetal rate, and body condition. If the doe was pregnant, she was then radio-collared using a fixed length, permanent collar. Each radio collar had Ritchey® neck band material stitched to the left side with a unique identifier engraved on it for visual identification purposes. We then inserted the VIT and released the deer. We performed the ultrasound and VIT insertion procedures in a 10 x 12 ft wall frame tent located at the processing site to avoid problems associated with weather conditions and helicopter rotor wash. We also recorded the weight of each deer, recorded a body condition score, and collected a blood sample for serology tests.

Ultrasonography

We estimated body fat using an Aloka 210 (Aloka, Inc., Wallinford, Conn.) portable ultrasound unit with a 5 MHz linear transducer. Maximum subcutaneous fat thickness on the rump was measured immediately cranial to the cranial process of the tuber ischium. Proper orientation was assured by scanning along a line between the spine, at its closest point to the tuber coxae (hip bone), and the caudal process of the tuber ischium (pin bone). A small area of hair was shaved to ensure contact between the transducer and the skin. A conducting gel was applied to the shaved area and fat thickness was measured using electronic calipers.

We quantified reproductive status using a 3 MHz linear transducer. To permit transabdominal scanning, a portion of the abdomen was shaved caudal to the last rib and left of the midline, and gel was applied. Both uterine horns were systematically scanned to identify fetal numbers ranging from 0 to 3. Upon identification of a fetus, we measured, whenever possible, eye diameter, crown-rump length, biparietal

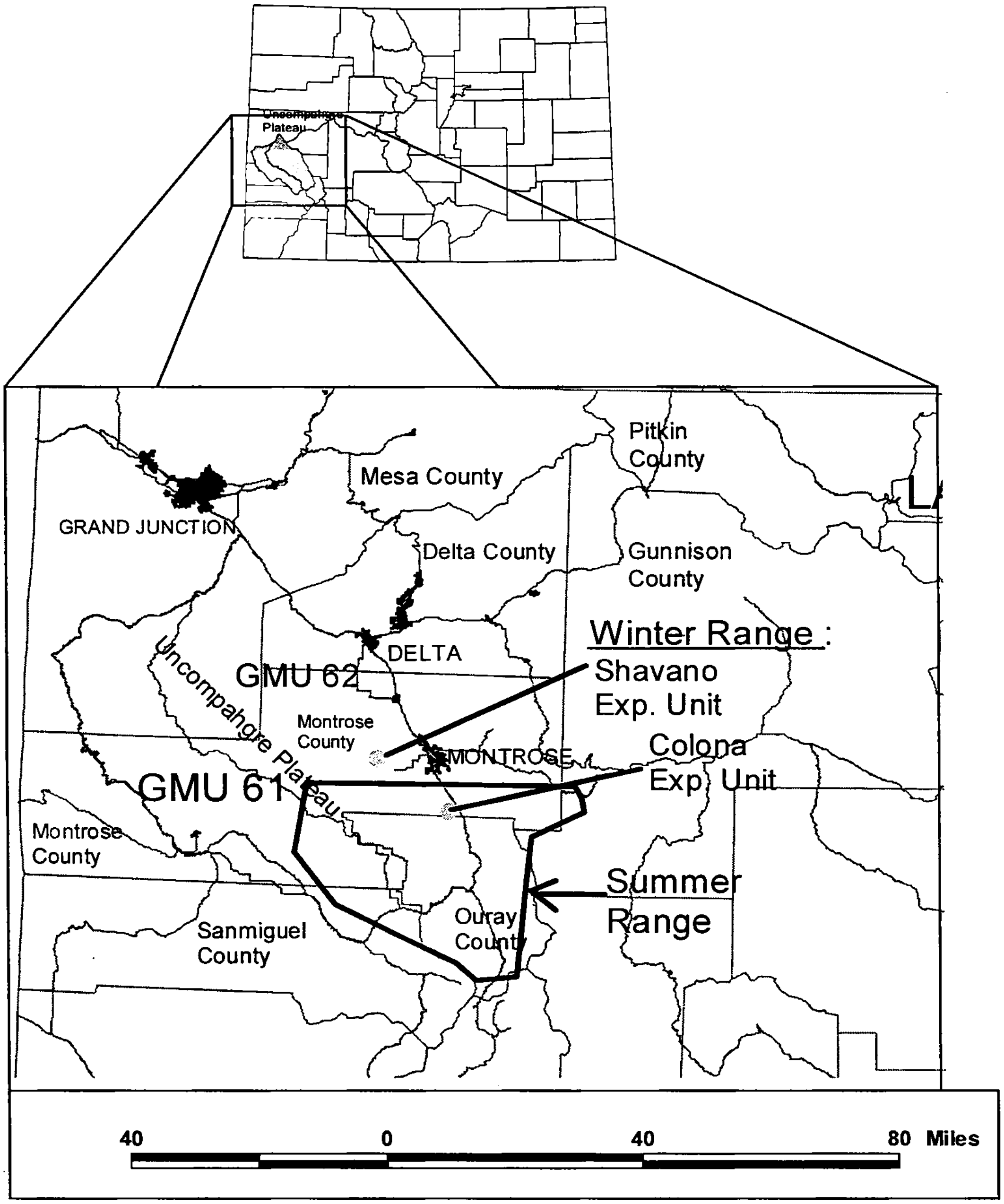

Figure 1. Map showing the locations of the Colona and Shavano experimental units (Units A and B) on winter range, and the location of deer summer range, on the Uncompahgre Plateau, southwest Colorado. The summer range study area was defined by the summer distribution of deer that were captured on the winter range experimental units.

distance, and skull length. In most cases, we only obtained an eye diameter measurement. Morphometric measurements were collected to estimate fetal age and parturition date.

Vaginal Implant Transmitters (VITs)

The VITs we used were manufactured by Advanced Telemetry Systems, Inc. (Isanti, MN). The VIT was 76 mm long, excluding antenna length, and had 2 plastic wings with a width of 57 mm when fully spread apart. The plastic wings were used to retain the transmitter in the vagina until parturition. The VIT weighed 15 grams and contained a 10-28 lithium battery. The diameter of the transmitter/battery was 14 mm, and was encased in an impermeable, water-proof, electrical resin. The transmitter contained an embedded heat-sensor which dictated the frequency pulse rate. When the heat sensor dropped below 86°F, synonymous with transmitter expulsion from the deer, the pulse rate changed from 40 PPM to 80 PPM. The VIT was inserted into deer using a vaginoscope (Jorgensen Laboratories, Inc., Loveland, CO) and alligator forceps. The vaginoscope was 6" long with a 5/8" internal diameter and had a machined end (smooth surface) to minimize trauma when inserted into the vagina. A discreet mark was placed on the applicator showing the appropriate distance it should be inserted into the deer. The length of a typical mule deer vaginal tract was obtained by taking measurements from road-killed deer and/or other fresh deer carcasses obtained in the study area.

Prior to use in the field, VITs were sterilized using a Chlorhexidine solution, air-dried, and sealed in a 3" x 8" sterilization pouch. Sterilization containers with Chlorhexidine solution were used on site during capture to sterilize the vaginoscope and alligator forceps between each use. A new pair of nitrile surgical gloves was used to handle the vaginoscope and VIT for each deer. To insert a VIT, the plastic wings were folded together and placed into the end of the vaginoscope. We then liberally applied sterile KY Jelly to the scope and inserted it into the deer's vagina to the point where the mark on the applicator was reached. The alligator forceps, which extended through the vaginoscope to hold the VIT, was held firmly in place while the scope was pulled out from the vagina. This procedure pushed the VIT out of the scope into the vagina, and the plastic wings spread apart to hold the transmitter in place. The transmitter antenna was typically flush with the vulva, but on occasion extended up to 1 cm beyond the vulva. The tip of the antenna was encapsulated is a wax bead to protect the deer.

Adult Doe Monitoring

From March through May, we regularly monitored the radioed does as part of our current research experimental design, which included daily monitoring for live/death status (Bishop and White 2002). We also used aerial telemetry to relocate each of the does every couple of weeks during the remainder of the winter.

Fetus Survival and Neonate Capture

During June 10-30, 2002, we relocated each of the radio-collared does having a VIT each morning using a fixed wing aircraft. Flights began at 6:00 AM and were usually completed by 10:00-11:00 AM. The early flights were crucial for detecting fast signals because shed VITs were often warmer than 86 °F by mid-day, which caused them to switch back to a slow ("pre-birth") pulse. When a fast ("postpartum") pulse rate was detected, we located the VIT from the ground to determine whether it was shed at the birth site. If the transmitter was located at the birth site, we identified whether any fawn(s) were stillborn. If the fawn(s) were no longer present at the birth site, or could not be found in the vicinity of the birth site, we located the radio-collared doe and searched for fawns at her location. All personnel involved wore surgical gloves to help minimize human scent when handling fawns. For each doe, we attempted to document whether any fawns were stillborn, locate each of her fawns, radio-collar and weigh the fawns, record basic vegetation characteristics of the birth site, and promptly exit the site. We attempted to account for each doe's fetuses in order to evaluate the efficacy of using this technique to quantify *in utero* fetal survival from February to birth. We then radio-monitored each of the radio-collared fawns on a daily basis to measure survival rates of treatment and control fawns and to assess cause-specific mortality.

We also periodically located other radio-collared does that did not have VITs and attempted to capture their fawns to help achieve our targeted sample size. Each of these does were part of the nutrition enhancement research, and were present on either the treatment or control experimental unit during winter.

RESULTS AND DISCUSSION

VIT Effectiveness

The proportion of VITs that were expelled at or near the birth site with the transmitter functioning correctly was 0.33 (SD = 0.083). Of 36 VIT trials, 3 were censored, 7 were shed prematurely, 15 had battery failures, and 11 were successful. *Censors:* Two adult does died in May well before fawning and were still carrying the VITs. One doe was never relocated after leaving winter range. These 3 deer were censored because there was no test of whether the VIT functioned correctly or not. *Premature Sheds:* Three VITs were shed in May or early June well before fawning (May 18, May 19, and June 6). The other 4 VITs were shed during the fawning period, but at least 1-2 days before the respective does gave birth. *Battery Failures:* With only 1 exception, all battery failures occurred just before or during the fawning period. This was the glaring problem with the VIT success rate. The battery we had hoped to use had a warranty life of 116 days and a capacity of 232 days. Unfortunately, this battery was discontinued by Advanced Telemetry Systems (ATS) just before our research study began due to poor results. The battery we subsequently used in the VITs had a warranty life of only 94 days, and a capacity of 188 days. We needed our batteries to last 120 days for this research. ATS had found good results with this shorter life battery, and recommended its use because it typically lasted well beyond the warranty battery life. We knew this was a risk at the onset of the research, but had confidence the batteries would last the necessary 120 days based on ATS recommendations. Had the batteries not failed, we likely would have had a 60-70% success rate. *Successes:* We had 11 transmitters function correctly. One transmitter was still in the doe and functioning at the end of our capture period. Of the remaining 10 VITs, 9 allowed us to efficiently locate and capture fawns, typically at the birth site, and account for each of the given doe's fetuses measured in February/March. We located 14 fawns, one of which was a stillborn, from these 9 VITs.

Our fawn capture success rate for the 33 available does was 0.61 (SD = 0.086), meaning we captured at least 1 fawn from 61% of the VIT radio-collared does. In 3 instances, we opportunistically located a VIT with a failed battery by radio-tracking the doe and searching for her fawns. In total, we located 30 fawns from VIT does, 3 of which were stillborn, and 1 we weren't able to radio-collar.

Fawn Capture

We captured and radio-collared a total of 54 fawns from 38 adult does (1.42 fawns/doe) during June 11-July 1, 2002 (Fig. 2). We found 4 stillborns at birthsites, and 2 suspected stillborns at or near birthsites which could have been early neonate mortalities. We captured 30 fawns from treatment does and 24 from control does. Twenty-six fawns were captured from 17 of the VIT does (1.53 fawns/VIT doe) and 28 fawns were captured from 21 radio-collared does that did not have VITs (1.33 fawns/non-VIT doe). We documented a total of 62 live fawns from the 38 does (1.63 fawns/doe), although we only captured 54 fawns because 1 fawn from a set of twins escaped on multiple occasions.

Capture Effort

The 15 VIT battery failures caused considerable problems during the fawn capture. As it turned out, VITs helped us capture only 13 fawns and locate 1 stillborn fawn. The other 41 fawns and 5 stillborns were captured/located by routinely radio-tracking collared does and searching for fawns at their locations. This required an intensive field effort. We worked approximately 1700 man-hours (212 man-days) during a 22-day period to capture the 54 fawns, or roughly 4 man-days/fawn. Our objective pre-fawning was to capture 55 fawns; thus, even with the VIT failures, we were able to capture the necessary fawns from radio-collared does. The field effort would have been considerably less had we not had the battery failures.

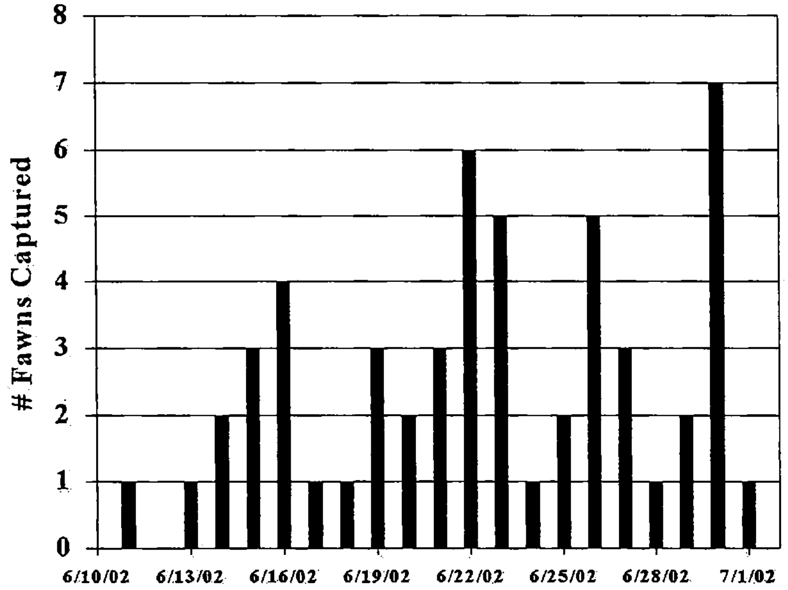

Figure 2. Number of newborn fawns captured by day during June 11-July 1, 2002. All fawns were captured from radio-collared does throughout the southern portion of the Uncompahgre Plateau and adjacent San Juan Mountains in southwestern Colorado.

Fetus Survival

In February-March 2002, we measured an average of 1.80 fetuses/doe (SE = 0.14, n = 36), which included 1.77 fetuses/doe (SE = 0.14, n = 18) in the treatment unit and 1.83 fetuses/doe (SE = 0.15, n = 18) in the control unit. In June 2002, considering all does that we located any fawn from, whether live or stillborn, we observed 1.42 (SE = 0.11, n = 43) live fawns/doe postpartum. This rate includes the 6 stillborns, and should represent a conservative estimate of live fawns/doe postpartum because we inevitably failed to locate all live fawns from each doe. In other words, this estimate would treat any unaccounted fetuses (from the February measurement) as if they were stillborns. For does that did not have VITs, and thus we did not have a winter fetus rate measurement, singletons would infer that either the deer only had 1 fetus, or that the other fetus died. It is likely that many of these singletons had a twin that we did not locate. This equates to a conservative fetus survival rate estimate of 0.79 (SE = 0.063). We accounted for all the fetuses of 14 VIT does in June 2002, 8 of which were the direct result of the VIT functioning correctly. Of these 14 does, the fetus survival rate was 0.86 (SD = .096). This data point lacks precision and may potentially be biased because we did not account for an adequate number of fetuses due to the VIT failures. Of 10 VITs that functioned correctly and were shed during fawning, we accounted for all recorded fetuses in 8 of the deer. One of the other 2 VITs that functioned correctly allowed us to account for 2 of 3 fetuses measured in February. Clearly, to gain a more reliable estimate of fetus survival, a high percentage of the VITs must function correctly so that more birth sites can be located, and more fetuses can be accounted for.

Neonate Survival

We accomplished our neonate capture objectives even with the VIT failures; it simply required a greater effort. If this technique were incorporated into the nutrition enhancement experiment at full scale, we would need to capture approximately 80 newborn fawns (40 each from treatment and control does). Assuming we can purchase implants with longer-lived batteries, we could feasibly capture 80 fawns by increasing our sample size of VIT does.

CONCLUSIONS

The VITs were largely successful except for the 15 battery failures. The battery problem can easily be corrected by working with Advanced Telemetry Systems to locate and utilize a reliable battery with a longer life. Such batteries exist, and have been used routinely in small mammal and avian radio transmitters. The 7 premature sheds were expected to some extent, and not a major concern. The VITs that did not fail were highly useful for determining the location and timing of birth, which is of critical importance for capturing fawns from individual, radio-collared does. We found the use of VITs to be a successful field technique given our objectives, assuming a reliable, longer-lived battery can be incorporated into the current design.

Literature Cited

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

Bishop, C. J., and G. C. White. 2000. Effects of habitat enrichment on mule deer recruitment and survival rates. Colorado Division of Wildlife, Wildlife Research Report, Federal Aid in Wildlife Restoration Project W-153-R-13, Progress Report. Fort Collins, CO, USA.

Bishop, C. J., and G. C. White. 2002. Effects of nutrition and habitat enhancements on mule deer recruitment and survival rates. Colorado Division of Wildlife, Wildlife Research Report, Federal Aid in Wildlife Restoration Project W-153-R, Progress Report. Fort Collins, CO, USA.

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

Garrott, R. A, and R. M. Bartmann. 1984. Evaluation of vaginal implants for mule deer. Journal of Wildlife Management 48:646-648.

Giessman, N. F., and C. J. Dalton. 1984. White-tailed deer fawn mortality in the southeastern Missouri Ozarks. Missouri Department of Conservation, Jefferson City, Pittman-Robertson Project W-13-R-35.

Nelson, T. A. 1984. Production and survival of white-tailed deer fawns on Crab Orchard National Wildlife Refuge. Thesis, Southern Illinois University, Carbondale, IL, USA.

Pojar, T. M. 2000. Investigating factors contributing to declining mule deer numbers. Colorado Division of Wildlife, Wildlife Research Report, Federal Aid in Wildlife Restoration Project W-153-R-13, Progress Report. Fort Collins, CO, USA.

Pojar, T. M., and W. F. Andelt. 1999. Investigating factors contributing to declining mule deer numbers. Colorado Division of Wildlife, Wildlife Research Report, Federal Aid in Wildlife Restoration Project W-153-R-12, Progress Report. Fort Collins, CO, USA.

Unsworth, J. W., D. F. Pac, G. C. White, and R. M. Bartmann. 1999. Mule deer survival in Colorado, Idaho, and Montana. Journal of Wildlife Management 63:315-326.

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

Colorado Division of Wildlife
Wildlife Research Report
July 2001 and July 2002

PROGRESS REPORT

State of Colorado : Division of Wildlife – Mammals Research

Work Package 3001 : Deer Conservation

Task No. 5 : Improved Population Modeling DEAMAN System Administration

Federal Aid Project No. W-185-R : Research and Development

and the following non-Federal Aid projects

Work Package No. 0661 : Grouse Conservation
Work Package No. 0664 : Prairie Dog Conservation
Work Package No. 0670 : Lynx Conservation
Work Package No. 0850 : Peregrine Falcon Recovery
Work Package No. 3006 : Other Small Game Conservation

Period Covered: July 1, 2001 - June 30, 2002

Author: G. C. White

Personnel: C. Bishop, G. Miller, T. E. Remington, D. J. Freddy, T. M. Shenk, L. Stevens, J. Craig, R. Kahn, D. C. Bowden, F. Pusateri, J. Dennis, M. M. Conner, D. Walsh, B. Lubow.

ABSTRACT

Progress towards the objectives of this job include:

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

The DEAMAN software package for the storage, summary, and analysis of big game population and harvest data was revised further as a Windows 95/98/NT/2000/ME/XP program. The capability to incorporate data on radio-collared animals to estimate survival with the Kaplan-Meier estimator and display movement data was added, and distributed to terrestrial biologist via the WWW at http://www.cnr.colostate.edu/~gwhite/deaman.

A 3-day workshop was conducted with CDOW Terrestial Biologists in the use of DEAMAN and population modeling procedures, mainly to instruct personnel on the use of spreadsheet models for ungulate population dynamics. In addition, numerous questions were answered via meetings with biologists, and via email.

A paper, coauthored with Bruce Lubow, was published in the Journal of Wildlife Management on past efforts to develop a realistic mule deer population model based on data collected with current CDOW procedures. Data from the Piceance Basin were used to illustrate the modeling technique. The full

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

A paper on use of population viability analyses applicable to animals monitored with mark-encounter data was published with T. M. Shenk and A. B. Franklin. The full citation is: White, G. C., A. B. Franklin, and T. M. Shenk. 2002. Estimating parameters of PVA models from data on marked animals. Pages 169-190 *in* S. R. Beissinger and D. R. McCullough, editors. Population Viability Analysis. University of Chicago Press, Chicago, Illinois, USA.

A paper on analysis of radio-tracking data for estimation of survival pertinent to monitoring the reintroduced lynx population in Colorado was published with T. M. Shenk: White, G. C., and T. M. Shenk. 2001. Population estimation with radio-marked animals. Pages 329-350 *in* J. J. Millspaugh and J. M. Marzluff, editors. Design and Analysis of Wildlife Radiotelemetry Studies. Academic Press, San Diego, California, USA

A paper on the estimation of population size from correlated sampling unit estimates of the variable of interest was submitted to the Journal of Wildlife Management. The methodology developed in this paper is proposed for use in a joint Colorado/Utah survey of the colony area of white-tailed and Gunnison prairie dogs in western Colorado and eastern Utah. The full citation is: Bowden, D. C., G. C. White, A. B. Franklin, and J. L. Ganey. 2003. Estimating population size with correlated sampling unit estimates. Journal of Wildlife Management 67:1-10.

A paper on the estimation of survival of Greater Sage-grouse in North Park, Colorado, was submitted to the Journal of Wildlife Management: Zablan, M. A., C. E. Braun, and G. C. White. 2003. Estimation of northern sage-grouse survival in North Park, Colorado. Journal of Wildlife Management 67:144-154.

Assistance in the analysis of candidate systems to estimate deer abundance in GMU 10 was provided.

A research study to examine the impact of nutrition on the decline of mule deer fecundity during the last 20 years was continued. I have provided input on estimation of the number of deer on the feed sites, and developed an estimator of fawn survival rates based on radio-collared does and fall and spring fawn:doe ratios.

Data were collected and analyzed on spatial distribution, movement of radio-collared animals, and population sizes related to estimating the spread and impacts of chronic wasting disease in deer populations. A report summarizing these findings was provided to CDOW personnel involved with the study.

A graduate research project by Dan Walsh to evaluate utility of lek counts of Greater Sage-grouse in Middle Park is ongoing. Mark-resight methods are being used to estimate lek attendance and population size. Preliminary results of this work were reported at the Sage-grouse Working Group Meeting on Population Analysis held June 24-25, 2002, in Torrey, Utah.

Computer programs to assist researchers with field data collection of feeding rates of tame Greater Sage-grouse were written for the HP Jornada Pocket Computer. In addition, a program for computing triangulation locations of radioed animals was written for the HP Jornada Pocket Computer for use in the field to evaluate interactively and graphically the quality of triangulated locations.

A model of the Colorado peregrine falcon population was constructed from estimates of survival and reproduction derived from banded birds (1973-2001) and monitored nests (1989-2001). Data were supplied by Jerry Craig. Survival estimates for 0-1, 1-2, and 2+ year old birds were 0.544, 0.670, and 0.800, respectively, with standard errors of 0.0765, 0.091, and 0.0544. Average young produced per pair was 1.660 (SE = 0.0443), but there was considerable variation across years (min = 1.388, SE = 0.1548, in 1995; max = 2.122, SE = 0.1393, in 2000). Based on a population model constructed from these estimates, the annual rate of population increase was 1.028957 for females first reproducing at 3 years of age, and 1.080316 for females first reproducing at 2 years of age. Given these high rates of population increase, some take by falconers could be accommodated by the Colorado peregrine population.

An analysis to estimate the effort required to estimate the percent of eastern Colorado inhabited by black-tailed prairie dogs was completed and results provided to CDOW personnel involved with the effort. For the first 5 strata surveyed, I have computed estimates of prairie dog colony areas to assist the CDOW personnel conducting the survey. Results to date suggest the survey is working well.

CONSULTING SERVICES FOR MARK-RECAPTURE ANALYSES

G. C. White

PROJECT OBJECTIVES

Assess the status of Colorado peregrine falcon population based on parameters estimated from banded birds and monitored nests.

SEGMENT OBJECTIVES

1. Develop a model of the Colorado peregrine falcon population based on survival and reproduction estimates derived from banded birds (1973-2001) and monitored nests (1989-2001).
2. Using this model, determine the impact of limited take by falconers on Colorado peregrine populations.

RESULTS AND DISCUSSION

Methods

Survival Rate Estimation

A total of 938 peregrines were banded as nestlings during the interval 1974-2000. From these, 11 live resightings and 53 dead recoveries were obtained. Survival was estimated with Program MARK (White and Burnham 1999) using the joint live and dead recoveries model of Burnham (1993). Program MARK uses the Seber (1970) parameterization for dead recoveries in the Burnham model, so parameters for survival (*S*), probability that a band from a dead bird is recovered (*r*), and the probability of a live bird being resighted and the band read (*p*). The fidelity parameter (*F*) was fixed to 1 because of the sparseness of the data.

Reproduction

A total of 142 nesting sites were monitored for the number of young fledged starting in 1973 through 2001, although the number of sites increased with year as the breeding population increased in Colorado. Only data from 1989 through 2001 were used in the analysis presented here because I wanted at least 30 nests per year to estimate the effects modeled. Mean number of young fledged per site was estimated by year. Estimates of the variance components by site and year was estimated with PROC MIXED of SAS (Littell et al. 1996). Structures considered for the variance of the repeated observations within sites were first order autoregressive, first order heterogeneous autoregressive, compound symmetry, heterogeneous compound symmetry, exponential local effects, also known as dispersion effects, in a log-linear variance model, and a null structure with zero covariances and constant variances across years, also commonly known as the variance components structure (Littell et al. 1996).

Random effects considered in the models were year and site effects. A fixed effect for even and odd years was also included in the models because there is a defined sequence of a year of high reproductive output, followed by a year of low reproductive output, followed by another year of high reproductive output, etc. The even/odd year fixed effect models this oscillating reproductive output.

Selection among models for both survival and reproduction parameter estimation was performed with the AICc criterion recommended by Burnham and Anderson (1998).

Population Model

A model of the female segment of the Colorado peregrine population based on the estimates of survival and reproduction was constructed in an Excel spreadsheet, and also as a SAS program. The model included 4 age classes (N_0, N_1, N_2, and N_3), even though the survival estimates used in the model had survival the same for all birds 3+ years old. The parameters in the deterministic model were number of fledglings per reproducing female (F), proportion of fledglings that are female (assumed to be SR = 0.5), survival for 4 age classes (S_0, S_1, S_2, and S_3), and the proportion of females that breed on their second birthday (B_2). In addition, a parameter for the proportion of fledglings removed by falconers was included in the model to allow the estimation of the effects of human take (T).

The difference equations for the transition from year t to year t+1 in model were:

$$N_{1,t+1} = N_{0,t} \; S_0,$$

$$N_{2,t+1} = N_{1,t} \; S_1,$$

$$N_{3,t+1} = N_{2,t} \; S_2 + N_{3,t} \; S_3, \text{ and}$$

$$N_{0,t+1} = (B_2 \; N_{2,t+1} + N_{3,t+1}) \; F \; \mathrm{SR} \; (1-\mathrm{T}).$$

A stochastic model was developed from the above deterministic model by replacing the mean fledglings per female with a value randomly drawn from the observed values for the years 1989 through 2001. The VLOOKUP function of Excel was used to randomly select one of the 13 observed values for each year in the model. That is, the fledgling rate was sampled with replacement from the observed values. This stochastic reproduction model was also extended to incorporate demographic stochasticity in the survival process. Instead of multiplying the population segment by a fixed survival rate to obtain the number of survivors, the process is treated as a binomial process, with the number of survivors drawn from a binomial distribution with the appropriate survival rate. However, given the size of the peregrine population in Colorado, demographic stochasticity had little or no effect on the model predictions.

Results

Survival Rate Estimation

The encounters of marked birds were sparse, and thus preclude complex models involving both time and age effects. The *a priori* list of models considered (Table 1) included models to evaluate age differences in survival for birds during their first 4 years of life, and time-specific effects in survival, live resighting rate, and dead recovery rate. The minimum AICc models all included time-specific variation in the band recovery rate, but did not suggest time-specific variation was required to model the live resighting rates. The minimum AICc model was $\{S(a2)\, p(.)\, r(t)\}$, with the second best model $\{S(a3)\, p(.)\, r(t)\}$ only 0.388 units above the minimum. I chose to use estimates from the 3-age model because this model is more realistic biologically, and the small difference in AICc values does not suggest that the 2-age class model is much better than the 3-age class model. Parameter estimates for the 3-age class model (Table 2) are reasonable in that survival increases with age, but all have large standard errors.

Reproduction Estimation

Average number of fledglings produced per nest during the interval 1989-2001 was 1.66059 with SE 0.044296 (Table 3). However, as shown in Table 3, there is considerable variation from year to year in the number of fledglings per breeding pair.

Model selection results (Table 4) for estimation of the variance components for site and year suggest that a first order autoregressive variance structure is required. Based on the minimum AICc model with the AR(1) variance structure, the estimate of the variance component for year was 0.01609, for site was 0.08438, with a residual variance component of 1.6069. The autocorrelation coefficient between consecutive years within a site as 0.1109. Thus, the variance components due to year and site were relatively minor compared to the residual variance in young fledged per breeding pair.

The even/odd year effect was estimated as 0.2482 with a SE of 0.1065 ($P < 0.0403$). Thus, the magnitude of the every-other-year oscillation is estimated to be 0.2482 young per nest.

Population Model

The deterministic population model provided an estimate of $\lambda = 1.028957$ with $T = 0$ and $F = 0$ for the survival parameter values in Table 2 and fledglings per reproducing female of 1.66059, estimated as the mean fledgling rate for the 1989-2001 interval. Thus, the model predicts that the Colorado peregrine population is increasing 2.9% per year, even with no 2-year old birds reproducing.

The effect of reproduction from 2-year birds is shown in Figure 1, and suggests that if all of the 2-year old birds breed, $\lambda = 1.080316$.

Results from the model with stochastic reproduction provided estimates of λ consistent with the deterministic model, e.g., for 10,000 simulations, $\overline{\lambda} = 1.0290287$ with SE = 0.000631839, giving a 95% confidence interval of 1.0277902 to 1.0302673 that encompasses the value estimated from the deterministic model.

The large standard errors of the parameter estimates used to build the population model (Tables 2 and 3) suggest that the estimate of λ obtained will also have a large standard error. I used Monte Carlo simulation techniques to draw values of each of the survival and reproduction parameters from a normal distribution with mean equal to the parameter estimate and standard deviation equal to the standard error of the parameter estimate. With a single set of parameters so obtained, 10,000 values of λ were averaged to obtain a mean for that parameter set. This process was repeated for 1000 parameter sets to obtain a SD of λ of 0.0612896. This value can be interpreted as a SE of the estimated λ that accounts for the SE of the input parameters. Average standard errors from the 10,000 simulations for the 1000 parameter sets was 0.0015142, suggesting that the preceding SD is not affected by the small amount of variation associated with each of the 1000 estimates.

Discussion

The best AICc model for estimation of survival required 28 parameters to estimate time-specific band recovery rates, $r(t)$. A more parsimonious model would provide estimates of survival with better precision. One approach to obtaining a more parsimonious model would be to include a covariate that models the variation in $r(t)$.

The estimated rate of increase from the population projection model is relatively high for a wildlife population. However, the number of nest sites monitored each year (Table 3) provides confirmation of the high estimates of λ. An exponential model regression, $\log_e$(No. Nest Monitored) = $\beta_0 + \beta_1$ Year, was used to estimate the rate of increase of numbers of nest monitored. From this regression, $\hat{\beta}_1 = 0.07883$ with SE = 0.00755 ($P < 0.0001$), giving an estimate of the annual rate of increase of the population (λ) of exp(0.07883) = 1.082. This value exceeds the maximum value predicted from the population model even with 100% of the 2-year old birds breeding. Although the estimate obtained from the number of nests monitored suffers from confounding with monitoring effort and effort to find new nests, the results still suggest that the Colorado peregrine population has had a high annual rate of increase, and that the predictions from the population model described here are consistent with another estimate of λ.

The high annual rate of increase suggests that moderate take can be accommodated by the Colorado peregrine population without affecting the population growth rate. Based on the population model presented with no 2-year old birds breeding, $\lambda = 1$ with 17.5% of the fledged young taken. With 50% of 2-year old birds breeding, $\lambda = 1$ with 26.7% of the fledged young taken, and with 100% of 2-year old birds breeding, $\lambda = 1$ with 34.0% of the fledged young taken.

Summary

A model of the Colorado peregrine falcon population was constructed from estimates of survival and reproduction derived from banded birds (1973-2001) and monitored nests (1989-2001). Survival estimates for 0-1, 1-2, and 2+ year old birds were 0.544, 0.670, and 0.800, respectively, with standard errors of 0.0765, 0.091, and 0.0544. Average young produced per pair was 1.660 (SE = 0.0443), but there was considerable variation across years (min = 1.388, SE = 0.1548, in 1995; max = 2.122, SE = 0.1393, in 2000). Based on a population model constructed from these estimates, the annual rate of population increase was 1.028957 for females first reproducing at 3 years of age, and 1.080316 for females first reproducing at 2 years of age. Given these high rates of population increase, some take could be accommodated by the Colorado peregrine population.

Literature Cited

Burnham, K. P. 1993. A theory for combined analysis of ring recovery and recapture data. Pages 199-213 in J.-D. Lebreton and P. M. North, editors. Marked individuals in the study of bird population. Birkhauser Verlag, Basel, Switzerland.

Burnham, K. P., and D. R. Anderson. 1998. Model selection and inference: a practical information-theoretic approach. Springer-Verlag, New York, New York, USA. 353 pp.

Littell, R. C., G. A. Milliken, W. W. Stroup, and R. D. Wolfinger. 1996. SAS® System for Mixed Models. SAS Institute Inc., Cary, NC, USA. 633pp.

Seber, G. A. F. 1970. Estimating time-specific survival and reporting rates for adult birds from band returns. Biometrika 57:313-318.

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

Table 1. Set of a priori models considered in Program MARK (White and Burnham 1999) for estimation of survival of peregrines banded as nestlings with the joint live-dead model of Burnham (1993). Model names include survival (*S*), live resighting probability (*p*) and probability that the band from a dead bird is recovered (*r*). For survival, models with time-specific survival (*t*), constant survival (.), and 2 (*a*2), 3 (*a*3), and 4 (*a*4) age classes were considered. Constant and time-specific models for both *p* and *r* were also considered. The fidelity parameter (*F*) was fixed to 1 in all models.

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Par	Deviance
{$S(a2)\ p(.)\ r(t)$}	710.841	0	0.46193	1	31	161.38
{$S(a3)\ p(.)\ r(t)$}	711.229	0.388	0.38047	0.8237	32	159.626
{$S(a4)\ p(.)\ r(t)$}	713.332	2.491	0.13294	0.2878	33	159.583
{$S(.)\ p(.)\ r(t)$}	716.701	5.86	0.02467	0.0534	30	169.377
{$S(a3)\ p(.)\ r(.)$}	742.565	31.724	0	0	5	247.202
{$S(a2)\ p(.)\ r(.)$}	742.803	31.962	0	0	4	249.462
{$S(t)\ p(.)\ r(.)$}	744.811	33.97	0	0	30	197.487
{$S(.)\ p(.)\ r(.)$}	753.754	42.913	0	0	3	262.429
{$S(a4)\ p(.)\ r(.)$}	886.175	175.334	0	0	6	388.786

Table 2. Parameter estimates from the 3-age class model $\{S(a3)\,p(.)\,r(t)\}$ of peregrine falcons in Colorado, estimated from birds banded 1974-2000.

Parameter	Estimate	SE	LCI	UCI
F (fixed to 1)	1	0	1	1
S age 0-1	0.543995	0.076538	0.394531	0.685934
S age 1-2	0.669762	0.098121	0.459491	0.828723
S age 2-3+	0.800291	0.054382	0.672873	0.886454
p	0.005662	0.002265	0.002581	0.012374
r 1974	0	1E-07	-3E-07	3E-07
r 1975	0	5E-07	-1.1E-06	1.1E-06
r 1976	0	3E-07	-7E-07	7E-07
r 1977	0.42494	0.275041	0.07526	0.870289
r 1978	0.781612	0.215533	0.231516	0.977021
r 1979	0.20686	0.101744	0.071797	0.467918
r 1980	0.190922	0.093857	0.066924	0.437053
r 1981	0	0	-1E-07	1E-07
r 1982	0	0	0	0
r 1983	0.074126	0.052037	0.017792	0.261367
r 1984	0.035033	0.034906	0.004775	0.215516
r 1985	0	0	0	0
r 1986	0.042528	0.042355	0.00575	0.254375
r 1987	0	0	0	0
r 1988	0.042219	0.029772	0.010304	0.157271
r 1989	0.016702	0.016695	0.002311	0.11077
r 1990	0.019441	0.01942	0.002685	0.127406
r 1991	0.021935	0.021894	0.003025	0.142181
r 1992	0.142769	0.053181	0.066349	0.280741
r 1993	0.01603	0.01601	0.002223	0.106429
r 1994	0.055134	0.031693	0.017401	0.161262
r 1995	0.083715	0.041537	0.030642	0.208902
r 1996	0.034717	0.024458	0.008529	0.130709
r 1997	0.060956	0.034981	0.019218	0.176984
r 1998	0	0	0	0
r 1999	0.040953	0.041348	0.005395	0.251596
r 2000	0.052539	0.053344	0.006742	0.311771
r 2001	0.069547	0.07131	0.008547	0.39323

Table 3. Summary of number of young fledged per nest for Colorado peregrines, 1989-2001.

Year	Number of Nests	Fledglings/Nest	SD	SE
1989	33	1.90909	1.35471	0.235825
1990	42	1.47619	1.15269	0.177864
1991	52	1.65385	1.16963	0.162198
1992	54	1.62963	1.29289	0.17594
1993	55	1.65455	1.36379	0.183893
1994	64	1.625	1.26617	0.158271
1995	67	1.38806	1.26677	0.154761
1996	83	1.71084	1.29285	0.141909
1997	71	1.42254	1.26109	0.149664
1998	81	1.95062	1.27379	0.141532
1999	88	1.59091	1.33594	0.142412
2000	98	2.12245	1.37927	0.139327
2001	90	1.35556	1.36003	0.14336
Mean	878	1.66059	1.31254	0.044296

Table 4. Model selection results for estimation of variance components of year and site with the MIXED procedure of SAS (Littell et al. 1996).

Variance Structure	Fixed Effects	Random Effects	AICc	Delta AICc
AR(1)	Even/Odd Years	Year Site	2950.4	0
AR(1)	Even/Odd Years		2951.8	1.4
AR(1)		Year Site	2952.3	1.9
AR(1)		Year	2953.7	3.3
Default	Even/Odd Years	Year Site	2954.6	4.2
CS	Even/Odd Years	Year Site	2954.6	4.2
Default		Year Site	2956.5	6.1
CS		Year	2956.5	6.1
CS		Year Site	2958.5	8.1
AR(1)		Site	2961.3	10.9
AR(1)			2962.8	12.4
ARH(1)	Even/Odd Years	Year Site	2970.2	19.8
EXP(YEAR)	Even/Odd Years	Year Site	2973.6	23.2

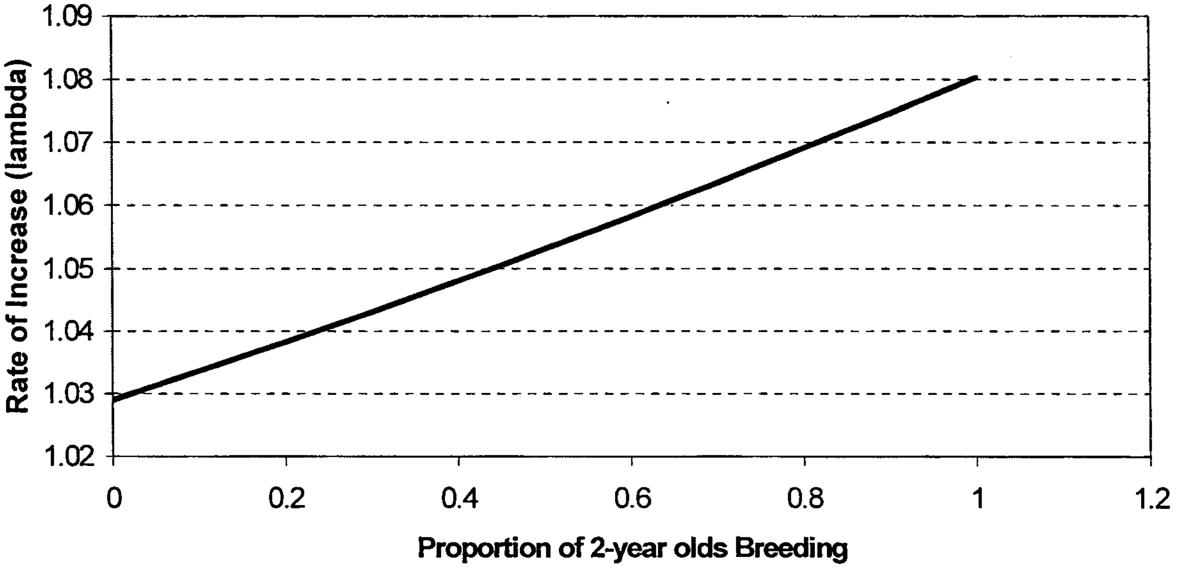

Figure 1. Predicted effect from the population model of the proportion of 2-year old females breeding on the rate of increase in the population (λ).

Colorado Division of Wildlife
Wildlife Research Report
July 2001 and July 2002

JOB PROGRESS REPORT

State of Colorado : Mammals Research

Work Package 3001 : Deer Conservation

Study No. 9 : Evaluation of GnRH-PAP as a Long-term Fertility Control Agent in Female Mule Deer (*Odocoileus hemionus hemionus*)

Federal Aid Project No. W-153-R-13 : Research and Development

Period Covered: July 1, 2001 - June 30, 2002

Author: Dan L. Baker, Ph.D.

Personnel: M. A. Wild, T. M. Nett, T. Davis, E. Jones, B. Hochmoth

ABSTRACT

We evaluated the effects of GnRH-PAP on mule deer pregnancy rates, duration of suppression of luteinizing hormone and progesterone secretion, blood chemistry and hematology, and reproductive behavior during 1 November to 30 December, 2001. Twenty-two adult female mule deer were assigned to one of 3 experimental groups. Nine female mule deer were treated with GnRH-PAP and 9 females served as untreated controls. The dose of GnRH-PAP used in this experiment did not lower pregnancy rates in female mule deer. Treated and control females tested positive for pregnancy specific protein B on all sampling dates and all delivered healthy fawns in July. At 30 days posttreatment, luteinizing hormone and progesterone were not different ($P > 0.58$) in treated and control mule deer. Reproductive behaviors of GnRH-PAP treated females were not different from controls. We conclude that the dose of GnRH-PAP administered in this experiment was ineffective in suppressing reproduction in female mule deer.

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EVALUATION OF GnRH-PAP AS A LONG-TERM FERTILITY CONTROL AGENT IN FEMALE MULE DEER (*ODOCOILEUS HEMIONUS HEMIONUS)*

Dan L. Baker

P. N. OBJECTIVES

1. Develop a practical and acceptable technology for long-term control of fertility in female mule deer.
2. Demonstrate the feasibility of controlling mule deer population growth in a field application.

SEGMENT OBJECTIVES

1. Evaluate the effectiveness of GnRH-PAP in preventing pregnancy in captive female mule deer.
2. Evaluate the duration of GnRH-PAP suppression of LH and progesterone secretion in female mule deer.
3. Assess the behavioral and physiological side-effects (if any) of GnRH-PAP in captive female mule deer.

INTRODUCTION

Controlling the growth of animal populations is fundamental to maintaining proper balance between wildlife and the habitats they occupy. This is particularly true for wild ungulates. Overabundant ungulates can cause serious degradation of plant communities, and preventing such damage requires controlling their numbers. Hunting has traditionally been used to control ungulate populations but there are increasingly more situations where hunting is infeasible. Such areas include urban areas where safety of people and property may be threatened, or national parks and refuges where populations are managed primarily for non-consumptive uses like wildlife viewing and photography or on military installations and industrial parks because of concerns for security. In these situations, alternatives to hunting or culling as a means of controlling ungulate numbers are needed.

Fertility control offers a potential alternative for controlling the growth of overabundant ungulate populations when traditional methods are infeasible or unacceptable (Kirkpatrick and Turner, 1985; Bomford, 1990; Garrot, 1995). However, current technology does not provide a means for controlling populations that is practical, economical and without undesirable side-effects (reviewed by Fagerstone *et al.,* 2001). For most free-ranging wild ungulate populations, permanent sterilization has been proposed as the most efficacious approach to population management (Hone 1992, Garrot 1995, Hobbs et al. 2000).

A promising new non-steroidal, non-immunological approach to permanent infertility involves analogs of gonadotropin-releasing hormone (GnRH). GnRH is a molecule produced in the hypothalamus of the brain. It directs specific cells in the anterior pituitary gland to synthesize and secrete two important reproductive hormones; follicle stimulating hormone (FSH) and luteinizing hormone (LH). These latter two hormones, known as gonadotropins, control the proper functioning of the ovaries in the female and the testes in the male.

Analogs of GnRH have the potential to permanently inhibit reproduction. By coupling a superactive analog of GnRH to a cytotoxin, it should be possible to specifically target that toxin to LH and FSH-secreting cells in the anterior pituitary gland (Collier and Kaplan 1984, Pastan et al. 1986). Therefore, a single GnRH-toxin conjugate has the potential to induce sterility in both sexes and numerous species of animals. There are many natural cytotoxins available for conjugating to GnRH. Toxins are composed of two subunits, a toxic subunit and a binding subunit. In order to target the toxin to specific cell types (rather than all cells) within the body, the binding subunit of the toxin can be removed and replaced by a molecule that will bind to only one cell type, in our case an analog of GnRH. This will target the toxin to gonadotropin secreting cells in the anterior pituitary gland. This approach has several potential advantages over other methods of contraception. These include:

1) a single treatment should permanently sterilize an animal;
2) the same treatment should be effective in both males and females and in different vertebrate species;
3) GnRH-toxin conjugate is a protein and is metabolized from the body within a few days of treatment, therefore it poses no threat to non-target species;
4) the small volume required for contraception facilitates microencapsulation and administration by syringe dart or biodegradable bullet.

Proposed Research

To our knowledge, only limited investigations have been conducted with GnRH-PAP in wild ungulates (Nett et al. 2001). In order to provide an estimate of the dose of GnRH-PAP conjugate required for contraception, it is essential that the potency of GnRH analog be determined in each species and at different phases of the reproductive cycle. We addressed this question in a series of GnRH challenge trials with captive mule deer at the Foothills Wildlife Research Facility in Fort Collins, Colorado (Baker et al. 1996). In these experiments, we determined the most effective dose of GnRH analog in female mule deer during the breeding season to be 1 μg/50 kg BW. This is the minimum dose of GnRH analog that will illicit maximum LH secretion.

The next questions that needed to be answered were "how effective is GnRH-PAP in preventing pregnancy, how durable are its effects over time, and are there unacceptable side effects? The objective of this experiment is to begin to address these questions. Specifically, our objectives were:

1) to evaluate the effectiveness of GnRH-PAP in preventing pregnancy in mule deer;
2) to evaluate the duration of GnRH-PAP suppression of LH and progesterone secretion;
3) to assess the behavioral and physiological side-effects (if any) of GnRH-PAP treatment.

MATERIALS AND METHODS

Reproductive Biology

Mule deer *(Odocoileus hemionus hemionus)* are polytocous, multiovular, spontaneous ovulators that exhibit highly seasonal patterns of reproduction that are controlled by photoperiod regimens. The onset of the breeding season occurs during decreasing daily photoperiods of autumn and is preceded by a period of deep anestrous in summer (Plotka et al.1977). The first ovulation of the breeding season is usually preceded by one or more silent ovulations associated with the formation of short-lived corpora lutea that serve to synchronize the first overt estrus within a herd (Thomas and McT.Cowan 1975). In temperate North America, the majority of conceptions occur in late November, but recurrent estrous cycles of 24 -28 days are possible through March if females fail to conceive (Knox et al. 1988). In early spring, coincidental with increasing day length, reproductive cycles cease and females remain anestrous until October. For pregnant females, parturition generally occurs in late May or early June, after a gestation period of about 200 days (Anderson and Medin 1966). Most females produce one fawn when they are two years old, and one or two annually thereafter (Cowan 1956).

Experimental Design

We evaluated the effects of GnRH-PAP on mule deer pregnancy rates, duration of suppression of LH and progesterone secretion, blood chemistry and hematology, and reproductive behavior during 1 November to 25 December 2002. Twenty-two adult female and 2 adult male mule deer were used in this experiment. Females were assigned to one of 3 experimental groups based on their tractability for handling and blood sampling. Nine female mule deer (**Group A**) were treated with GnRH-PAP and 9 females (**Group B**) served as untreated controls and were used to compare pregnancy rates, blood chemistry and hematology, and reproductive behavior to those of treated animals. Immediately following the pretreatment GnRH challenge trial, and before catheters were removed, 9 females in **Group A** were administered an optimum dose of GnRH-PAP ($1\mu g/50kgBW$) IV. Females in **Groups A** and **B** were maintained together with 2 adult male mule deer in a 2 hectare pasture. The remaining 4 females (**Group C**) served as untreated, non-pregnant controls and were placed in a separate pasture (0.5 ha) without direct contact with male deer. We compared LH and progesterone secretion of these females to those treated with GnRH-PAP (**Group A**). Sample size requirements were based on the variances observed in these measurements from previous studies with captive mule deer and expected effectiveness of treatment (Baker et al. 1996, Nett et al. 2001).

Experimental Animals

In order to meet sample size requirements calculated for this experiment (see pages 5-7), 5, adult, free-ranging female mule deer were captured from urban areas of the front range of Colorado and transported to FWRF. We attempted to capture the most human-habituated deer as possible in order to minimize any stress related to captivity.

All deer were captured and handled under the supervision of a veterinarian using one of several previously approved methods (Conner and Miller, CDOW ACUC 12-1999 & addenda); however thiafentanil oxalate (0.1 mg/kg) was substituted for carfentanil citrate as a primary tranquilization drug. Once tranquilized, does were blindfolded, condition and vital signs checked, eartagged, collared, vaccinated with 7-way clostridial vaccine, treated with Ivermectin (0.1 mg/kg) and long-acting penicillin. Each doe was then placed in a closed vehicle (covered horse trailer), and sedation reversed and blindfold removed. After release at FWRF, deer were observed daily for any signs of post-capture injuries.

Response Measurements

Hormonal evaluation. Prior to application of GnRH-PAP, we measured the LH response of each female in **Groups A** and **C** to a challenge dose of GnRH analog. Results from this trial provided a pretreatment baseline for comparison to future posttreatment LH responses. This and succeeding LH challenge trials were conducted as follows: On day 1 of the trial, deer were moved from 2 ha pastures to individual isolation pens, sedated (4-6 ml, 2:1 ketamine (200 mg/ml):xylazine hydrochloride (100 mg/ml, IM), and fitted nonsurgically with indwelling jugular catheters. Animals were reversed with yohimbine (0.125 mg/kg, IV). On day 2, we administered GnRH analog (1μ /50 kg BW) through the cannula and collect blood samples (5 ml) at 0, 60, 120, 180, 240, 300, 360, and 480 minutes postinjection. Following the last blood collection, catheters were removed and each animal given an antibiotic (ceftiofur, (1 mg/kg, IV). Animals were then returned to 2 ha pastures. Serum was stored at -20 ^{0}C until analyzed for LH (Niswender et al. 1969). The duration of contraceptive effectiveness was assessed by conducting similar GnRH challenge trials each month from November, 2001 to December 2003.

Analysis. Responsiveness of the pituitary to GnRH challenge was assessed in three ways: 1) maximum LH (ng/ml) response achieved postinjection minus baseline, 2) time required to reach maximum LH, and 3) total amount of LH secreted (ng/ml/min).

Pregnancy rates. We assessed contraceptive effectiveness by determining the pregnancy rates of treated (Group A) and control (Group B) deer. A single blood sample (10 ml) was taken via jugular venipuncture from each animal for pregnancy-specific protein B (PSPB) analysis approximately 60, 90, and 220 days post-conception (Willard et al. 1998). Animal handling and blood collections for PSPB followed methods previously described for hormonal assessment and were collected in conjunction with these measurements. Neonates born to any experimental animal were incorporated into the resident FWRF mule deer herd.

General health. Limited knowledge of the effects of GnRH-PAP on nutrition, body weight dynamics, blood chemistry and general health of mule deer have been reported in a previous study at this facility (Nett et al. 2001). However, since a different toxin conjugate is being tested in this experiment, we evaluated these potential side-effects here as well. We assessed physiological side-effects of GnRH by comparing serum chemistry, hematology, and body weight dynamics of treated **(Group A)** and untreated, non-pregnant mule deer **(Group C)**. Blood collections and body weight measurements were made in conjunction with GnRH challenge trials. Blood samples for hematology and serum chemistry analysis were collected prior to treatment and at 90 days posttreatment then submitted for analysis to Colorado State University, Veterinary Teaching Hospital, Clinical Pathology Laboratory, Fort Collins, Colorado, USA.

Serum chemistry profiles were obtained using a Hatachi 917 autoanalyzer (Roche/Boehringer Mannheim, Indianapolis, Indiana, USA) for the following parameters: glucose, creatinine, phosphorus, calcium, magnesium, total protein, albumin, globulin, albumin/globulin ratio, bilirubin, creatinine kinase, aspartate aminotransferase, gamma-glutamyltransferase, sorbitol dehydrogenase, sodium, potassium, chloride, and biocarbonate.

Values for the following hematological parameters were obtained using an ADVIA 12O autoanalyzer (Bayer Corporation, Tarrytown, New York, USA): nucleated cells, neutrophils, lymphocytes, monocytes, eosinophils, plasma protein, erythrocyte, hemoglobin, packed cell volume, mean corpuscular volume, mean corpuscular hemoglobin concentration, platelets, and fibrinogen.

Reproductive behavior. The effectiveness of GnRH-PAP as a fertility control agent is dependent upon permanent suppression of ovulation and steroidogenesis. Thus, we tested 2 hypotheses relative to the effects of leuprolide on reproductive behavior of mule deer: (1) because GnRH-PAP is expected to suppress gonadotrophin secretion and ovulation, we predicted that sexual interactions during the breeding season (Nov 1 - Dec 20) would be reduced in treated females (Group A) compared to untreated controls (Group B), and (2) once untreated females become pregnant, reproductive behaviors would cease and sexual interactions would be similar between untreated and treated females during the post-breeding season (Jan 10 - Mar 31).

To test these hypotheses, we examined the effects of GnRH-PAP on reproductive interactions of male and female deer during 2 time periods; breeding season (defined as the period November 1- December 20, 2001) and postbreeding season (defined as the period January 10 - March 27, 2002). On November 1, 2001, female deer in Group A were treated with GnRH-PAP and released with untreated controls (Group B) into 2 ha paddocks. Four days later (November 5), we placed 2 adult male mule deer with these groups and initiate behavioral observations. All females were individually identified with color/numeric-coded neck collars. Animals selected as treatments and controls were unknown to observers. Behavioral measurements were made from a distance of 50-350 m from an elevated tower (10 m) using binoculars and a spotting scope during the day, and a spotlight and night vision scope at night. We recorded selected behaviors using a lap-top computer with a behavioral software program.

We used focal animal sampling procedures to sample reproductive behaviors of all experimental animals over a 24-hour period (Lehner, 1996). Previous studies (Baker et al. 2000) have shown that mule deer are most active in morning (0500-0800), late day (1400-1700) and night (2000-2400). Thus, time-of-day sampling periods was randomly assigned each week using a randomized block design. Each sampling period consisted of at least two hours of continuous observations.

Sample size estimation for pregnancy rate and behavior measurements. Sample size calculations were based on results of previous investigations (Baker 2001). We used male pre-copulatory behavioral rates to estimate sample size because these rates were much higher than other rates (Table 1).

Table 1. Behavior rates for mule deer (Baker 2001).

Behavior Category Treatment Group	Mean (# behaviors/day)	SE
Copulatory		
Control	0.20	0.17
Leuprolide	0.29	0.24
Male Pre-Copulatory		
Control	8.28	1.77
Leuprolide SQ	22.18	2.50
Female Pre-Copulatory		
Control	0.22	0.34
Leuprolide SQ	1.35	0.47
General Breeding		
Control	2.00	0.41
Leuprolide SQ	2.96	0.58

For control females, we directly bootstrapped a given sample size from the male pre-copulatory rates exhibited towards control does from the Table 1. That is, for a sample size of 6, we randomly selected 6 does (with replacement) for the given observation period, from the 8 control does. For treated does, we followed the same procedure except that we multiplied the response by the effect size. For example, for a +50% effect size, we multiplied the control response by 1.5. We then ran sample sizes for increased behavioral rates because this would be the most problematic to the animal. However, the power should be almost the same for a -50% effect size. We considered the higher behavior rates because increased behavior and corresponding energy output would be the most critical to the animal. This approach captured the day to day variability in behavior rates, because we bootstrapped for each observation period, but it assumes that the variability in behavior is the same for the control and treatment does.

Next, we ran the procedure for 52 and 104 observation periods. We assumed 104 observation periods would be acceptable for 2 reasons. First, our proposed collection schedule was:

a. November – 4 weeks x 3 observation periods/day x 5 days/week = 60 obs periods

b. December – 4 weeks x 2 observation periods/day x 5 days/week = 40 obs periods

Total = 100 observation periods.

Since power was not nearly as sensitive to the number of observation periods as to the number of animals used in the experiment; we decided that if we were somewhat below the 104 observations used in sample size simulations, it would not change the power meaningfully. Power results were based on the number of times an effect was detected during 100 simulations. Results from male precopulatory behavioral rates indicated that a sample size of 14 does (7 control and 7 treatment) should provide power of >90% to detect a 50% effect size.

Table 2. Sample size calculations for a given effect size using male precopulatory behavior rates.

Effect size	Sample Size *	Number of Observation Periods	α	Power
25%	12	104	0.05	57%
			0.10	74%
	16	104	0.05	81%
			0.10	91%
30%	8	104	0.05	68%
			0.10	70%
	10	104	0.05	72%
			0.10	83%
	12	104	0.05	90%
			0.10	95%
	12	52	0.05	68%
			0.10	81%
40%	**9**	**104**	**0.05**	**91%**
			0.10	**97%**
50%	**7**	**104**	**0.05**	**94%**
			0.10	**96%**
	8	**104**	**0.05**	**97%**
			0.10	**100%**
	8	52	0.05	74%
			0.10	88%

* Sample size for each group, e.g. 12 means 12 treatment and 12 control does.

The daily male precopulatory rate for the control group was 8.3 behaviors/day. For a 50% effect size, we could detect a difference between the control mean of 8.3 behaviors/day and a treatment mean of <4.2 and >12.5 behaviors per day. For a 40% difference in behavior rates, we could detect a difference between the control mean of 8.3 behaviors/day and a treatment mean of <5 and >11.6 behaviors per day.

After estimating the number of animals needed to detect behavioral differences, we calculated power to detect differences in pregnancy rates. If we have 7 control and 7 treatment animals, and 1 treatment animal gets pregnant, and 1 control animal does not get pregnant, we had >95% power to detect this difference. Basically, to detect a difference in pregnancy rates in the case where 1 treatment animal gets pregnant, and 1 control animal does not get pregnant, we could have as low as 5 treatment and 5 control animals and still have >90% power to detect a difference. Thus, the sample size needed to detect differences in behavior rates was sufficient to detect differences in pregnancy rates. Our calculations indicated that the optimum sample size for these measurements to be 14 animals (7 control : 7 treated), however, there is a high probability of losing at least one or two animals per year to non-treatment related mortality. Therefore, in order to insure meaningful measurements over the 2-year investigation, we increased our sample size to 18 animals (9 control: 9 treated).

Statistical Analysis

We analyzed for differences among hormone levels using least squares analysis of variance for general linear models (SAS Institute 1993). Responses to treatments were analyzed with one-way analysis of variance for a randomized complete block design with repeated measures structure. Treatment effects were tested using the animal-within-treatment variance as the error term. Time was treated as a within-subject effect using a multivariate approach to repeated measures (Morrison, 1976). A "protected" least significant difference test (Milliken and Johnson 1984) was used to separate means when the overall F-test indicated significant treatment effects ($P < 0.05$).

We tested specific reproductive behavior hypotheses that mean behavior rate was not different between treatment and control groups for both the breeding and postbreeding seasons using an ANOVA model with a repeated measures structure. Similar to the hormonal analysis, time was be treated as a within subject effect using multivariate approach to repeated measures (Morrison, 1976). To test for treatment effects, we accounted for time-of-day, date effects and their interactions. PROC GENMOD (SAS Institute 1993) was used to estimate and test for differences in mean behavior rate by treatment, time-of-day, and date. Means and standard errors were estimated using least squares, and hypothesis tests were based on type III generalized estimating equations that account for correlation in repeated measurements.

RESULTS AND DISCUSSION

Pregnancy rates. This dose of GnRH-PAP did not lower pregnancy rates in female mule. Treated and control females tested positive for PSPB on all sampling dates and all delivered healthy fawns in July - August, 2002. All fawns were incorporated into the existing captive mule deer herd at the FWRF.

Hormonal evaluation. GnRH-PAP did not cause a significant reduction in LH in treated female mule deer. Peak serum LH concentrations for treated animals, after 30 days posttreatment, averaged 8.6 ± 1.97 ng/ml and 9.7 ± 3.0 ng/ml for controls. Based on these responses, GnRH challenge trials were terminated at + 30 days posttreatment (4 Dec 2001).

Reproductive behavior. We observed male to male dominance interactions immediately following their release into the pastures with treated and untreated females. Within 10 days, one male established dominance. Thereafter, the subdominant male retreated to remote locations within the pastures and rarely interacted with females or the dominant male for the remainder of the experiment. Contrary to our hypothesis, sexual interactions were not different ($P > 0.65$) during the breeding and post-breeding seasons between GnRH-treated females and untreated controls for any of the breeding behavior categories. We observed almost no sexual interactions between the dominant male and treated or untreated females during the postbreeding season.

We conclude from these measurements that the dose of GnRH-PAP administered in this experiment was ineffective in suppressing reproduction in female mule deer. Future experiments should investigate the effects of higher levels of GnRH-PAP on reproductive performance in this species.

LITERATURE CITED

Anderson, A. E., and D. E. Medin. 1966. The breeding season in migratory mule deer. Outdoor Facts, Number 60, Colorado Division of Wildlife.

Baker, D. L. 2001. Technical support for deer population management at the Rocky Mountain Arsenal National Wildlife Refuge, Denver, Colorado. Pages 215-232 *in* Wildlife Research Report, Mammals Research, Federal Aid Projects, Job Progress Report, Project W-153-R-4, SP 1, J1. Colorado Division of Wildlife, Fort Collins, Colorado, USA.

_______. 1996. Regulation of mule deer population growth by fertility control: laboratory, field, and simulation experiments. Pages 81-87 *in* Wildlife Research Report, Mammals Research, Federal Aid Projects, Job Progress Report, Project W-153-R-4, SP 1, J1. Colorado Division of Wildlife, Fort Collins, Colorado, USA.

Bomford, M. 1990. A role for fertility control in wildlife management? Department of Primary Industries and Energy Bureau of Rural Resources Bulletin No 7 Australian Government Publishing Service Canberra Australia..

Collier, R. J., and D. A. Kaplan. 1984. Immunotoxins. Scientific American 251:64.

Cowan, I. McT. 1956. Life and times of the coast black-tailed deer. Pages 56-78 *in The Deer of North America,* ed. W. P. Taylor. Wildlife Management Institute, Washington, D. C.

Fagerstone K. A., M. Coffey, P. Curtis, R. Dolbeer, G. Killian, L. A. Miller, and L. Wilmot. 2001. Wildlife contraception. Wildlife Society Technical Review. Proceedings of the Wildlife Society 8th Annual Conference, Reno, USA.

Garrot, R. A. 1995. Effective management of free-ranging ungulate populations using contraception Wildlife Society Bulletin 23:445-452.

Hone, J. 1992. Rate of increase and fertility control. Journal of Applied Ecology 29:695-698.

Hobbs, N. T., D. C. Bowden, and D. L. Baker. 2000. Effects of fertility control on populations of ungulates: general, stage-structured models. Journal of Wildlife Management 64: 473-491.

Knox, W. M., K. V. Miller, and R. L. Marchinton. 1988. Recurrent estrous cycles in white-tailed deer. Journal of Mammalogy 69:384-386.

Lehner, P. N. 1996. *Handbook of Ethological Methods. Second Edition.* Cambridge University Press, Cambridge, UK.

Milliken, G. A., and D. E. Johnson. 1984. *Analysis of Messy Data. Volume I. Designed Experiments.* Lifetime Learning Publications, Belmont,California, USA

Morrison, D. F. 1976. *Multivariate Statistical Methods.* McGraw-Hill Book Co., New York, USA

Pastan, I., M. C. Willingham, and D. J. FitzGerald. 1986. Immunotoxins. Cell 47:641-648.

Plotka, E. D., U. S. Seal, G. C. Schmoller, P. D. Karns, and K. D. Keenlyne. 1997. Reproductive steroids in the white-tailed deer (*Odocoileus virginianus borealis*). 1. Seasonal changes in the female. Biology of Reproduction 16:340-343.

Thomas, D. C., and I. McT. Cowan. 1975. The pattern of reproduction in female Columbian black-tailed deer, *Odocoileus hemionus columbianus.* Journal of Reproduction and Fertility 44:261-272.

Nett, T. M., D. L. Baker, and M. A. Wild. 2001. Evaluation of GnRH-PAP as a chemosterilant in captive mule deer (*Odocoileus hemionus hemionus*). Proceedings of the 5th International Symposium on Fertility Control in Wildlife, Kruger National Park, South Africa, August 19-22.

Niswender G. D., L. E. Reichert, Jr., A. R. Midgley, and A. V. Nalbandov. 1969. Radioimmunoassay for bovine and ovine luteinizing hormone. Endocrinology 84:1166-1173.

Willard, S. T., R. G. Sasser, J. T. Jaques, D. R. White, D. A. Neuendorff, and R. D. Randel. 1998. Early pregnancy detection and hormonal characterization of embryonic-fetal mortality in fallow deer (*Dama dama*). Theriogenology 49:861-869.

Colorado Division of Wildlife
Wildlife Research Report
July 2001 and July 2002

PROGRESS REPORT

State of Colorado : Division of Wildlife – Mammals Research

Work Package No. 3001 : Deer Conservation

Task 10 : Chronic Wasting Disease in Mule Deer

Federal Aid Project W-185-R : Monitoring & Management

Period Covered: July 1, 2000 through June 30, 2001

Author: Michael W. Miller, D.V.M.

Personnel: T. R. Davis, L. L. Wolfe, T. H. Baker, K. T. Larsen, E. S. Williams

Interim Report – Preliminary Results
This work continues, and precise analysis of data has yet to be accomplished. Manipulation or interpretation of these data beyond that contained in this report should be labeled as such and is discouraged.

ABSTRACT

We continued conducting research on various aspects of chronic wasting disease (CWD) epidemiology and management. Results of original research, as well as two review articles, were published or accepted for publication during this segment, and citations are included in the body of the report.

In addition to published studies, we completed a study of CWD pathogenesis in mule deer. Seven of 10 orally inoculated deer that survived >12 mo postinoculation (PI) developed clinical CWD. Five of the seven deer that showed clinical signs either died or were euthanized in end-stage clinical CWD 20-26 mo PI; the other two were euthanized showing mild or marked clinical signs 20 mo PI according to the established sampling schedule. Based on observations of the seven deer that developed clinical CWD, earliest signs were first noticed in individuals about 14.5 to 19 mo PI (mean ± SE = 17.3 ± 0.7 mo PI). Early clinical signs were both subtle and inconsistent. As clinical disease progressed, behavioral changes and loss of body condition became more pronounced and more consistent. Ptyalism (drooling), polydypsia (excessive water consumption), and polyuria (excessive urination), widely regarded as "classic" signs of CWD, occurred relatively late in clinical courses and were not seen in all cases. Among the five deer that lived long enough to develop terminal CWD, clinical courses ranged from about 3.5 to 9.5 mo (mean ± SE = 5.7 ± 1.2 mo); the shortest clinical course (about 3.5 mo) was complicated by acute aspiration pneumonia. Immunohistochemistry and histopathology results are pending.

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INTRODUCTION

We continued conducting research on various aspects of chronic wasting disease (CWD) epidemiology and management.

METHODS

Epidemiology & Management

Two review articles on CWD epidemiology were accepted for publication during this segment in the *Journal of Wildlife Management* and in the *Revue Scientifique et Technique Office international des Épizooties*. Results of three earlier studies on CWD epidemiology were published during this segment in the *Journal of Wildlife Diseases* and the *Journal of Wildlife Management.*

Pathogenesis & Diagnosis

Results of two original studies on CWD diagnosis in mule deer were accepted for publication in the *Journal of Wildlife Management* and in *The Veterinary Record.*

We completed a study of CWD pathogenesis in mule deer. The methods for this project were included in previous progress reports.

We also initiated preliminary field work to develop and evaluate reliable methods for collecting tonsil biopsies from live mule deer for use as a diagnostic and management tool. No results are available for reporting in this reporting period.

RESULTS AND DISCUSSION

Epidemiology & Management

Two review articles on CWD epidemiology were published during this segment:

Williams, E. S., and M. W. Miller. 2002. Chronic wasting disease in deer and elk in North America. *Revue Scientifique et Technique Office international des Épizooties* 21:305-316.

Williams, E. S., M. W. Miller, T. J. Kreeger, R. H. Kahn, and E. T. Thorne. 2002. Chronic wasting disease of deer and elk: A review with recommendations for management. *Journal of Wildlife Management* 66:551–563.

Results of three studies on CWD epidemiology were published during this segment:

Conner, M. M., C. W. McCarty, and M. W. Miller. 2000. Detection of bias in harvest-based estimates of chronic wasting disease prevalence in mule deer. Journal of Wildlife Diseases 36:691–699.

Gross, J. E., and M. W. Miller. 2001. Chronic wasting disease in mule deer: disease dynamics and control. Journal of Wildlife Management 65:205–215.

Miller, M. W., E. S. Williams, C. W. McCarty, T. R. Spraker, T. J. Kreeger, C. T. Larsen, and E. T. Thorne. 2000. Epizootiology of chronic wasting disease in free-ranging cervids in Colorado and Wyoming. Journal of Wildlife Diseases 36:676–690.

Pathogenesis & Diagnosis

Nineteen of 20 mule deer orally inoculated with 5 g brain homogenate from CWD-infected mule deer survived ≥ 3 months postinoculation (PI) and were examined as described in the original study plan;

one fawn died <1 day PI of capture-related complications, and was not evaluated here. Of the 19 remaining deer, one died from a cervical fracture at 3 mo PI and 12 others were euthanized at 3, 6, 9, 12, 16, or 20 mo PI according to the study schedule; the other 6 were allowed to survive to terminal stages of CWD or study termination.

Seven of 10 orally inoculated deer that survived >12 mo postinoculation (PI) developed clinical CWD; four of these were males and three were females. Of the three that did not show at least early clinical signs, two were euthanized 16 mo PI but the third appeared clinically normal when euthanized 26 mo PI. Five of the seven deer that showed clinical signs either died or were euthanized in end-stage clinical CWD 20-26 mo PI; the other two were euthanized showing mild or marked clinical signs 20 mo PI according to the established sampling schedule.

Based on observations of the seven deer that developed clinical CWD, earliest signs (dullness in eyes, diminished alertness, misdirected behaviors, piloerection) were first noticed in individuals about 14.5 to 19 mo PI (mean ± SE = 17.3 ± 0.7 mo PI). Early on, clinical signs were both subtle and inconsistent. As clinical disease progressed, behavioral changes (e.g., blank staring, uncharacteristic or subdued responses to aversive stimuli, lowered head or other unusual postures, ataxia, inefficient foraging activity) and loss of body condition became more pronounced and more consistent. Ptyalism, polydypsia, and polyuria occurred relatively late in clinical courses, and were not seen in all cases. Among the five deer that lived long enough to develop terminal CWD, clinical courses ranged from about 3.5 to 9.5 mo (mean ± SE = 5.7 ± 1.2 mo); the shortest clinical course (about 3.5 mo) was complicated by acute aspiration pneumonia. Immunohistochemistry and histopathology results are pending.

Results of two original studies on CWD diagnosis in mule deer were accepted for publication. One of these (Wolfe et al. 2001) represents the first report of a method for detecting CWD infection in live animals. These publications were:

Miller, M. W., and E. S. Williams. 2002. Detecting PrP^{CWD} in mule deer by immunohistochemistry of lymphoid tissues. Veterinary Record151:610–612.

Wolfe, L. L., M. M. Conner, T. H. Baker, V. J. Dreitz, K. P. Burnham, E. S. Williams, N. T. Hobbs, and M. W. Miller. 2002. Evaluation of antemortem sampling to estimate chronic wasting disease prevalence in free-ranging mule deer. Journal of Wildlife Management 66:564–573.

Colorado Division of Wildlife
Wildlife Research Report
July 2001 and July 2002

JOB PROGRESS REPORT

State of Colorado : Mammals Research – Terrestrial Section

Work Package No. 3001 : Deer Conservation

Task No. A : Deer Aerial Survey Population Estimation Rangely Deer Data Analysis Unit D-6, GMU 10

Project No. W-153-R-14

Period Covered: July 1, 2000 – June 30, 2001

Author: D. J. Freddy

Personnel: V. Graham, W. deVergie, J. Ellenberger, C. Wagner, P. Schnurr, R. Kahn, R. Velarde, G. Miller, T. Wygant, F. Pusateri of CDOW, Dr. G. White and M. Kneeland of Colorado State University, J. Unsworth, Idaho Department of Fish and Game, consultants V. Howard, Jr. and T. Bickle, Colorado Mule Deer Association, Colorado Bowhunters Association, Dynamic Aviation, and New Air Aviation.

ABSTRACT

Sportsmen expressed concerns about the credibility of Colorado's survey sampling methodology to estimate numbers of mule deer (*Odocoileus hemionus*) in specific populations. We therefore conducted an aerial survey in Colorado Deer Analysis Unit D-6 which was an area of concern to sportsmen. We used helicopters from 28 February to 5 March 2001 to count mule deer on randomly selected quadrats 0.25-mi^2 or 1.00-mi^2 in size distributed within 11 strata encompassing 364 mi^2 of deer winter range composed of sagebrush (*Artemisia tridentata*) and pinyon-juniper (*Pinus edulis-Juniperous osteosperma*) habitats. From these counts, we estimated population size using standard stratified random sample estimators and the Idaho mule deer sightability model. Stratified population estimate was 6,782 ± 2,497 (90% CI) deer. Counts corrected for sightability increased the estimate to 11,052 ± 3,503 (90% CI) deer. Both aerial survey estimates buttressed population estimates of 7,000 to 7,300 deer derived from computer models and were substantially greater than sportsmen's estimate of 1,750 deer. Cost of this validation exercise exceeded 50,000 $US. We interpreted this exercise as a forerunner of the public's interest in challenging agency integrity or methods used to estimate status of ungulate populations. We caution agencies to use tested methodology that can withstand dispassionate public scrutiny.

Copies of this report containing the original colored versions of the figures are available for review from the Research Center Library, Colorado Division of Wildlife, 317 West Prospect Road, Fort Collins, CO, 80526, USA.

All information in this report is preliminary and subject to further evaluation.

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PROJECT SUMMARY REPORT
DEER AERIAL SURVEY POPULATION ESTIMATION
RANGELY DEER DATA ANALYSIS UNIT D-6, GAME MANAGEMENT UNIT 10
COLORADO DIVISION OF WILDLIFE
PRESENTED APRIL 19, 2001

DOCUMENT PREPARED TO INFORM
COLORADO DIVISION OF WILDLIFE
COLORADO WILDLIFE COMMISSION
COLORADO MULE DEER ASSOCIATION
COLORADO BOWHUNTERS ASSOCIATION

Includes Draft Manuscript Subject to Future Editorial Review©

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DEER AERIAL SURVEY POPULATION ESTIMATION
RANGELY DEER DATA ANALYSIS UNIT D-6, GAME MANAGEMENT UNIT 10,
28 FEBRUARY- 5 MARCH 2001

REPORT CONTENTS

SECTION A – EXECUTIVE SUMMARY

DEER AERIAL SURVEY POPULATION ESTIMATION RANGELY DEER DATA ANALYSIS UNIT D-6, GAME MANAGEMENT UNIT 10

A. Sportsmen in Colorado alleged that estimates for numbers of mule deer in western Colorado were substantially over-estimated by the Colorado Division of Wildlife (CDOW). Sportsmen believed there were only 128,000 deer in Colorado in areas west of the Continental Divide where CDOW estimated 409,000 deer. This level of discrepancy also existed for specific deer populations such as in the Rangely Deer Analysis Unit D-6 where sportsmen estimated 1,750 deer compared to CDOW estimates of 7,000 deer.

B. A series of meetings between CDOW and sportsmen from September 2000 through February 2001 did not resolve fundamental issues of sportsmen's mistrust of estimated deer population status.

C. On February 16, 2001 CDOW Director Russell George authorized the Terrestrial Section to implement aerial surveys to estimate numbers of deer in Rangely Unit D-6 in accordance with survey methodologies agreed to by all interested parties, including participation in surveys by individuals independently representing sportsmen's concerns. Financial costs for the survey were paid primarily with Wildlife Commission Discretionary Funds with additional contributions from the Colorado Mule Deer Association and Colorado Bowhunters Association.

D. CDOW conducted an aerial survey to estimate numbers of deer in D-6 using Colorado quadrat survey techniques that incorporated adjustments in estimated population size based on Idaho mule deer sightability models as requested by sportsmen. The survey was conducted 28 February to 5 March, 2001.

E. Estimated numbers of deer in D-6 were 6,782 ± 2,497 based on Colorado quadrat system and 11,052 ± 3,503 when adjusted for the Idaho mule deer sightability model. Population estimates based on CDOW computer models were 7,000 to 7,312 deer. All estimates were substantially higher than the 1,750 deer estimated by sportsmen.

F. Financial and personnel costs to design, implement, and analyze survey results likely exceed $50,000. Final costs estimates are not yet available.

G. This validation exercise challenged the credibility of CDOW personnel and methodologies and the credibility of sportsmen groups. All parties participated within a certain level of risk. Not to be overlooked was a near fatal helicopter incident that threatened lives of personnel involved in an aerial survey conducted to alleviate mistrust among interested parties.

H. We interpret this validation exercise as a potential forerunner of the public's interest in either challenging or understanding methods used to estimate status of wildlife populations. We can only caution that wildlife agencies should gather information using methodology that can withstand public scrutiny. We would hope that this exercise would restore a certain level of public confidence in the CDOW's efforts to manage wildlife in Colorado.

SECTION B – DRAFT TECHNICAL MANUSCRIPT

April 18, 2001 **Draft**
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RH: Deer Population Estimates

ESTIMATING MULE DEER POPULATION SIZE USING COLORADO QUADRAT SYSTEM CORRECTED FOR IDAHO MULE DEER SIGHTABILITY: A SPORTSMEN'S ISSUE.

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Abstract: Sportsmen expressed concerns about the credibility of Colorado's survey sampling methodology to estimate numbers of mule deer (*Odocoileus hemionus*) in specific populations. We therefore conducted an aerial survey in Colorado Deer Analysis Unit D-6 which was an area of concern to sportsmen. We used helicopters from 28 February to 5 March 2001 to count mule deer on randomly selected quadrats 0.25-mi^2 or 1.00-mi^2 in size distributed within 11 strata encompassing 364 mi^2 of deer winter range composed of sagebrush (*Artemisia tridentata*) and pinyon-juniper (*Pinus edulis-Juniperous osteosperma*) habitats. From these counts, we estimated population size using standard stratified random sample estimators and the Idaho mule deer sightability model. Stratified population estimate was 6,782 ± 2,497 (90% CI) deer. Counts corrected for sightability increased the estimate to 11,052 ± 3,503 (90% CI) deer. Both aerial survey estimates buttressed population estimates of 7,000 to 7,300 deer derived from computer models and were substantially greater than sportsmen's estimate of 1,750 deer. Cost of this validation exercise exceeded 50,000 $US. We interpreted this exercise as a forerunner of the public's interest in challenging agency integrity or methods used to estimate status of ungulate populations. We caution agencies to use tested methodology that can withstand dispassionate public scrutiny.

Key Words: bias, Colorado, helicopter surveys, Idaho, mule deer, *Odocoileus hemionus*, population estimates, sightability

Sportsmen in Colorado alleged that estimates for numbers of mule deer (*Odocoileus hemionus*) in western Colorado were substantially over-estimated by the Colorado Division of Wildlife (CDOW). For example during post-hunting season 2000, sportsmen believed there were only 128,000 deer in Colorado in areas west of the Continental Divide where CDOW estimated 409,000 deer. This level of discrepancy also existed for specific deer populations such as in the Rangely Deer Analysis Unit D-6, where sportsmen estimated 1,750 deer compared to CDOW estimates of 7,000 deer after hunting season 2000 (Pers. comm. Colorado Mule Deer Association). These 4-fold differences in estimated numbers of deer explained why perceptions about the status of mule deer in Colorado varied between some sportsmen and CDOW.

Sportsmen focused their concerns on the credibility of Colorado's quadrat survey sampling methodology to estimate numbers of deer in specific populations. This methodology, based on stratified random sampling theory (Thompson et al. 1998), was initially developed for helicopter counts of mule deer on 1-mi^2 sample quadrat units used to estimate total numbers of deer in a population inhabiting extensive sagebrush habitats during winter (Gill 1969). This system was later expanded to estimate size of selected deer populations inhabiting pinyon-juniper habitats in western Colorado where quadrat sample unit size was reduced to 0.25-mi^2 to compensate for the detrimental effects that dense pinyon-juniper canopy cover had on detecting and counting mule deer (Kufeld et al. 1980, Bartmann 1983, Bartmann et al. 1986).

Aerial counting of deer using random quadrats provided estimates of deer numbers sufficiently suitable for herd management decisions but implementation costs prevented such systems from being employed in most deer management units in western Colorado (Gill et al. 1983). Alternative approaches to estimating trends in numbers of deer in every population included: intensively estimating numbers of deer, age and sex ratios, and survival rates in a few populations whose trends in population parameters could represent many deer populations inhabiting ecologically similar areas (White and Bartmann 1998, Bartmann 2000, Bowden et al. 2000); and, using computer modeling that incorporated measured parameters from appropriately similar ecological core areas in conjunction with less intense measurements of age and sex ratios and hunter harvests that could be obtained yearly for nearly every deer population (CDOW 1991, White and Bartmann 1998, Bartholow 2000,).

The discrepancy in perceived numbers of deer in western Colorado more accurately reflected a concern about modeled as opposed to aerial survey estimates of deer population size because only about 10% of the deer populations were monitored using aerial quadrat sampling protocols. Nevertheless, sportsmen focused their concerns on aerial survey sampling fearing that such techniques inflated estimates of deer numbers and therefore, misrepresented the declining plight of mule deer in western Colorado. Furthermore, sportsmen desired to assess the Idaho Mule Deer Sightability survey system (Ackerman 1988, Unsworth et al. 1994) as an alternative to Colorado's approach to estimating numbers of deer on the premise that the Idaho system would provide more acceptable estimates of deer numbers.

This project was prompted by sportsmen's concerns about the legitimacy of deer population estimates based upon aerial surveys employing random sampling and counts of deer on sample quadrats. We conducted an aerial quadrat survey in a deer population unit of concern to sportsmen using Colorado quadrat survey techniques incorporating adjustments in estimated population size based on Idaho mule deer sightability models (Unsworth et al. 1994). Our survey and results were monitored by participating individuals independently representing sportsmen's concerns. We then compared estimates based on aerial surveys to ongoing population models used to guide management of deer.

STUDY AREA

We estimated numbers of mule deer inhabiting winter range in the Rangely Deer Analysis Unit D-6 consisting of Game Management Unit 10 in northwestern Colorado near the town of Rangely. D-6 includes 837 mi^2 with large expanses of public lands administered by the U. S. Department of Interior Bureau of Land Management and National Park Service. Deer typically move onto winter range in November and begin returning to summer ranges in April.

The project area is semi-desert with yearly precipitation ranging from 8 to 20 inches and winters having moderate temperatures and snow depths. Deer winter range occurs between 5,000 and 7,200 feet elevation and is a mixture of pinyon-juniper, sagebrush, and greasewood (*Sarcobatus vermiculatus)* - desert shrub habitats and is shared with domestic sheep, cattle, and elk (*Cervus elaphus*). During winters with low snow depths, deer distribution could encompass 612 mi^2 but under severe snow depth conditions, deer distribution may collapse to 106 mi^2 (CDOW 2001).

Deer have been managed in D-6 under a limited permit hunting system since 1991 resulting in average yearly harvests of 118 bucks (range 70-252) and 60 antlerless does and fawns (range 2-132). Helicopter surveys of population ratios post-hunting season in December have shown 9-26 bucks:100 does and 29-64 fawns:100 does. Previous efforts to estimate population size of deer in D-6 involved assessing the practicality of using helicopter line transects (White et al. 1989) on a trial basis in 1990 and 1991 with resulting estimates of 21,630 ± 12,321 and 13,596 ± 5,427 (90% CI) deer, respectively (CDOW 1991).

METHODS

Sampling Protocols

We estimated deer population size using stratified random sampling and counts of deer on randomly selected quadrat units (quadrats) (Thompson et al. 1998). Counts of animals on random units assume that units are completely searched by observers and all animals present are detected and counted. These assumptions, therefore, assume 100% sightability of target animals and resulting estimates would not incorporate correction factors for animals not counted. We delineated our sampling area (frame) based upon the distribution of deer observed during systematic strip-surveys of potential winter range in the project area conducted with a Hiller 12-E Soloy helicopter on 6 February 2001.

Using ESRI ArcView©, we delineated a frame of 364 mi^2 that encompassed the distribution of deer observed during the survey flight. Each cadastral square-mile within the frame was subjectively rated by flight observers as to high, medium, or low expected deer densities. Guidelines for relative deer densities were: >20 for high, 5-20 for medium, and < 4 deer/mi^2 for low. We then defined 11 strata based upon expected deer densities for the purpose of distributing quadrats through out the frame. Low, medium, and high density strata encompassed 113 mi^2 (31%), 157 mi^2 (43%), and 94 mi^2 (26%), respectively, within the frame (Table 1).

Proportions of vegetation types within each strata were estimated using ArcView© and Colorado GAP® vegetation coverage (Schrupp et al. 2000). We used 1- mi^2 quadrats in strata where open sagebrush-type habitats comprised > 50% of a stratum (Gill 1969) and 0.25-mi^2 quadrats where pinyon-juniper habitats comprised > 50% of a stratum recognizing that tree canopy would hinder detection of deer (Bartmann 1983) (Table 1).

We allocated quadrats among strata using optimum allocation (Thompson et al. 1998, pages 341-342) with estimated variances based upon variance to mean ratios derived from quadrat sample units previously flown in Colorado since 1968 (Expected Standard Deviation = 3.6379 + 1.0891 * [mean deer density], n = 1,192 quadrats). We calculated number of quadrats needed to achieve precision of ± 20% of the mean population estimate with $\alpha = 0.10$ for potential population sizes ranging from 2,000 to 8,000 deer. We selected a sample size of 161 quadrats distributed among 11 strata for an expected population of 6,000 deer. We assumed the cost of flying 1-mi^2 and 0.25-mi^2 quadrats was the same based on a proportional per area basis (Table 1).

We established a grid of point coordinates (UTM [x, y]; NAD 27, all standardized to Zone 13) every 0.25 mi within the frame using ArcView©. We then used the random number option in MS Excel97© to assign a random number to each grid point. Grid point random numbers were then ordered from low to high to initiate the process of randomly selecting locations for quadrats within strata, with quadrat location selection beginning with the lowest ordered grid point and continuing until all quadrats were assigned within each strata. We restricted locations of quadrats by defining a minimum distance between randomly selected grid points of 0.50 mi in strata using 0.25-mi^2 quadrats and 1 mi in strata using 1-mi^2 quadrats to reduce quadrats having common boundaries and to reduce clustering of quadrats within strata.

Quadrats were irregular in shape with boundaries following terrain ridges and gullies or cultural features such as roads or trails that could be discerned on USGS 1:24,000 topographic maps and recognized by observers while flying in a helicopter (Freddy 1994, Unsworth et al. 1994). Quadrat polygons were digitized on digital topographic maps using ArcView© with quadrat area and perimeters calculated by ArcView©. Range of actual areas for 0.25-mi^2 units was generally 0.22-0.28 mi^2 and for 1-mi^2 units, 0.9-1.1 mi^2, shaped with the intent to minimize perimeter to area ratios (Thompson et al. 1998). Randomly selected grid points had to be included within the defined quadrat and preferably centered within the quadrat. Flight path starting latitude-longitude coordinates, back-corrected for UTM Zone 12 or Zone 13 as necessary, were defined for each quadrat and labeled on flight navigation digital topographic maps printed in color using ArcView© layouts and MS PowerPoint97©.

Flight Protocols

We used Hiller 12-E Soloy (Hiller) and Bell Jet Ranger III (Ranger) helicopters to count deer on quadrats. While searching for deer, helicopters were flown at 35-50mph at 50-100 feet AGL. Observer, navigator, and pilot comprised flight crews, with observer and navigator having primary responsibilities to detect and count deer with the observer tape-recording all pertinent data. In the Hiller, the observer was seated in the starboard outside seat with the navigator seated in the middle. In the Ranger, the observer was seated in the port outside seat with the navigator in the port rear seat.

Crews first flew boundaries of quadrats and then systematically searched the interior of quadrats using strips or strip-contours depending on steepness of terrain following standard procedures (Gill 1969, Kufeld et al. 1980, Freddy 1998, Unsworth et al. 1994). To optimize the visual scanning position of the observer when flying quadrat boundaries, the Hiller crew flew boundaries clock-wise and the Ranger crew flew boundaries counter-clockwise. Navigators and pilots determined proper starting locations of quadrats using previously calculated latitude-longitude coordinates entered into on-board Garmin Pilot III© global positioning units (GPS). Navigators then directed pilots along quadrat boundaries and suitable search paths within the quadrat using topographic maps and real-time flight traces recorded on GPS units. Navigators, observers, and pilots constantly adjusted flight speed, altitude and angle of attack to optimize viewing for the observer. Objectives were to fly quadrats to obtain 100% search coverage.

Observers and navigators collectively detected and counted groups of deer on quadrats with the highest count by either person recorded by the observer. Observers and navigators collectively made decisions on whether to count deer detected near quadrat boundaries: groups moving onto quadrats when detected were considered outside quadrats; groups moving off quadats when detected were considered on quadrats; one-half of the deer in groups detected on boundaries were considered on quadrats. Observers and navigators also collectively kept mental track of group locations, movements and presence of unique antlered deer in groups to reduce chances of counting groups more than once.

Flights were conducted when weather conditions were favorable. Flights were conducted only when wind speeds were low enough in the judgement of pilots to fly safely at desired slow airspeeds and low AGL. Lighting conditions varied from overcast to hazy or bright sunshine while snow cover background varied from 0 to 100 percent. Flights continued through short episodes of snow flurries provided safety was not compromised. For each quadrat, observers recorded flight conditions and total flight time.

Idaho Sightability Protocols

Sightability models correct for undercounting, or negative bias, that is generally associated with counts of ungulates (Caughley 1974, Bartmann et al. 1986, Samuel et al. 1987, Steinhorst and Samuel 1989, Unsworth et al. 1990, Otten et al. 1993, Pojar et al. 1995, White et al. 1989, Anderson and Lindzey 1996, Anderson et al. 1998, Cogan and Diefenbach 1998, Freddy 1998). To correct for potential negative bias in deer detected and counted on quadrats, we obtained values for sighting variables on each group of deer counted following guidelines for the Idaho mule deer sightability model (Unsworth et al. 1994).

Sighting variables were total group size, behavior, vegetation type, and percent snow cover. Behavior of the most active deer when a group was first detected was recorded as bedded, standing, or moving. Although deer could have been detected in several vegetation types, we reduced types to broad categories to simplify the process of classifying vegetation: agricultural fields/open meadows; sagebrush, representing all low brush types; and pinyon-juniper, representing all pinyon or juniper dominated areas. Deer were not detected in tall conifer, aspen, or tall mountain brush habitats. Percent snow cover on the ground where each group was detected was classified as a categorical value of low (21-79%) or high ($\geq$ 80%).

The Idaho mule deer model most appropriate to correct undercounting deer was the spring sightability model which contained the following sighting variables (Unsworth et al. 1994:

$$\mu = -0.254 + \text{activity} + \text{vegetation class} + \text{snow cover} + 0.047 * (\text{group size})$$

Coefficients for each variable were developed in Idaho in similar but different vegetation and terrain types than might occur in Colorado. Knowing that Idaho coefficients may only approximate coefficients suitable for use in Colorado, we used the following Idaho coefficients for sighting variables (Unsworth et al. 1994):

Activity:	Bedded = 0.000, Standing = 1.56, Moving = 4.43
Vegetation:	Agriculture/meadow = 0.00, Sagebrush = -0.88, Pinyon-Juniper (Idaho Juniper/Mountain mahogany) = -2.383
Snow Cover:	Low 21-79% = -1.37, High ≥ 80% = -0.60

Estimates of population size based on counts of deer on quadrats were corrected for sightability of each group using Idaho Aerial Survey© program for Windows© beta-version (Unsworth et al. 1994). Program Aerial Survey was limited to accepting only 10 defined strata from which to calculate population size. Our survey design incorporated 11 strata so we therefore, combined strata 1 and strata 2 (Table 1) into 1 strata to accommodate the program. We compared quadrat and quadrat sightability corrected population estimates using a standard *z* -test (Thompson et al. 1998). Both Idaho and Colorado systems were predicated on using stratified random sampling and thus, these systems complimented each other in conceptual design and application (Gill 1969, Unsworth et al. 1994).

Modeling Protocols

Estimating trends in deer population size over several years in D-6 was an ongoing CDOW management evaluation process based upon computer modeling using POP-II software (Bartholow 2000). Computer models were constructed independently of data obtained during our aerial survey and by personnel who did not participate in the aerial survey. This model used yearly hunter harvest estimates (Steinert et al. 1994), deer survival rates (White et al. 1987), estimated post-season December doe:fawn and buck:doe ratios collected during yearly helicopter surveys (CDOW 1991), and winter severity values to estimate trends in population size. Such models provided an assessment of deer status independent of aerial quadrat surveys, and conversely, aerial quadrat surveys provided point estimates of population size to evaluate models.

RESULTS

We estimated deer density from 28 February to 5 March 2001 using about 35 hours of helicopter flight time to complete the survey (Table 2). Mechanical malfunctions with the Hiller resulted in using the Ranger more extensively than anticipated, altered availability of survey navigators and observers, and in conjunction with impending unfavorable weather, caused us to reduce sampling intensity in 3 strata in order to complete the survey (Table 1). Adjustments in flight crew members and survey sampling were completed with the approval of independent evaluators.

Survey Population Estimates

Estimated deer population size was 6,782 with 90% CL of 4,285 to 9,279 for Colorado quadrats assuming 100% sightability of deer (Table 3). Reduced sampling in strata 10, 11, and 13 (Table 1) likely contributed to increasing variability resulting in wide CI of ± 36% of the mean estimate. Additionally, deer also became more concentrated in their distribution after the sampling frame flight of 6 February due to increasing snow depths at upper elevation limits of winter range. This shift in deer distribution contributed markedly to not detecting deer on 66% of the quadrats.

Using a 100% Idaho sightability model for deer, a point estimate of population size was 6,481 (Table 5). Colorado and Idhao 100% sightability population estimates would have been equivalent except the Idaho estimate was based only on 10 strata (strata 1 and 2 were combined, Tables 1, 4) instead of 11 Colorado strata due to limitations of program Aerial Survey©.

Estimated deer population size was 11,052 with 90% CL of 7,549 to14,555 for Colorado quadrats corrected for the Idaho sightability mule deer model (Table 4). Confidence intervals represented ± 32% of the mean estimate. Idaho sightability increased the standard Colorado quadrat estimate by 1.63x resulting in population estimates tending to be statistically different ($z = 1.63$, $P = 0.103$). Within individual strata, sightability increased estimates by 1.37 to 6.26x (Table 4). The highest correction 6.26x occurred in strata 11-MDL and should be viewed cautiously and may reflect the sensitivity of sightability correction factors to low counts of deer on few sample units (Table 3).

The considerable increase in estimated population size due to sightability corrections reflected that 62% of the deer groups contained $\leq$ 5 deer, 34% of the groups were in pinyon-juniper vegetation and 66% were in sagebrush-type vegetation, and 82% were detected in areas having low and broken snow cover on the ground (Table 2). In essence, many groups of deer were associated with a factor that decreased the sightability, or probability of detecting a group.

Model Population Estimates

Computer modeled point estimates of population size for post-season deer populations in 2000 ranged from 7,000 to 7,312 deer. Modeled estimates were similar in magnitude to aerial survey estimates and were within or nearly within the confidence intervals of all aerial survey estimates of population size. Modeled and aerial survey estimates were substantially larger than the population estimate promoted by sportsmen (Table 5).

Flight Survey Variables

Search times on quadrats were acceptable and comparable to previous surveys in Colorado. Flight crews spent 20.2 ± 1.1 (SE, n = 38) and 6.4 ± 0.2 (SE, n = 105) minutes on 1-mi^2 and 0.25-mi^2 quadrats, respectively. Search times were relatively proportional to total area searched. Wind and lighting conditions were conducive to effectively searching quadrats. Low percent snow cover or broken snow ground cover on many quadrats reduced the probability of detecting deer and made observers more dependent on deer movement to detect groups (Table 2).

Compared to the Hiller, flight crews in the Ranger collectively had reduced visibility primarily because the navigator seated in the rear seat had a limited scanning view and could not as effectively help the primary observer detect or count deer. We would expect counts from the Ranger to be more negatively biased than from the Hiller (pers. comm. J. W. Unsworth). Conversely, the 200-shaft horsepower advantage of the Ranger allowed effective slow and low flying in steep and variable terrain.

DISCUSSION

We conducted an aerial survey in response to demands by sportsmen who strongly believed that methods used to estimate numbers of mule deer over-estimated deer numbers in Colorado. Resulting survey estimates of deer numbers, whether based on the Colorado quadrat system (Gill 1969, Kufeld 1980, Bartmann 1983, Bartmann et al. 1986) or quadrats adjusted for the Idaho mule deer sightablilty model (Unsworth et al. 1994), strongly indicated that sportsmen's estimates of deer numbers were substantially below likely true population size. Furthermore, aerial survey estimates supported population estimates derived in computer population models, and as such, supported the concept that models can provide reasonable estimates of population size to adequately guide decisions for managing mule deer.

Colorado quadrats, as expected, provided lower estimates of deer numbers (6,782) than quadrats corrected for sightabiltiy factors (11,052). The Idaho mule deer model (Unsworth et al. 1994) increased estimates by 1.63x compared to the correction factor of 1.51x developed for deer in pinyon-juniper habitats in Colorado (Bartmann et al. 1986). We are confident that Colorado quadrats, without sightability corrections, will provide conservative estimates of deer numbers when proper and adequate sampling procedures and flight protocols are followed. Although applying a calibrated correction factor (Bartmann et al. 1986) would improve accuracy of population estimates, we question whether higher estimates would be more palatable to some sportsmen's groups.

We fully recognize the limitations of our population estimates generated from this validation exercise. Our estimates were of low precision for which there a 2 primary reasons. Our efforts to estimate a sampling frame were based on only 1 aerial survey conducted quickly in response to time constraints invoked by pressure to obtain a population estimate. Normally, quadrat sampling frames are determined with several years of deer distribution data obtained when winter snow conditions would optimize counting deer. In Colorado, quadrat surveys would normally be flown in January when deer distribution and snow cover tend to be stable. In our specific case, major shifts in distribution of deer occurred after the distribution flight and prior to conducting the survey reducing the effectiveness of our sampling allocations. We then reduced sampling intensity in 3 strata to complete the survey with impending unfavorable weather conditions.

Observations also suggested that some deer moved off or outside of the frame which would inherently lower estimates of population size. Appropriateness of applying sightability correction factors developed in Idaho for Colorado deer in different habitats can be argued and therefore, the legitimacy of the resulting higher estimates may elicit even less confidence from concerned sportsmen.

We foresee worthwhile potential research efforts emanating from this survey effort. Colorado and Idaho both use stratified random sampling procedures in their respective survey systems. However, Idaho often uses sampling units or quadrats having search areas > 3-mi^2 while Colorado uses quadrats $\leq$ 1-mi^2. Cooperative experiments designed to compare effects of sample unit size on population estimates and precision, especially if simultaneously compared against robust mark-resight estimators (Bartmann et al. 1987, Neal et al. 1993, Bowden and Kufeld 1995), may provide valuable insight into designing more efficient aerial survey systems.

We believe lessons from this exercise apply more appropriately to human dimension rather than biological issues. Sportsmen demanded a validation process of aerial survey protocols based on their perceptions of deer numbers and not on technical demerits of the survey system in use or reasonably obtained estimates of deer population size. Such demands were not tempered by discussions between CDOW and sportsmen over several months that attempted to resolve mistrust by explaining population estimation procedures, limitations, and likely biases. The result was CDOW spending approximately $50,000 in operating and personnel expenses to estimate numbers of deer in a management unit having low priority for spending limited deer inventory resources. We suspect that our survey exercise minimally mediated concerns of some sportsmen.

MANAGEMENT IMPLICATIONS

Sportsmen challenged estimates of mule deer populations provided by CDOW and demanded a validation exercise to compare sportsmen's estimates of deer numbers in a specific population with estimates on record with CDOW. Subsequent aerial surveys conducted with sportsmen approval and independent oversight provided deer population estimates that substantiated previous CDOW estimates and that were at least 4x greater than the estimate provided by sportsmen.

We interpret this validation exercise as a forerunner of the public's interest in either challenging or understanding methods used to estimate status of ungulate populations. We can only caution that if estimates of population status are part of a routine management process, that estimates should be based on tested methodology that can withstand public scrutiny.

ACKNOWLEDGMENTS

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Table 1. Characteristics of sampling strata for estimating mule deer population size in Rangely Deer Analysis Unit D-6, Colorado, February-March 2001.

Strata Name	Strata[1] No.	Density Rank	Strata Mi²	Area[2] PJ (%)	Area[3] Open (%)	Sample Unit Size Mi²	Total Quadrat Units	Sample[4] Quadrats	Sampled[5] Quadrats
Yampa Monument	1	Low	28.74	66	34	0.25	115	9	9
Yampa Monument	2	Medium	30.40	59	41	0.25	122	15	15
Utah White River	3	Low	31.64	10	90	1.00	32	5	5
Utah White River	4	Medium	22.75	35	65	1.00	23	8	8
Upper White River	5	High	54.16	78	22	0.25	217	41	41
Upper White River	6	Medium	30.96	40	60	1.00	31	10	10
Upper White River	7	Low	31.96	20	80	1.00	32	5	5
Massadona Dinosaur	10	Medium	44.09	69	31	0.25	176	22	15
Massadona Dinosaur	11	Low	20.07	62	38	0.25	80	6	4
Massadona Dinosaur	13	High	40.46	54	46	0.25	162	31	21
Twelvemile	12	Medium	28.93	47	53	1.00	29	10	10
Totals	11		364.15				1018	161	143

[1] Strata numbered 8 and 9 did not exist; there were 11 total strata.

[2] Percent of strata area having pinyon-juniper canopy vegetation types.

[3] Percent of strata area in sagebrush or low brush vegetation types.

[4] Number of sample quadrat units assigned to each strata based on optimum allocation formulas.

[5] Represents number of sample quadrat units actually flown. Quadrats flown in strata 10, 11, and 13 were reduced by random selection to allow completion of aerial survey considering impending weather conditions.

Table 2. Summary of aerial survey characteristics for Rangely Deer Analysis Unit D-6, Colorado, February-March 2001.

Survey Characteristic	Data Summary
Aerial Survey Flight Dates	28 February - 5 March 2001; about 35 hours of helicopter flight time.
Total Sample Quadrats Flown	143; 38 sized 1-mi²; 105 sized 0.25-mi²; 129 flown by Ranger (90%), 14 flown by Hiller (10%)
Search Minutes Per Quadrat	1-mi² quadrats = 20.2 ± 1.1 (SE); 0.25-mi² quadrats = 6.4 ± 0.2 (SE)
Observers for Counting Deer	deVergie = 112 quadrats (78%), Graham = 14 (10%), Ellenberger = 17 (12%)
Navigators for Counting Deer	Freddy = 82 quadrats (57%), Bickle = 30 (21%), Graham = 17 (12%), Howard = 14 (10%)
Flight Wind Speed on Quadrats	Low = 136 (95%), Moderate = 7 (5%), High = 0 (0%)
Flight Lighting on Quadrats	Bright sunshine = 92 (64%), Dull sunshine = 7 (5%), Hazy sunshine = 44 (31%)
Snow Cover on Quadrats	Fresh snow = 4 (3%), Old snow = 139 (97%)
Time Period Quadrats Flown	7 AM - 12 PM = 65 (45%), 12PM - 5PM = 78 (55%)
Total Deer Counted on Quadrats	1,180 seen on 48 of 143 sample quadrats
Total Deer Groups Detected	179; Average group size = 6.6 ± 0.6 (SE), range = 1 - 58
Deer Group Size by Quadrat Size	On 1-mi² quadrats = 6.2 ± 0.6 (SE) (n = 94); On 0.25-mi² quadrats = 7.1 ± 1.0 (SE) (n = 85)
Frequency of Group Sizes	(1, n=27, 15%), (2, n=25, 14%), (3-5, n=59, 33%), (6-9, n=36, 20%), (10-19, n=22, 12%), (20-58, n=10, 6%)
Group Size by Vegetation Class	In sagebrush = 7.2 ± 0.7 (SE) (n = 118), In pinyon-juniper = 5.4 ± 0.9 (SE) (n = 61)
Group Size by Helicopter Type	In Ranger = 7.0 ± 0.8 (SE)(n = 127), In Hiller = 5.6 ± 0.6 (SE) (n = 52)
Deer Group Behavior at Detection	123 (69%) Moving; 55 (31%) Standing; 1 (<1%) Bedded
Deer Group Vegetation Type	118 (66%) sagebrush-type; 61 (34%) pinyon-juniper; (0%) agriculture/meadows
Deer Group Snow Cover	146 (82%) low snow cover; 33 (18%) high snow cover
Total Elk Counted	1,297 approximately; seen on 32 of 143 sample quadrats

Table 3. Summary for stratified random sample of mule deer counted on sample unit quadrats in Rangely Deer Analysis Unit D-6, Colorado, February-March 2001.

	Strata Number With Abbreviated Name and Density Ranking										
	1	2	3	4	5	6	7	10	11	13	12
Summary Statistics	YML	YMM	UWL	UWM	WRH	WRM	WRL	MDM	MDL	MDH	TMM
Quadrat Sampled Units (u_h)	9	15	5	8	41	10	5	15	4	21	10
Deer Counted Per Stratum(N_h)	114	11	31	66	322	178	112	10	9	133	194
Mean Deer Per Quadrat ($N_{h\,bar}$)	12.67	0.73	6.20	8.25	7.85	17.80	22.40	0.67	2.25	6.33	19.40
Quadrat Unit Variance (S^2_{Nh})	1116	3	54	181	214	957	760	7	20	274	1020
Estimated Deer Per Stratum (N^$_h$)	1456	89	196	188	1702	551	716	118	181	1025	561
Stratum Variance (Var^)(N^$_h$)	1510126	2156	9137	7607	198905	62121	131021	12645	31002	297438	55874
Stratum Quadrat Size (Mi^2)	0.25	0.25	1.00	1.00	0.25	1.00	1.00	0.25	0.25	0.25	1.00
Total Stratum Quadrat Units (U_h)	115	122	32	23	217	31	32	176	80	162	29
Stratum Area (Mi^2)	29	30	32	23	54	31	32	44	20	40	29
Quadrats With 0 Deer Counted	7	11	2	5	27	4	1	14	3	15	6
Percent Quadrats With 0 Deer	78	73	40	63	66	40	20	93	75	71	60

Total Deer Counted All Strata (sum N_h)	1,180		
Total Estimated Deer All Strata (sum N^$_h$)	6,782		
Total Variance All Strata (sum Var^[N^$_h$])	2,318,031		
Coefficient of Variation CV^(N^) %	22.45		
90% Confidence Interval for N^ [Lower][Upper]	4,285	9,279	± 36% of Population Estimate
95% Confidence Interval for N^ [Lower][Upper]	3,798	9,766	± 44% of Population Estimate

Table 4. Estimates of mule deer numbers in individual strata compared between Colorado quadrat and quadrats corrected for Idaho mule deer sightability model and Idaho sightability estimate summary statistics for Rangely deer Analysis Unit D-6, Colorado, February-March 2001.

	Numbers of Mule Deer Estimated in Each Strata Numbered with Names Abbreviated											
	1	2	3	4	5	6	7	10	11	13	12	All
Estimator	YML	YMM	UWL	UWM	WRH	WRM	WRL	MDM	MDL	MDH	TMM	Total
Colorado Quadrats	1456	89	196	188	1702	551	716	118	181	1025	561	6,782
Sightability Corrected	1422[1]		293	375	3183	851	1397	154	1133	1403	841	11,052
Sightability Increase	0.92		1.49	1.99	1.87	1.54	1.95	1.31	6.26	1.37	1.50	1.63

Idaho Sightability Estimate Summary Statistics

Total Deer Counted All Strata (sum N_h)	1,180		
Total Estimated Deer All Strata (sum N^$_h$)	11,052		
Total Variance All Strata (sum Var^[N^$_h$])	4,534,872	Due to Sampling (4,365,014), Sightability (149,173), Model (20,685)	
Coefficient of Variation CV^(N^) %	19.27		
90% Confidence Interval for N^ [Lower][Upper]	7,549	14,555	± 32% of Population Estimate

[1] Sightability corrected estimate based on pooling strata 1 and 2 resulting in no estimate for strata 2-YMM.

Table 5. Summary of computer modeled, aerial helicopter survey, and sportsmen estimates of December post-hunting season mule deer population size in Rangely Deer Analysis Unit D-6, Colorado, 1990 - 2001.

Year	Computer[1] Model	Computer[3] Model	Aerial Survey	90 Percent Confidence Interval	Sportsman Estimate[9]
1990	8,017		21,630[5]	9.309 - 33,951	
1991	8,016		13,596[5]	8,169 - 19,023	
1992	7,563				
1993	7,917				
1994	9,141				
1995	9,171				
1996	8,409				
1997	7,801				
1998	7,856				
1999	8,176				
2000	7,312	7,000[4]	6,782[6]	4,285 - 9,279	1,750
2000			6,481[7]		
2000			11,052[8]	7,549 - 14,555	
2001	6,989[2]				

[1] Computer model constructed in February 2001 with POP-II software (Bartholow 2000) .

[2] Estimate represents a value projected for December 2001 given assumptions about likely deer recruitment and harvest June to December 2001.

[3] Computer model constructed in February 2000 with POP-II software (Bartholow 2000).

[4] Estimate represented a value projected for December 2000 given assumptions about likely deer recruitment and harvest June to December 2000. Estimate represents value contested by Colorado Mule Deer Association.

[5] Estimate from helicopter line transects (White et al. 1989) conducted on a trial basis.

[6] Estimate from Colorado helicopter quadrat survey technique assuming 100% deer sightability.

[7] Estimate from Colorado helicopter quadrat survey technique assuming 100% Idaho mule deer sightability model (Unsworth et al. 1994).

[8] Estimate from Colorado helicopter quadrat survey technique adjusted for Idaho mule deer sightability model incorporating sightability correction factors (Unsworth et al. 1994).

[9] Estimate provided by Colorado Mule Deer Association on behalf of sportsmen.

LITERATURE CITED

Ackerman, B. B. 1988. Visibility bias of mule deer aerial census procedures in southeast Idaho. Dissertation, University of Idaho, Moscow, Idaho USA.

Anderson, C.R., Jr., and F. G. Lindzey. 1996. A sightability model for moose developed from helicopter surveys. Wildlife Society Bulletin 24:247-259.

Anderson, C.R., Jr., D. S. Moody, B. L. Smith, F. G. Lindzey, and R. P. Lanka. 1998. Development and evaluation of sightability models for summer elk surveys. Journal of Wildlife Management 62:1055-1066.

Bartholow, J. 2000. Pop-II for Windows©, version 1.0. Fossil Creek software. Fort Collins, CO USA.

Bartmann, R.M. 1983. Appraisal of a quadrat census for mule deer in pinyon-juniper vegetation. Colorado Division of Wildlife Game Information Leaflet 109. Colorado Division of Wildlife, Fort Collins, CO USA

Bartmann, R.M. 2000. Colorado mule deer population monitoring system procedures, user's manual. Colorado Division of Wildlife, Fort Collins, CO USA.

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

Bartmann, R.M., G.C. White, L.H. Carpenter, and R.A. Garrott. 1987. Aerial mark-recapture estimates of confined mule deer in pinyon-juniper woodland. Journal of Wildlife Management 51:41-46.

Bowden, D.C., and R.C. Kufeld. 1995. Generalized mark-sight population size estimation applied to Colorado moose. Journal of Wildlife Management 59:840-851.

Bowden, D.C., G.C. White, and R.M. Bartmann. 2000. Optimal allocation of sampling effort for monitoring a harvested mule deer population. Journal of Wildlife Management 64:1013-1024.

Caughley, G. 1974. Bias in aerial survey. Journal of Wildlife Management 38:921-933.

Cogan, R.D., and D.R. Diefenbach. 1998. Effect of undercounting and model selection on a sightability-adjustment estimator for elk. Journal of Wildlife Management 62:269-279.

Colorado Division of Wildlife. 1991. POPII simulation model, DEAMAN database manager, and POPMOD parameter estimation workshop manual. Colorado Division of Wildlife. Fort Collins, CO USA

Colorado Division of Wildlife. 2001. WRIS database. Colorado Division of Wildlife, Grand Junction, CO, USA

Freddy, D.J. 1994. Estimating survival rates of elk and developing techniques to estimate population size. Colorado Division of Wildlife Game Research Report. July: 27-42. Colorado Division of Wildlife, Fort Collins, CO USA.

Freddy, D.J. 1998. Estimating survival rates of elk and developing techniques to estimate population size. Colorado Division of Wildlife Game Research Report. July: 177-206. Colorado Division of Wildlife, Fort Collins, CO USA.

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

Gill, R.B., L.H. Carpenter, and D.C. Bowden. 1983. Monitoring large animal populations: the Colorado experience. Transactions North American Wildlife Conference 48:330-341.

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

Neal, A.K., G.C. White, R.B. Gill, D.F. Reed, and J.H. Olterman. 1993. Evaluation of mark-resight model assumptions for estimating mountain sheep numbers. Journal of Wildlife Management 57:436-450.

Otten, M. R. M., J. B. Haufler, S. R. Winterstein, and L. C. Bender. 1993. An aerial censusing procedure for elk in Michigan. Wildlife Society Bulletin 21:73-80.

Pojar, T.M., D.C. Bowden, and R.B. Gill. 1995. Aerial counting experiments to estimate pronghorn density and herd structure. Journal of Wildlife Management 59:117-128.

Samuel, M.D., E.O. Garton, M.W. Schlegel, and R.G. Carson. 1987. Visibility bias during serial sruveys of elk in northcentral Idaho. Journal of Wildlife Management 51:622-630.

Schrupp, D.L., W.A. Reiners, T.G. Thompson, L.E. O'Brien, J.A. Kindler, M.B. Wunder, J.F. Lowsky, J.C. Buoy, L. Satcowitz, A.L. Cade, J.D. Stark, K.L. Driese, T.W. Owens, S.J. Russo, and F. D'Erchia. 2000. Colorado Gap Analysis Program: A geographic approach to planning for biological diversity- Final Report. USGS Biological Resources Division, Gap analysis Program and Colorado Division of Wildlife, Denver, CO USA.

Steinert, S.F., H.D. Riffel, and G.C. white. 1994. Comparison of big game harvest estimates from check station and telephone surveys. Journal of Wildlife Management 57:336-341.

Steinhorst, R.K., and M.D. Samuel. 1989. Sightability adjustment methods for aerial surveys of wildlife populations. Biometrics 45:415-425.

Thompson, W.L., G.C. White, and C. Gowan. 1998. Monitoring vertebrate populations. Academic Press, Inc., San Diego, California, USA.

Unsworth, J.W., L. Kuck, and E.O. Garton. 1990. Elk sightability model validation at the National Bison Range, Montana. Wildlife Society Bulletin. 18:113-115.

Unsworth, J.W., F.A. Leban, D.J. Leptich, E.O. Garton, and P. Zager. 1994. Aerial survey: user's manual, with practical tips for designing and conducting aerial big game surveys. Idaho Department of Fish and Game, Boise, ID USA.

White, G.C., and R.M. Bartmann. 1998. Mule deer management–what should be monitored? Pages 104-118 in J.C. deVos, Jr., editor. Proceedings of the 1997 deer/elk workshop, Rio Rico, Arizona. Arizona Game and Fish Department, Phoenix, Arizona, USA.

White, G.C., R.A. Garrott, R.M. Bartmann, L.H. Carpenter, and A.W. Alldredge. 1987. Survival of mule deer in northwest Colorado. Journal of Wildlife Managemetn 51:852-859.

White, G.C., R.M. Bartmann, L.H. Carpenter, and R.A. Garrott. 1989. Evaluation of aerial line transects for estimating mule deer densities. Journal of Wildlife Management 53:625-635.

CALCULATIONS FOR TOTAL NUMBER SAMPLE QUADRATS AND SAMPLE SIZES FOR EACH STATUM

SAMPLE SIZES BASED ON FORMULAS ON PAGES 341 AND 342 FOR STRATIFIED RANDOM SAMPLING IN: THOMPSON, W.L., G.C. WHITE, AND C. GOWAN. 1998. MONITORING VERTEBRATE POPULATIONS. ACADEMIC PRESS, INC. , SAN DIEGO, CALIFORNIA, USA.

ESTIMATED SAMPLE VARIANCES FOR STRATA BASED ON REGRESSION OF VARIANCE STANDARD DEVIATION (S) ON MEAN DEER DENSITY FOR 1192 QUADRAT DEER SAMPLE UNITS PREVIOUSLY FLOWN IN COLORADO. ANALYSIS CONDUCTED BY G.C. WHITE. STRATA VARIANCE TO MEAN REGRESSION WAS S = 3.638 + 1.089 (MEAN DENSITY).

BECAUSE SAMPLE SIZE CALCULATIONS ARE BASED ON ESTIMATES OF VARIANCES PER STRATA, AND VARIANCE IS DEPENDENTLY RELATED TO DEER DENSITY, THEN WE SHOULD CALCULATE SAMPLES SIZES REQUIRED FOR A RANGE OF POPULATION SIZES. SPORTSMEN ESTIMATE ABOUT 2000 DEER IN UNIT 10 WHILE CDOW COMPUTER MODEL ESTIMATES ARE 7-8000 DEER. THEREFORE THIS IS THE RANGE OF POPULATION SIZE TO ESTIMATE SAMPLE SIZE REQUIREMENTS.

SAMPLING AREA FRAME BASED ON FEBRUARY SURVEY FLIGHT WAS 364 MILES^2 OF WHICH LOW DENSITY STRATA ENCOMPASSED 113 MILES^2 (31%), MEDIUM DENSITY 157 MILES^2 (43%) AND HIGH DENSITY 94 MILES^2 (26%).

ESTIMATED DEER DENSITIES BELOW ENCOMPASS RANGES OF DENSITIES SEEN ON PINYON-JUNIPER WINTER RANGES SAMPLED WITH QUADRAT SAMPLE UNITS IN COLORADO. VALUES ALLOW ADJUSTMENTS IN SAMPLE SIZE CALCULATIONS BASED ON BEST ESTIMATES OF VARIANCES (S) ASSOCIATED WITH DIFFERENT EXPECTED DEER DENSITIES AND 2 DIFFERENT SIZED SAMPLE UNITS. DENISITES ON 1/4 MI^2 UNITS EQUAL DENSITY PER MI^2 / 4.

VALUES IN TABLE ARE LINKED AND USED IN CALCULATIONS ON NEXT PAGES

	GUESSED DEER DENSITY/MI^2 / STRATA				ESTIMATED VARIANCES (S) PER SAMPLE UNIT SIZE PER RELATIVE DENSITY					
	LOW	MEDIUM	HIGH	PROJECTED	LOW DENSITY		MEDIUM DENSITY		HIGH DENSITY	
	113 MI^2	157 MI^2	94 MI^2	POPULATION	1/4 MI^2 UNIT	1 MI^2 UNIT	1/4 MI^2 UNIT	1 MI^2 UNIT	1/4 MI^2 UNIT	1 MI^2 UNIT
IF TRUE POP. SIZE =										
2000 TOTAL DEER	1.5	5	10	1895	4.05	5.27	5.00	9.08	6.36	14.53
4000 TOTAL DEER	4	11	21	4153	4.73	7.99	6.63	15.62	9.36	26.51
6000 TOTAL DEER	5	16	31	5991	5.00	9.08	7.99	21.06	12.08	37.40
8000 TOTAL DEER	7	21	41	7942	5.54	11.26	9.36	26.51	14.80	48.29

CALCULATION OF TOTAL NUMBER OF SAMPLE UNITS (u) ASSUMING DIFFERENT DEER POPULATION SIZES AND ASSOCIATED AVERAGE STRATA DENSITIES AND ESTIMATED VARIANCES (S) PER SAMPLE UNIT SIZE

					PopSize =2000		PopSize =4000		PopSize = 6000		PopSize=8000	
AREA	STRATA GIS NO.(h)	DENSITY RANK	TOTAL MILE^2	TOTAL (U) SAMPLE UNITS	$(U_h \cdot S_{Nh})$ VALUE	$(U_h \cdot S^2_{Nh})$ VALUE	$(U_h \cdot S_{Nh})$ VALUE	$(U_h \cdot S^2_{Nh})$ VALUE	$(U_h \cdot S_{Nh})$ VALUE	$(U_h \cdot S^2_{Nh})$ VALUE	$(U_h \cdot S_{Nh})$ VALUE	$(U_h \cdot S^2_{Nh})$ VALUE
YAMPA-MONUMENT	1	LOW	29	115	465	1882	543	2569	575	2873	637	3533
YAMPA-MONUMENT	2	MEDIUM	30	122	608	3039	806	5349	972	7770	1137	10641
UTAH-WHITE RIVER	3	LOW	32	32	167	879	253	2022	287	2610	356	4012
UTAH-WHITE RIVER	4	MEDIUM	23	23	207	1876	151	1001	479	10090	603	15981
UPPER WHITE RIVER	5	HIGH	54	217	1378	8765	2027	18962	2617	31604	3207	47458
UPPER WHITE RIVER	6	MEDIUM	31	31	281	2554	483	7551	652	13734	821	21752
UPPER WHITE RIVER	7	LOW	32	32	168	888	255	2042	290	2636	360	4052
MASADONA-DINO	10	MEDIUM	44	176	882	4407	1170	7758	1410	11269	1650	15434
MASADONA-DINO	11	LOW	20	80	325	1314	379	1794	401	2006	445	2467
TWELVEMILE	12	MEDIUM	29	29	263	2387	452	7056	609	12835	767	20329
MASADONA-DINO	13	HIGH	40	162	1029	6548	1514	14165	1955	23609	2395	35452
TOTALS SUMS	**11**		**364**	**1018**	**5773**	**34540**	**8035**	**70268**	**10247**	**121036**	**12378**	**181112**
TOTALS SQUARED					**33324511**		**64553941**		**105006872**		**153217028**	

SAMPLE SIZE FORMULA FROM COCHRAN 1977 AND PAGE 341 THOMPSON ET AL. 1998

Total Sample Quadrat Units (u) =

$$\frac{[\text{sum}_{1\text{ to }H}(U_h \cdot S_{Nh})]^2}{(eN/t)^\wedge 2 + [\text{sum}_{1\text{ to }H}(U_h {*} S^2_{Nh})]}$$

CALCULATION OF TOTAL NUMBER OF SAMPLE UNITS CONTINUED

SAMPLES SIZES CALCULATED FOR ESTIMATED ERROR OF +/-20% OF MEAN ESTIMATE

AT Alpha = 0.10, t = 1.645 df>120

AT Alpha = 0.05, t = 1.96 df>120

	POTENTIAL DEER POPULATION SIZE			
	2000	4000	6000	8000
Error Bound (e) +/- 20%	400	800	1200	1600
WHEN t = 1.645	1.645	1.645	1.645	1.645
Error Term (eN/t)^2 =	**59127**	**236509**	**532146**	**946037**
WHEN t = 1.96	1.96	1.96	1.96	1.96
Error Term (eN/t)^2 =	**41649**	**166597**	**374844**	**666389**
Total Sample Units (u)				
SampleUnits Alpha=0.10	**356**	**210**	**161**	**136**
SampleUnits Alpha=0.05	**437**	**273**	**212**	**181**

Where For Each Pop.

Size Total Sample

Quadrat Units (u) =

$$\frac{[\text{sum}_{1 \text{ to } H}(U_h \cdot S_{Nh})]^2}{(eN/t)^2 + [\text{sum}_{1 \text{ to } H}(U_h * S^2_{Nh})]}$$

Example For Population of 2000 Deer

Error Bound +/- 20% @ Alpha =0.05

$$\frac{33324511}{41649 + 34540}$$

Total Sample Units = 437

CALCULATING NUMBER OF SAMPLE UNITS FOR INDIVIDUAL STRATA

ASSUME POPULATION OF 6000 DEER, Alpha = 0.10, AND TOTAL SAMPLE UNITS = 161, SEE PREVIOUS PAGE FOR CALCULATIONS

ASSUME COSTS OF FLYING QUADRATS IN EACH STRATUM ARE THE SAME

COST TO FLY 1 MI^2 QUADRAT IN OPEN VEGETATION ABOUT 25 MINUTES OF HELICOPTER TIME

COST TO FLY 1/4 MI^2 QUADRAT IN PINYON JUNIPER VEGETATION ABOUT 20 MINUTES OF HELICOPTER TIME

AREA	STRATA GIS NO.(h)	DENSITY RANK	TOTAL MILE^2	TOTAL (U) SAMPLE UNITS	($U_h \cdot S_{Nh}$) VALUE	SAMPLE UNITS	% UNITS SAMPLED	% AREA MI^2 SAMPLED	AREA MI^2 FLOWN	Strata Test Sum Column G
YAMPA-MONUMENT	1	LOW	29	115	575	9	8	7.9	2	9
YAMPA-MONUMENT	2	MEDIUM	30	122	972	15	13	12.6	4	15
UTAH-WHITE RIVER	3	LOW	32	32	287	5	14	14.3	5	5
UTAH-WHITE RIVER	4	MEDIUM	23	23	479	8	33	33.1	8	8
UPPER WHITE RIVER	5	HIGH	54	217	2617	41	19	19.0	10	41
UPPER WHITE RIVER	6	MEDIUM	31	31	652	10	33	33.1	10	10
UPPER WHITE RIVER	7	LOW	32	32	290	5	14	14.3	5	5
MASADONA-DINO	10	MEDIUM	44	176	1410	22	13	12.6	6	22
MASADONA-DINO	11	LOW	20	80	401	6	8	7.9	2	6
TWELVEMILE	12	MEDIUM	29	29	609	10	33	33.1	10	10
MASADONA-DINO	13	HIGH	40	162	1955	31	19	19.0	8	31
TOTAL SUMS	**11**		**364.149**	**1018**	**10247**	**161**	**16**		**68**	**162**
						162	**=actual sum**			
							anomaly			
						See Note Below				

FORMULA FOR ALLOCATING SAMPLE UNITS TO STRATA (Neyman Allocation after Cochran 1977; In Thompson et al. 1998, page 342)

STRATA ALLOCATION FORMULA

$$u_h = u[\, U_h S_{Nhl} / (_{\text{sum 1 to H}}\, U_h S_{Nhl})]$$

EXAMPLE CALCULATION

$$u_h = 161*[575 / 10247]$$

for Yampa-Monument Low Density Strata from above.

= 9 sample units in this stratum

NOTE: Due to weather conpromising ability to complete necessary flying of units on March 3 and 4 , 2001, number of sample units flown in the Massadon-Dinosaur strata were reduced to 21, 15, and 4 in the high, medium, and low density strata, respectively. This reduced total sample units flown to 143 (162-19). The 161 sum in column G is an arithmetic anomaly that must have something to due with rounding corrections in automatic calculations. The strata sample sizes when added as whole numbers in column L sum to 162 which was the number of quadrats orginally drawn to be sampled. This problem discovered when we reduced sampling in Massadona strata by 19 quadrats and the total flown for the entire Unit 10 was 143 (ie--161-19 did not equal 143 flown).

2. MODIFICATION OF SAMPLE SIZE DURING PROJECT

Random Subsample of MASSADONA-DINO Unit 10 Strata
March 3, 2001
Reduce total sample from 59 quadrat units to 40 quadrat units proportionately across strata.
Minimum of 4 sample units in Low Density Strata, reduced from 6 (1/3 reduction)
Reduction in Low Density Established the Proportion reduced in High and Medium Density
Decisions Made and Technique of Random Subsample completed with V.W. Howard approval and support
Sample reduction was made to allow completion of a reasonable number of sample units to
obtain an estimate within limited time frame and flyable weather patterns
Used Quattro Sample Tool Random function to select subsamples within each of 3 strata

Howard, Bickle and Freddy discussed (3/2/01)options for completing the Massadona Unit with reduced
sampling, inclusive of dropping entire strata and/or proportional reduction in samples within
each of 3 strata. Reducing samples in each strata was considered preferable to dropping
a strata.

Howard, Bickle and Freddy also discussed merits of doing or not doing the Yampa-Monument Strata
under given time constraints. Howard thought this was the least priority of strata because
Sportsmen do not believe deer assoicated with the Monument a part of the available huntable deer
population. However, CDOW does include Monument deer in the Unit 10
deer population model. At this stage of discussion, Howard and Bickle comfortable with
not completing the Yampa-Monument strata.

Massadona High Density Strata; Units Sorted/Ordered by Sample Tool Selection Order
Sample Tool Set to assign random order to a sample of 31 and took first 21 because duplicate
numbers will get assigned so ignored ties due to assigned numbers

Original High Density Quadrats	Quads Numeric Listing Equivalent	Selection Order Number Assigned Using Quattro Sample Tool	First 21 Selected By Random Order
20-MDH	20	1	1
26-MDH	26	3	2
15-MDH	15	3	3
8-MDH	8	5	4
10-MDH	10	5	5
21-MDH	21	6	6
30-MDH	30	7	7
24-MDH	24	9	8
31-MDH	31	9	9
19-MDH	19	11	10
7-MDH	7	14	11
16-MDH	16	15	12
3-MDH	3	16	13
4-MDH	4	16	14
11-MDH	11	16	15
25-MDH	25	18	16
22-MDH	22	19	17
1-MDH	1	21	18
13-MDH	13	21	19
9-MDH	9	23	20
29-MDH	29	23	21
17-MDH	17	23	
12-MDH	12	24	
23-MDH	23	25	
14-MDH	14	26	
18-MDH	18	26	
28-MDH	28	27	
2-MDH	2	27	
5-MDH	5	29	
6-MDH	6	31	
27-MDH	27	31	

Massadona Medium Density Strata; Units Sorted/Ordered by Sample Tool Selection Order

Sample Tool Set to assign random order to a sample of 22 and took first 15 because duplicate numbers will get assigned so ignored ties due to assigned numbers

Original High Density Quadrats	Quads Numeric Listing Equivalent	Selection Order Number Assigned Using Quattro Sample Tool	First 15 Selected By Random Order
10-MDM	10	1	1
11-MDM	11	2	2
7-MDM	7	3	3
20-MDM	20	4	4
21-MDM	21	5	5
14-MDM	14	6	6
3-MDM	3	8	7
13-MDM	13	8	8
1-MDM	1	8	9
9-MDM	9	11	10
12-MDM	12	15	11
18-MDM	18	15	12
17-MDM	17	17	13
22-MDM	22	17	14
4-MDM	4	17	15
16-MDM	16	18	
2-MDM	2	18	
5-MDM	5	19	
8-MDM	8	20	
15-MDM	15	20	
6-MDM	6	20	
19-MDM	19	21	

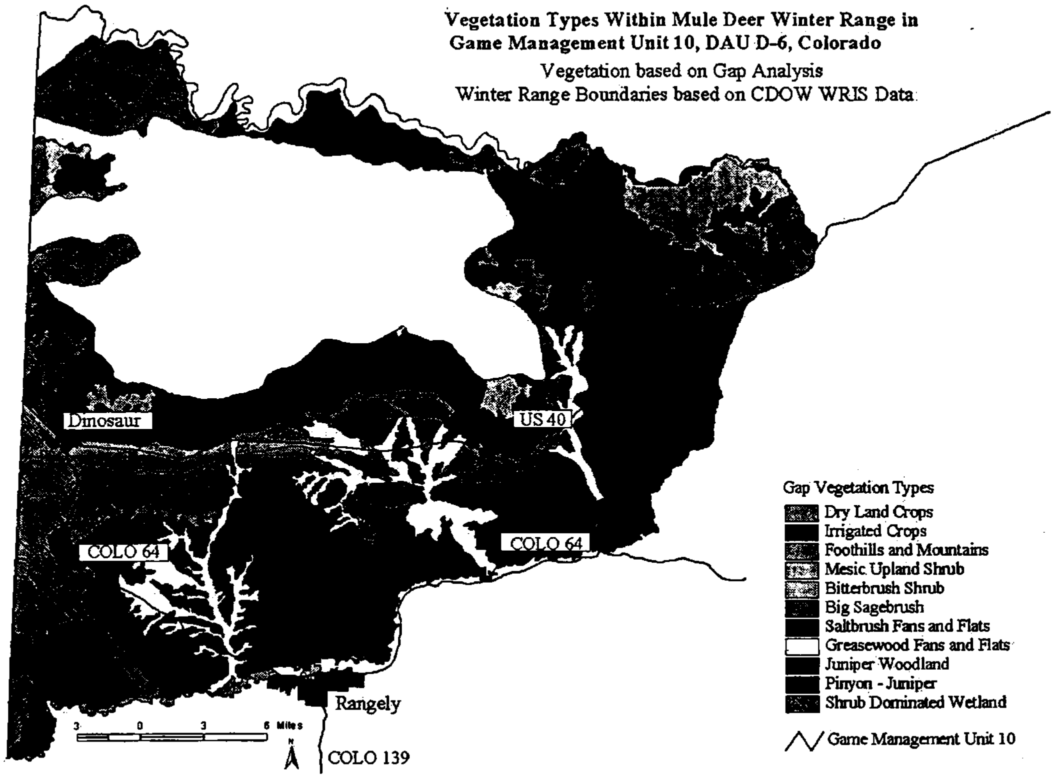
Massadona Low Density Strata; Units Sorted/Ordered by Sample Tool Selection Order

Sample Tool Set to assign random order to a sample of 6 and took first 4 because duplicate numbers will get assigned so ignored ties due to assigned numbers

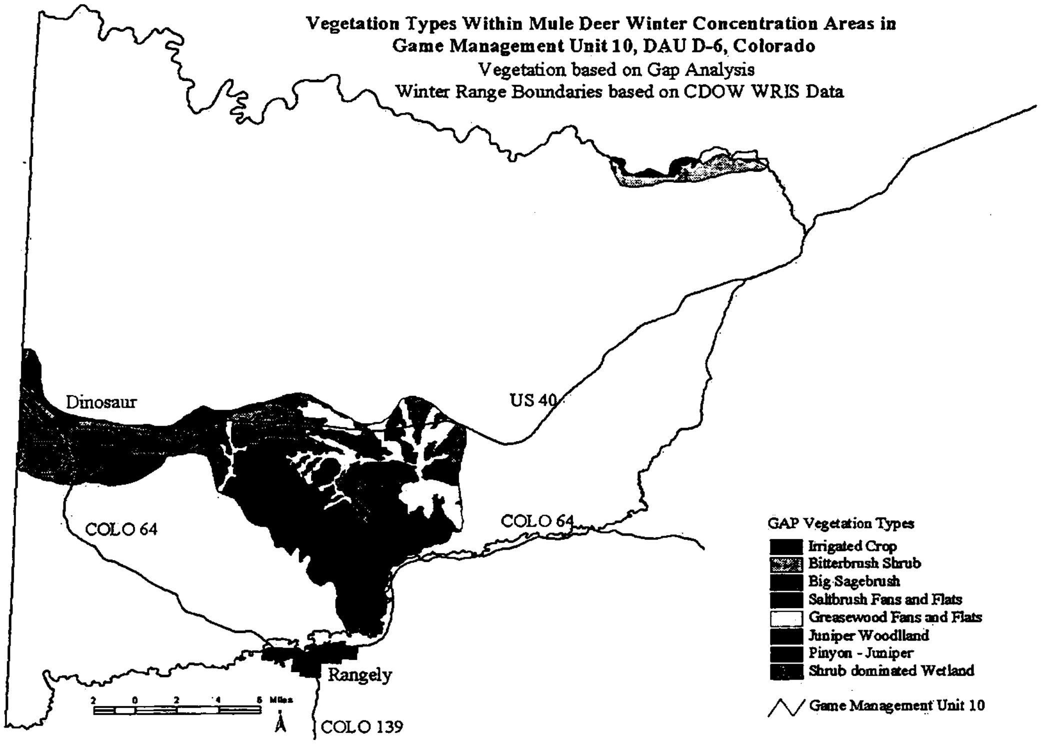
Original High Density Quadrats	Quads Numeric Listing Equivalent	Selection Order Number Assigned Using Quattro Sample Tool	First 15 Selected By Random Order
6-MDL	6	1	1
2-MDL	2	3	2
5-MDL	5	3	3
4-MDL	4	4	4
1-MDL	1	4	
3-MDL	3	5	

SECTION D

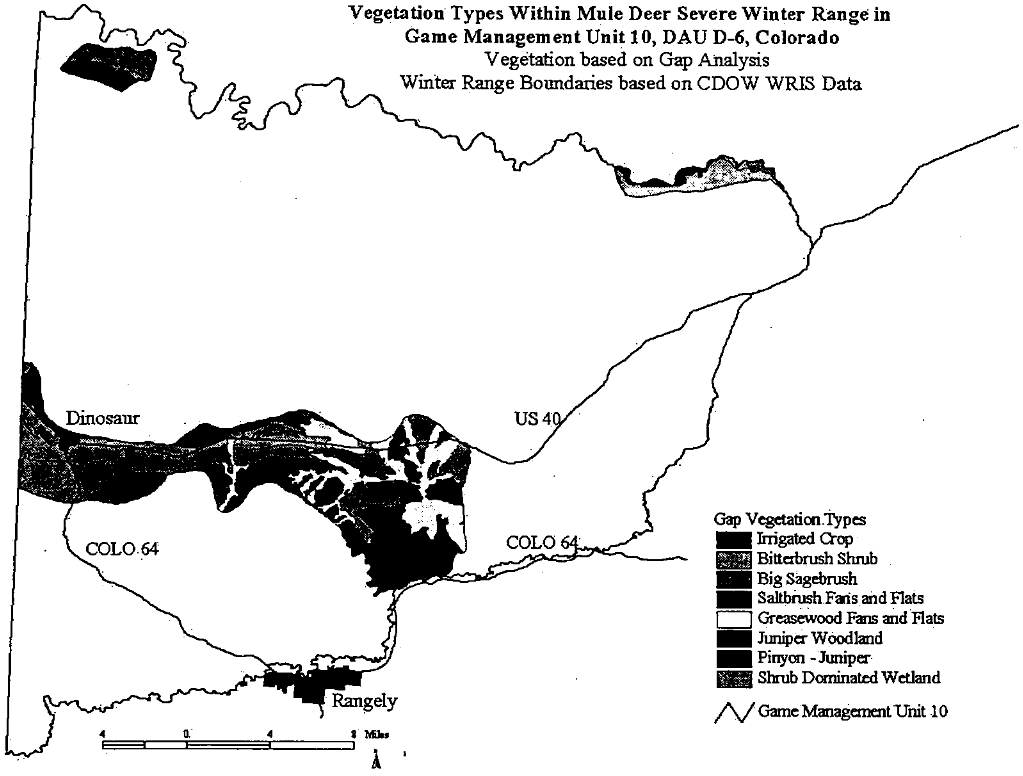
1. D-6, UNIT 10 DEER WINTER RANGE MAP



2. D-6, UNIT 10 DEER WINTER CONCENTRATION AREA MAP

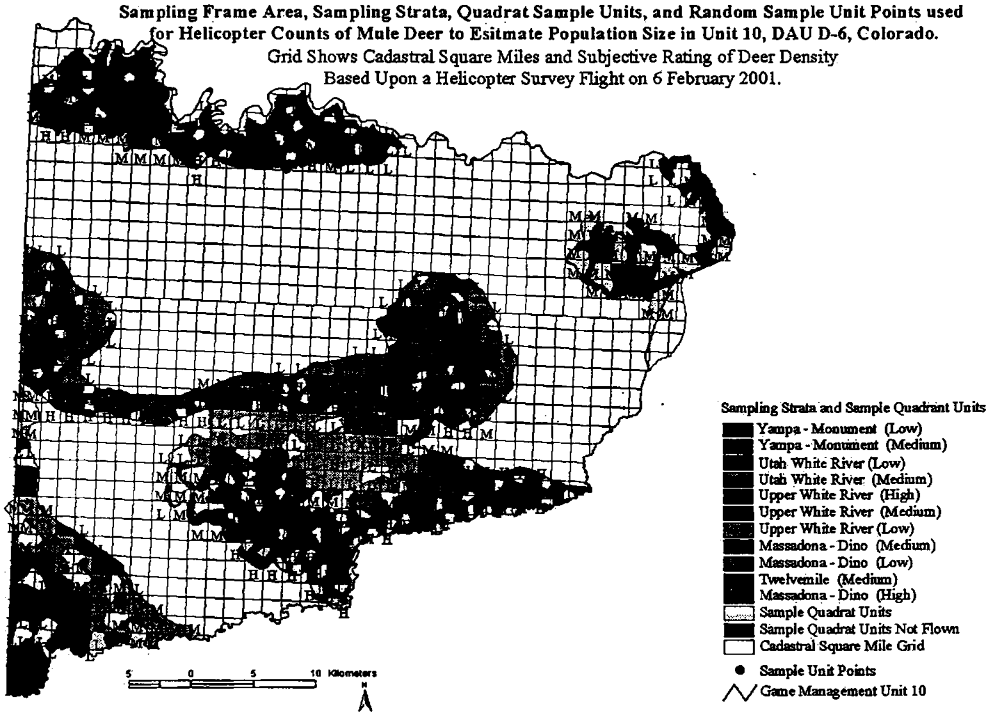


3. D-6, UNIT 10 DEER WINTER SEVERE RANGE MAP



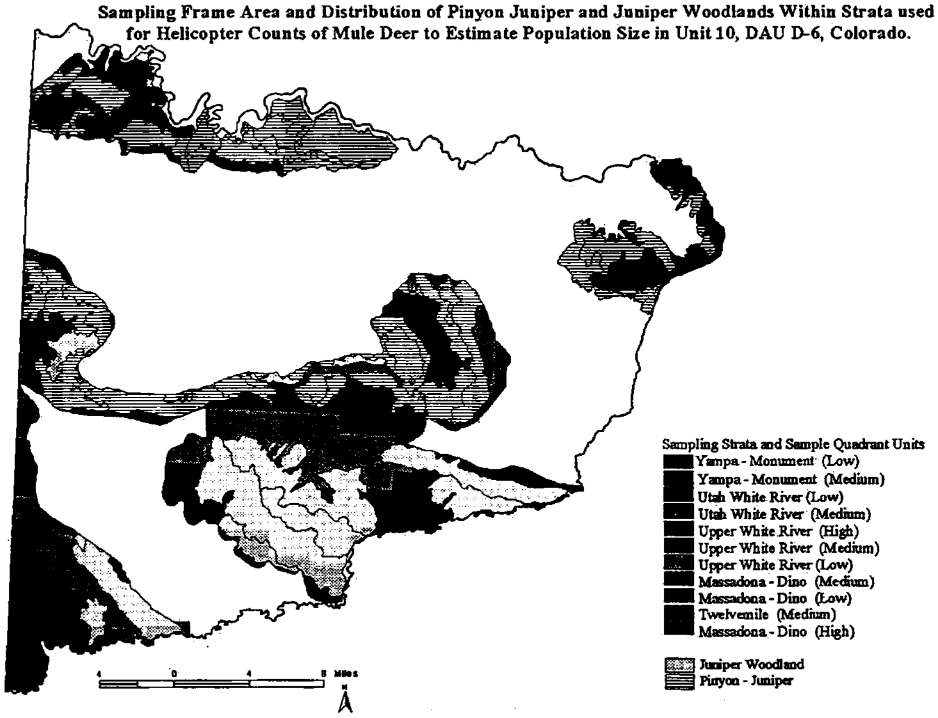
SECTION E

1. SAMPLING FRAME AND SAMPLING STRATA MAP



Sampling Frame Area, Sampling Strata, Quadrat Sample Units, and Random Sample Unit Points used for Helicopter Counts of Mule Deer to Esitmate Population Size in Unit 10, DAU D-6, Colorado.
Grid Shows Cadastral Square Miles and Subjective Rating of Deer Density
Based Upon a Helicopter Survey Flight on 6 February 2001.

2. SAMPLING FRAME AND PRIMARY VEGETATION TYPES



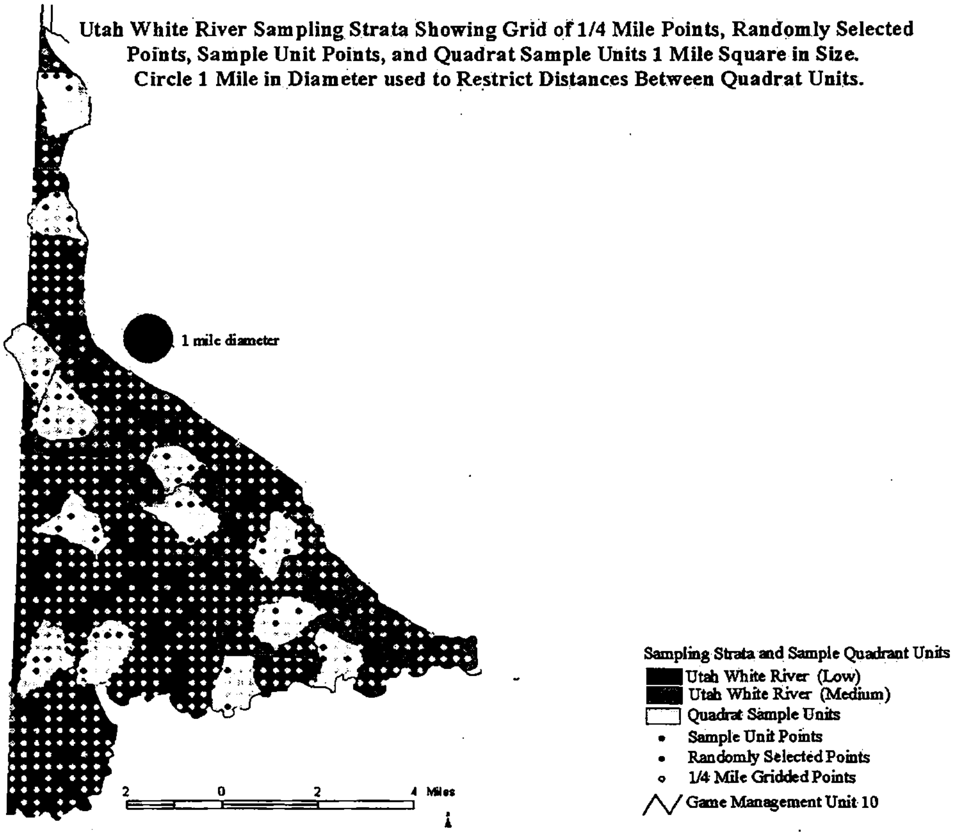
Sampling Frame Area and Distribution of Pinyon Juniper and Juniper Woodlands Within Strata used for Helicopter Counts of Mule Deer to Estimate Population Size in Unit 10, DAU D-6, Colorado.

3. YAMPA MONUMENT STRATA 1 AND 2 MAP

Yampa - Monument Sampling Strata Showing Grid of 1/4 Mile Points, Randomly Selected Points, Sample Unit Points, and Quadrat Sample Units 1/4 Mile Square in Size. Circle 1/2 Mile in Diameter used to Restrict Distances Between Quadrat Units.

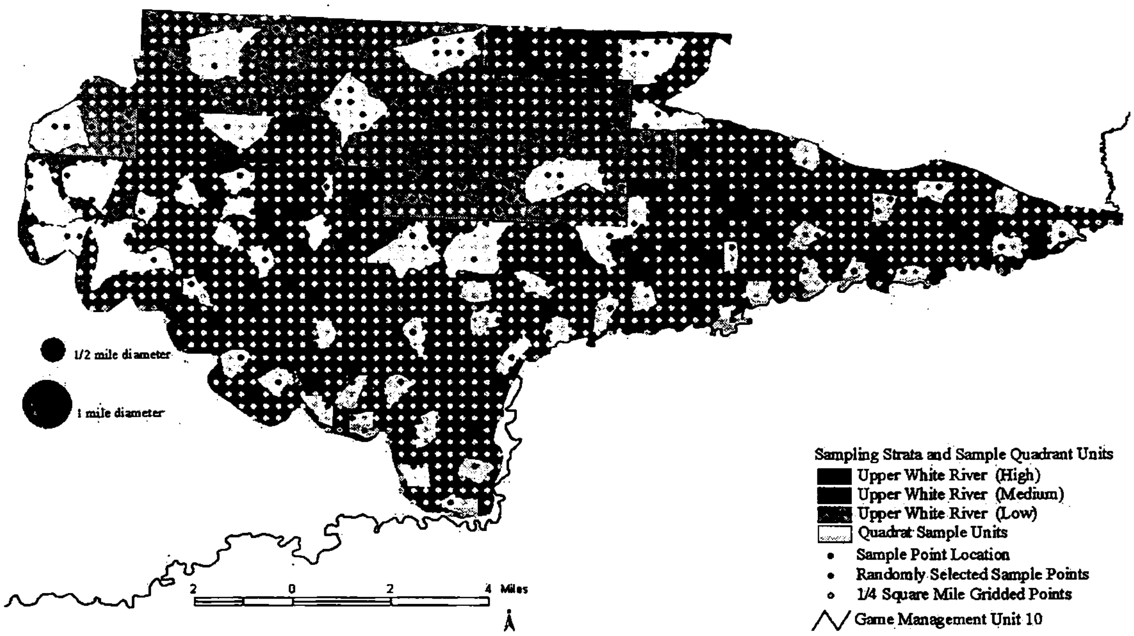
4. UTAH WHITE RIVER STRATA 3 AND 4 MAP

Utah White River Sampling Strata Showing Grid of 1/4 Mile Points, Randomly Selected Points, Sample Unit Points, and Quadrat Sample Units 1 Mile Square in Size. Circle 1 Mile in Diameter used to Restrict Distances Between Quadrat Units.



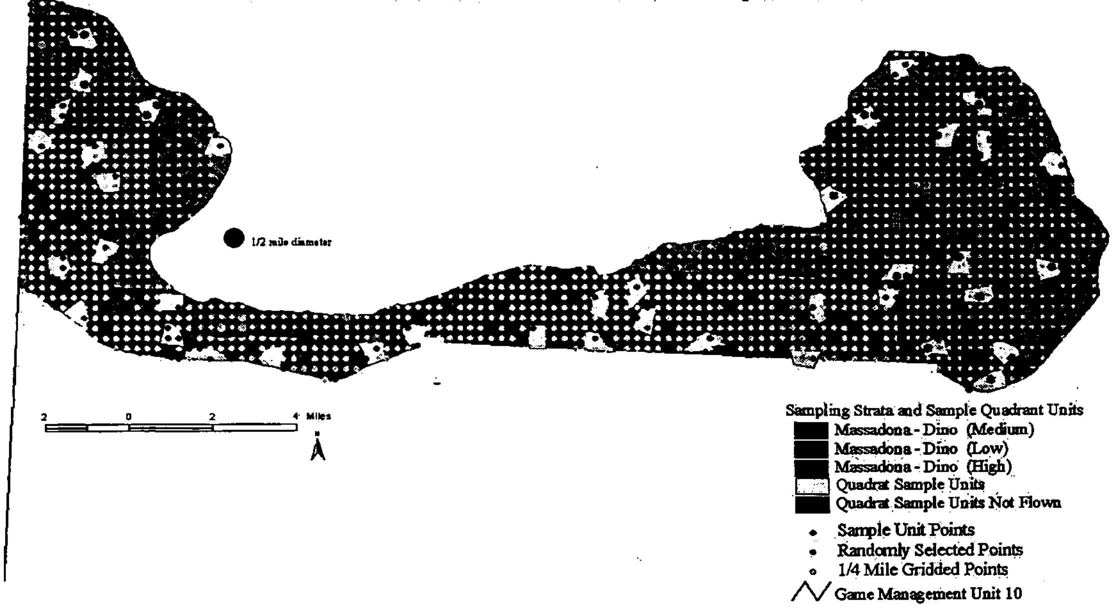
5. UPPER WHITE RIVER STRATA 5, 6, AND 7 MAP

Upper White River Sampling Strata Showing Grid of 1/4 Mile Points, Randomly Selected Points, Sample Unit Points, and Quadrat Sample Units 1/4 and 1 Mile Square in Size. Circle 1/2 and 1 Mile in Diameter used to Restrict Distances Between Quadrat Units.



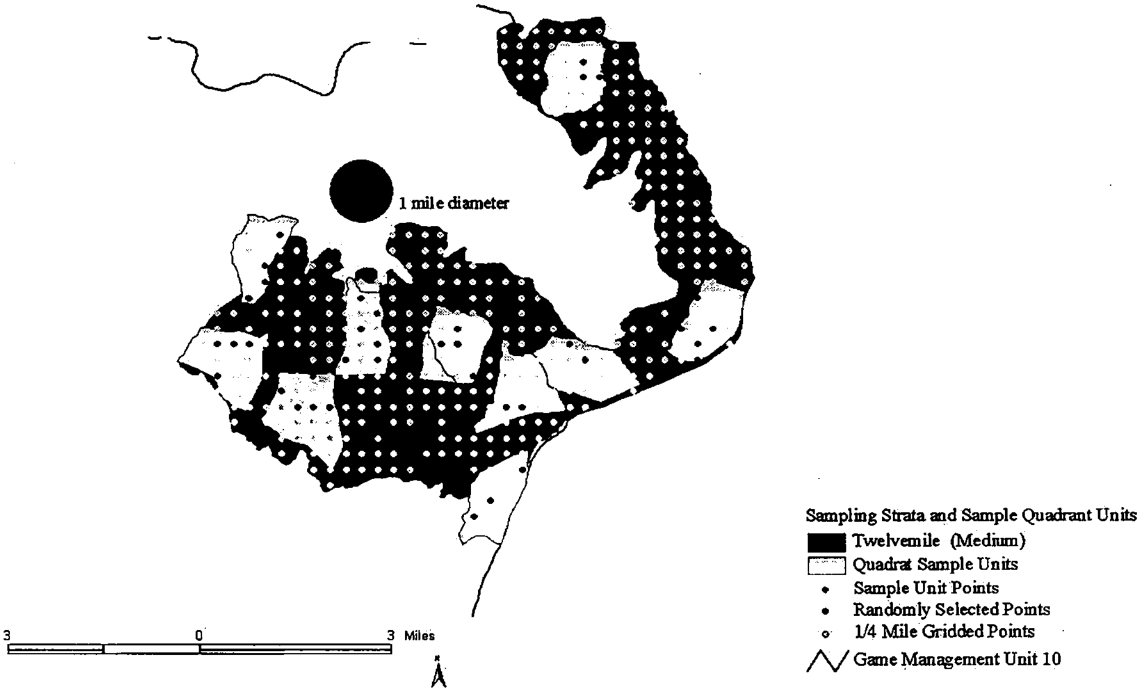
6. MASSADONA - DINOSAUR STRATA 10, 11, AND 13 MAP

Massadona - Dinosaur Sampling Strata Showing Grid of 1/4 Mile Points, Randomly Selected Points, Sample Unit Points, and Quadrat Sample Units 1/4 Mile Square in Size. Circle 1/2 Mile in Diameter used to Restrict Distances Between Quadrat Units.



7. TWELVEMILE STRATA 12 MAP (Clarification: No strata numbered 8 & 9;11 total strata)

Twelvemile Sampling Strata Showing Grid of 1/4 Mile Points, Randomly Selected Points, Sample Unit Points, and Quadrat Sample Units 1 Mile Square in Size. Circle 1 Mile in Diameter used to Restrict Distances Between Quadrat Units.



SECTION F

1. SURVEY FLIGHT PROTOCOLS

PROCEDURES FOR FLYING HELICOPTER SAMPLE QUADRATS
GMU 10, DEER POPULATION ESTIMATE FEBRUARY 2001
COLORADO QUADRAT WITH IDAHO SIGHTABILITY CORRECTIONS
D.J. FREDDY, MAMMALS RESEARCH, COLO. DIV. WILDLIFE
J.W. UNSWORTH, IDAHO DEPT. FISH & GAME
(PROVIDED SIGHTABILITY TECHNIQUE SUGGESTIONS)
FEBRUARY 8, 2001

I. BACKGROUND INFORMATION:

AREAS OCCUPIED BY DEER IN UNIT 10 WERE DELINEATED (364 SQUARE MILES) AND STRATIFIED ACCORDING TO RELATIVE DEER DENSITIES INTO HIGH, MEDIUM, AN LOW STRATA (11 STRATA) BASED ON A HELICOPTER SURVEY FLIGHT CONDUCTED BY V. GRAHAM (CDOW) IN FEBRUARY 6, 2001. THE OCCUPIED DEER RANGE DELINEATED REPRESENTS A CONDENSED PORTION OF THE EXTENSIVE WINTER RANGE AREA DELINEATED IN THE CDOW WRIS INVENTORY SYSTEM BECAUSE SNOW-DEPTHS HAVE CONCENTRATED DEER TO SOME EXTENT. SAMPLE UNITS, OR QUADRATS, WITH AN AREA SIZE OF 1 SQUARE MILE (USED IN OPEN VEGETATION HABITATS) OR 1/4 SQUARE MILE (USED IN PINYON-JUNIPER FORESTED HABITATS) WERE SELECTED AT RANDOM WITHIN EACH STRATUM ACCORDING TO STANDARD STATISTICAL SAMPLING FORMULAS. BOUNDARIES OF ALL SAMPLE UNITS WERE BASED ON TOPOGRAPHIC OR CULTURAL FEATURES. FROM THE STRATIFIED RANDOM SAMPLE OF QUADRATS WE WILL OBTAIN 2 ESTIMATES OF POPULATION SIZE FOR THE 364 SQUARE MILE AREA SAMPLED: 1) AN ESTIMATE BASED ON UNADJUSTED COUNTS OF DEER ON QUADRATS, AND, 2) AN ESTIMATE BASED ON COUNTS OF DEER ON EACH QUADRAT ADJUSTED FOR SIGHTING OR DETECTION PROBABILITY OF EACH GROUP OF DEER USING A SIGHTING BIAS CORRECTION FACTOR (IDAHO MULE DEER SIGHTABILITY MODEL).

II. AIRCRAFT:

THE PRIMARY HELICOPTER WILL BE A HILLER 12E SOLOY AND THE SECONDARY HELICOPTER WILL LIKELY BE FRENCH A-STAR OR TWIN-STAR, ALL TURBINE POWERED AIRCRAFT. THE HILLER PROVIDES THE BEST VISIBILITY PLATFORM FOR COUNTING DEER AND WILL BE USED PRIMARILY IN AREAS OF HIGHER DEER DENSITY. FLIGHT CREWS WILL CONSIST OF A PRIMARY OBSERVER, NAVIGATOR, AND PILOT. ALL 3 PERSONS SHOULD SIT ABREAST IN THE HELICOPTER WITH THE NAVIGATOR POSITIONED IN THE MIDDLE. THE HELICOPTER MUST HAVE FUNCTIONING INTERCOM HEADSETS SO THAT ALL 3 MEMBERS CAN READILY COMMUNICATE VOICE INSTRUCTIONS OR INFORMATION.

SUNNY AND COOL DAYS WITH GOOD SNOW BACKGROUND AND LOW WIND SPEEDS ARE THE MOST DESIRABLE FLYING AND COUNTING CONDITIONS. HAZY OR FLAT LIGHTING ON OVERCAST DAYS IS ACCEPTABLE, BUT NOT PREFERRED. CREWS SHOULD AVOID PUSHING TO GET WORK ACCOMPLISHED IF THERE ARE CONSTANT SNOW FLURRIES OR WIND SPEEDS THAT NECESSITATE FLYING AT HIGHER SPEEDS AND ELEVATIONS ABOVE THE GROUND.

III. SAFETY:

HELICOPTERS WILL HAVE A SURVIVAL GEAR BAG FOR SUPPORTING 3 PERSONS, A FUNCTIONING ELT, FIRE EXTINGUISHER, AND PORTABLE PACKSET FOR EMERGENCY COMMUNICATIONS. IT IS RECOMMENDED FLIGHT CREWS PERIODICALLY REPORT THEIR GENERAL LOCATION TO COUNTY SHERIFF DISPATCH VIA HELICOPTER RADIO IF POSSIBLE. FLIGHT CREW MEMBERS ARE ENCOURAGED TO WEAR NOVEX FLIGHT SUITS AND CLOTHING MADE ONLY OF COTTON OR WOOL FIBERS, NO SYNTHETICS.

PILOT, NAVIGATOR, AND OBSERVER MUST ALL WORK TOGETHER TO DETECT AND COMMUNICATE THE PRESENCE OF POWER LINES WITHIN THE WORKING AREA. IF BUILDINGS ARE IN THE AREA, ALWAYS ASSUME THAT A POWER LINE IS NEARBY. IF WEATHER CONDITIONS DETERIORATE, CREWS MUST RECOGNIZE THE CHANCE FOR ICING CONDITIONS OR VISIBILITY CONDITIONS THAT CAN GREATLY COMPROMISE SAFETY.

PLANNING SHOULD INSURE THAT THE FUEL TRUCK AND DRIVER ARE AT A LOCATION KNOWN TO THE PILOT AND WITHIN 15-20 MINUTES FLIGHT TIME OF THE HELICOPTER'S ANTICIPATED DESTINATION AFTER FLYING FOR 1 HOUR AND 45 MINUTES.

IV. PERSONNEL:

A. THE PRIMARY OBSERVER SHOULD BE A PERSON EXPERIENCED IN DETECTING AND COUNTING DEER FROM A HELICOPTER, CAPABLE OF CONCENTRATING AND FLYING SEVERAL HOURS/DAY FOR SEVERAL DAYS, CAPABLE OF MAKING RAPID DECISIONS REGARDING GROUP SIZE AND SIGHTABILITY VARIABLES, AND CAPABLE OF ACCURATELY RECORDING DATA ONTO A TAPE RECORDER AND TRANSCRIBING THAT DATA TO DATA FORMS. THE PRIMARY OBSERVER IS PRIMARILY RESPONSIBLE FOR DETECTING GROUPS FORWARD AND TO THE RIGHT OF THE AIRCRAFT AND TOTALLY RESPONSIBLE FOR RECORDING GROUP SIZE AND SIGHTING VARIABLES OF ANY DEER GROUP SEEN. THIS PERSON MUST WORK IN COORDINATION WITH THE NAVIGATOR AND PILOT TO POSITION THE AIRCRAFT AT A FAVORABLE ALTITUDE AND SPEED. THE PRIMARY OBSERVER IS RESPONSIBLE FOR RECORDING ALL DATA PERTINENT TO EACH QUADRAT AND SHOULD REFER TO THE OBSERVER 'CHEAT SHEET' FREQUENTLY TO INSURE THAT PROPER DATA ARE RECORDED.

B. THE NAVIGATOR SHOULD BE A PERSON CAPABLE OF NAVIGATING THE HELICOPTER TO THE PROPER LOCATION OF EACH SAMPLE QUADRAT USING LAT/LONG COORDINATES AND TOPOGRAPHIC MAPS PREPARED FOR EACH QUADRAT. THE NAVIGATOR MUST BE ABLE TO DIRECT THE PILOT TO FLY THE CORRECT BOUNDARY OF THE QUADRAT BASED ON VISUAL INTERPRETATION OF THE TOPOGRAPHIC MAP AND THE TERRAIN OVER WHICH THE HELICOPTER IS FLYING. FURTHERMORE, THE NAVIGATOR IS RESPONSIBLE FOR DIRECTING THE FLIGHT PATH TRAVERSED THROUGH THE QUADRAT TO INSURE PROPER 100% COVERAGE AND COUNTING CONDITIONS. THE NAVIGATOR WORKS IN COORDINATION WITH THE PRIMARY OBSERVER AND THE PILOT. NAVIGATOR ASSISTS THE PRIMARY OBSERVER BY DETECTING GROUPS FORWARD AND TO THE LEFT OF THE AIRCRAFT, AND ASSISTS THE PRIMARY OBSERVER IN KEEPING DIFFERENT GROUPS OF DEER SEPARATE. THE NAVIGATOR SHOULD KEEP A RUNNING TALLY OF DEER COUNTED ON EACH QUADRAT USING A TALLY-WHACKER COUNTING DEVICE. THIS PROVIDES A BASIC BACKUP TO THE TAPE RECORDER OF THE PRIMARY OBSERVER. ALTHOUGH THE OBSERVER AND NAVIGATOR WILL USE THE PRESENCE OF DEER TRACKS IN SNOW AS AN INDICATOR THAT DEER ARE PRESENT, THE NAVIGATOR SHOULD MAKE SURE THAT GROUPS OF DEER ARE NOT ACTUALLY FOUND BY TRACKING DOWN INDIVIDUAL ANIMALS BY FOLLOWING SETS OF TRACKS WITH THE HELICOPTER. SIGHTABILITY MODELS ARE BASED ON VISUAL DETECTION OF ANIMALS, NOT FROM TRACKING.

C. THE PILOT'S PRIMARY RESPONSIBILITY IS TO CONCENTRATE ON FLYING THE AIRCRAFT SAFELY AND IN A MANNER THAT SUPPORTS THE PRIMARY OBSERVER. THE PILOT WILL DETECT GROUPS OF DEER NOT SEEN BY THE PRIMARY OBSERVER OR NAVIGATOR. THE PILOT WILL RELAY INFORMATION TO THE NAVIGATOR ON GROUPS HE SEES AND THE OBSERVER AND NAVIGATOR WILL COLLECT THE DATA FOR SUCH GROUPS.

V. DATA COLLECTED:

A. QUADRAT: AT THE BEGINNING OF EACH QUADRAT SAMPLE UNIT, THE PRIMARY OBSERVER WILL RECORD THE QUADRAT IDENTIFICATION NUMBER, APPROXIMATE LAT/LONG STARTING POINT, GENERAL FLIGHT LIGHT, SNOW, AND WIND COUNTING CONDITIONS, AND CLOCK STARTING ENDING TIME FOR EACH QUADRAT. NAVIGATOR SHOULD ASSIST OBSERVER IN MAKING SURE THIS INFORMATION IS RECORDED.

B. DEER: THE PRIMARY OBSERVER WILL COUNT EACH GROUP OF DEER DETECTED AND DETERMINE SIGHTING VARIABLES FOR EACH GROUP, REGARDLESS OF WHO FIRST DETECTS THE GROUP. ON THE TAPE RECORDER THE OBSERVER WILL SAY NEXT OR NEW GROUP OF DEER WHEN EACH GROUP IS DETECTED. THE OBSERVER WILL RECORD THE *ACTIVITY* OF THE DEER WHO IS MOST ACTIVE WHEN THE GROUP IS FIRST DETECTED, THE *VEGETATION TYPE* AND RELATIVE *PERCENT SNOW* COVER IN THE CIRCULAR AREA *WITHIN 10 METERS (30 FEET)* OF WHERE THE INITIAL DEER WAS DETECTED, AND THE *TOTAL NUMBER* OF DEER IN EACH GROUP. THESE 4 VARIABLES CONSTITUTE THE IDAHO SIGHTABILITY MODEL INPUT VARIABLES.

SIGHTING VARIABLES:

1. DEER ACTIVITY IS EITHER BEDDED, STANDING, OR MOVING. THE ACTIVITY IS RECORDED FOR THE DEER WITHIN THE GROUP THAT IS MOST ACTIVE WHEN THE GROUP IS FIRST DETECTED. A DEER THAT IS GETTING UP FROM A BEDDED POSITION WHEN FIRST DETECTED IS RECORDED AS A STANDING DEER BECAUSE THE MOVEMENT OF THE DEER GETTING UP IS LIKELY WHY THE DEER WAS DETECTED. A DEER MUST REMAIN BEDDED FOR A BRIEF PERIOD AFTER INITIAL DETECTION TO BE RECORDED AS BEDDED. STANDING DEER MUST REMAIN RELATIVELY

MOTIONLESS AFTER INITIAL DETECTED, AND MOVING DEER ARE DEER THAT ARE WALKING TO RUNNING.

2. VEGETATION TYPE WILL BE ONE OF SEVERAL CATEGORIES AND OBSERVERS SHOULD DO THEIR BEST TO CLASSIFY VEGETATION PROPERLY TO THE MOST DOMINANT TYPE AT THE LOCATION WHERE GROUP FIRST DETECTED BUT DO NOT SPEND A GREAT DEAL OF TIME TRYING TO DIFFERENTIATE LOW BRUSH VEGETATION TYPES. IN ALL LIKELIHOOD DURING DATA SUMMARIES AND ANALYSES, VEGETATION TYPES WILL BE POOLED INTO LOW BRUSH TYPES VERSUS PINYON AND JUNIPER TYPES. VEGETATION TYPES WERE BASED ON CLASSIFICATIONS USED IN THE *GAP* DATABASE FOR UNIT 10.

VEGETATION TYPES
SAGEBRUSH
BITTERBRUSH
GREASEWOOD FLATS
SALTBUSH FLATS
PINYON-JUNIPER WOODLAND
JUNIPER WOODLAND
AGRICULTURAL AND NATURAL CLEARINGS
RIPARIAN SHRUB
TALL CONIFER

SIGHTABILITY CORRECTIONS FOR VEGETATION TYPES WILL MOST LIKELY BE BASED ON CORRECTION FACTORS DEVELOPED IN IDAHO FOR THEIR VEGETATION CLASSES OF 1) GRASS/OPEN/AGRICULTURE, 2) SAGEBRUSH, 3)JUNIPER/MOUNTAIN MAHOGANY, AND 4), POSSIBLY CONIFER. NO CORRECTION FACTORS HAVE BEEN DIRECTLY DEVELOPED FOR DEER IN OUR PINYON-JUNIPER OR JUNIPER WOODLAND HABITATS SO WE MUST USE IDAHO INFORMATION TO APPROXIMATE OUR VEGETATION CONDITIONS.

3. PERCENT SNOW COVER AT THE LOCATION WHERE EACH GROUP OF DEER IS FIRST DETECTED. SNOW COVER PERCENTAGES WILL BE CLASSIFIED BY THE OBSERVER AS LOW = 0-79%, AND HIGH = >80% OF THE GROUND COVERED BY SNOW. THESE CLASSIFICATIONS MUST BE USED TO BEST MATCH THE IDAHO SIGHTABILITY MODEL. IDAHO DOES HAVE A SNOW COVER CLASSIFICATION OF 0-19% BUT THIS SITUATION APPLIES TO COUNTS OF DEER DURING SPRING-GREENUP WHEN DEER ARE IN LARGER GROUPS IN OPEN HABITATS.

4. TOTAL NUMBER OF DEER IN EACH GROUP. A NUMERIC COUNT OF ALL DEER SEEN IN EACH GROUP. DEER *WILL NOT* BE CLASSIFIED TO AGE OR SEX.

VI. IN-FLIGHT PROCEDURES

1. NAVIGATOR AND OBSERVER WILL OBTAIN PROPER MAPS, ARRANGE IN ORDER OF NEED, AND DECIDE ON GENERAL ROUTE TO QUADRATS TO BE FLOWN DURING EACH FUEL LOAD. PRIMARY OBSERVER MAKES SURE THAT TAPE RECORDER IS FUNCTIONING AND ADDITIONAL BATTERIES AND TAPES ARE AVAILABLE. NAVIGATOR SHOULD HAVE A SPARE TAPE RECORDER AVAILABLE.

2. OBTAIN A GPS POSITION AT STARTING POINT AND NOTE A GENERAL DESCRIPTION, ie SE OR NW CORNER, MAKE SURE CREW IS ON PROPER QUADRAT SAMPLE UNIT.

3. FLY PERIMETER OF QUADRAT FIRST IN A CLOCKWISE MANNER SO THE INSIDE OF THE QUADRAT IS TO THE RIGHT OF THE PRIMARY OBSERVER. FLIGHT SPEEDS SHOULD BE 40-50MPH AT ABOUT 100 FEET ABOVE TERRAIN. IF HIGHER SPEEDS ARE NEEDED TO BE SAFE DUE TO WIND SPEEDS, CONSIDER ABORTING THE FLIGHT. SOME QUADRATS INCLUDE LOWLAND PRIVATE LAND WITH HOUSES, LIVESTOCK, ETC. USE YOUR BEST JUDGEMENT AS TO WHAT AREAS YOU NEED TO FLY TO SEARCH FOR DEER AND AVOID BUILDINGS & LIVESTOCK.

4. DETERMINE STATUS OF GROUPS OF DEER ON PERIMETER.
   A. DEER MOVING OFF THE QUADRAT WHEN DETECTED ARE CONSIDERED ON THE QUADRAT.
   B. DEER MOVING ONTO THE QUADRAT WHEN DETECTED ARE CONSIDERED OFF THE QUADRAT.
   C. IF A GROUP IS STANDING ON THE PERIMETER BOUNDARY, COUNT THOSE DEER INSIDE THE QUADRAT.

D. RESIST THE TEMPTATION TO LEAVE THE PERIMETER TO COUNT A GROUP ON THE INSIDE OF THE QUADRAT BEFORE COMPLETING THE PERIMETER. USE YOUR BEST JUDGEMENT AT THE TIME OF DETECTION.

5. FLY INTERIOR OF QUADRAT.

A. FLY THE INTERIOR OF THE QUADRAT SYSTEMATICALLY IN STRIPS OR STRIP-CONTOURS AT ABOVE RECOMMEND AIR SPEEDS AND AGL. USE PROMINENT TERRAIN FEATURES TO DIVIDE THE QUADRAT INTO SMALLER COUNTING BLOCKS AND SEARCH EACH SUB-BLOCK INTENSELY. IF YOU DECIDE TO FLY STRIP-CONTOURS, WORKING FROM THE LOWEST TO HIGHEST ELEVATION USUALLY WORKS BEST AS DEER ARE MORE RELUCTANT TO RUN UPHILL THAN DOWNHILL. ON OPEN FLAT TERRAIN, SYSTEMATIC STRIPS WORK WELL WHEN USING LANDMARKS OR GPS LOCATIONS. TRY TO MENTALLY KEEP TRACK OF DEER GROUPS TO AVOID DOUBLE-COUNTING.

B. BE PATIENT AND STRIVE FOR 100% COVERAGE OF THE QUADRAT.

6. WHEN MULTIPLE GROUPS OF DEER ARE DETECTED SIMULTANEOUSLY, FOLLOW THESES GUIDELINES.

A. PRIMARY OBSERVER SHOULD BEGIN OBTAINING DATA ON GROUP NEAREST THE HELICOPTER AND USE HELICOPTER TO KEEP GROUPS SEPARATED.
B. NAVIGATOR SHOULD FOCUS MOMENTARILY ON SECOND GROUP OBSERVED AND NOTE LOCATION, ACTIVITY AND NUMBER OF ANIMALS FIRST SEEN.
C. AFTER COMPLETING DATA COLLECTION ON FIRST GROUP, PROCEED TO LOCATION OF WHERE SECOND GROUP FIRST SEEN, DETERMINE VEGETATION TYPE, AND SNOW COVER% AT SITE OF DETECTION, THEN FIND AND COUNT SECOND GROUP.

7. AFTER EACH GROUP OF DEER IS COUNTED, OBSERVER SHOULD VERBALLY NOTIFY NAVIGATOR OF GROUP TOTAL SO NAVIGATOR CAN RECORD A RUNNING SUM OF DEER COUNTED ON THE TALLY-WHACKER. AT THE END OF THE QUADRAT, OBSERVER SHOULD TAPE RECORD THE TALLY-WHACKER SUM AS A CRUDE CHECK ON THE NUMBER OF DEER DETECTED. NAVIGATOR COULD RECORD TALLY-WHACKER SUM ON THE FLIGHT MAP ON THE QUADRAT.

8. BEFORE LEAVING THE QUADRAT, MAKE SURE YOU HAVE NOT FAILED TO SEARCH ANY OBVIOUS GEOGRAPHIC PORTIONS OF THE QUADRAT. OBSERVER AND NAVIGATOR SHOULD AGREE THEY ARE DONE BEFORE PROCEEDING TO NEXT QUADRAT.

VII. DATA TRANSCRIPTION

1. PRIMARY OBSERVERS WILL BE RESPONSIBLE FOR TRANSCRIBING THEIR TAPE-RECORDED DATA ONTO STANDARD DATA FORMS. ALL OBSERVERS WILL LABEL EACH OF THEIR TAPES AS TO THEIR NAME AND DATE. DATA SHOULD BE TRANSCRIBED THE SAME DAY AS COLLECTED. IT MAY BE POSSIBLE TO HAVE AN ADDITIONAL PERSON TRANSCRIBE THE TAPES TO SAVE TIME, AND SUCH PERSON WOULD NOTE ANY QUESTIONS THAT ONLY THE OBSERVER COULD ANSWER REGARDING ANY PROBLEMS ON THE TAPE RECORDINGS.

2. STANDARD DATA FORMS WILL BE AVAILABLE AT PROJECT LOCATION.

END

C:\DEERCENSUS\QUADPROC.MEM

2. SURVEY DATA FORM

QUADRAT DATA RECORDING FORM
DEER GMU 10 2001

quad4frm.PRE c:\deercensus

DATE (M/D/Y) ______________ HOBBS TIME: START ______________ END ______________
WEATHER: TEMP.(F) ___ WIND ______ LIGHT COND. __________ SNOWTYPE ______
PILOT ______________ NAVIGATOR ______________ OBSERVER ______________
PAGE ____ OF ____

QUAD # ______ STRATUM ____ TIME START: ________ END QUAD: _______ TOT.TIME: ______
LORAN/GPS LOCATION QUAD STARTING POINT: ______________________________

GROUP NO.	DEER ACTIVITY	VEGE. TYPE	%SNOW COVER	TOTAL GROUP SIZE			
TOTAL DEER SEEN							

COMMENTS:

DEFINITIONS:
WIND: Light=L, Moderate=M, Strong=S; LIGHT COND: Bright=B, Hazy=H, Dull=D;
SNOWTYPE: Fresh =F less than 48hrs; Old=O older than 48hrs.
DEER ACTIVITY: Bedded=B, Standing=S, Moving=M;
VEGE. TYPE: Big Sagebrush=SG, Bitterbrush=BB, Greasewood Flats=GW, Saltbush Flats=SB,
Pinyon-Juniper=PJ, Juniper Woodland=JW, Agriculture & Clearings=CA,
Riparian Shrub=RP, Tall Conifer=TC
PERCENT SNOW COVER: Low = L = 0-79%, High = H = >80%

3. SURVEY OBSERVER HELP SHEET

OBSERVER CHEAT SHEET

QUAD STARTING POINT GPS

QUAD NUMBER

QUAD TIME START/END

QUAD WIND, LIGHT, SNOW TYPE

GROUP INITIAL DEER ACTIVITY
Bedded, Standing, Moving

GROUP VEGETATION TYPE
Sagebrush, Bitterbrush, Greasewood, Saltbush, PinyonJuniper, Juniper Woodland, Agriculture & Clearings, Riparian Shrub, Tall Conifer

GROUP PERCENT SNOW COVER
0-79%=Low >80%=High

TOTAL GROUP SIZE
All deer counted in each group

SECTION G

SURVEY FLIGHT QUADRAT SAMPLE UNIT MAP INDEX

UNIT 10 DEER POPULATION ESTIMATE FEBRUARY 2001					
INDEX TO QUADRAT SAMPLE UNIT MAPS (QuadMapList.wb3)					
FLIGHT SEQUENCE IS ORDER OF FLYING UNITS WITHIN AN ENTIRE BLOCK AREA, INDEPENDENT OF STRATA					
STRATUM	STRATUM NAME	QUADRAT UNIT NO.	11" x 17" MAP NO.	FLIGHT SEQUENCE	LOCALE DESCRIPTION
1	Yampa-Monument Low Density	1 YML	5	1	Bear Draw Mantle Ranch Rd.
1	Yampa-Monument Low Density	2 YML	5	2	Bear Draw Mantle Ranch Rd.
1	Yampa-Monument Low Density	3 YML	5	3	Dry Woman Canyon Mantle Rd
1	Yampa-Monument Low Density	4 YML	6	4	Dry Woman Canyon Mantle Rd
1	Yampa-Monument Low Density	5 YML	6	6	Schoonover Pasture Mantle Rd
1	Yampa-Monument Low Density	6 YML	6	5	Schoonover Pasture Mantle Rd
1	Yampa-Monument Low Density	7 YML	9	18	Sand Canyon Mantle Rd
1	Yampa-Monument Low Density	8 YML	9	20	Chew Ranch
1	Yampa-Monument Low Density	9 YML	10	22	Trail Draw Chew Ranch
		9 Units			
2	Yampa-Monument Medium Density	10 YMM	6	7	Johnson Canyon Mantle Rd
2	Yampa-Monument Medium Density	11 YMM	6	9	Johnson Draw Mantle Rd
2	Yampa-Monument Medium Density	12 YMM	6	8	Johnson Draw South Mantle Rd
2	Yampa-Monument Medium Density	13 YMM	7	10	West Serviceberry Draw Mantle Rd
2	Yampa-Monument Medium Density	14 YMM	8	12	Yampa River Overlook Mantle Rd
2	Yampa-Monument Medium Density	15 YMM	8	11	Marthas Peak Dangerous
2	Yampa-Monument Medium Density	16 YMM	8	13	Mantle Ranch Cave
2	Yampa-Monument Medium Density	17 YMM	8	14	Rock Bench Very Steep
2	Yampa-Monument Medium Density	18 YMM	9	15	Red Rock Ranch Site Steep
2	Yampa-Monument Medium Density	19 YMM	9	16	Pearl Park North
2	Yampa-Monument Medium Density	20 YMM	9	17	Pearl Park South
2	Yampa-Monument Medium Density	21 YMM	10	21	Sand Canyon Rim
2	Yampa-Monument Medium Density	22 YMM	9	19	Lower Sand Canyon
2	Yampa-Monument Medium Density	23 YMM	10	23	Pool Creek Rim
2	Yampa-Monument Medium Density	24 YMM	10	24	Stateline Pool Creek
		15 Units			

INDEX TO QUADRAT SAMPLE UNIT MAPS					
STRATUM	STRATUM NAME	QUADRAT UNIT NO.	11" x 17" MAP NO.	FLIGHT SEQUENCE	LOCALE DESCRIPTION
3	Utah White River Low Density	9-UL	11	2	Stateline W.Dripping Rock Ck
3	Utah White River Low Density	10-UL	12	5	Dripping Rock Ck Open Flats
3	Utah White River Low Density	11-UL	13	7	White River Dripping Rock Ridge
3	Utah White River Low Density	12-UL	13	6	Stateline Dripping Rock Ck
3	Utah White River Low Density	13-UL	15	13	White River Cliffs
		5 Units			
4	Utah White River Medium Density	1-UM	11	1	SnakeJohnReef W.Dinosaur
4	Utah White River Medium Density	2-UM	12	3	Stateline Raven Ridge
4	Utah White River Medium Density	3-UM	12	4	Raven Ridge Morman Gap
4	Utah White River Medium Density	4-UM	14	8	Raven Ridge South
4	Utah White River Medium Density	5-UM	14	9	Raven Ridge South
4	Utah White River Medium Density	6-UM	15	10	Raven Ridge Southeast
4	Utah White River Medium Density	7-UM	15	11	Raven Ridge Hardware Draw
4	Utah White River Medium Density	8-UM	15	12	Raven Ridge White River
		8 Units			

INDEX TO QUADRAT SAMPLE UNIT MAPS

STRATUM	STRATUM NAME	QUADRAT UNIT NO.	11" x 17" MAP NO.	FLIGHT SEQUENCE	LOCALE DESCRIPTION
5	Upper White River High Density	1-WRH	24	56	On White River
5	Upper White River High Density	2-WRH	24	55	On White River
5	Upper White River High Density	3-WRH	24	54	North of main ridge
5	Upper White River High Density	4-WRH	23	53	Ridge North Slope
5	Upper White River High Density	5-WRH	23	52	On Ridge
5	Upper White River High Density	6-WRH	23	51	On White River
5	Upper White River High Density	7-WRH	22	48	On White River
5	Upper White River High Density	8-WRH	22	47	On White River
5	Upper White River High Density	9-WRH	22	49	North Slope Road
5	Upper White River High Density	10-WRH	22	46	South Slope Road
5	Upper White River High Density	11-WRH	22	45	On White River
5	Upper White River High Density	12-WRH	22	44	On White River
5	Upper White River High Density	13-WRH	22	50	North of Coal Ridge
5	Upper White River High Density	14-WRH	21	43	North of White River
5	Upper White River High Density	15-WRH	21	42	On White River Cliff
5	Upper White River High Density	16-WRH	21	41	On White River Dirt Road
5	Upper White River High Density	17-WRH	21	40	Main Road on Ridge
5	Upper White River High Density	18-WRH	19	37	On White River Cliff & Mine
5	Upper White River High Density	19-WRH	19	38	Steep Gullies North of Mine
5	Upper White River High Density	20-WRH	19	39	Steep Gullies Northwest of Mine
5	Upper White River High Density	21-WRH	19	32	PinyonJuinper Ridge Road
5	Upper White River High Density	22-WRH	19	31	Chase Ck Steep Cliffs Gulley Jct.
5	Upper White River High Density	23-WRH	19	33	Top of Mesa
5	Upper White River High Density	24-WRH	19	34	Coal Oil Rim Mesa
5	Upper White River High Density	25-WRH	18	29	Coal Oil Rim East
5	Upper White River High Density	26-WRH	19	36	Coal Oil Rim Mesa Northeast
5	Upper White River High Density	27-WRH	19	35	ChaseCk Mesa
5	Upper White River High Density	28-WRH	18	28	Dead Dog Draw Mesa Cliff
5	Upper White River High Density	29-WRH	18	30	Chase Draw Mesa
5	Upper White River High Density	30-WRH	18	27	Upper Dead Dog Draw
5	Upper White River High Density	31-WRH	18	26	Dead Dog Reservoir
5	Upper White River High Density	32-WRH	17	25	Dead Dog Reservoir
5	Upper White River High Density	33-WRH	17	24	Nate Spring Reservoir
5	Upper White River High Density	34-WRH	17	20	Nate Spring
5	Upper White River High Density	35-WRH	17	21	Nate Spring East
5	Upper White River High Density	36-WRH	17	19	Nate Spring North
5	Upper White River High Density	37-WRH	18	22	Scullion Gulch Lincoln Reservoir
5	Upper White River High Density	38-WRH	18	23	Scullion Gulch North
5	Upper White River High Density	39-WRH	17	18	Nate Spring North Pipeline
5	Upper White River High Density	40-WRH	17	17	Upper Nate Spring
5	Upper White River High Density	41-WRH	16	16	Upper Nate Spring
		41 Units			

INDEX TO QUADRAT SAMPLE UNIT MAPS

STRATUM	STRATUM NAME	QUADRAT UNIT NO.	11" x 17" MAP NO.	FLIGHT SEQUENCE	LOCALE DESCRIPTION
6	Upper White River Medium Density	1-WRM	28A	1	Hwy40 Box Elder CK
6	Upper White River Medium Density	2-WRM	28A	2	Red Wash Box Edler Ck
6	Upper White River Medium Density	3-WRM	21	4	Red Wash Prairie Dog Reservoir
6	Upper White River Medium Density	4-WRM	20	5	Raven Park Dam Scullion Gulch
6	Upper White River Medium Density	5-WRM	20	6	Raven Park Dam Scullion Gulch
6	Upper White River Medium Density	6-WRM	17	9	Rock Shale Reservoir
6	Upper White River Medium Density	7-WRM	16	12	Stinking Water Ck
6	Upper White River Medium Density	8-WRM	16	13	Stinking Water Ck
6	Upper White River Medium Density	9-WRM	16	14	Stinking Water Ck
6	Upper White River Medium Density	10-WRM	16	15	Stinking Water Ck
		10 Units			
7	Upper White River Low Density	1-WRL	21	3	S.Hwy40 Red Wash
7	Upper White River Low Density	2-WRL	29	7	Hwy 40 Red Wash
7	Upper White River Low Density	3-WRL	30-A	8	Red Wash Reservoir #1
7	Upper White River Low Density	4-WRL	30	10	S.Hwy40 Skyline Reservoir
7	Upper White River Low Density	5-WRL	16	11	W. of Stinking Water Ck
		5 Units			

INDEX TO QUADRAT SAMPLE UNIT MAPS					
STRATUM	STRATUM NAME	QUADRAT UNIT NO.	11" x 17" MAP NO.	FLIGHT SEQUENCE	LOCALE DESCRIPTION
10	Massadon-Dino Medium Density	1-MDM	35	57	K-Creek
10	Massadon-Dino Medium Density	2-MDM	35	58	Miners Draw Trail Ck
10	Massadon-Dino Medium Density	3-MDM	35	59	Miners Draw Road
10	Massadon-Dino Medium Density	4-MDM	34	54	Middle Ck (Fly Contours 66 & 7700)
10	Massadon-Dino Medium Density	5-MDM	32	41	Twin Wash Dino Headquarters
10	Massadon-Dino Medium Density	6-MDM	28	22	Skull Ck (Fly Contour 6200)
10	Massadon-Dino Medium Density	7-MDM	28	20	Skull Ck Rim
10	Massadon-Dino Medium Density	8-MDM	28	19	Skull Ck Rim
10	Massadon-Dino Medium Density	9-MDM	27	14	Three Springs
10	Massadon-Dino Medium Density	10-MDM	27	13	Three Springs
10	Massadon-Dino Medium Density	11-MDM	27	12	Massadona
10	Massadon-Dino Medium Density	12-MDM	27	11	East Massadona
10	Massadon-Dino Medium Density	13-MDM	27	10	Horse Draw E.Massadona
10	Massadon-Dino Medium Density	14-MDM	25	1	Lower 3 Springs Draw
10	Massadon-Dino Medium Density	15-MDM	25	3	Lower Peterson Draw
10	Massadon-Dino Medium Density	16-MDM	25	9	Peterson Draw Reservoir
10	Massadon-Dino Medium Density	17-MDM	25	8	Peterson Draw
10	Massadon-Dino Medium Density	18-MDM	26	7	The Sloughs
10	Massadon-Dino Medium Density	19-MDM	26	15	Skull Ck Rim Road
10	Massadon-Dino Medium Density	20-MDM	25	6	Petes Post The Sloughs
10	Massadon-Dino Medium Density	21-MDM	26	16	Bear Canyon Spring
10	Massadon-Dino Medium Density	22-MDM	28	18	Upper Skull Ck
		22 Units			
11	Massadon-Dino Low Density	1-MDL	25	2	Peterson Draw Reservoir
11	Massadon-Dino Low Density	2-MDL	25	4	North Peterson Reservoir
11	Massadon-Dino Low Density	3-MDL	25	5	Wolf Creek Spring
11	Massadon-Dino Low Density	4-MDL	26	17	Petes Post Wolf Ck
11	Massadon-Dino Low Density	5-MDL	34	53	Buckwater Draw
11	Massadon-Dino Low Density	6-MDL	35	56	K-Creek
		6 Units			

INDEX TO QUADRAT SAMPLE UNIT MAPS					
STRATUM	STRATUM NAME	QUADRAT UNIT NO.	11" x 17" MAP NO.	FLIGHT SEQUENCE	LOCALE DESCRIPTION
12	Twelvemile Medium Density	1-TMM	1	1	Yampa River Twelvemile Gulch Rd.
12	Twelvemile Medium Density	2-TMM	1	2	N.Hwy 40 Radio Tower Road
12	Twelvemile Medium Density	3-TMM	2	3	N.Hwy 40 Radio Tower Road
12	Twelvemile Medium Density	4-TMM	2	4	N.Hwy 40 Buffalo Gulch
12	Twelvemile Medium Density	5-TMM	2	5	S.Hwy40 Springs Ridge
12	Twelvemile Medium Density	6-TMM	3	6	N.Hwy 40 Buffalo Gulch
12	Twelvemile Medium Density	7-TMM	3	7	N.ElkSprings Buffalo Gulch
12	Twelvemile Medium Density	8-TMM	4	8	Elk Springs Road
12	Twelvemile Medium Density	9-TMM	4	9	Elk Springs Road
12	Twelvemile Medium Density	10-TMM	4	10	Bay Gulch NW Elk Springs
		10 Units			

INDEX TO QUADRAT SAMPLE UNIT MAPS

STRATUM	STRATUM NAME	QUADRAT UNIT NO.	11" x 17" MAP NO.	FLIGHT SEQUENCE	LOCALE DESCRIPTION
13	Massadon-Dino High Density	1-MDH	28	21	SkullCk
13	Massadon-Dino High Density	2-MDH	28	23	Massadona Hwy 40
13	Massadon-Dino High Density	3-MDH	28	24	South of Skull Ck Town Site
13	Massadon-Dino High Density	4-MDH	28	25	SkullCk Hwy 40
13	Massadon-Dino High Density	5-MDH	29	26	Miller Ck
13	Massadon-Dino High Density	6-MDH	29	27	Upper Jones Twist
13	Massadon-Dino High Density	7-MDH	29	28	Jones Twist Hwy 40
13	Massadon-Dino High Density	8-MDH	29	29	Martin Gap
13	Massadon-Dino High Density	9-MDH	29	30	Little Red Wash
13	Massadon-Dino High Density	10-MDH	30	31	Red Wash Hwy 40
13	Massadon-Dino High Density	11-MDH	30	32	Martin Gap West
13	Massadon-Dino High Density	12-MDH	30	33	Red Wash
13	Massadon-Dino High Density	13-MDh	30	35	Skyline Reservoir Hwy 40
13	Massadon-Dino High Density	14-MDH	30	34	Upper Red Wash
13	Massadon-Dino High Density	15-MDH	31	36	Blue Mountain Town Site
13	Massadon-Dino High Density	16-MDH	31	37	Willow Ck, Hwy 40, east
13	Massadon-Dino High Density	17-MDH	31	38	Spencer-Willow Ck Hwy 40
13	Massadon-Dino High Density	18-MDH	31	39	Spencer Draw Hwy 40
13	Massadon-Dino High Density	19-MDH	32	40	Spencer Draw West Hwy 40
13	Massadon-Dino High Density	20-MDH	32	42	Dino Headquarters Hwy 40
13	Massadon-Dino High Density	21-MDH	32	43	Dinosaur Quarry
13	Massadon-Dino High Density	22-MDH	32	44	Dripping Rock Ck-Dino Road
13	Massadon-Dino High Density	23-MDH	33	45	Sand Ck
13	Massadon-Dino High Density	24-MDH	33	46	W. Dinosaur Hwy 40
13	Massadon-Dino High Density	25-MDH	33	47	Lower Spring, NW of Dinosaur
13	Massadon-Dino High Density	26-MDH	33	48	Upper Spring
13	Massadon-Dino High Density	27-MDH	33	49	Bull Canyon Rim
13	Massadon-Dino High Density	28-MDH	33	50	K-Ranch
13	Massadon-Dino High Density	29-MDH	33	51	Buckwater Draw
13	Massadon-Dino High Density	30-MDH	33	52	K-Creek
13	Massadon-Dino High Density	31-MDH	33	55	Stateline K-Creek
		31 Units			

SECTION H

1. STRATIFIED RANDOM SAMPLE POPULATION ESTIMATE DATA AND CALCULATIONS

CALCULATION OF ESTIMATED DEER POPULATION IN UNIT 10 USING STRATIFIED RANDOM SAMPLING PROTOCOL

STANDARD FORMULAS FOR ESTIMATORS OF POPULATION SIZE AND VARIANCE FROM THOMPSON ET AL. 1998 AS BASED ON COCHRAN 1977.

Stratified Random Sample Statistical Calculations	Stratum Quadrat Unit	Deer Counted/ Quadrat	Stratum Quadrat Unit	Deer Counted/ Quadrat	Stratum Quadrat Unit	Deer Counted/ Quadrat	Stratum Quadrat Unit	Deer Counted/ Quadrat	Stratum Quadrat Unit	Deer Counted/ Quadrat	Stratum Quadrat Unit	Deer Counted/ Quadrat	Stratum Quadrat Unit	Deer Counted/ Quadrat	Stratum Quadrat Unit	Deer Counted/ Quadrat	Stratum Quadrat Unit	Deer Counted/ Quadrat	Stratum Quadrat Unit	Deer Counted/ Quadrat	Stratum Quadrat Unit	Deer Counted/ Quadrat
	1 YML	0	10 YMM	0	9-UL	3	1-UM	0	1-TMM	91	1-WRL	8	1-WRM	0	1-WRH	0	2-MDL	9	1-MDM	0	1-MDH	1
	2 YML	0	11 YMM	0	10-UL	0	2-UM	0	2-TMM	50	2-WRL	0	2-WRM	3	2-WRH	9	4-MDL	0	3-MDM	0	3-MDH	0
	3 YML	0	12 YMM	1	11-UL	0	3-UM	18	3-TMM	0	3-WRL	1	3-WRM	0	3-WRH	0	5-MDL	0	4-MDM	0	4-MDH	65
	4 YML	0	13 YMM	0	12-UL	12	4-UM	0	4-TMM	0	4-WRL	61	4-WRM	63	4-WRH	0	6-MDL	0	7-MDM	0	7-MDH	0
	5 YML	0	14 YMM	1	13-UL	16	5-UM	0	5-TMM	46	5-WRL	42	5-WRM	4	5-WRH	0			9-MDM	0	8-MDH	0
	6 YML	0	15 YMM	0			6-UM	0	6-TMM	0			6-WRM	87	6-WRH	0			10-MDM	0	9-MDH	0
	7 YML	101	16 YMM	0			7-UM	37	7-TMM	0			7-WRM	11	7-WRH	54			11-MDM	0	10-MDH	0
	8 YML	13	17 YMM	4			8-UM	11	8-TMM	0			8-WRM	10	8-WRH	0			12-MDM	0	11-MDH	0
	9 YML	0	18 YMM	0					9-TMM	0			9-WRM	0	9-WRH	0			13-MDM	0	13-MDH	0
			19 YMM	0					10-TMM	7			10 WRM	0	10-WRH	0			14-MDM	10	15-MDH	22
			20 YMM	0											11-WRH	18			17-MDM	0	16-MDH	0
			21 YMM	0											12-WRH	0			18-MDM	0	19-MDH	0
			22 YMM	5											13-WRH	0			20-MDM	0	20-MDH	40
			23 YMM	0											14-WRH	20			21-MDM	0	21-MDH	3
			24 YMM	0											15-WRH	8			22-MDM	0	22-MDH	0
															16-WRH	42					24-MDH	0
															17-WRH	0					25-MDH	2
															18-WRH	13					26-MDH	0
															19-WRH	15					29-MDH	0
															20-WRH	40					30-MDH	0
															21-WRH	0					31-MDH	0
															22-WRH	0						
															23-WRH	0						
															24-WRH	0						
															25-WRH	0						
															26-WRH	0						
															27-WRH	0						
															28-WRH	0						
															29-WRH	0						
															30-WRH	0						
															31-WRH	0						
															32-WRH	0						
															33-WRH	0						
															34-WRH	46						
															35-WRH	5						
															36-WRH	0						
															37-WRH	0						
															38-WRH	0						
															39-WRH	2						
															40-WRH	34						
															41-WRH	16						
Stratum Sampled Units (u_h)	YML	9	YMM	15	UL	5	UM	8	TMM	10	WRL	5	WRM	10	WRH	41	MDL	4	MDM	15	MDH	21
Total Deer Counted Per Stratum (N_h)		114.00		11.00		31.00		66.00		194.00		112.00		178.00		322.00		9.00		10 00		133 00
Mean Deer Per Sampled Unit ($N_{h\,bar}$)		12 67		0.73		6 20		8.25		19.40		22.40		17.80		7.85		2.25		0.67		6.33
Deer Per Sample Unit Variance (S^2_{Nh})		1115.75		2.50		54.20		161.36		1020 27		760.30		957.29		214 28		20 25		6 07		274 03
Total Sample Units Per Stratum (U_h)		114.96		121.59		31.64		22 75		28 93		31.96		30 96		216.66		80 28		176 34		161 84
Estimated Deer Per Stratum ($N^{\wedge}_h$)		1456.16		89.17		196.17		187.69		561.24		715 90		551.09		1701.57		180.63		117.56		1024 98
Stratum Variance $Var^{\wedge}(N^{\wedge}_h)$		1510125 67		2155 93		9136.92		7607 08		55874 38		131021.22		62120 54		198904.88		31001.53		12644.75		287437 68
Stratum Sample Unit Size		1/4mi²		1/4mi²		1mi²		1mi²		1mi²		1mi²		1mi²		1/4mi²		1/4mi²		1/4mi²		1/4mi²
Stratum Square Mile Area		28 74		30.40		31.64		22.75		28 93		31 96		30.96		54 16		20 07		44 09		40 46
Total Deer Counted All Strata N (sum N_h)	1180																					
Total Estimated Deer All Strata $N^{\wedge}$ (sum $N^{\wedge}_h$)	6782																					
Total Estimated Variance $Var^{\wedge}N^{\wedge}$ (sum $Var^{\wedge}(N^{\wedge}_h)$)	2318031																					
Percent Coefficient of Variation $CV^{\wedge}(N^{\wedge})$	22.45																					
90% Confidence Interval for $N^{\wedge}$ [Lower] [Upper]	4285	9279	= +/- 36% of Population Estimate $N^{\wedge}$																			
95% Confidence Interval for $N^{\wedge}$ [Lower] [Upper]	3798	9766	= +/- 44% of Population Estimate $N^{\wedge}$																			

WHERE:				
Stratum Sampled Units (u_h)	= number of sampled units or quadrats in each Stratum			
Total Deer Counted Per Stratum (N_h)	= total deer actually counted on sampled units in each Stratum			
Mean Deer Per Sampled Unit ($N_{h\,su}$)	= average number of deer counted on each sampled unit in each Stratum; = deer counted / number of sample units			
Deer Per Sample Unit Variance ($S^{\wedge 2}_{nh}$)	= standard sample variance of deer counted per sample unit in each stratum; calculated using Excel "VAR" function for sample variance.			
Total Sample Units Per Stratum (U_h)	= total number of potential sample units or quadrats in each Stratum			
Estimated Deer Per Stratum ($N^\wedge_h$)	= average number of deer counted on each sampled unit in each Stratum multiplied by potential number of sample units in each Stratum			
Stratum Variance Var^($N^\wedge_h$)	= standard estimated Stratum variance for deer counted in each Stratum			
	formula			
	Var^($N^\wedge_h$	=	$U^2_h[(1-u_h/U_h)*(S^{\wedge 2}_h/u_h)]$	see Thompson et al. 1998 page 341
Total Deer Counted All Strata N (sum N_h)	= sum of all deer counted in each Stratum			
Total Estimated Deer All Strata N^ (sum $N^\wedge_h$)	= sum of all estimated number of deer in each Stratum; this is estimated population size for Unit 10 sampled area			
Total Estimated Variance Var^N^ (sum Var^($N^\wedge_h$))	= sum of all estimated Stratum variances			
Percent Coefficient of Variation CV^(N^)	= SquareRoot(Var^N^) divided by N^ multiplied by 100 to express as a percentage			
90% Confidence Interval for N^ [Lower] [Upper]	= Population Estimate (N^) +/- (1.64)*SquareRoot (Var^N^)			
95% Confidence Interval for N^ [Lower] [Upper]	= Population Estimate (N^) +/- (1.96)*SquareRoot (Var^N^)			

2. LETTER FROM IDAHO DEPARTMENT OF FISH & GAME SHOWING POPULATION

April 5, 2001

V.W. Howard, Jr.
1025 Hickory Drive
Las Cruces, NM 88005

Tommy S. Bickle
P.O. Box 750
Hatch, NM 87937

Dear Drs. Howard and Bickle:

Find enclosed 3 files representing the results of my analysis of the Colorado Unit 10 mule deer survey data. Colorado Division of Wildlife personnel flew the survey Feb 25 – Mar 5, 2001. The survey was flown using a stratified random sample. Eleven strata were delineated and sample unit size varied from ¼ - 1 $mi.^2$. The ¼ $mi.^2$ sampling units were used in the high canopy closure habitat types of pinyon-juniper and/or juniper woodland. The 1 $mi.^2$ sampling units were used in more open canopy types.

One hundred and forty three units were sampled across the 11 strata and 1180 mule deer were observed. Because the Idaho Aerial Survey program has a ten strata maximum, 2 strata were combined for the analysis. Based only on the stratified random sample, without correction for visibility bias, the population estimate was 6481 mule deer. Using the Idaho Department of Fish and Game's Sightability Method the population estimate was 11,052 (90% CI 7549 – 14,555). This represents a sightability factor of 1.7. Bartmann et al. (1986. Wildlife Society Bulletin 14:356-363) recommended a 1.5 sightability factor for Colorado pinyon-juniper woodland. You can find a copy of the Idaho Aerial Survey software and a downloadable manual on the web at: http://members.nbci.com/fred_leban/survey.html. Please call with any questions.

Sincerely,

James W. Unsworth
Principal Wildlife Research Biologist

Cc. G. Miller, CDOW

ESTIMATE USING IDAHO SIGHTABILITY CORRECTIONS

```
Aerial Survey for Windows, Version 1.00 Beta 6.1.4 (12-Feb-2000)
Thursday, April 05, 2001  09:06 AM
Model: Mule Deer, Hiller 12-E, Idaho (Spring)

[Files]
Title   = C:\PROGRAM FILES\IDFG\AERIAL SURVEY\colo2.ttl
Summary = C:\PROGRAM FILES\IDFG\AERIAL SURVEY\colo2.sum
..........................................................................
Colorado Unit 10 Mule Deer Survey , Feb 28 - Mar 5, 2001

Section 1:  Summary of Raw Counts
--------------------------------------------------------------------------
           Units
 Stratum  Sampled   Total
 ------- ------- ----------------
   1        24      125
   2         5       31
   3         8       66
   4        41      322
   5        10      178
   6         5      112
   7        15       10
   8         4        9
   9        21      133
  10        10      194
 ------ ----------- ---------
 Total     143     1180
 ======= ======= ======

Section 2:  Summary of Raw Counts for Perfect Visibility Model
--------------------------------------------------------------------------
This table projects the number of animals that would have been counted if every unit had been flown and
visibility had been perfect (no animals obscured by vegetation, etc.)

         No of Units
 Strat   Popn   Sample    Total
 ----- ---- ------ ------------------------
   1      237     24      1234
   2       32      5       198
   3       23      8       190
   4      217     41      1704
   5       31     10       552
   6       32      5       717
   7      176     15       117
   8       80      4       180
   9      162     21      1026
  10       29     10       563
 ----- ---- ------ ------------------------
 Total   1019    143       6481
 ===== ===== ====== ==========
```

Section 3: Estimates for Total Number

Total

Stratum	Number of Units Popn.	Sample	Estimate	Variance Sampling	Sightability	Model	Bound 90%
1	237	24	1422	1158993	4492	349	1774
2	32	5	293	27155	2570	218	285
3	23	8	375	25316	8143	1529	308
4	217	41	3183	654838	44009	6681	1382
5	31	10	851	154826	5916	538	661
6	32	5	1397	388737	14884	1333	1047
7	176	15	154	21812	376	17	245
8	80	4	1133	1219118	53969	8787	1862
9	162	21	1403	572711	10224	784	1257
10	29	10	841	141508	4590	449	630
Total	1019	143	11052	4365014	149173	20685	3503

3. COMPLETE DATA LISTING FOR AERIAL SURVEY

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1	DATA ANALYSIS UNIT 6 & GAME MANAGEMENT UNIT 10 DEER POPULATION ESTIMATE FEB 28-MARCH 5, 20001.																							
2	COLORADO DIVISION OF WILDLIFE; D.FREDDY																							
3	DATA FIELDS CREATED FOR COMPATABILITY WITH COLORADO(CO) AND IDAHO (ID) SIGHTABILITY DATABASES																							
4																								
5	EXPLANATION OF DATA FIELDS																							
6																								
7	Quad=Quadrat Unit ID for CO; SubUnit=Quadrat Unit ID for ID							Sta=Stratum ID for CO; Stratum=Stratum ID for ID																
8	Tdeer=Total Deer Counted/Quadrat for CO; Total=Deer Counted for ID							Act2=Deer Activity for CO, B=Bedded,S=Standing,M=Moving; Act=Deer Activity for ID, 1=Bedded,2=Standing, 3=Moving																
9	Snow=%SnowCover for CO; SnowCover=%SnowCover for ID							Vege=Vege Type for CO; VegeClass=Vege Type for ID																
10	Snow= L=1-79% coded as 50% for patchy snow, H=>80%																							
11	Date=Date flown for CO; Yr=Year flown for CO																							
12	TimeQ=Flight Time Minutes on Quadrat for CO							Time=A=AM or P=PM when Quadrat flown for CO																
13	Nav=Navigator for Quadrat for CO, 1=Bickle, 2=Howard, 3=Graham, 4=Freddy																							
14	Obs=Observer for Quadrat for CO, 1=deVirgle, 2=Graham, 3=Ellenberger																							
15	Wind=Wind status for Quadrat for CO; L=light,M=Moderate,S=Strong																							
16	Lite=Observation Light for CO;B=Bright, H=Hazy, D=Dull																							
17	Snw=Condition of Snow for Quadrat for CO; F=fresh, <48hrs old; O=older >48hrs old																							
18	Pilot=Pilot for Quadrat for CO; ET=EdTracy, JR=JimRichards																							
19	Helio=Helicopter Type for CO; JR=JetRanger3, HR=Hiller12E																							
20	Telk=Elk Seen on Quadrat for CO:																							
21																								
22																								
23	Colo	Idaho	Colo	Idaho	Colo	Idaho	Colo	Idaho	Colo	Idaho	Colo	Idaho	Colo	Colo	Colo	Colo	Colo	Colo	Colo	Colo	Colo	Colo	Colo	Colo
24	Quad	SubUnit	Sta	Stratum	Tdeer	Total	Act2	Act	Snow	SnowCover	Vege	VegClass	Date	Yr	Time	Nav	Obs	TimeQ	Wind	Lite	Snw	Pilot	Helio	Telk
25	1YML	1	YML	1	0	0		0		0		0	03/01/2001	1	P	1	1	9	L	B	O	ET	JR	0
26	2YML	2	YML	1	0	0		0		0		0	03/01/2001	1	P	1	1	8	L	B	O	ET	JR	100
27	3YML	3	YML	1	0	0		0		0		0	03/01/2001	1	P	1	1	8	L	B	O	ET	JR	100
28	4YML	4	YML	1	0	0		0		0		0	03/01/2001	1	P	1	1	4	L	B	O	ET	JR	0
29	5YML	5	YML	1	0	0		0		0		0	03/01/2001	1	P	1	1	3	L	B	O	ET	JR	100
30	6YML	6	YML	1	0	0		0		0		0	03/01/2001	1	P	1	1	8	L	B	O	ET	JR	0
31	7YML	7	YML	1	58	58	M	3	L	50	SG	2	03/04/2001	1	P	3	3	6	L	H	O	ET	JR	0
32	7YML	7	YML	1	26	26	M	3	L	50	SG	2	03/04/2001	1	P	3	3		L	H	O	ET	JR	
33	7YML	7	YML	1	17	17	S	2	L	50	SG	2	03/04/2001	1	P	3	3		L	H	O	ET	JR	
34	8YML	8	YML	1	13	13	M	3	L	50	SG	2	03/04/2001	1	P	3	3	9	L	H	O	ET	JR	4
35	9YML	9	YML	1	0	0		0		0		0	03/04/2001	1	P	3	3	6	L	B	O	ET	JR	0
36	10YMM	10	YMM	2	0	0		0		0		0	03/01/2001	1	P	1	1	9	L	B	O	ET	JR	20
37	11YMM	11	YMM	2	0	0		0		0		0	03/05/2001	1	A	3	3	9	L	B	O	ET	JR	0
38	12YMM	12	YMM	2	1	1	M	3	L	50	PJ	3	03/05/2001	1	A	3	3	10	L	B	O	ET	JR	4
39	13YMM	13	YMM	2	0	0		0		0		0	03/05/2001	1	A	3	3	5	L	H	O	ET	JR	0
40	14YMM	14	YMM	2	1	1	M	3	L	50	PJ	3	03/05/2001	1	A	3	3	11	L	H	O	ET	JR	0
41	15YMM	15	YMM	2	0	0		0		0		0	03/05/2001	1	A	3	3	8	L	H	O	ET	JR	0
42	16YMM	16	YMM	2	0	0		0		0		0	03/05/2001	1	A	3	3	7	L	H	O	ET	JR	0
43	17YMM	17	YMM	2	2	2	M	3	H	80	PJ	3	03/04/2001	1	P	3	3	7	L	H	O	ET	JR	0
44	17YMM	17	YMM	2	2	2	M	3	H	80	PJ	3	03/04/2001	1	P	3	3		L	H	O	ET	JR	
45	18YMM	18	YMM	2	0	0		0		0		0	03/04/2001	1	P	3	3	5	L	H	O	ET	JR	0
46	19YMM	19	YMM	2	0	0		0		0		0	03/04/2001	1	P	3	3	6	M	H	O	ET	JR	0
47	20YMM	20	YMM	2	0	0		0		0		0	03/04/2001	1	P	3	3	6	L	H	O	ET	JR	34
48	21YMM	21	YMM	2	0	0		0		0		0	03/04/2001	1	P	3	3	7	M	B	O	ET	JR	14
49	22YMM	22	YMM	2	3	3	M	3	L	50	PJ	3	03/04/2001	1	P	3	3	9	L	H	O	ET	JR	0
50	22YMM	22	YMM	2	2	2	M	3	L	50	PJ	3	03/04/2001	1	P	3	3		L	H	O	ET	JR	
51	23YMM	23	YMM	2	0	0		0		0		0	03/04/2001	1	P	3	3	3	L	B	O	ET	JR	0
52	24YMM	24	YMM	2	0	0		0		0		0	03/04/2001	1	P	3	3	8	L	B	O	ET	JR	1
53	9UL	9	UL	3	3	3	M	3	L	50	SG	2	02/28/2001	1	A	1	1	15	L	H	O	ET	JR	0
54	10UL	10	UL	3	0	0		0		0		0	02/28/2001	1	A	1	1	16	L	D	O	ET	JR	0
55	11UL	11	UL	3	0	0		0		0		0	02/28/2001	1	P	1	1	16	L	B	O	ET	JR	0
56	12UL	12	UL	3	2	2	M	3	L	50	SG	2	02/28/2001	1	P	1	1	23	L	H	O	ET	JR	0
57	12UL	12	UL	3	5	5	M	3	L	50	SG	2	02/28/2001	1	P	1	1		L	H	O	ET	JR	
58	12UL	12	UL	3	5	5	M	3	L	50	SG	2	02/28/2001	1	P	1	1		L	H	O	ET	JR	
59	13UL	13	UL	3	16	16	S	2	L	50	SG	2	02/28/2001	1	P	1	1	17	M	D	O	ET	JR	0
60	1UM	1	UM	4	0	0		0		0		0	02/28/2001	1	A	1	1	25	L	H	O	ET	JR	0
61	2UM	2	UM	4	0	0		0		0		0	02/28/2001	1	A	1	1	11	L	H	O	ET	JR	0

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
62	3UM	3	UM	4	3	3	M	3	H	80	PJ	3	02/28/2001	1	A	1	1	23	L	H	O	ET	JR	0
63	3UM	3	UM	4	5	5	M	3	L	50	PJ	3	02/28/2001	1	A	1	1		L	H	O	ET	JR	
64	3UM	3	UM	4	4	4	M	3	L	50	PJ	3	02/28/2001	1	A	1	1		L	H	O	ET	JR	
65	3UM	3	UM	4	4	4	M	3	L	50	PJ	3	02/28/2001	1	A	1	1		L	H	O	ET	JR	
66	3UM	3	UM	4	2	2	M	3	L	50	PJ	3	02/28/2001	1	A	1	1		L	H	O	ET	JR	
67	4UM	4	UM	4	0	0		0		0		0	02/28/2001	1	A	1	1	24	L	B	O	ET	JR	0
68	5UM	5	UM	4	0	0		0		0		0	02/28/2001	1	P	1	1	17	L	B	O	ET	JR	50
69	6UM	6	UM	4	0	0		0		0		0	02/28/2001	1	P	1	1	19	L	H	O	ET	JR	0
70	7UM	7	UM	4	4	4	M	3	L	50	PJ	3	02/28/2001	1	P	1	1	27	L	H	O	ET	JR	0
71	7UM	7	UM	4	1	1	M	3	L	50	PJ	3	02/28/2001	1	P	1	1		L	H	O	ET	JR	
72	7UM	7	UM	4	2	2	M	3	L	50	PJ	3	02/28/2001	1	P	1	1		L	H	O	ET	JR	
73	7UM	7	UM	4	20	20	M	3	L	50	PJ	3	02/28/2001	1	P	1	1		L	H	O	ET	JR	
74	7UM	7	UM	4	1	1	S	2	L	50	SG	2	02/28/2001	1	P	1	1		L	H	O	ET	JR	
75	7UM	7	UM	4	1	1	M	3	L	50	PJ	3	02/28/2001	1	P	1	1		L	H	O	ET	JR	
76	7UM	7	UM	4	8	8	M	3	L	50	PJ	3	02/28/2001	1	P	1	1		L	H	O	ET	JR	
77	8UM	8	UM	4	11	11	B	1	L	50	GW	2	02/28/2001	1	P	1	1	18	L	D	O	ET	JR	0
78	1WRH	1	WRH	5	0	0		0		0		0	03/03/2001	1	A	4	1	6	L	B	O	ET	JR	0
79	2WRH	2	WRH	5	7	7	S	2	L	50	SG	2	03/03/2001	1	A	4	1	8	L	B	O	ET	JR	0
80	2WRH	2	WRH	5	2	2	S	2	L	50	PJ	3	03/03/2001	1	A	4	1		L	B	O	ET	JR	
81	3WRH	3	WRH	5	0	0		0		0		0	03/03/2001	1	A	4	1	9	L	B	O	ET	JR	0
82	4WRH	4	WRH	5	0	0		0		0		0	03/03/2001	1	A	4	1	7	L	B	O	ET	JR	20
83	5WRH	5	WRH	5	0	0		0		0		0	03/03/2001	1	A	4	1	5	L	B	O	ET	JR	5
84	6WRH	6	WRH	5	0	0		0		0		0	03/03/2001	1	A	4	1	4	L	B	O	ET	JR	0
85	7WRH	7	WRH	5	4	4	M	3	L	50	SG	2	03/03/2001	1	A	4	1	5	L	B	O	ET	JR	0
86	7WRH	7	WRH	5	15	16	M	3	L	50	SG	2	03/03/2001	1	A	4	1		L	B	O	ET	JR	
87	7WRH	7	WRH	5	13	13	M	3	L	50	SG	2	03/03/2001	1	A	4	1		L	B	O	ET	JR	
88	7WRH	7	WRH	5	10	10	M	3	L	50	SG	2	03/03/2001	1	A	4	1		L	B	O	ET	JR	
89	7WRH	7	WRH	5	4	4	M	3	L	50	SG	2	03/03/2001	1	A	4	1		L	B	O	ET	JR	
90	7WRH	7	WRH	5	6	6	M	3	L	50	SG	2	03/03/2001	1	A	4	1		L	B	O	ET	JR	
91	7WRH	7	WRH	5	2	2	S	2	L	50	SG	2	03/03/2001	1	A	4	1		L	B	O	ET	JR	
92	8WRH	8	WRH	5	0	0		0		0		0	03/03/2001	1	A	4	1	6	L	H	O	ET	JR	0
93	9WRH	9	WRH	5	0	0		0		0		0	03/03/2001	1	A	4	1	4	L	B	O	ET	JR	100
94	10WRH	10	WRH	5	0	0		0		0		0	03/03/2001	1	A	4	1	5	L	B	O	ET	JR	150
95	11WRH	11	WRH	5	4	4	S	2	L	50	SG	2	03/03/2001	1	A	4	1	4	L	B	O	ET	JR	0
96	11WRH	11	WRH	5	9	9	M	3	L	50	SG	2	03/03/2001	1	A	4	1		L	B	O	ET	JR	
97	11WRH	11	WRH	5	5	5	S	2	L	50	SG	2	03/03/2001	1	A	4	1		L	B	O	ET	JR	
98	12WRH	12	WRH	5	0	0		0		0		0	03/03/2001	1	A	4	1	5	L	B	O	ET	JR	0
99	13WRH	13	WRH	5	0	0		0		0		0	03/03/2001	1	A	4	1	4	L	B	O	ET	JR	0
100	14WRH	14	WRH	5	5	5	M	3	L	50	SG	2	03/03/2001	1	A	4	1	6	L	H	O	ET	JR	0
101	14WRH	14	WRH	5	15	15	S	2	L	50	PJ	3	03/03/2001	1	A	4	1		L	H	O	ET	JR	
102	15WRH	15	WRH	5	8	8	M	3	L	50	SG	2	03/03/2001	1	A	4	1	7	L	H	O	ET	JR	0
103	16WRH	16	WRH	5	6	6	S	2	L	50	SG	2	03/03/2001	1	A	4	1	8	L	H	O	ET	JR	0
104	16WRH	16	WRH	5	10	10	S	2	L	50	SG	2	03/03/2001	1	A	4	1		L	H	O	ET	JR	
105	16WRH	16	WRH	5	6	6	S	2	L	50	SG	2	03/03/2001	1	A	4	1		L	H	O	ET	JR	
106	16WRH	16	WRH	5	8	8	M	3	L	50	SG	2	03/03/2001	1	A	4	1		L	H	O	ET	JR	
107	16WRH	16	WRH	5	1	1	S	2	L	50	PJ	3	03/03/2001	1	A	4	1		L	H	O	ET	JR	
108	16WRH	16	WRH	5	6	6	S	2	L	50	SG	2	03/03/2001	1	A	4	1		L	H	O	ET	JR	
109	16WRH	16	WRH	5	2	2	M	3	L	50	SG	2	03/03/2001	1	A	4	1		L	H	O	ET	JR	
110	16WRH	16	WRH	5	1	1	M	3	L	50	SG	2	03/03/2001	1	A	4	1		L	H	O	ET	JR	
111	17WRH	17	WRH	5	0	0		0		0		0	03/03/2001	1	A	4	1	4	L	H	O	ET	JR	0
112	18WRH	18	WRH	5	2	2	M	3	L	50	SG	2	03/03/2001	1	A	4	1	10	L	H	O	ET	JR	75
113	18WRH	18	WRH	5	2	2	M	3	L	50	SG	2	03/03/2001	1	A	4	1		L	H	O	ET	JR	
114	18WRH	18	WRH	5	2	2	M	3	L	50	SG	2	03/03/2001	1	A	4	1		L	H	O	ET	JR	
115	18WRH	18	WRH	5	2	2	M	3	L	50	SG	2	03/03/2001	1	A	4	1		L	H	O	ET	JR	
116	18WRH	18	WRH	5	5	5	S	2	L	50	SG	2	03/03/2001	1	A	4	1		L	H	O	ET	JR	
117	19WRH	19	WRH	5	5	5	S	2	L	50	PJ	3	03/03/2001	1	A	4	1	7	L	H	O	ET	JR	0
118	19WRH	19	WRH	5	1	1	M	3	L	50	SG	2	03/03/2001	1	A	4	1		L	H	O	ET	JR	
119	19WRH	19	WRH	5	2	2	M	3	L	50	SG	2	03/03/2001	1	A	4	1		L	H	O	ET	JR	
120	19WRH	19	WRH	5	2	2	S	2	L	50	SG	2	03/03/2001	1	A	4	1		L	H	O	ET	JR	
121	19WRH	19	WRH	5	1	1	M	3	L	50	SG	2	03/03/2001	1	A	4	1		L	H	O	ET	JR	
122	19WRH	19	WRH	5	4	4	M	3	L	50	SG	2	03/03/2001	1	A	4	1		L	H	O	ET	JR	

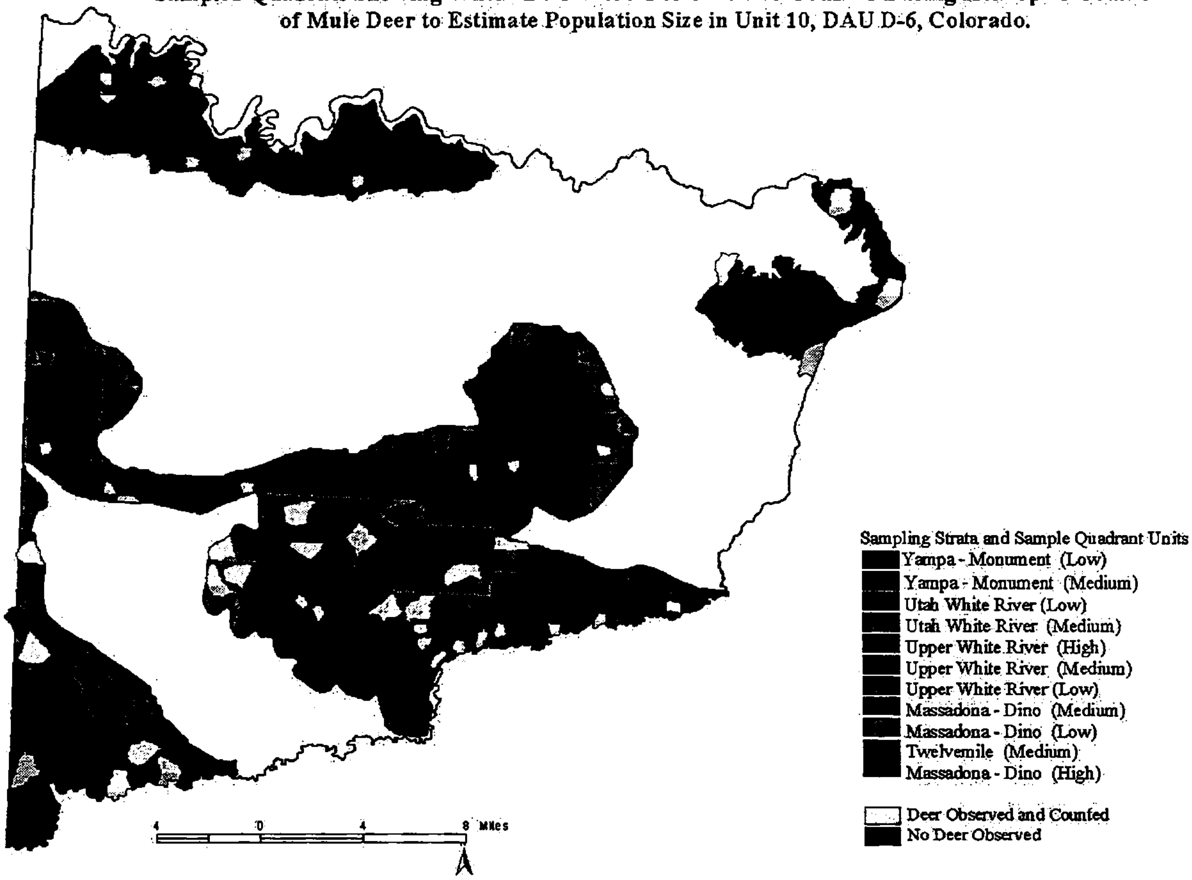
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
123	20WRH	20	WRH	5	5	5	S	2	L	50	SG	2	03/03/2001	1	A	4	1	5	L	H	O	ET	JR	0
124	20WRH	20	WRH	5	6	6	M	3	L	50	SG	2	03/03/2001	1	A	4	1		L	H	O	ET	JR	
125	20WRH	20	WRH	5	5	5	M	3	L	50	SG	2	03/03/2001	1	A	4	1		L	H	O	ET	JR	
126	20WRH	20	WRH	5	3	3	M	3	L	50	SG	2	03/03/2001	1	A	4	1		L	H	O	ET	JR	
127	20WRH	20	WRH	5	6	6	M	3	L	50	SG	2	03/03/2001	1	A	4	1		L	H	O	ET	JR	
128	20WRH	20	WRH	5	5	5	S	2	L	50	SG	2	03/03/2001	1	A	4	1		L	H	O	ET	JR	
129	20WRH	20	WRH	5	9	9	M	3	L	50	PJ	3	03/03/2001	1	A	4	1		L	H	O	ET	JR	
130	20WRH	20	WRH	5	1	1	M	3	L	50	SG	2	03/03/2001	1	A	4	1		L	H	O	ET	JR	
131	21WRH	21	WRH	5	0	0		0		0		0	03/02/2001	1	P	4	1	7	L	B	O	ET	JR	0
132	22WRH	22	WRH	5	0	0		0		0		0	03/02/2001	1	P	4	1	8	L	B	O	ET	JR	5
133	23WRH	23	WRH	5	0	0		0		0		0	03/02/2001	1	P	4	1	12	L	B	O	ET	JR	0
134	24WRH	24	WRH	5	0	0		0		0		0	03/02/2001	1	P	4	1	9	L	B	O	ET	JR	0
135	25WRH	25	WRH	5	0	0		0		0		0	03/02/2001	1	P	4	1	4	L	B	O	ET	JR	0
136	26WRH	26	WRH	5	0	0		0		0		0	03/02/2001	1	P	4	1	6	L	B	O	ET	JR	0
137	27WRH	27	WRH	5	0	0		0		0		0	03/02/2001	1	P	4	1	7	L	B	O	ET	JR	0
138	28WRH	28	WRH	5	0	0		0		0		0	03/02/2001	1	P	4	1	6	L	B	O	ET	JR	0
139	29WRH	29	WRH	5	0	0		0		0		0	03/02/2001	1	P	4	1	7	L	B	O	ET	JR	0
140	30WRH	30	WRH	5	0	0		0		0		0	03/02/2001	1	P	4	1	4	L	B	O	ET	JR	2
141	31WRH	31	WRH	5	0	0		0		0		0	03/02/2001	1	P	4	1	8	L	B	O	ET	JR	0
142	32WRH	32	WRH	5	0	0		0		0		0	03/02/2001	1	P	4	1	5	L	B	O	ET	JR	0
143	33WRH	33	WRH	5	0	0		0		0		0	03/02/2001	1	P	4	1	5	L	B	O	ET	JR	0
144	34WRH	34	WRH	5	28	28	M	3	L	50	PJ	3	03/02/2001	1	A	4	1	7	L	H	O	ET	JR	0
145	34WRH	34	WRH	5	7	7	M	3	L	50	SG	2	03/02/2001	1	A	4	1		L	H	O	ET	JR	
146	34WRH	34	WRH	5	3	3	M	3	L	50	SG	2	03/02/2001	1	A	4	1		L	H	O	ET	JR	
147	34WRH	34	WRH	5	4	4	M	3	L	50	SG	2	03/02/2001	1	A	4	1		L	H	O	ET	JR	
148	34WRH	34	WRH	5	4	4	S	2	L	50	PJ	3	03/02/2001	1	A	4	1		L	H	O	ET	JR	
149	35WRH	35	WRH	5	5	5	M	3	L	50	SG	2	03/02/2001	1	P	4	1	6	L	H	O	ET	JR	0
150	36WRH	36	WRH	5	0	0		0		0		0	03/02/2001	1	A	4	1	6	L	H	O	ET	JR	0
151	37WRH	37	WRH	5	0	0		0		0		0	03/02/2001	1	P	4	1	11	L	B	O	ET	JR	0
152	38WRH	38	WRH	5	0	0		0		0		0	03/02/2001	1	P	4	1	9	L	B	O	ET	JR	0
153	39WRH	39	WRH	5	2	2	M	3	L	50	PJ	3	03/02/2001	1	A	4	1	9	L	B	O	ET	JR	0
154	40WRH	40	WRH	5	5	5	M	3	L	50	PJ	3	03/02/2001	1	A	4	1	9	L	B	O	ET	JR	0
155	40WRH	40	WRH	5	15	15	M	3	L	50	PJ	3	03/02/2001	1	A	4	1		L	B	O	ET	JR	
156	40WRH	40	WRH	5	1	1	S	2	L	50	PJ	3	03/02/2001	1	A	4	1		L	B	O	ET	JR	
157	40WRH	40	WRH	5	3	3	S	2	L	50	SG	2	03/02/2001	1	A	4	1		L	B	O	ET	JR	
158	40WRH	40	WRH	5	5	5	M	3	L	50	SG	2	03/02/2001	1	A	4	1		L	B	O	ET	JR	
159	40WRH	40	WRH	5	5	5	M	3	L	50	PJ	3	03/02/2001	1	A	4	1		L	B	O	ET	JR	
160	41WRH	41	WRH	5	7	7	M	3	L	50	SG	2	03/02/2001	1	A	4	1	7	L	B	O	ET	JR	0
161	41WRH	41	WRH	5	3	3	M	3	L	50	SG	2	03/02/2001	1	A	4	1		L	B	O	ET	JR	
162	41WRH	41	WRH	5	1	1	M	3	L	50	SG	2	03/02/2001	1	A	4	1		L	B	O	ET	JR	
163	41WRH	41	WRH	5	4	4	M	3	L	50	SG	2	03/02/2001	1	A	4	1		L	B	O	ET	JR	
164	41WRH	41	WRH	5	1	1	M	3	L	50	SG	2	03/02/2001	1	A	4	1		L	B	O	ET	JR	
165	1WRM	1	WRM	6	0	0		0		0		0	02/28/2001	1	A	2	2	20	M	H	O	JR	HR	0
166	2WRM	2	WRM	6	1	1	M	3	L	50	PJ	3	02/28/2001	1	A	2	2	37	M	D	O	JR	HR	200
167	2WRM	2	WRM	6	1	1	M	3	L	50	PJ	3	02/28/2001	1	A	2	2		M	D	O	JR	HR	
168	2WRM	2	WRM	6	1	1	M	3	H	80	PJ	3	02/28/2001	1	A	2	2		M	D	O	JR	HR	
169	3WRM	3	WRM	6	0	0		0		0		0	02/28/2001	1	A	2	2	23	M	D	O	JR	HR	0
170	4WRM	4	WRM	6	7	7	M	3	H	80	SG	2	02/28/2001	1	A	2	2	27	L	B	O	JR	HR	0
171	4WRM	4	WRM	6	3	3	M	3	H	80	PJ	3	02/28/2001	1	A	2	2		L	B	O	JR	HR	
172	4WRM	4	WRM	6	4	4	S	2	H	80	PJ	3	02/28/2001	1	A	2	2		L	B	O	JR	HR	
173	4WRM	4	WRM	6	14	14	M	3	L	50	SG	2	02/28/2001	1	A	2	2		L	B	O	JR	HR	
174	4WRM	4	WRM	6	10	10	M	3	L	50	SG	2	02/28/2001	1	A	2	2		L	B	O	JR	HR	
175	4WRM	4	WRM	6	6	6	S	2	H	80	SG	2	02/28/2001	1	A	2	2		L	B	O	JR	HR	
176	4WRM	4	WRM	6	9	9	S	2	L	50	SG	2	02/28/2001	1	A	2	2		L	B	O	JR	HR	
177	4WRM	4	WRM	6	7	7	S	2	H	80	PJ	3	02/28/2001	1	A	2	2		L	B	O	JR	HR	
178	4WRM	4	WRM	6	1	1	M	3	H	80	SG	2	02/28/2001	1	A	2	2		L	B	O	JR	HR	
179	4WRM	4	WRM	6	2	2	S	2	H	80	PJ	3	02/28/2001	1	A	2	2		L	B	O	JR	HR	
180	5WRM	5	WRM	6	3	3	M	3	H	80	PJ	3	02/28/2001	1	A	2	2	28	L	B	O	JR	HR	28
181	5WRM	5	WRM	6	1	1	M	3	H	80	SG	2	02/28/2001	1	A	2	2		L	B	O	JR	HR	
182	6WRM	6	WRM	6	3	3	S	2	H	80	SG	2	02/28/2001	1	P	2	2	17	L	H	O	JR	HR	0
183	6WRM	6	WRM	6	9	9	M	3	L	50	SG	2	02/28/2001	1	P	2	2		L	H	O	JR	HR	

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
184	6WRM	6	WRM	6	5	5	M	3	L	50	SG	2	02/28/2001	1	P	2	2		L	H	O	JR	HR	
185	6WRM	6	WRM	6	4	4	M	3	H	80	SG	2	02/28/2001	1	P	2	2		L	H	O	JR	HR	
186	6WRM	6	WRM	6	4	4	M	3	H	80	SG	2	02/28/2001	1	P	2	2		L	H	O	JR	HR	
187	6WRM	6	WRM	6	4	4	M	3	L	50	SG	2	02/28/2001	1	P	2	2		L	H	O	JR	HR	
188	6WRM	6	WRM	6	7	7	M	3	L	50	SG	2	02/28/2001	1	P	2	2		L	H	O	JR	HR	
189	6WRM	6	WRM	6	12	12	S	2	L	50	SG	2	02/28/2001	1	P	2	2		L	H	O	JR	HR	
190	6WRM	6	WRM	6	6	6	M	3	L	50	SG	2	02/28/2001	1	P	2	2		L	H	O	JR	HR	
191	6WRM	6	WRM	6	4	4	M	3	H	80	SG	2	02/28/2001	1	P	2	2		L	H	O	JR	HR	
192	6WRM	6	WRM	6	3	3	M	3	L	50	SG	2	02/28/2001	1	P	2	2		L	H	O	JR	HR	
193	6WRM	6	WRM	6	2	2	M	3	L	50	SG	2	02/28/2001	1	P	2	2		L	H	O	JR	HR	
194	6WRM	6	WRM	6	3	3	M	3	L	50	SG	2	02/28/2001	1	P	2	2		L	H	O	JR	HR	
195	6WRM	6	WRM	6	11	11	M	3	L	50	SG	2	02/28/2001	1	P	2	2		L	H	O	JR	HR	
196	6WRM	6	WRM	6	5	5	M	3	L	50	SG	2	02/28/2001	1	P	2	2		L	H	O	JR	HR	
197	6WRM	6	WRM	6	5	5	M	3	H	80	SG	2	02/28/2001	1	P	2	2		L	H	O	JR	HR	
198	7WRM	7	WRM	6	11	11	M	3	H	80	SG	2	03/01/2001	1	A	2	2	26	L	B	F	JR	HR	0
199	8WRM	8	WRM	6	10	10	S	2	H	80	SG	2	03/01/2001	1	P	2	2	19	L	B	F	JR	HR	0
200	9WRM	9	WRM	6	0	0		0		0		0	03/01/2001	1	A	2	2	19	L	B	F	JR	HR	0
201	10WRM	10	WRM	6	0	0		0		0		0	03/02/2001	1	A	4	1	24	L	B	O	ET	JR	0
202	1WRL	1	WRL	7	8	8	S	2	L	50	SG	2	02/28/2001	1	A	2	2	18	M	D	O	JR	HR	0
203	2WRL	2	WRL	7	0	0		0		0		0	02/28/2001	1	P	2	2	32	L	D	O	JR	HR	0
204	3WRL	3	WRL	7	1	1	S	2	L	50	PJ	3	02/28/2001	1	P	2	2	25	L	H	O	JR	HR	0
205	4WRL	4	WRL	7	2	2	M	3	L	50	SG	2	02/28/2001	1	P	2	2	38	L	H	O	JR	HR	0
206	4WRL	4	WRL	7	19	19	S	2	H	80	SG	2	02/28/2001	1	P	2	2		L	H	O	JR	HR	
207	4WRL	4	WRL	7	4	4	S	2	L	50	SG	2	02/28/2001	1	P	2	2		L	H	O	JR	HR	
208	4WRL	4	WRL	7	7	7	M	3	H	80	SG	2	02/28/2001	1	P	2	2		L	H	O	JR	HR	
209	4WRL	4	WRL	7	1	1	M	3	H	80	PJ	3	02/28/2001	1	P	2	2		L	H	O	JR	HR	
210	4WRL	4	WRL	7	9	9	S	2	H	80	SG	2	02/28/2001	1	P	2	2		L	H	O	JR	HR	
211	4WRL	4	WRL	7	3	3	S	2	L	50	SG	2	02/28/2001	1	P	2	2		L	H	O	JR	HR	
212	4WRL	4	WRL	7	6	6	M	3	L	50	SG	2	02/28/2001	1	P	2	2		L	H	O	JR	HR	
213	4WRL	4	WRL	7	3	3	M	3	H	80	PJ	3	02/28/2001	1	P	2	2		L	H	O	JR	HR	
214	4WRL	4	WRL	7	3	3	M	3	L	50	SG	2	02/28/2001	1	P	2	2		L	H	O	JR	HR	
215	4WRL	4	WRL	7	1	1	M	3	L	50	SG	2	02/28/2001	1	P	2	2		L	H	O	JR	HR	
216	4WRL	4	WRL	7	3	3	M	3	L	50	PJ	3	02/28/2001	1	P	2	2		L	H	O	JR	HR	
217	5WRL	5	WRL	7	4	4	S	2	H	80	SG	2	03/01/2001	1	A	2	2	24	L	B	F	JR	HR	0
218	5WRL	5	WRL	7	23	23	S	2	H	80	SG	2	03/01/2001	1	A	2	2		L	B	F	JR	HR	
219	5WRL	5	WRL	7	6	6	S	2	H	80	PJ	3	03/01/2001	1	A	2	2		L	B	F	JR	HR	
220	5WRL	5	WRL	7	1	1	S	2	H	80	SG	2	03/01/2001	1	A	2	2		L	B	F	JR	HR	
221	5WRL	5	WRL	7	8	8	S	2	H	80	PJ	3	03/01/2001	1	A	2	2		L	B	F	JR	HR	
222	1MDM	1	MDM	10	0	0		0		0		0	03/04/2001	1	P	4	1	6	L	B	O	ET	JR	0
223	3MDM	3	MDM	10	0	0		0		0		0	03/04/2001	1	P	4	1	4	L	B	O	ET	JR	0
224	4MDM	4	MDM	10	0	0		0		0		0	03/04/2001	1	P	4	1	5	L	B	O	ET	JR	0
225	7MDM	7	MDM	10	0	0		0		0		0	03/04/2001	1	A	4	1	7	L	B	O	ET	JR	3
226	9MDM	9	MDM	10	0	0		0		0		0	03/03/2001	1	P	4	1	3	L	H	O	ET	JR	0
227	10MDM	10	MDM	10	0	0		0		0		0	03/03/2001	1	P	4	1	6	L	H	O	ET	JR	0
228	11MDM	11	MDM	10	0	0		0		0		0	03/04/2001	1	A	4	1	6	L	B	O	ET	JR	0
229	12MDM	12	MDM	10	0	0		0		0		0	03/03/2001	1	P	4	1	6	L	H	O	ET	JR	20
230	13MDM	13	MDM	10	0	0		0		0		0	03/03/2001	1	P	4	1	7	L	H	O	ET	JR	50
231	14MDM	14	MDM	10	9	9	M	3	L	50	PJ	3	03/03/2001	1	P	4	1	7	L	B	O	ET	JR	20
232	14MDM	14	MDM	10	1	1	M	3	L	50	PJ	3	03/03/2001	1	P	4	1		L	B	O	ET	JR	
233	17MDM	17	MDM	10	0	0		0		0		0	03/03/2001	1	P	4	1	5	L	H	O	ET	JR	0
234	18MDM	18	MDM	10	0	0		0		0		0	03/03/2001	1	P	4	1	4	L	H	O	ET	JR	0
235	20MDM	20	MDM	10	0	0		0		0		0	03/03/2001	1	P	4	1	6	L	H	O	ET	JR	0
236	21MDM	21	MDM	10	0	0		0		0		0	03/03/2001	1	P	4	1	8	L	H	O	ET	JR	0
237	22MDM	22	MDM	10	0	0		0		0		0	03/03/2001	1	P	4	1	8	L	H	O	ET	JR	4
238	2MDL	2	MDL	11	9	9	S	2	L	50	PJ	3	03/03/2001	1	P	4	1	8	L	H	O	ET	JR	25
239	4MDL	4	MDL	11	0	0		0		0		0	03/03/2001	1	P	4	1	6	L	H	O	ET	JR	0
240	5MDL	5	MDL	11	0	0		0		0		0	03/04/2001	1	P	4	1	7	L	B	O	ET	JR	0
241	6MDL	6	MDL	11	0	0		0		0		0	03/04/2001	1	P	4	1	4	L	B	O	ET	JR	0
242	1MDH	1	MDH	13	1	1	M	3	L	50	PJ	3	03/04/2001	1	A	4	1	9	L	B	O	ET	JR	0
243	3MDH	3	MDH	13	0	0		0		0		0	03/04/2001	1	A	4	1	7	L	B	O	ET	JR	0
244	4MDH	4	MDH	13	25	25	S	2	L	50	SG	2	03/04/2001	1	A	4	1	6	L	B	O	ET	JR	0

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
245	4MDH	4	MDH	13	3	3	S	2	L	50	SG	2	03/04/2001	1	A	4	1		L	B	O	ET	JR	
246	4MDH	4	MDH	13	35	35	S	2	L	50	SG	2	03/04/2001	1	A	4	1		L	B	O	ET	JR	
247	4MDH	4	MDH	13	2	2	S	2	L	50	SG	2	03/04/2001	1	A	4	1		L	B	O	ET	JR	
248	7MDH	7	MDH	13	0	0		0		0		0	03/04/2001	1	A	4	1	9	L	B	O	ET	JR	0
249	8MDH	8	MDH	13	0	0		0		0		0	03/04/2001	1	A	4	1	8	L	B	O	ET	JR	8
250	9MDH	9	MDH	13	0	0		0		0		0	03/04/2001	1	A	4	1	8	L	B	O	ET	JR	0
251	10MDH	10	MDH	13	0	0		0		0		0	03/04/2001	1	A	4	1	8	L	B	O	ET	JR	0
252	11MDH	11	MDH	13	0	0		0		0		0	03/04/2001	1	A	4	1	5	L	B	O	ET	JR	5
253	13MDH	13	MDH	13	0	0		0		0		0	03/04/2001	1	A	4	1	4	L	B	O	ET	JR	0
254	15MDH	15	MDH	13	14	14	S	2	L	50	SG	2	03/04/2001	1	A	4	1	8	L	B	O	ET	JR	0
255	16MDH	16	MDH	13	1	1	M	3	L	50	SG	2	03/04/2001	1	A	4	1		L	B	O	ET	JR	
256	15MDH	15	MDH	13	7	7	M	3	L	50	SG	2	03/04/2001	1	A	4	1		L	B	O	ET	JR	
257	18MDH	18	MDH	13	0	0		0		0		0	03/04/2001	1	A	4	1	5	L	B	O	ET	JR	0
258	19MDH	19	MDH	13	0	0		0		0		0	03/04/2001	1	A	4	1	5	L	B	O	ET	JR	0
259	20MDH	20	MDH	13	38	38	M	3	L	50	PJ	3	03/04/2001	1	P	4	1	6	L	B	O	ET	JR	0
260	20MDH	20	MDH	13	2	2	M	3	L	50	PJ	3	03/04/2001	1	P	4	1		L	B	O	ET	JR	
261	21MDH	21	MDH	13	3	3	M	3	L	50	PJ	3	03/04/2001	1	P	4	1	5	L	B	O	ET	JR	0
262	22MDH	22	MDH	13	0	0		0		0		0	03/04/2001	1	P	4	1	7	L	B	O	ET	JR	0
263	24MDH	24	MDH	13	0	0		0		0		0	03/04/2001	1	P	4	1	7	L	B	O	ET	JR	0
264	25MDH	25	MDH	13	2	2	M	3	L	50	PJ	3	03/04/2001	1	P	4	1	6	L	B	O	ET	JR	0
265	26MDH	26	MDH	13	0	0		0		0		0	03/04/2001	1	P	4	1	4	L	B	O	ET	JR	0
266	29MDH	29	MDH	13	0	0		0		0		0	03/04/2001	1	P	4	1	6	L	B	O	ET	JR	0
267	30MDH	30	MDH	13	0	0		0		0		0	03/04/2001	1	P	4	1	6	L	B	O	ET	JR	0
268	31MDH	31	MDH	13	0	0		0		0		0	03/04/2001	1	P	4	1	1	L	B	O	ET	JR	0
269	1TMM	1	TMM	12	4	4	M	3	H	80	PJ	3	03/01/2001	1	A	1	1	20	L	B	O	ET	JR	30
270	1TMM	1	TMM	12	3	3	M	3	L	50	PJ	3	03/01/2001	1	A	1	1		L	B	O	ET	JR	
271	1TMM	1	TMM	12	5	5	M	3	L	50	PJ	3	03/01/2001	1	A	1	1		L	B	O	ET	JR	
272	1TMM	1	TMM	12	7	7	S	2	L	50	SG	2	03/01/2001	1	A	1	1		L	B	O	ET	JR	
273	1TMM	1	TMM	12	2	2	S	2	L	50	SG	2	03/01/2001	1	A	1	1		L	B	O	ET	JR	
274	1TMM	1	TMM	12	8	8	M	3	L	50	SG	2	03/01/2001	1	A	1	1		L	B	O	ET	JR	
275	1TMM	1	TMM	12	15	15	M	3	H	80	PJ	3	03/01/2001	1	A	1	1		L	B	O	ET	JR	
276	1TMM	1	TMM	12	10	10	M	3	L	50	PJ	3	03/01/2001	1	A	1	1		L	B	O	ET	JR	
277	1TMM	1	TMM	12	3	3	M	3	L	50	PJ	3	03/01/2001	1	A	1	1		L	B	O	ET	JR	
278	1TMM	1	TMM	12	2	2	M	3	L	50	SG	2	03/01/2001	1	A	1	1		L	B	O	ET	JR	
279	1TMM	1	TMM	12	4	4	S	2	L	50	SG	2	03/01/2001	1	A	1	1		L	B	O	ET	JR	
280	1TMM	1	TMM	12	6	6	S	2	L	50	SG	2	03/01/2001	1	A	1	1		L	B	O	ET	JR	
281	1TMM	1	TMM	12	6	6	S	2	H	80	PJ	3	03/01/2001	1	A	1	1		L	B	O	ET	JR	
282	1TMM	1	TMM	12	16	16	M	3	L	50	PJ	3	03/01/2001	1	A	1	1		L	B	O	ET	JR	
283	2TMM	2	TMM	12	23	23	M	3	L	50	SG	2	03/01/2001	1	A	1	1	11	L	B	O	ET	JR	0
284	2TMM	2	TMM	12	19	19	M	3	L	50	SG	2	03/01/2001	1	A	1	1		L	B	O	ET	JR	
285	2TMM	2	TMM	12	8	8	S	2	L	50	SG	2	03/01/2001	1	A	1	1		L	B	O	ET	JR	
286	3TMM	3	TMM	12	0	0		0		0		0	03/01/2001	1	A	1	1	15	L	B	O	ET	JR	30
287	4TMM	4	TMM	12	0	0		0		0		0	03/01/2001	1	A	1	1	13	L	B	O	ET	JR	35
288	5TMM	5	TMM	12	32	32	M	3	L	50	SG	2	03/01/2001	1	P	1	1	14	L	B	O	ET	JR	0
289	5TMM	5	TMM	12	1	1	M	3	L	50	SG	2	03/01/2001	1	P	1	1		L	B	O	ET	JR	
290	5TMM	5	TMM	12	3	3	M	3	L	50	SG	2	03/01/2001	1	P	1	1		L	B	O	ET	JR	
291	5TMM	5	TMM	12	9	9	M	3	L	50	SG	2	03/01/2001	1	P	1	1		L	B	O	ET	JR	
292	5TMM	5	TMM	12	1	1	S	2	L	50	PJ	3	03/01/2001	1	P	1	1		L	B	O	ET	JR	
293	6TMM	6	TMM	12	0	0		0		0		0	03/01/2001	1	P	1	1	16	L	B	O	ET	JR	40
294	7TMM	7	TMM	12	0	0		0		0		0	03/01/2001	1	P	1	1	9	L	B	O	ET	JR	0
295	8TMM	8	TMM	12	0	0		0		0		0	03/01/2001	1	P	1	1	14	L	B	O	ET	JR	0
296	9TMM	9	TMM	12	0	0		0		0		0	03/01/2001	1	P	1	1	16	L	B	O	ET	JR	0
297	10TMM	10	TMM	12	5	5	S	2	L	50	SG	2	03/01/2001	1	P	1	1	13	L	B	O	ET	JR	15
298	10TMM	10	TMM	12	2	2	M	3	L	50	PJ	3	03/01/2001	1	P	1	1		L	B	O	ET	JR	
299																								

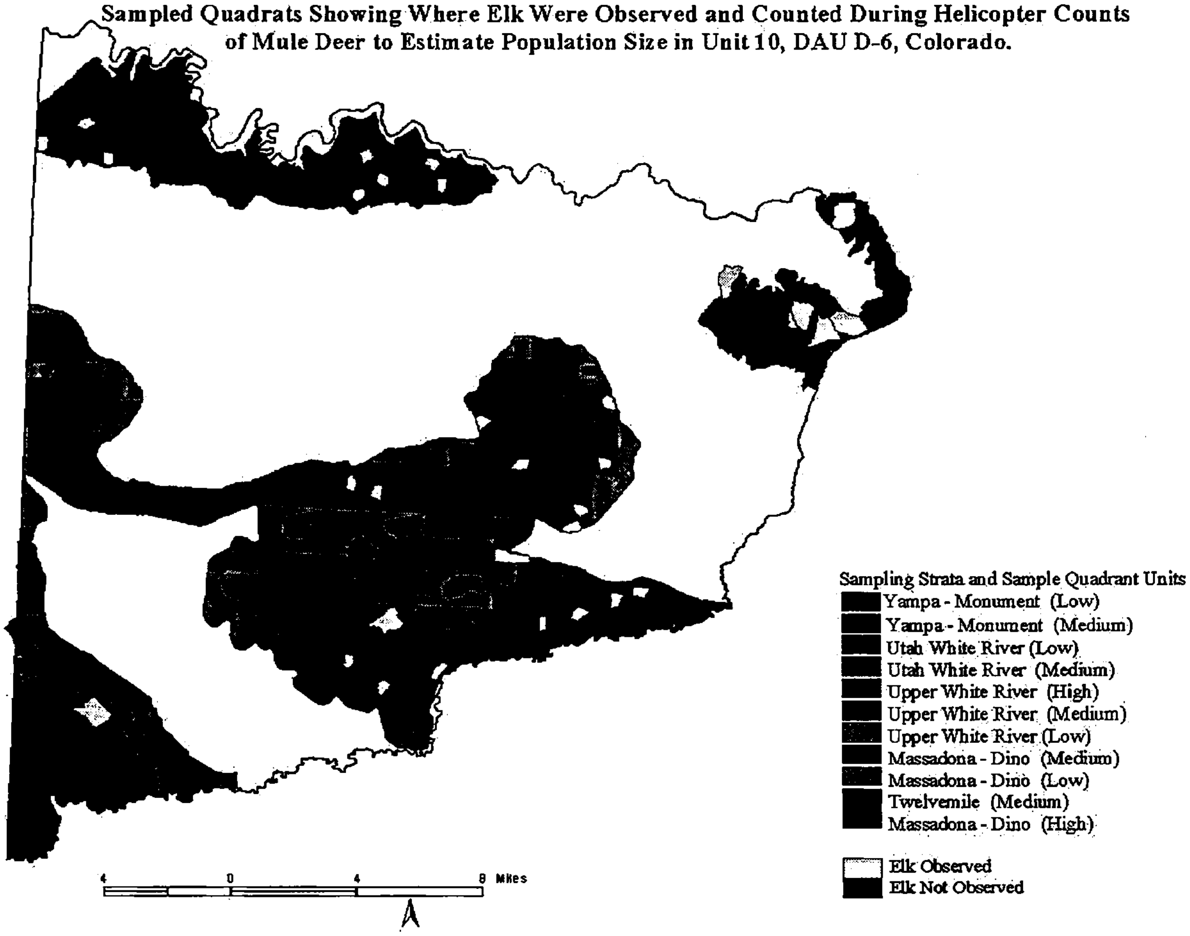
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
300																								
301																								
302	Totals	274	274	274	1180	1180	179	179	179	179	179	179	274	274	151	62	197	143	268	151	266	218	218	1297
303	Subject	Entries	Entries	Entries	Deer	Deer	DeerGrps	DeerGrps	DeerGrps	DeerGrps	DeerGrps	DeerGrps	Entries	Entries	AM cnts	Bickle	deVergie	Quadrats	LiteWind	BriteLite	OldSnow	EdTracy	JetRngr	ElkCntd
304					Counted	Counted	w/Act	w/Act	w/Snow	w/Snow	w/Vege	w/Vege			123	56	56	Flown &	9	114	8	68	56	143
305					179	179	123	123	146	146	117	118			PM cnts	Howard	Graham	Time	ModWind	HazyLite	FrshSnw	JimRich	Hiller	Quadrats
306					Groups	Groups	Groups	Groups	Groups w/	Groups w/	Groups	Groups				21	21		0	9				32
307					Counted	Counted	Moving	Moving	Low Snow	Low Snow	In Sage	InSageGW				Graham	Ellenbrgr		StrgWind	DullLite				Quadrats
308					95	95	55	55	33	33	61	61				135								with elk
309					Quadrats	Quadrats	Groups	Groups	Groups w/	Groups w/	Groups	Groups				Freddy								
310					w/ 0 deer	w/ 0 deer	Standing	Standing	HighSnow	HighSnow	In PJ	In PJ												
311							1	1			1													
312							Group	Group			Group In													
313							Bedded	Bedded			GreaseWd													

4. MAP SHOWING WHERE DEER WERE COUNTED



Sampled Quadrats Showing Where Deer Were Observed and Counted During Helicopter Counts of Mule Deer to Estimate Population Size in Unit 10, DAU D-6, Colorado.

5. MAP SHOWING WHERE ELK WERE COUNTED


Sampled Quadrats Showing Where Elk Were Observed and Counted During Helicopter Counts of Mule Deer to Estimate Population Size in Unit 10, DAU D-6, Colorado.

6. SUMMARY OF SPORTSMEN AND CDOW DEER POPULATION ESTIMATES FOR WESTERN COLORADO, DECEMBER 2000

DEER POPULATION AND DENSITY ESTIMATES

DAU	Sportsman's Population Estimate	Modeled Population Estimate*	where applicable Quadrat Population Estimate	# of Deer Classified			mi2 WRIS winter range	Sportsman's Density/mi2 WRIS winter range	Modeled Density/mi2 WRIS winter range	Quadrat Densitymi2 WRIS winter range
				1997	1998	1999				
D-1	4,100	13,500		401	497	464	1190	3.45	11.34	
D-2	13,300	37,800	24,198	3,058	3,839	7,076	1122	11.85	33.69	21.57
D-3	2,700	1,800		306	N/A	558	473	5.71	3.81	
D-6	1,750	7,000		623	446	407	615	2.85	11.38	
D-7	17,500	67,000	34,957	3,559	5,611	5,361	2014	8.69	33.27	17.36
D-8	8,000	6,000		2,049	N/A	2,099	353	22.66	17.00	
D-9	7,800	13,500	11,016	3,835	912	N/A	425	18.35	31.76	33.48
D-11	5,100	12,000		524	N/A	844	1005	5.07	11.94	
D-43	1,750	7,700		1,963	1,432	982	170	10.29	45.29	
D-41	3,700	13,800		1,195	N/A	730	387	9.56	35.66	
D-42	2,300	7,900		N/A	605	N/A	187	12.30	42.25	
D-18	2,700	7,300		N/A	1,355	N/A	488	5.53	14.96	
D-12	8,300	31,500	34,619	5,134	2,972	2,091	539	15.40	58.44	64.23
D-13	2,200	10,000		868	926	1,071	156	14.10	64.10	
D-14	1,200	4,900		1,055	522	740	128	9.38	38.28	
D-15	2,650	5,900		586	639	643	301	8.80	19.60	
D-38	1,750	2,400		N/A	N/A	N/A	490	3.57	4.90	
D-51	2,200	6,700		395	716	352	232	9.48	28.88	
D-20	1,850	5,000		998	917	481	124	14.92	40.32	
D-21	1,600	3,900		N/A	N/A	N/A	280	5.71	13.93	
D-23	900	2,400		N/A	N/A	N/A	310	2.90	7.74	
D-19	6,100	31,000	25,128	1,190	1,065	509	1308	4.66	23.70	19.21
D-39	1,100	3,000		927	1,344	767	230	4.78	13.04	
D-40	3,800	11,800		N/A	1,860	N/A	266	14.29	44.36	
D-25	3,600	5,300		1,068	365	1,608	433	8.31	12.24	
D-24	9,200	34,000	20,018	4,222	4,342	2,684	1,309	7.03	25.97	15.29
D-29	1,970	12,500		870	784	824	248	7.94	50.40	
D-52	2,400	9,300		1,151	1,107	1,202	500	4.80	18.60	
D-30	3,300	20,800		2,992	2,745	3,719	1,126	2.93	18.47	
D-35	1,750	7,600		1,363	N/A	773	491	3.56	15.48	
D-37	750	2,000		226	N/A	167	355	2.11	5.63	
D-53	1,100	3,200		N/A	345	394	97	11.34	32.99	
TOTALS	**128,420**	**408,500**		**40,558**	**35,346**	**36,545**	**17,352**	**7.40**	**23.54**	

* DOW 2000 Post-hunt Population Projections
ml::deer pop_den est.xls - 11/09/00

Colorado Division of Wildlife
Wildlife Research Report
July 2001 and July 2002

JOB PROGRESS REPORT

State of Colorado : Division of Wildlife – Mammals Research
Work Package No. 3002 : Elk Management
Study No. RMNP : Technical Support for Elk and Vegetation Management for Rocky Mountain National Park – Environmental Impact Statement

Period Covered: July 1, 1999 - June 30, 2002

Author: Dan L. Baker, Ph.D.

Personnel: M. Wild, T. Nett, D. Finley, M. Conner, J. Ritchie, L. Wheeler, E. Jones, D. Hussain

ABSTRACT

Fertility control offers a potential alternative to traditional methods for regulating the growth of overabundant wild ungulate populations. However, current technology is limited due to practical treatment application, undesirable side-effects, and economic considerations. A promising non-steroidal, non-immunological approach to contraception involves potent GnRH agonist. During 1999-2002, we conducted a series of experiments to evaluate the effectiveness of a GnRH agonist (leuprolide) as a contraceptive agent in captive female elk. In experiment 1, we determined the optimum dose of GnRH agonist treatment by measuring serum luteinizing hormone (LH) and progesterone (P_4) response of female elk to 4 formulations of leuprolide administered as subcutaneous bioimplants. In experiment 2, we evaluated the effects of leuprolide on elk pregnancy rates, duration of suppression of LH and P_4 secretion, and short-term behavioral and physiological side-effects. In experiment 3, we evaluated the effects of leuprolide on pregnant elk, and in experiment 4, assessed the potential for delivering leuprolide remotely in a syringe dart. All concentrations of leuprolide were equally effective in reducing serum LH and P_4 to non-detectable levels for the duration of the 130 day experiment. Leuprolide administered prior to the breeding season was 100% effective in preventing pregnancy in treated females. Serum LH and P_4 concentrations were reduced to baseline levels by day 92 and remained at these levels for 195-251 days posttreatment with a return to pretreatment concentrations the following breeding season. Reproductive behavior rates were similar for treated and untreated elk for all behavior categories for both the breeding and postbreeding seasons. Hematology and blood chemistry parameters of treated and untreated females were similar and seasonal intake and body weight dynamics appeared normal. Initial results indicate that leuprolide can be effectively delivered in a syringe dart but additional research is needed to confirm these observations. Thus, we conclude that leuprolide is a safe, effective contraceptive agent and has the potential for suppressing fertility in female wapiti for one breeding season.

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TECHNICAL SUPPORT FOR ELK AND VEGETATION MANAGEMENT FOR ROCKY MOUNTAIN NATIONAL PART ENVIRONMENTAL IMPACT STATEMENT

Dan L. Baker

P. N. OBJECTIVE

Conduct captive elk experiments to implement fertility control as an alternative for managing elk in Rocky Mountain National Park.

SEGMENT OBJECTIVES

1. Develop and test a reversible contraceptive agent for free-ranging elk.
2. Determine the duration of effectiveness of a selected contraceptive agent in captive elk.
3. Assess contraceptive effects on pregnancy, and behavioral and physiological side-effects in captive elk.
4. Develop and test a remote delivery system for administering the contraceptive agent to free-ranging elk.

INTRODUCTION

Overabundant wild ungulate populations have become a significant problem for natural resource managers in North America. Unregulated populations can cause adverse effects that are ecological, economic, or political in scope and resolving these issues often requires controlling animal abundance (Jewell and Holt 1981, Garrott et al. 1993, McCullough et al.1997, Smith 2001).

In Rocky Mountain National Park (RMNP), Colorado, the impact of herbivory by elk has emerged as a fundamentally important problem for those who manage the Park and its wildlife (Hess 1993, Zeignefuss et al. 1996). In 1968, RMNP adopted a natural-regulation policy for management of ungulates (Cole 1971, Houston 1971) with the objective of allowing density dependent processes to regulate elk numbers within park boundaries and use sport hunting to harvest as many animals as possible in areas surrounding the Park.

Recently, however, Park managers have become concerned that possible unnatural concentrations of elk may be altering natural plant communities and ecosystem sustainability. Soil conditions and the status of willow and aspen plant communities have declined. Wet meadow, dry grasssland, and alpine and subalpine sites show evidence of deterioration from overgrazing by elk (Singer et al. 1998, White et al. 1998). As a result of the decline in these vegetation types and the diversity of the animal species that are associated with them, the Park and other natural resource agencies are evaluating alternative management strategies for reducing elk densities within RMNP and the surrounding Estes Valley.

One alternative being considered is controlling the fertility of female elk. Fertility control has been widely advocated as an alternative to lethal methods of population control for wildlife and considerable research has been directed toward development of different contraceptive agents (see reviews by Kirkpatrick and Turner 1985, Fagerstone et al. 2001). Field and laboratory studies have evaluated the efficacy of delivery of contraceptives to ungulates (Jacobsen et al. 1995, DeNicola et al. 1997, Kirkpatrick et al. 1997) and models have been developed to represent effects of fertility control on the population dynamics of individual species and populations (Garrott and Siniff 1992, Seagle and Close 1996, Hobbs et al. 2000).

To date, most contraceptive research for wild ungulates has focused on the development of immunocontraceptive vaccines and steroidal hormonal agents. However, after more than 40 years of research, the success of these approaches have been primarily limited to captive wildlife and small localized urban populations of wild ungulates. To meet this challenge, new technologies and approaches are needed if fertility control is to become practical and acceptable management tool for controlling overabundant wildlife species.

A promising new non-steroidal, non-immunological approach to contraception involves potent analogs of gonadotropin-releasing hormone (GnRH). GnRH is a molecule produced in the hypothalamus of the brain. It directs specific cells in the pituitary gland to synthesize and secrete two important reproductive hormones; follicle stimulating hormone (FSH) and luteinizing hormone (LH). These latter two hormones, known as gonadotrophs, control the proper functioning of the ovaries in the female and testes in the male. Chronic treatment with continuous, high doses of GnRH agonists results in temporary suppression of pituitary responsiveness and gonadotropin secretion. Resulting decreases in plasma LH and FSH in females leads to suppression of ovulation, estrus cyclicity, and gonadal steroidogenesis (Belchetz et al.1978, Evans and Rawlings 1994). Once GnRH agonist treatments are terminated, normal pituitary function is gradually restored (Bergfeld et al. 1996).

GnRH agonists have been shown to inhibit ovulation in several domestic ungulate species including sheep (McNeilly and Fraser 1987), cattle (D'Occhio et al. 1996, D'Occhio and Aspden 1999), and horses (Montovan et al. 1990). However, studies on wild ungulates are limited (Becker and Katz, 1995; Brown et al. 1999) and none have demonstrated their effectiveness as a contraceptive agent. GnRH agonists provide a potential biotechnology for achieving a controlled, reversible suppression of fertility in both captive and free-ranging female wild ungulates. However, their practicality as a contraceptive agent is dependent on effective inhibition of reproduction without negative behavioral or physiological side-effects.

During 1999-2002, we conducted a series of experiments with sustained release formulations of GnRH agonist in captive female elk to evaluate these factors. Specifically, our objectives were: (1) to evaluate the effectiveness of GnRH agonist in preventing pregnancy, (2) to determine the duration of GnRH agonist suppression of LH and progesterone (P_4) secretion, (3) to assess the behavioral and physiological side-effects (if any) of GnRH agonist treatments, and (4) to develop a remote delivery system for administering the contraceptive agent to free-ranging animals.

MATERIALS AND METHODS

A. Experiment 1: Dose response

1. Objective

Determine the minimum effective dose of GnRH agonist (leuprolide) that will induce half-maximal release of luteinizing hormone in female elk during estrus and evaluate duration of effectiveness.

2. Methods

We determined the optimum dose of leuprolide (desGly^{10}-D-Leu^6-LH-RH ethylamide acetate) required for suppression of serum LH secretion in 8 female elk (6-12 years of age; 240-300 kg). Females were monitored for occurrence of oestrus cycles by measuring serum progesterone concentrations at weekly intervals beginning 1 November 1998 and were considered reproductively active when concentrations were greater than 1 ng ml^{-1} for two consecutive sampling periods (Adam et al. 1985). Females were randomly selected to receive one of four doses (0, 45, 90, 180 mg leuprolide acetate) of 90 day sustained release leuprolide formulation using the ATRIGEL® drug delivery system (Atrix Laboratories, Inc. Ft. Collins, CO, USA) (Dunn et al.1994). These formulations at lower doses have demonstrated a sustained release and activity in rats and dogs for a period of at least 90-120 days (Ravivarapu et al. 2000).

On the day before treatment application, animals were moved from paddocks, weighed (± 0.5 kg), moved to individual isolation pens (5 x10 m), sedated with xylazine hydrochloride (Rompun; Bayer AG, Leverkusen, Germany; 25-200 mg animal^{-1} i.m.) and fitted nonsurgically with indwelling jugular catheters. Sedation was reversed with yohimbine (30 mg) (Antagonil®, Wildlife Laboratories, Fort Collins, CO, USA). The sampling period began the next day (20 November 1998) at 0900. A patch of hair (3 cm in diameter) was shaved in the shoulder region of each female (controls did not receive a placebo formulation) and leuprolide formulations were injected under the skin using an 18 gauge needle and 3 cc syringe. Blood samples (5 ml) were collected at 0, 60, 120, 180, 240, 300, 360, 480 min, then at 12, 24, 36, 48, 84, and 240 h postinjection. Catheters were flushed daily with sterile saline solution. Following the last blood collection, catheters were removed and animals returned to 5 ha paddocks.

We compared the effective duration of leuprolide treatments by measuring pituitary responsiveness to an exogenous dose of GnRH analogue (D-Ala^6-GnRH-Pro^9-ethylamide; Sigma Chemical Co., St. Louis, MO) administered at 35, 70, 110, and 130 days posttreatment. Animal handling and blood sampling protocols were similar to those previously described. We administered a previously determined dose (Baker et al. 1995) of GnRH analog (1 μg 50 kgBW^{-1}) through the jugular cannula and collected blood samples at 0, 30, 60, 90, 120, 180, 240, 300, 360, 420, and 480 min postinjection. After collection, blood was held at 4^0 C for 24 h until serum was obtained by centrifugation. Serum was then stored at - 20^0 C until analyzed for LH.

B. Experiment 2: Antifertility and behavioral effects on nonpregnant female elk

1. Objectives

a. Determine the effectiveness of GnRH agonist in preventing pregnancy in female elk

b. Determine the duration of GnRH agonist suppression of LH and P_4 secretion

c. Evaluate the behavioral and physiological side-effects (if any) of GnRH agonist treatments.

1. Methods

We evaluated the effects of the optimum dose of leuprolide formulation established in Experiment 1, on elk pregnancy rates, duration of suppression of LH and P_4 secretion, blood chemistry, and reproductive behavior during 2 November 1999 to 15 May 2000. Fourteen adult female (7-13 years of age; 240-320 kg) and 3 adult male elk (4-13 years of age; 375- 400 kg) were used in this experiment. Females were assigned to one of 3 experimental groups based on their tractability for handling and blood sampling. Four elk cows **(Group A)** were treated with 32.5 mg of leuprolide and 5 cows **(Group B)** served as untreated controls and were used to compare pregnancy rates, blood chemistry, and reproductive behavior to those of treated females. These two groups of females were maintained together with 3 adult male elk in adjoining paddocks (2-ha each). The remaining 4 females **(Group C)** served as untreated, non-pregnant controls and were placed in a separate pasture (1 ha) without direct contact with male elk. We compared LH and progesterone secretion of these females to those treated with leuprolide **(Group A)**.

a. **Pregnancy rates, hormonal measurements, and blood parameters.**

We determined the effects of leuprolide on pregnancy rates of treated and untreated elk by measuring pregnancy-specific protein B (PSPB)(BioTracking, Moscow, Idaho, USA) in serum at about 70, 160, and 215 days of gestation (Huang et al. 2000). We compared the effects of leuprolide on extent and duration of LH and P_4 suppression in treated and untreated, non-pregnant elk during 2 November 1999 to 11 November 2000. GnRH challenge trials were conducted prior to application of leuprolide treatments and at 30, 90, 145, 180, 225, 250, and 373 days posttreatment. The final GnRH challenge trial was conducted to assess reversibility of treatment. Protocol for GnRH challenge trials followed procedures previously described in Experiment 1.

We assessed physiological side-effects of leuprolide by comparing serum chemistry, hematology, and body weight dynamics of treated **(Group A)** and untreated, non-pregnant elk **(Group C)**. Blood collections and body weight measurement were made in conjunction with GnRH challenge trials. Blood samples for hematology and serum chemistry analysis were collected at 90 days posttreatment then submitted for analysis to Colorado State University, Veterinary Teaching Hospital, Clinical Pathology Laboratory, Fort Collins, Colorado, USA.

Serum chemistry profiles were obtained using a Hatachi 917 autoanalyzer (Roche/Boehringer Mannheim, Indianapolis, Indiana, USA) for the following parameters: glucose, creatinine, phosphorus, calcium, magnesium, total protein, albumin, globulin, albumin/globulin ratio, bilirubin, creatinine kinase, aspartate aminotransferase, gamma-glutamyltransferase, sorbitol dehydrogenase, sodium, potassium, chloride, and biocarbonate.

Values for the following hematological parameters were obtained using an ADVIA 12O autoanalyzer (Bayer Corporation, Tarrytown, New York, USA): nucleated cells, neutrophils, lymphocytes, monocytes, eosinophils, plasma protein, erythrocyte, hemoglobin, packed cell volume, mean corpuscular volume, mean corpuscular hemoglobin concentration, platelets, and fibrinogen.

b. **Reproductive behavior**. The effectiveness of the leuprolide formulation as a contraceptive agent is dependent upon suppression of ovulation and steroidogenesis for the duration of the breeding season. Thus, we tested 2 hypotheses relative to the effects of leuprolide on reproductive behavior of elk: (1) because leuprolide was expected to suppress gonadotrophin secretion and ovulation, we predicted that sexual interactions during the breeding season would be reduced in leuprolide treated females **(Group A)** compared to untreated controls **(Group B)**, and (2) since depletion of the leuprolide implant (90 days) was expected prior to anoestrus (late March), we predicted that behavioral oestrus would resume in treated females **(Group A)** and the rate of sexual interactions would be higher than that for untreated controls **(Group B)**

To test these hypotheses, we examined the effects of leuprolide on reproductive interactions of male and female elk during 2 time periods; breeding season (defined as the period 10 November - 23 December 1999) and postbreeding season (defined as the period 7 February - 27 March 2000). On 2 November 1999, female elk in **Group A** were treated with leuprolide and released with untreated controls (**Group B**) into adjoining paddocks (2 ha each). Seven days later (10 November), we placed 3 adult male elk with these groups and initiated behavioral observations. All females were individually identified with color/numeric-coded neck collars. Animals selected as treatments and controls were unknown to observers. Behavioral measurements were made from a distance of 50-250 m from an elevated tower (10 m) situated between adjacent pastures using binoculars and a spotting scope during the day, and a spotlight and night vision scope at night. We recorded selected behaviors using a lap-top computer with a behavioral software program.

We used focal animal sampling procedures to sample reproductive behaviors of all experimental animals over a 24 -hour period (Lehner 1996). Preliminary observations indicated that elk were most active in morning (0500-0800), late day (1400-1700) and night (2000-2400). Thus, time-of-day sampling periods were randomly assigned each week using a randomized block design. Each sampling period consisted of at least two hours of continuous observations. Based on previously reported elk breeding behavior (Morrison et al. 1960, Geist 1982, Rapley 1985), we identified and recorded 19 sexual interactions. Because sample sizes were small, we grouped individual behaviors into 4 general categories: male copulatory, male precopulatory, female precopulatory, and general breeding (Table 1). Copulatory, male precopulatory, and general breeding were interactions of a male directed toward a specific female, while female precopulatory behaviors were actions of a specific female towards a male. Thus, our experimental unit for analyses was the individual female in each breeding group. Behavioral interactions were generally short duration (<30 sec) relative to sampling interval, therefore we recorded the number of occurrences of each event rather than length of time and calculated sexual interaction rates as acts per animal per hour, then multiplied hourly behavioral rates by 24 for a daily rate.

Table 1. Description of elk reproductive behavior and associated behavior categories.

Behavior category	Reproductive behavior
General breeding :	Male directed behavior related to establishing, maintaining, and defending a group or harem of female elk (e.g. herding guarding, tending)
Male precopulatory	Male courtship behavior directed toward an individual female to induce or detect oestrus or ovulation (e.g. urine testing, flehmen, tongue flick, lick , smell, or rub female's body, chivy)
Female precopulatory	Female courtship behavior directed toward dominant male to arouse copulatory behavior (e.g. lick and rub male, mount, lordosis, twitch hocks)
Copulatory	Male behavior directed toward a receptive female in oestrus (e.g. precopulatory mounts, intromission, pelvic thrust)

c. **Hormone radioimmunoassay**. Serum concentrations of LH were quantified by means of an ovine (o) LH RIA (Niswender et al. 1969). Elk serum was demonstrated to inhibit binding of ^{125}I-oLH to LH antiserum in a parallel manner. Likewise, when varying quantities of oLH standard (NIH-OLH-S24) were added to elk serum and samples were subjected to RIA, the values obtained were increased by the quantity of oLH added ($r^2 = 0.99$, slope = 0.92, $SE_b = 0.22$, $P = 0.002$). These data indicate that the radioimmunoassay (RIA) provided a quantitative assessment of LH in elk serum. The limit of sensitivity of the LH assay was 0.4 ng ml^{-1}. Serum concentrations of progesterone were determined by RIA (Niswender 1973). Sensitivity of the progesterone assay was 0.12 ng ml^{-1}. Intra- and inter-assay coefficients of variation for each of these assays were less than 10%.

d. **Statistical analysis**. Hormone concentrations are reported as untransformed arithmetic means ± standard error of the mean (SE). Responsiveness of the pituitary to GnRH analog challenge was assessed in two ways: 1) maximum response (highest concentration of LH (ng ml^{-1}) achieved postinjection minus baseline), and 2) total amount of LH secreted (ng ml^{-1} min^{-1}) estimated by calculating the area under the LH response curve (Abramowitz and Stegun 1968).

We analyzed differences among hormone levels using least squares analysis of variance for general linear models (SAS Institute 1993). Responses to treatments were analyzed with one-way analysis of variance for a randomized complete block design with repeated measures structure. Levels of leuprolide formulations were treatments; individual animals were blocks. Factors in the analysis were dose and time. Treatment effects were tested using the animal-within-treatment variance as the error term. Time was treated as a within-subject effect using a multivariate approach to repeated measures (Morrison 1976). A "protected" least significant difference test (Milliken and Johnson 1984) was used to separate means when the overall *F*-test indicated significant treatment effects ($P < 0.05$).

We tested specific reproductive behavior hypotheses that mean behavior rate was not different between treatment and control groups for both the breeding and postbreeding seasons using an ANOVA model with a repeated measures structure. Similar to the hormonal analysis, time was treated as a within subject effect using multivariate approach to repeated measures (Morrison 1976). To test for treatment effects, we accounted for time-of-day, date effects and their interactions. PROC GENMOD (SAS Institute 1993) was used to estimate and test for differences in mean behavior rate by treatment, time-of-day, and date. Means and standard errors were estimated using least squares, and hypothesis tests were based on type III generalized estimating equations that accounted for correlation in repeated measurements.

D. Experiment 3: Antifertility effects on pregnant elk

1. Objectives

a. Evaluate the effects of GnRH agonist (leuprolide)on female elk treated during the first trimester of pregnancy.

b. Assess nutritional, physiological, or behavioral side-effects that might result from treatment.

2. Methods

a. **Animals.** We conducted controlled experiments with 12 adult female elk and 2 adult male elk at the Colorado Division of Wildlife's Foothills Wildlife Research Facility (FWRF), Fort Collins, Colorado during September 1, 2000 to December 15, 2001. On September 1, 2000, two intact male elk were released with 12 female elk. The purpose of mating was to confirm the reversibility of leuprolide from previous experimental treatments (Baker et al. 2002, in press). Pregnant animals from this mating would then provide the experimental elk for the experiment described in this study plan.

b. **Treatments.** Approximately 60 days postconception (1 December for cows at FWRF), all females were evaluated for pregnancy and fetal age determined using transrectal ultrasonography (Willard et al. 1994). Using ultrasound and selected measurements reported for known-age embryos (Morrison et al. 1959), we estimated fetal ages of all pregnant elk. Eight elk with embryos estimated to be 60-75 days old were randomly selected to receive a subcutaneous implant containing 32.5 mg of leuprolide formulation. Leuprolide was injected subcutaneously on the lateral thorax using an 18 g x 4 cm needle. The remaining four pregnant elk were designated as untreated controls. Treatment and control elk were maintained in the same pastures, fed similar diets, and handled similarly throughout the study. All treatments were applied without tranquilization by moving elk from 5 ha pastures to individual isolation pens, then into a restraining chute, where treatments were applied, then returning elk back into 5 ha paddocks. Animals were observed daily by trained caretakers for general health and for signs of abortion or parturition.

c. **Sample size.** Based on previous reproduction studies with captive elk at FWRF, 4-6 elk per treatment is the minimum sample size needed to provide biologically significant differences among treatment means (Baker et al. 1995, Baker et al. 2002, in press). We used an unbalanced experimental design to minimize the number of untreated pregnant control elk, since most neonates will be euthanized. Pregnant, control elk were needed to insure that treatment results were not biased due to handling procedures, and/or other uncontrolled variables.

d. **Measurements**

1) ***Pregnancy Rates***. We assessed contraceptive effectiveness by determining pregnancy status of all experimental elk. Using transrectal ultrasonography (Willard et al. 1994, 1998), we determined pregnancy rates of treated and control elk prior to treatment, and at 60, and 120 days posttreatment. On the day of pregnancy assessment, elk were moved from 5 ha pastures to a handling chute where they were sedated with xylazine hydrochloride (20-200 mg/animal, IM), then scanned using real-time transrectal ultrasound to determine pregnancy status and/or fetal age. Elk were then reversed with yohimbine (0.125 mg/kg, IV) and returned to their original pastures. We determined the reversibility of leuprolide by releasing a epididymectomized male elk with treated female elk in October 2001 and conducting a GnRH challenge trial (Baker et al. 1995) to measure LH and P_4 levels.

2) ***Reproductive Behavior***. The effects of leuprolide on the breeding behavior of captive elk treated prior to the breeding season is known (Baker et al. 2002, in press), however, these reported effects may or may not be extended to elk treated during early pregnancy.

Down-regulation of gonadotroph cells by the action of leuprolide and subsequent reduced secretion of LH could effectively inhibit progesterone secretion by the corpus luteum. If the effective action of leuprolide is luteolytic, then early embryonic loss could occur (Plotka et al. 1982, Asher et al. 1988, Flint et al. 1991). However, the efficacy of induction of luteolysis by leuprolide in Cervidae is unknown. Furthermore, it's not known if following early embryonic loss, whether female elk will regain normal estrus cycles and behavior. We evaluated these potential behavioral side-effects by monitoring maintenance and breeding behavior of male and female elk before and after leuprolide treatments. Each animal was individually identified using color-coded neck bands or ear tags. We tested the null hypothesis that the frequency of sexual interactions between males and females is similar before and after contraceptive treatment.

e. **Statistical Analysis.** We analyzed data using least squares ANOVA for General Linear Models and the SAS Interactive Matrix Language. Response to contraceptive treatment was analyzed with a two-way factorial analysis of variance for a randomized complete block design with repeated measures structure. Factors in the analysis were treatment and time. Treatment was tested using the animal-within-treatment variance as the error term. Time was treated as a within subject effect using a multivariate approach to repeated measures. We used orthogonal contrast to test for differences among individual means (Morrison 1976).

E. Experiment 4: Development of a remote delivery system

1. Objective.

Begin evaluating a remote delivery system by comparing effectiveness of subcutaneous and intramuscular administration of leuprolide formulation in suppressing reproduction in female elk.

2. Methods.

a. **Animals and treatment.** We conducted a controlled experiment with 13 adult female elk (7-13 years of age; 250-300 kg), 1intact male elk, and 1 epididymectomized male elk at the Colorado Division of Wildlife's Foothills Wildlife Research Facility (FWRF), Fort Collins, Colorado during 15 August 2001 to 28 March, 2002. Between 15 August and 1 September, 2001, the epididymectomized male elk was released with 13 adult female elk into 2 adjoining paddocks (2 ha). Females were monitored for occurrence of estrus cycles by measuring progesterone levels beginning 1 September 2001and were considered reproductively active when concentrations were greater than 1 ng/ml. Treatments were assigned as follows: 3 females were randomly selected to receive a subcutaneous formulation of leuprolide (32.5 mg)(ATRIGEL, Atrix Laboratories, Inc. Fort Collins, Colorado, USA) by syringe injection; 3 elk were selected to receive an intramuscular leuprolide formulation (32.5 mg) via syringe injection; 4 elk received the leuprolide formulation via a 1 cc, PneDart dart (16 gauge, 3.39 cm. needle) fired from a CO_2 - powered Dan-Inject pistol, and 3 elk were designated as untreated controls.

Treatments were applied as follows. On the day before application (6 September 2001), experimental elk were moved from pastures to individual isolation pens (5 m x 10 m), weighed (± 0.5 kg), sedated with xylazine hydrochloride (Rompun; Bayer AG, Leverkusen; 25-200 mg/animal, i.m) and fitted nonsurgically with indwelling jugular catheters. The next day, treatment and placebo treatments were administered. In order to accurately determine the precise dose of leuprolide formulation remotely delivered to each elk, syringe darts were weighed (0.001 g) before and after injection. Prior to darting, elk were placed in a handling chute and lightly sedated with xylazine hydrochloride (15-20 mg/animal, i.v.). This dose allowed animals to remain standing in the chute and minimized excitation associated with discharge of the dart gun. With the exception of two animals, one dart per animal was fired from approximately 3 meters into the middle gluteus maximus muscle of the standing elk. Once all elk had been treated, sedation was reversed with yohimbine (30 mg) (Antagonil®, Wildlife Laboratories, Fort Collins, Colorado, USA) and animals were returned to individual isolation pens.

b. **Measurements**. Approximately 1 hour following treatment applications, we measured 24-hour LH response of elk treated with the leuprolide formulation and untreated control elk. Blood samples (5 ml) were collected via jugular catheters at 0, 120, 180, 240, 300, 360, 480 min then at 10, 16, and 24 hr after injection. Catheters were flushed after each collection with sterile saline solution. After the last blood collection, catheters were removed and animals returned to 5 ha pastures. The effect of leuprolide formulation on the duration of suppression of LH was determined by periodically conducting pituitary stimulation trials. These trials were conducted during 29 October 2001 to 28 March 2002 to determine the capability of LH cells to respond to stimulation with an exogenous dose of GnRH analog (D-Ala^6-GnRH-Pro^9-ethylamide; Sigma Chemical Company, St. Louis, Missouri, USA). Pituitary stimulation trials were conducted with treated and control elk at 30, 60, 90, 120, 160, and 190 days posttreatment. Stimulation trials were conducted according to the following procedures: On the day of testing, treated and control elk were moved from 5 ha pastures to individual isolation pens, weighed, sedated (as previously described), and fitted nonsurgically with indwelling jugular catheters. GnRH analog (1 μg/50 kg body weight) was administered through the cannula and blood samples were collected (5 ml) at 0, 60, 120, 180, 240, 300, 360, and 480 minutes posttreatment. After collections, blood was stored at 4^0 C for 24 hours until serum was obtained by centrifugation (1500 RCF for 15 minutes). Serum samples for progesterone levels were also collected from each elk on each of these trial days. Serum was stored at -20^0 C until analyzed for LH and progesterone. Following the last blood collection, catheters were removed and elk were returned to the holding pastures.

The effect of leuprolide formulation on reproduction in treated and control elk was determined by measuring pregnancy rates using the presence or absence of pregnancy specific protein B (PSPB) (BioTracking, Moscow, Idaho, USA) in serum collected at approximately 100 and 215 days of gestation (Huang et al. 2000).

c. **Statistical analysis.** Responsiveness of the pituitary gland to GnRH analog stimulation was assessed in two ways: (1) maximum response (highest concentration of LH (ng/ml) achieved after injection minus baseline), and (2) total amount of LH secreted (ng/ml/min) estimated by calculating the area under the LH response curve (Abramowitz and Stegun, 1968). Differences among hormone concentrations were tested using least squares ANOVA for general linear models (SAS Institute, 1997). Responses to treatment were analyzed with one-way ANOVA for a randomized complete block design with repeated measures. Treatment effects were determined using the total animal-within-treatment variances as the error term. Time was treated as a within-subject effect, using a multivariate approach to repeated measures (Morrison 1976). A "protected" least significant difference test (Milliken and Johnson, 1984) was used to separate means when the overall *F* test indicated significant treatment effects ($P < 0.05$).

RESULTS

A. Experiment 1: Dose response

Administration of sustained release formulations of leuprolide to female elk resulted in an acute, transient rise in serum LH concentrations irrespective of dose. Maximum LH concentrations (15.6 ± 0.93 ng ml^{-1}) occurred approximately 3 hours following treatment and were similar across all treatment levels (Fig. 1). Following peak response, there was a rapid decline in LH to basal levels during the next 24 hours. Total LH secretion (ng ml^{-1} min^{-1}) did not differ among treatments and all treatments resulted in higher LH secretion than controls ($P \leq 0.002$). Leuprolide reduced serum LH secretion to non-detectable levels in treated females for 130 days posttreatment (Fig. 2). Differences in mean maximum serum LH were significantly lower ($P \leq 0.031$) in treated elk compared to untreated controls at all sampling periods. For untreated females, mean maximum LH fluctuated from a high of 19.3 ± 4.2 to a low of 3.5 ± 0.06 ng ml^{-1}. This variation was likely related to the phase of the oestrous cycle when control females were challenged with GnRH and the influence of fluctuating levels of estradiol and progesterone on LH secretion (Goodman and Karsch 1980).

B. Experiment 2: Antifertility and behavioral effects on nonpregnant female elk

a. Pregnancy rates, hormonal measurements, and blood parameters. Because Experiment 1 did not establish a minimum effective dose of leuprolide for LH suppression, we arbitrarily reduced the leuprolide formulation by approximately 20% below the lowest concentration tested in Experiment 1, to 32.5 mg. This dose of leuprolide prevented pregnancy in all treated females **(Group A)** while the pregnancy rate of control females **(Group B)** was 100%. Treated females tested negative and controls positive for PSPB on all sampling dates. Estimated conception dates for pregnant elk ranged from 10 November to 19 November 1999 and parturition occurred between 12 July and 26 July 2000.

Leuprolide caused a significant reduction ($P \leq 0.035$) in mean maximum serum LH (Fig. 3) and P_4 (Fig. 4) concentrations in treated females **(Group A)** with a return to pretreatment levels the following breeding season (11 November 2000). Serum LH was reduced to non-detectable concentrations by 92 days posttreatment and remained at this level until day 225. In one treated female, LH remained at baseline for 250 days posttreatment. Maximum LH response was lower ($P \leq 0.012$) in treated compared to non-pregnant controls **(Group C)** at 30, 92, 135, 165, and 193 days following treatment. Serum LH of untreated elk declined significantly ($P = 0.024$) between April and May with the onset of anestrus, then returned to pretreatment levels indicative of estrus in November 2000.

Serum P_4 levels of treated females followed a similar pattern to that observed for serum LH (Fig. 4). Progesterone levels were similar in treated and control elk until day 30, thereafter, serum progesterone remained at basal concentrations in treated females until day 225 of the trial, indicating that additional ovulations did not occur. Control females maintained increased serum P_4 content, reflecting continued regular estrous cycles within this group until day 165 (18 April) when the effects of anestrus reduced P_4 to basal levels. Similar to serum LH, P_4 content then increased during November 2000 to pretreatment concentrations in both treated and untreated elk (Fig. 4).

We evaluated 13 hematology and 19 serum chemistry parameters in treated and untreated elk females. With the exception of creatinine kinase (CK), a muscle derived enzyme, all individuals were clinically similar. Elk in the treatment group showed moderately elevated CK levels (400-702 IU L^{-1}). Creatinine kinase levels can increase in unconditioned animals following vigorous exercise and remain elevated for 4-6 hours (Lefebvre et al. 1994). Handling procedures for blood sampling in treated females were often more physically rigorous than those for controls due to the need to separate females from males. Thus, the elevated CK levels in treated elk compared to controls likely reflect a bias due to a difference in animal handling prior to blood sample collections, rather than a treatment-induced response.

b. Reproductive behavior. We observed male to male dominance interactions immediately following their release into the pastures with treated and untreated females. Within 2.5 weeks, one male established dominance over the other two. Thereafter, subdominant males retreated to remote locations in the pastures and rarely interacted with females or the dominant male for the remainder of the experiment.

During the breeding season, we observed reproductive interactions of males and females on 34 days during 10 November to 23 December 1999. We analyzed 63 sampling periods (134.5 h): 20 periods at dawn (45.7 h), 6 at mid-day (13.5 h), 20 at dusk (42.8 h), and 17 at night (32.6 h). The average length of the observation periods was 2.1 (SE = 0.10) h. Postbreeding observations occurred on 14 days during 7 February to 27 March. We analyzed data from 16 sampling periods (54.7 h): 6 periods at dawn (22.5 h), 2 at mid-day (7.5 h), 7 at dusk (22.2 h), and 1 at night (2.5 h). Observation periods averaged 3.4 (SE = 0.24) h.

Contrary to our first hypothesis, sexual interactions during the breeding season were not diminished in leuprolide-treated females compared to controls. Instead, breeding behavior rates were similar for treated and untreated females for all behavior categories (Fig. 5). Although we did not detect a significant treatment × time interaction, copulatory ($P = 0.064$), male precopulatory ($P = 0.083$), and female precopulatory ($P = 0.072$) behaviors approached significance and are notable. For these 3 behavior categories, the daily behavior rate decreased over time for untreated females, but remained constant for treated elk.

We also failed to reject our second hypothesis. Treated females did not resume normal oestrus cycles during the postbreeding season and reproductive behavior rates did not increase compared to untreated controls. We observed almost no sexual interactions between the dominant male and treated or untreated females during the postbreeding season. There were no copulatory or female precopulatory behaviors recorded, and too few male precopulatory (≤ 0.17 day^{-1}) and general breeding (≤ 0.30 day^{-1}) behaviors to analyze.

C. Experiment 3: Antifertility effects on pregnant elk.

Leuprolide administered has a 32.5 mg subcutaneous formulation to elk during the first trimester of pregnancy failed to induce fetal loss. Fetal age at the time of treatment of treated females ranged from 30 - 90 days of age and from 50 - 90 days for control elk. Treated and control females were positive for PSPB at all sampling dates during gestation and all produced a calf at parturition. Dystocia was observed in 3 of 6 females but did not appear to be related to treatment.

During the breeding season reproductive behaviors were similar ($P = 0.45$) for treated and control female elk. We observed almost no sexual interactions during the postbreeding season.

D. Experiment 4: Development of a remote delivery system.

Administration of a 90-day sustained release formulation of leuprolide to female elk resulted in an acute, transient rise in serum LH levels irrespective of mode of delivery (Fig. 6). Maximum LH concentrations occurred approximately 3.5-4.5 h following treatment and were highest (84.9 ± 5.3 ng/ml) for the intramuscular syringe treatment, followed by intramuscular dart (42.2 ± 15.8 ng/ml) and subcutaneous syringe (23.0 ± 5.1 ng/ml). Following peak response, there was a rapid decline in LH basal levels during the next 24 hours. Leuprolide reduced serum LH secretion to non-detectable levels in all treatment groups for 120 days posttreatment. Between 120 and 160 days posttreatment, LH levels in the intramuscular syringe and dart treatments increased substantially over the subcutaneous syringe treatment and control females and remained elevated for the duration of the experiment. In contrast, LH levels for the subcutaneous syringe group remained at basal levels (Fig. 6). Serum P_4 levels followed a different pattern than that observed for serum LH (Fig. 7). After 60 days posttreatment, P_4 concentrations in all treatment groups declined to basal levels and remained at these levels for the remainder of the experiment.

Regardless of mode of delivery, leuprolide formulation prevented pregnancy in all treatment groups, whereas pregnancy rate of control females was 100%. Leuprolide-treated females tested negative and controls positive for PSPB on both sampling dates.

DISCUSSION

Successful application of fertility control technology for wildlife is dependent on development of contraceptive agents that are safe, practical, and effective. Current technology is limited due to problems of treatment implementation and concerns for the health of target and non-target species. In the present study, we evaluated a promising non-steroidal, non-immunological contraceptive technology for controlling fertility in female elk.

Administration of a sustained release formulation containing leuprolide to captive female elk prior to the breeding season, resulted in decreased LH and progesterone secretion, temporary suppression of ovulation and steroidogenesis, and effective contraception without detrimental behavioral or physiological side-effects. The acute increase in serum LH immediately following leuprolide treatment was consistent with previous studies in cattle (D'Occhio et al. 1996), sheep (Nett et al. 1981), horses (Montovan et al. 1990) and African elephants (*Loxodonta africana)* (Brown et al. 1993). There was little variation among elk in their serum LH response to different doses of leuprolide, indicating either low variability in the amount and duration of agonist released or doses so high that any variation was masked. The minimum level of leuprolide needed to suppress estrus in female elk was not determined in this study. All doses of leuprolide were equally successful in reducing LH concentrations for the duration of the 130 trial. Additional research to establish a minimum effective dose of leuprolide would enhance the economic practicality of this contraceptive agent.

The cessation of estrous cycles in females treated with leuprolide and the return to apparently normal ovarian function after depletion of the agonist implant was consistent with findings for females in other species (D'Occhio et al. 1996; Evans and Rawlings, 1994; Fraser et al. 1989). The effectiveness of leuprolide as a contraceptive agent is dependent on suppression of ovulation from the inception of the breeding season to the onset of anestrus, a period of approximately 200 days for elk. Leuprolide inhibited ovulation for >190 days, 2 times longer that the formulated 90 day delivery period. The prolonged suppression of gonadotrophin secretion may occur for several reasons. Among these are that release of leuprolide from the implant may have continued beyond the formulated 90 day period. Certainly, LH secretion remained suppressed for more that 130 days in Experiment 1. Likewise, leuprolide treatment may have induced prolonged suppression of gonadotroph function (i.e. extending beyond the duration of the implant). In other ruminants, if gonadotroph function is suppressed for an extended duration, a recovery period of 30-60 days following removal of the suppression is necessary before pituitary content of LH and gonadotropin secretion can return to normal levels (Nett 1987). Thus, if duration of leuprolide release from the implant was 130 days and recovery of gonadotroph function requires approximately 60 days, this would be sufficient to carry the reduced secretion of LH into the normal anoestrous period when secretion of LH would be photoperiodically suppressed. If this is indeed true, then a single treatment should provide a contraceptive effect for approximately one breeding season.

The effectiveness of leuprolide in preventing pregnancy in female elk is conditional. Successful prevention of fertility was achieved by treating elk prior to the breeding season. The use of leuprolide as a contragestive in female elk during early pregnancy was unsuccessful. Since we did not measure LH responses to leuprolide treatment in pregnant elk, the mechanism for failure is unknown. We speculate that complete down-regulation of LH receptors did not occur and LH levels were high enough to stimulate an LH surge and subsequent ovulation.

The overall rates of sexual interactions between treated and control elk were not different during the breeding and postbreeding seasons. During the breeding season, the dominant male established and defended a single harem of treated and untreated females. Reproductive behaviors during the breeding season between the dominant male and harem females followed a pattern similar to that described for free-ranging elk (Geist 1982). Treated and untreated females were courted, bred, and defended with equal frequency, however the pattern of reproductive interactions changed over time. Once untreated females became pregnant, reproductive behavior rates decreased, whereas, copulatory, and male and female precopulatory rates remained constant over time in treated females. These extended sexual interactions were generally intermittent and may have been related to fluctuating levels of progesterone and oestradiol. Estrus can occur with relatively low estradiol concentrations, if coupled with low progesterone content. In domestic sheep, pre-exposure to progesterone stimulates estrus behavior at much lower concentrations of estradiol once progesterone is decreased in circulation (Robinson 1954). Therefore, since these animals had ovulated prior to leuprolide treatment, they became very sensitive to low levels of estradiol, and since ovulation and corpus luteum formation were blocked they continued to show estrus behavior with basal estradiol levels.

Regardless of the mechanism involved, disruption of normal behavioral patterns are not a desirable side-effect of contraceptive treatments. However, without carefully designed large-scale investigations with larger sample sizes, and under more natural conditions, we can only speculate on the significance of these behavioral alterations on the health and social organization of treated populations.

Before leuprolide can be considered a practical and efficacious approach for wildlife contraception, development of a reliable remote delivery system is needed. Our pilot efforts to develop such a system were promising, however, the small sample size (n = 3) used in this experiment support only guarded optimism. It appears that the rise in LH levels observed in females treated with syringe dart delivery of leuprolide formulation were not high enough to stimulate ovulation and conception. Clearly, additional research with larger sample sizes is needed to confirm or reject these findings.

CONCLUSION

The objective of the work reported here was to evaluate the contraceptive potential of a GnRH agonist (leuprolide) formulation in female elk, provide evidence of physiological and behavioral side effects of treatment (if any), and assess the potential for remote delivery. We conclude that leuprolide administered as a controlled release formulation prior to the breeding season, offers a new approach to reversible contraception in wild ungulates that overcomes problems associated with existing technology.

First, leuprolide formulation improves practical application of contraception because a single treatment can induce infertility in females without relocating and treating specific individuals each year. Second, leuprolide acetate is a neuropeptide, thus the proteinaceous nature of this agent eliminates the possibility of passage through the food chain to non-target species. Third, behavioral side-effects were minimal. Sexual interactions of treated females were extended early in the breeding season but recurrent estrous cycling and ovulation did not occur. Fourth, there were no short-term physiological side-effects of treatment. Treated animals appeared healthy and seasonal intake and body weight dynamics normal. However, before this technology can be considered a practical and efficacious approach for wildlife, additional research is needed to ascertain minimum effective dose, verify effective treatment duration, and develop a remote delivery system for administering leuprolide formulation to unrestrained animals.

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LITERATURE CITED

Abramowitz, M., and L. A. Stegun. 1968. *Handbook of Mathematical Functions.* Dover Publications, New York, USA.

Adam, C. L., C. E. Moir, and T. Atkinson. 1985. Plasma concentrations of progesterone in female red deer (*Cervus elaphus*) during the breeding season, pregnancy, and anoestrus. Journal of Reproduction and Fertility 74:631-636.

Asher, G. W. 1988. Hormonal changes during the luteal regression in farmed fallow deer, *Dama dama.* Journal of Reproduction and Fertility 84:379-386.

Baker, D. L., M. A. Wild, M. M. Conner, H. B. Ravivarapu, R. L. Dunn, and T. M. Nett. 2002. Effects of GnRH agonist (leuprolide) on reproduction and behavior in female wapiti (*Cervus elaphus nelsoni)*. Reproduction (Suppl) 60: (in press).

______, M. W. Miller, and T. M. Nett. 1995. Gonadotropin-releasing hormone analog-induced patterns of luteinizing hormone secretion in female wapiti (*Cervus elaphus nelsoni)* during the breeding season, anestrus, and pregnancy. Biol. of Reprod. 52:1193-1197.

Becker, S. E., and L. S. Katz. 1995. Effects of gonadotropin-releasing hormone agonist on serum LH concentrations in female white-tailed deer. Small Ruminant Research 18:145-150.

Belchetz, P. E., T. M. Plant, Y. Nakai, E. J. Keogh, and E. Knobil. 1978. Hypophysial response to continuous and intermittent delivery of hypothalamic gonadotropin-releasing hormone. Science 202: 631-633.

Bergfeld E., M. J. D'Occhio, and J. E. Kinder. 1996. Pituitary function, ovarian follicular growth, and plasma concentrations of 17β-oestradiol and progesterone in prepubertal heifers during and after treatment with the luteinizing hormone-releasing hormone agonist deslorelin. Biology of Reproduction 54:776-782.

Brown, J. L., D. L. Schmitt, A. Bellem, L. H. Graham, and J. Lehnhardt. 1999. Hormone secretion in the Asian elephant (*Elaphus maximus):* Characterization of ovulatory and anovulatory LH surges. Biology of Reproduction 61:1294-1299.

Cole, G. F. 1971. An ecological rationale for the natural or artificial regulation of native ungulates in parks. Transactions of the North American Wildlife and Natural Resources Conference 36:417-426.

D'Occhio, M. H., W. J. Aspden, and T. Whyte. 1996. Controlled reversible suppression of oestrous cycles in beef heifers and cows using agonist of luteinizing hormone - releasing hormone. Journal of Animal Science 74:218-225.

_____, M. J., and W. J. Aspden. 1999. Endocrine and reproductive responses of male and female cattle to agonist of gonadotrophin-releasing hormone. Journal of Reproduction and Fertility Supplement 54:101-114

DeNicola, A. J., D. J. Kesler, and R. K. Swihart. 1997. Remotely delivered prostaglandin F- 2 alpha implants terminate pregnancy in white-tailed deer. Wildlife Society Bulletin 25:527-531.

Dunn, R. L., J. P. English, D. R. Cowan, and D. P. Vanderbilt. 1994. Biodegradable *in situ* forming implants and methods of producing the same. U. S. patent no. 5,278,201.

Evans, A. C. O., and N. C. Rawlings. 1994. Effects of a long-acting gonadotrophin-releasing hormone agonist (Leuprolide) on ovarian follicular development in prepubertal heifer calves. Canadian Journal of Animal Science 74:649-656.

Goodman, R. L., and F. J. Karsch. 1980. Pulsatile secretion of luteinizing hormone: differential suppression by ovarian steroids. Endocrinology 107:1286-1290.

Fagerstone, K. A, M. Coffey, P. Curtis, R. Dolbeer, G. Killian, L. A. Miller, and L. Wilmot. 2001. Wildlife contraception. Wildlife Society Technical Review. Proceedings of the Wildlife Society 8th Annual Conference, Reno, USA

Flint, A.P.F., E. L. Sheldrick, T. J. McCann, B. R. Brinklow, and A.S.I. Loudon. 1991. Prostaglandin-induced secretion of oxytocin and prolactin in red deer *(Cervus elaphus)* and Pere David's *(Elaphurus davidianus)* deer hinds: Evidence for oxytocin of luteal origin. General and Comparative Endocrinology 83:432-438.

Garrott, R. A., P. J. White, and C. A. Vanderbilt-White. 1993. Overabundance: an issue for conservation biologist? Conservation Biology 7:946-949.

_____, and D. B. Siniff. 1992. Limitations of male-oriented contraception for controlling feral horse populations. Journal of Wildlife Management 56:456-464.

Geist, V. 1982. Adaptive behavioral strategies. Pages 219-277 *in* Elk of North America: Ecology and Management. J. W. Thomas and D. E. Toweill, editors. Stackpole Books, Harrisburg, USA.

Jacobsen, N. K., D. A. Jessup, and D. J. Kesler. 1995. Contraception in captive black-tailed deer by remotely delivered norgestomet ballistic implants. Wildlife Society Bulletin 23:718-722.

Hess, K. H. 1993. Rocky Times in Rocky Mountain National Park. University of Colorado Press. Niwot Colorado, USA.

Huang, F., D. C. Cockrell, T. R. Stephenson, J. H. Noyes, and R. G. Sasser. 2000. A serum pregnancy test with specific radioimmunoassay for moose and elk pregnancy specific protein B. Journal of Wildlife Management 64:492-499.

Hobbs, N. T., D. C. Bowden, and D. L. Baker. 2000. Effects of fertility control on populations of ungulates: general, stage-structured models. Journal of Wildlife Management 64:473-491.

Houston, D. B. 1971. Ecosystems of national parks. Science 172:648-651.

Jewell, P. A., and S. Holt. 1981. Problems in management of locally abundant wild animals. Academic Press. 321pp.

Lefebvre, H. P., P. L. Toutain, J. P. Serthelon, V. Lassourd, L. Gardey, and J. P. Braun. 1994. Pharmcokinetic variables and bioavailability from muscle of creatinine kinase in cattle American Journal of Veterinary Research 55:487-497

Lehner, P. N. 1996. Handbook of Ethological Methods. Second Edition. Cambridge University Press, Cambridge, UK.

Kirkpatrick, J. F., and J. W. Turner, Jr. 1985. Chemical fertility control and wildlife management. Bioscience 35:485-491.

_____, _____, I. K. M. Lui, R. C. Fayrer Hosken, and A. T. Rutberg. 1997. Case studies in wildlife immunocontraception: wild and feral equids and white-tailed deer. Reproduction, Fertility, and Development 9:105-110.

McCullough, D. R., K. W. Jennings, N. B. Gates, B. G. Elliot, and J. E. Didonato. 1997. Overabundant deer populations in California. Wildlife Society Bulletin 25:478-483.

McNeilly, A. S., and H. M. Fraser. 1987. Effect of gonadotrophin-releasing hormone agonist-induced suppression of LH and FSH on follicle growth and corpus luteum function in the ewe. Journal of Endocrinology 115:273-282.

Milliken, G. A., and D. E. Johnson. 1984. Analysis of Messy Data. Volume I. Designed Experiments. Lifetime Learning Publications, Belmont,California, USA

Montovan, S. M., P. P. Daels, J. Rivier, G. H. Hughes, G. H. Stabenfeldt, and B.L. Lasley. 1990. The effect of potent GnRH agonist on gonadal and sexual activity in the horse. Theriogenology 33:1305-1321.

Morrison, D. F. 1976. Multivariate Statistical Methods. McGraw-Hill Book Co., New York, USA.

Morrison, J. A. 1960. Characteristics of estrus in captive elk. Behavior 16:84-92.

Nett, T. M., M. E. Crowder, G. E. Moss, and T. M..Duello. 1981. GnRH-receptor interaction. V. down-regulation of pituitary receptors for GnRH in ovariectomized ewes by infusion of homologous hormone. Biology of Reproduction 24:1145-1155.

Nett, T. M. 1987. Function of the hypothalamic-hypophyseal axis during the post-partum period in ewes and cows. Journal of Reproduction and Fertility Supplement 34:210-213.

Niswender, G. D., L. E. Reichert, Jr., A. R. Midgley, Jr., and A. V. Nalbandov. 1969. Radioimmunoassay for bovine and ovine luteinizing hormone. Endocrinology 84:1166-1173.

_____. 1973. Influence of the site of conjugation on the specificity of antibodies to progesterone. Steroids 22:413-424.

Plotka, E. D., U. S. Seal, L. J. Verme, J. J. Ozoga. 1982. Reproductive steroids in white-tailed deer. IV. Origin of progesterone during pregnancy. Biology of Reproduction 26:258-262.

Ravivarapu, H. B., K. L. Moyer, and R. L. Dunn. 2000. Sustained activity and release of leuprolide acetate from an in situ forming polymeric implant. AAPS PharSciTech 1:23-26.

Rapley, M. D. 1985. Behavior of wapiti during the rut. *In* Biology of Deer Production Eds. P. F. Fennessy and K. R. Drew. Bulletin No. 22, Royal Society of New Zealand, Wellington 357-361.

Robinson, T. J. 1954. Relationship of oestrogen and progesterone in oestrous behavior of the ewe. Nature 173:870-874.

SAS Institute. 1993. SAS/STAT user's guide. Release 6.03 edition. SAS Institute, Cary, North Carolina, USA.

Seagle, S. W., and J. D. Close. 1996. Modeling white-tailed deer population control by contraception. Biological Conservation 76:87-91.

Singer, F. J., L. C. Zeigenfuss, R. G. Cates, and D. T. Barnett. 1998. Elk, multiple factors, and persistence of willows in national parks. Wildlife Society Bulletin 26:419-428.

Smith, B. L. 2001. Winter feeding of elk in western North America. Journal of Wildlife Management 65:173-190.

White, C. A., C. E. Olmsted, and C. E. Kay. 1998. Aspen, elk, and fire in the Rocky Mountain national parks of North America. Wildlife Society Bulletin 26:449-462.

Willard, S. T., R. G. Sasser, J. C. Gillespie, J. T. Jaques, T. H. Welsh, Jr., and R. D. Randel. 1994. Methods for pregnancy determination and the effects of body condition on pregnancy status in Rocky Mountain elk. Theriogenology 42:1095-1102.

_____, R. G. Sasser, J. T. Jaques, D. R. White, D. A. Neuendorff, and R. D. Randel. 1998. Early pregnancy detection and the hormonal characteristics of embryonic-fetal mortality in fallow deer (*Dama dama*). Theriogenology 49:861-869.

Zeignefuss, L., F. J. Singer, and D. C. Bowden. Vegetation and elk responses following release from artificial controls within Rocky Mountain National Park, 1968-1996. Report to the Superintendent, Rocky Mountain National Park.

Fig. 1

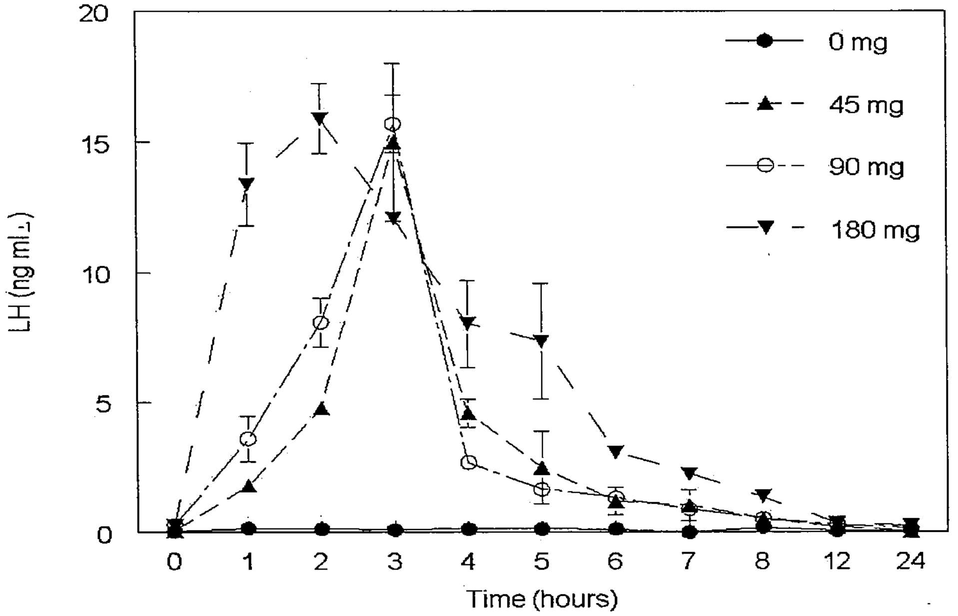

Figure 1. Twenty-four hour profile of serum LH concentrations in untreated female elk (●, n = 2) and elk treated with a sustained release formulation containing 45 (▲ , n = 2), 90 (o, n = 2), and 180 mg (▼, n = 2) of leuprolide. Results are shown as ± SE.

Fig. 2

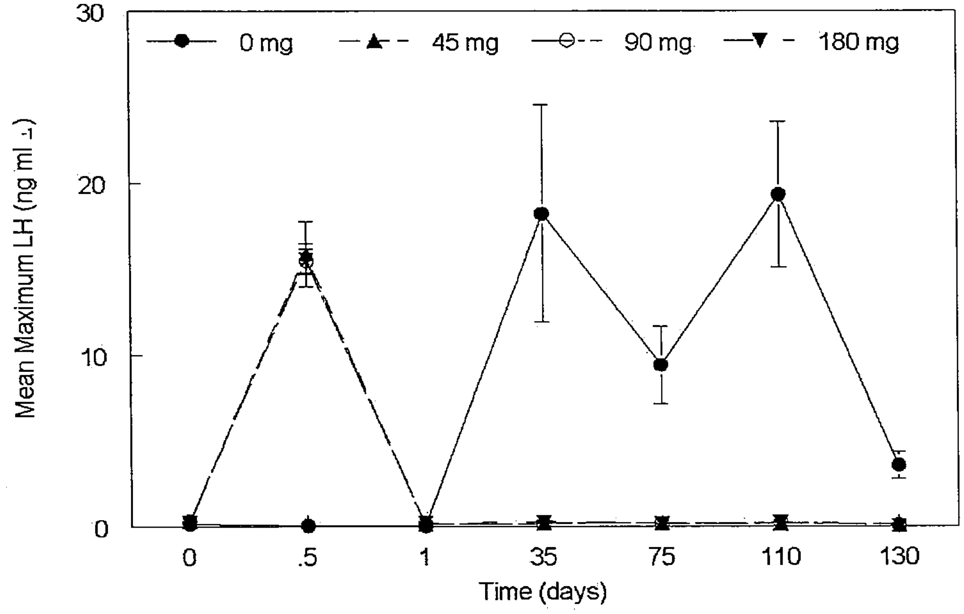

Figure 2. Profiles of 130-day LH concentrations in untreated (●, n = 2) female elk and elk treated with a sustained release formulation containing 45 (▲ , n = 2), 90 (o, n = 2), and 180 mg (▼, n = 2) of leuprolide. Results are shown as ± SE.

Fig. 3

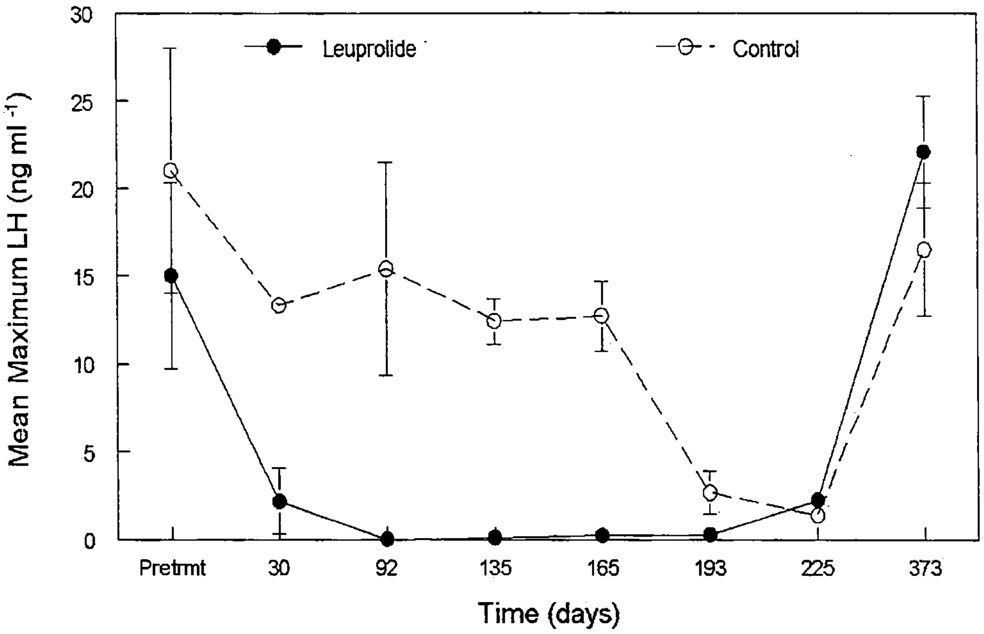

Figure 3. Profiles of mean maximum serum LH concentrations for untreated female elk (●, n = 4), and elk treated with a sustained release formulation containing 32.5 mg leuprolide (○, n = 4). Results are shown as ± SE.

Fig. 4

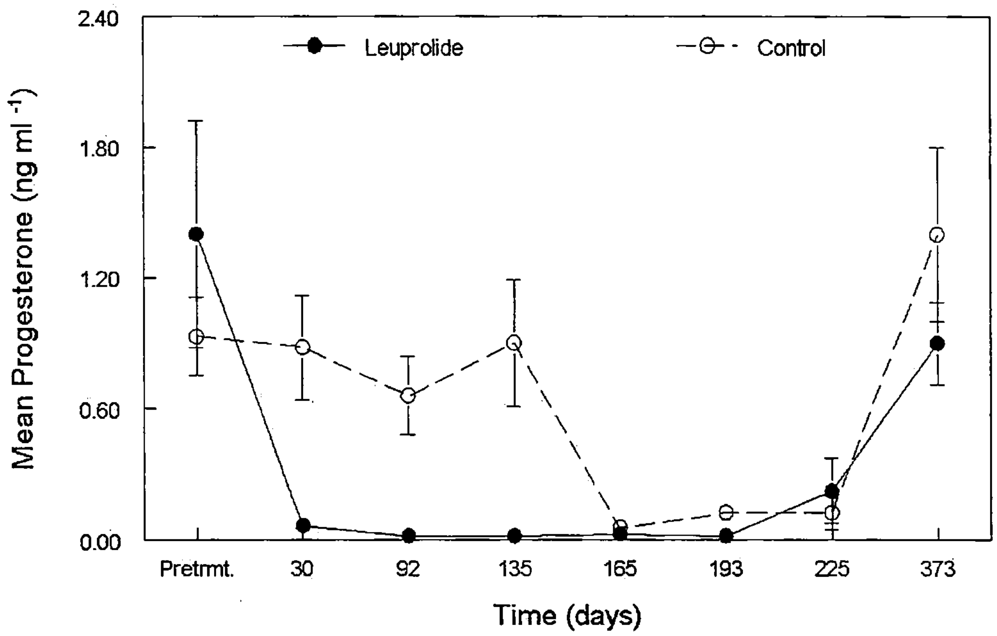

Figure 4. Profiles of mean maximum serum progesterone concentrations for untreated female elk (●, n = 4), and elk treated with a sustained release formulation containing 32.5 mg leuprolide (○, n = 4). Results are shown as ± SE.

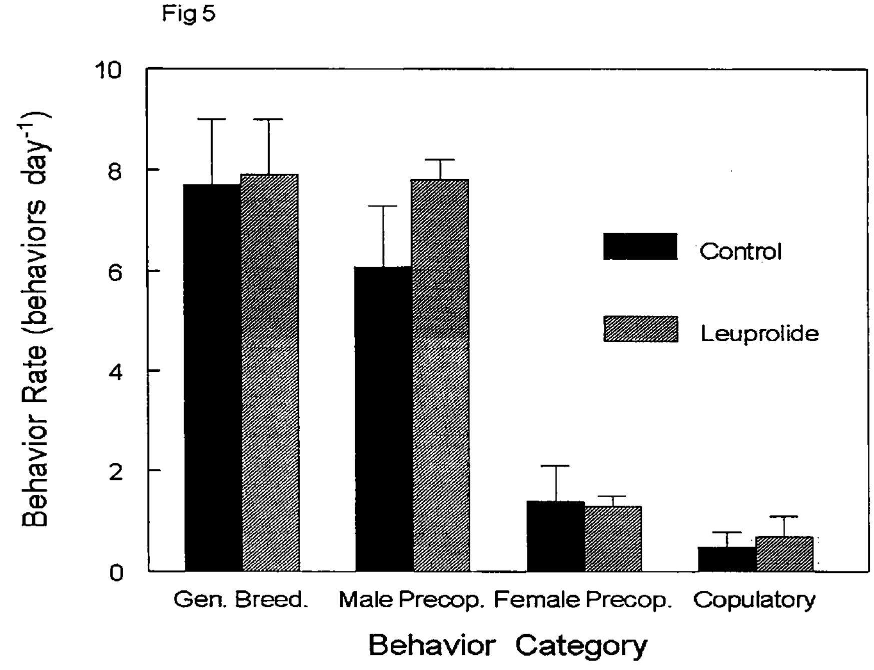

Figure 5. Mean (± SE) reproductive behavior rates during the breeding season for untreated (n = 5) and leuprolide-treated (n = 5) female elk. Results are shown as ± SE.

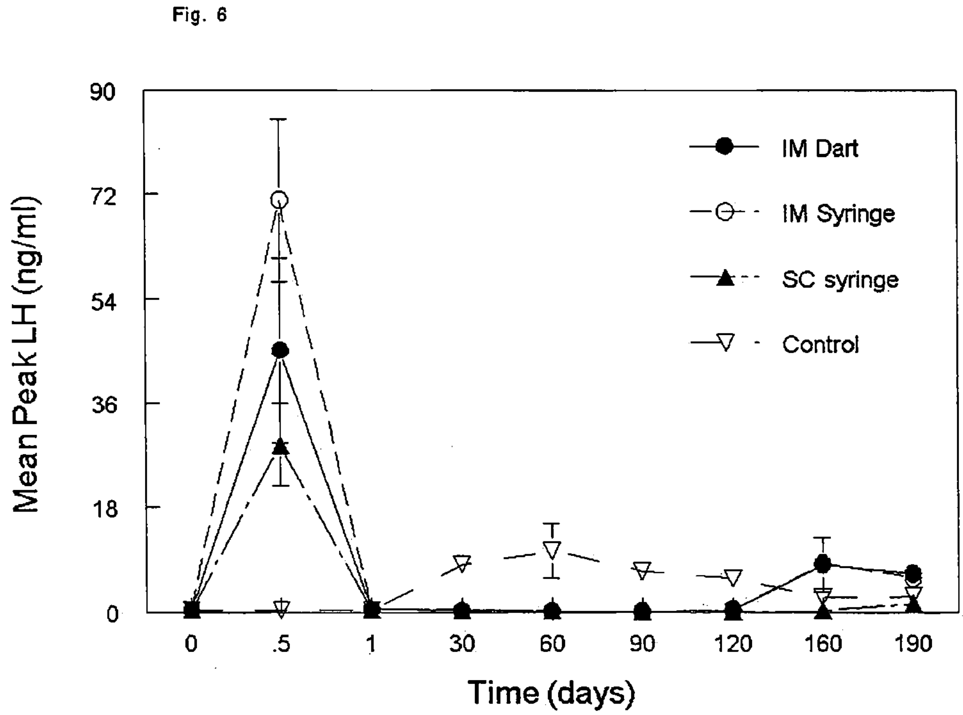

Figure 6. Profiles of mean maximum serum LH concentrations for untreated female elk (●, n = 3), and elk treated with a 32.5 mg leuprolide formulation delivered intermuscularly via syringe dart (O, n = 3), intermuscular syringe (▲, n = 3), and subcutaneous syringe (▼, n = 3). Results are shown as ± SE.

Fig. 7

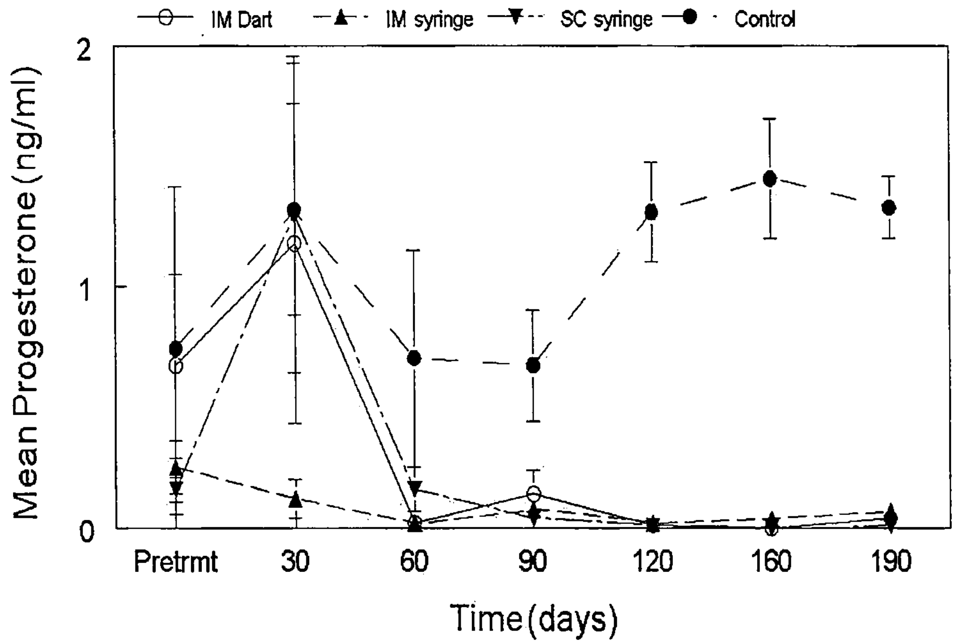

Figure 7. Profiles of mean maximum serum progesterone concentrations for untreated female elk (●, n = 3), and elk treated with a 32.5 mg leuprolide formulation delivered intermuscularly via syringe dart (O, n = 3), intermuscular syringe (▲, n = 3), and subcutaneous syringe (▼, n = 3). Results are shown as ± SE.

Colorado Division of Wildlife
Wildlife Research Report
July 2001 and July 2002

JOB PROGRESS REPORT

State of Colorado : Mammals Research
Work Package 3002 : Elk Conservation
Task No. 3 : Estimating Calf and Adult Survival Rates and Pregnancy Rates of Gunnison Basin Elk
Project No. W-153-R-14, 15 : Research and Development

Period Covered: July 1, 2000 - June 30, 2001, and July 1, 2001 - June 30, 2002

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ABSTRACT

We estimated survival rates and pregnancy rates of elk (*Cervus elaphpus nelsonii*) in the Gunnison Basin of Colorado during 2000 and 2001. During mid-December each year, we captured and radio-collared calves age 6 months and adult females age ≥2 years and during November and December each year, we had hunters collect and submit reproductive organs from female elk harvested during late-rifle seasons. During winter-spring, survival rates of calves were 0.89 ± 0.08 (CL) ($n = 71$), 0.83 ± 0.09 ($n = 75$), and 0.86 ± 0.06 ($n = 146$) for 2000-01, 2001-02, and both years combined, respectively. Survival of calves was not different between years ($P = 0.2965$) or sexes ($P = 0.1456$) but tended to be different among 3 management DAUs ($P = 0.0737$) with survival being lowest at 0.78 ± 0.12 in DAU E-41. For years combined, 21 calves died with proximate causes of death being 53% predation-related, 24% malnutrition-related, 9% accidents, and 14% unknown causes. In 2000-01, calves tended to die after mid-March while in 2001-02, mortalities occurred from early January through May. Patterns of calf mortalities were not strongly associated with calf body mass. Calf body mass at capture averaged 99.1 ± 2.2 kg, ranged from 52.0 to 133.0 kg , and was not different between years or sexes ($P > 0.259$), but calves were larger in DAU E-41 ($P = 0.003$) where calf survival was lowest. Survival rate of adult females age ≥2 years was 1.00 during winter-spring as no deaths occurred during 2000-01 ($n = 39$) and 2001-02 ($n = 48$) and annual survival was 0.92 ± 0.08 ($n = 39$) including hunting and other causes of death and 0.97 ± 0.05 ($n = 37$) including only natural deaths. Survival for yearling female elk, age 12-17 months, during summer-fall was 0.89 ± 0.10 ($n = 38$) including hunting and other causes of death and 1.00 ($n = 34$) including only natural deaths. Survival for the same cohort of yearling male elk during summer-fall was 0.86 ± 0.15 ($n = 22$) including hunting and other causes of death and 0.90 ± 0.13 ($n = 21$) including only natural deaths. Survival rates for both yearling female and male elk, age 18-23

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months, were 1.00 ($n = 34$ F, $n = 19$ M) during winter-spring as no deaths occurred. Harvest removal rates during summer-fall 2001 were 0.05 for adult females, 0.11 for yearling females, 0.08 for all adult females age $\geq$12 months, and 0.06 for yearling males.

Based on biological collections provided by hunters, pregnancy rate averaged 85% for all adult female elk age $\geq$1 year ($n = 89$). Conceptions peaked 23 September, spanned 68 days, and followed an expected asymmetrical pattern in timing with 17% of the adult females likely conceiving after 10 October. Litter size was 1 in all uteri with detectable fetuses ($n = 69$) and female fetuses predominated with fetal sex ratio (37F:21M) deviating from 50:50 ($P = 0.036$). Estimated percent total body fat based on kidney fat measurements indicated 65% of the adult females age $\geq$1 year were in moderate, 30% in low, and <5% in very low or very good body condition. Probability (*logit(P)*) of adult females being pregnant was dependent on estimated percent total body fat ($P = 0.033$). Measures of reproductive and survival rate parameters were consistent with predictions of performance outcomes for adult female elk having low to moderate body condition status in the fall. More than likely, marginally deficient levels of seasonal nutrition were depressing optimal reproductive performance of adult female elk.

All information in this report is preliminary and subject to further evaluation.

JOB PROGRESS REPORT

ESTIMATING CALF AND ADULT SURVIVAL AND PREGNANCY RATES OF GUNNISON BASIN ELK POPULATIONS

David J. Freddy

P. N. OBJECTIVE

Estimate survival rates of calf, adult female, and adult male elk and estimate pregnancy rates of adult female elk in Gunnison Basin elk populations for 3 years.

SEGMENT OBJECTIVES

1. Prepare study plan program narrative.
2. Estimate calf, adult female, and adult male survival rates during winter, December-June.
3. Estimate adult male and female survival rates during summer-fall, June-November.
4. Estimate harvest removal rates for yearling and adult males and females.
5. Estimate pregnancy rates, fetal rates, conception dates, and body condition of female elk collected in December.
6. Summarize data in Research Progress reports and prepare peer-reviewed publications.

INTRODUCTION

The elk (*Cervus elaphpus nelsonii*) resource has many benefits but frequent social, political, and economic conflicts suggest elk can reach "social" if not "biological" carrying capacities (Freddy et al. 1993). Recent controversy surrounding elk in the Gunnison Basin of Colorado (Roath et al. 1999) exemplifies conflicting social and biological agendas regarding appropriate numbers of elk.

The core of conflict in elk management often centers on establishing management objectives for numbers of elk that are agreeable to competing interests and then monitoring elk populations to demonstrate that objectives are achieved. This type of conflict is paramount in Colorado Division of Wildlife (CDOW) elk population Data Analysis Units (DAUs) E-25, E-41, and E-43 in the Gunnison Basin where a combination of resource carrying capacity objectives for elk on winter ranges and difficulties associated with knowingly achieving those objectives has fostered argumentative distrust among public groups and management agencies. Accomplishing management by population objective can depend on reliably estimating elk population size which is expensive and intensive (Samuel et al. 1987, Bear et al. 1989, Unsworth et al. 1990, Anderson et al. 1998, Cogan and Diefenbach 1998, Eberhardt et al. 1998, Freddy 1998).

Alternatively, population size and trend can be estimated using computer models that incorporate harvest, age and sex ratios, and survival rates (White 1992, Bartholow 1999). Model outputs are extremely sensitive to estimates of survival rates such that, reliable measurements of survival can greatly enhance the quality of models (Nelson and Peek 1982).

We chose to estimate survival rates of calf and adult elk during winter and adults year-around to aid in developing improved population models for the Gunnison Basin elk. The Gunnison Basin in south-central Colorado encompasses the entire headwaters of the main Gunnison River and the centrally located town of Gunnison. Between 12-16,000 elk and 8-10,000 mule deer (*Odocoileus hemionus*) are thought to exist within the Basin. Elk are managed as 3 populations representing DAUs E-25 (Game Management Units [GMU] 66, 67), E-41 (GMU 54), and E-43(GMUs 55, 551). The 3 DAUs encompass about 9,291 km^2 of which 3,648 km^2 are considered potential winter range for elk (CDOW WRIS database). DAUs are contiguous with few major geographic barriers separating DAUs that would absolutely prevent interchange of elk among DAUs (see Program Narrative [PN] Appendix I Figure 1).

The Basin represents a high altitude, cold winter range for both elk and mule deer which is similar to ecosystems in North Park, Middle Park, and the San Luis Valley, Colorado. The sagebrush (*Artemisia tridentata*) steppe winter ranges (2,250- 2,700 m elevation) can receive both extreme snow depths and cold temperatures that cause severe mortality among ungulates (Carpenter et al. 1984) while the conifer meadow and alpine summer ranges (3,000 - 4,200 m elevation) can be lush sources of forage subjected to periodic drought. Overall, these ranges collectively are thought to be less productive and nutritious for elk than the milder climate oakbrush-pinyon-juniper winter ranges and aspen and subalpine summer ranges of the Grand Mesa, Colorado where elk survival was measured from 1993-2000 (Freddy 2000).

METHODS

Capture

Adult female (age ≥2 years) and calf (age 6 months) male and female elk were captured and radio-collared using helicopter net-gunning from 16-22 December, 2000 and 16-20 December 2001 (Freddy 1993, see PN Appendix III). All radio-collars were 172-176 MHz and contained 4-6 hour mortality sensors (Lotek, Inc., see PN Appendix I). Calf collars were expandable allowing collars to remain on elk as they matured to adults (see PN Appendix I).

Objectives were to capture and radio-collar 78 calves each year with 13 calves of each sex in each of the 3 Gunnison Basin DAUs. For adult females, objectives were to capture and radio-collar 39 during the first year with 13 in each DAU and in subsequent years, capture sufficient adult females to maintain ≥13 adult radioed females in each DAU (see PN, Sample Sizes). Prior to capturing elk, the 3 DAUs demarcating the entire Gunnison Basin were divided into 10 geographic trap-zones (Figure 1 A-J, see PN Figure 1). Numbers of elk to be captured in each trap-zone within a DAU were based upon the proportion of elk observed in each trap-zone within each DAU during elk sex and age composition surveys conducted with a helicopter during December-January post-harvest 1995-1999. We attempted, therefore, to distribute our sample of radioed elk across the landscape in proportion to relative elk numbers during early winter within each DAU.

Elk were captured within a 3-km radius of 39 processing sites with some sites common to both years (Figure 1). Capture sites were systematically distributed within trap-zones within DAUs to radio-collar elk representing multiple segments of the entire Gunnison Basin population. Although our capture sites were not based on previously selected random coordinates, we believe we achieved a representative sample of elk from the population to provide relatively unbiased estimates of survival rates. Capture sites were accessed via vehicles when possible or by ferrying capture crews in the helicopter to more remote locations inhabited by elk.

Calves were ferried by helicopter from individual elk capture locales to processing sites where body mass (kg), total body length (cm), hind foot length (cm), and rectal body temperature (F) were measured and then calves were radio-collared and released (see PN Appendix III). All body measurements were made with the same instrumentation by the same individuals both years. Adult females were captured, aged as 2-4 years, 5-9 years, and >9+ years old based on incisor replacement or relative wear, radio-collared, and released at location of capture. We avoided capturing yearling 18-month-old females. Photographs of incisor replacement and wear by elk age-class were provided to handlers responsible for judging the age of adult elk prior to releasing adults. No ear-tags were applied to calf or adult elk. Calf body measurements were compared among years, sexes, and DAUs using SAS (1988, PROC FREQ, PROC GLM[ANOVA]). All capture protocols were approved by the CDOW Animal Care and Use Committee.

Telemetry Monitoring

We monitored life or death status of radioed elk daily from December through June from accessible roads using a truck equipped with magnetic-mounted omni-directional and 3-element hand-held Yagi antennas and at 1-4 week intervals from December through November using a Cessna 185 or 182 equipped with strut and/or belly mounted 'H' antennas. We used Lotek® SRX400 and Telonics® TR2 receiver-scanners for monitoring telemetry signals. Elk survival data were compiled using the RADIOS module of the CDOW program DEAMAN® (White 1991).

Mortality Assessments

All suspected mortalities based on telemetry mortality signals were confirmed using ground searches. Once carcasses were located, criteria for assigning probable cause of death followed standardized written procedures that included assessment of body position and body condition, presence of bite or claw marks and sub-dermal hemorrhaging or gunshot wounds, presence of tracks or drag marks, and collection of organ, muscle, and femur marrow samples for laboratory analyses, if available (Wade and Browns 1982, Freddy 1998). Multiple photographs were taken of the carcass along with any potential evidence for assessing cause of death and when appropriate, an outside expert (T. D. I. Beck, CDOW) was consulted to assess evidence.

Field necropsies were performed to the extent possible depending on completeness of carcass. We routinely collected muscle samples from large muscle groups in the hind- and forequarters of carcasses when available to assess for evidence of capture myopathy (Lewis et al. 1977, Spraker 1982, Haigh and Hudson 1993). Histopathology assessments of organ and muscle samples were completed by the Colorado State University Veterinary Diagnostic Laboratory and analyses of percent femur marrow fat on a dry-matter basis were conducted by the CDOW research laboratory.

Field technicians provided a standardized written summary for each death. The principal investigator made the final assessment for probable cause of death based upon field summaries, photographs, and laboratory analyses. Potential causes of death included malnutrition, predation by black bears (*Ursus americanus*), mountain lions, (*Felis concolor*), coyotes (*Canis latrans*), and domestic dogs (*Canis familiaris*), legal and illegal hunter harvest, accidental trauma, plant poisoning, capture-induced , and unknown (Freddy 1997). Causes of death were broadly summarized as malnutrition, predation, suspected malnutrition, suspected predation, accident, unknown, hunter harvest, and capture-induced. Mortalities classed as malnutrition were usually nearly intact carcasses with little or no evidence of predator presence whereas mortalities classed as predation usually had evidence of bite wounds and sub-dermal hemorrhaging indicating bites were inflicted on a live animal. In those cases classed as suspected malnutrition or suspected predation a preponderance of collective evidence was used to assign cause of death to the most likely class. Telemetry collars that prematurely slipped-off elk causing a mortality signal to be emitted were confirmed by locating and retrieving the collar.

Elk were subjected to multiple hunting seasons during fall 2000 and 2001. These seasons with approximate dates were: archery, 25 August-23 September; muzzleloading, 8-16 September; elk-only, 13-17 October; deer-elk first combined, 20-26 October; deer-elk second combined, 3-9 November; deer-elk third combined, 10-14 November; late antlerless elk only, 24 November - 16 December in GMUs 54 and 55 (portions of DAUs E-41 and E-43); and, late antlerless elk only, 1-31 December in GMU 66 (portion of DAU E-25).

Survival Rates

Survival rates of radioed elk were calculated for this report using the binomial estimator and in final analyses will be calculated using a Kaplan-Meier estimator without staggered entry (White and Garrott 1990). Binomial estimates of survival rates were calculated as mean survival ($\hat{s}$) = [Alive / Alive+Dead collared elk], with a variance of [VAR ($\hat{s}$) =($\hat{s}$)*(1- $\hat{s}$) / n collars], and 95% confidence intervals of ($\hat{s}$) $\pm$ [$t_{\alpha=0.05,\, n-1\, df}$ *$\sqrt{}$(VAR ($\hat{s}$))]. Survival rates were estimated for time intervals of winter-spring (15 December - 14 June), summer-fall (15 June - 14 December), and yearly (15 December - 14 December) which coincided with capturing and radio-collaring elk and thus represented a biological year. By definition, calf elk became 12-month-old yearlings on 15 June and calves surviving to this date were considered to be recruited into the population. For adult elk during time intervals that included hunting seasons, we calculated survival rates inclusive of natural and hunting related mortalities, exclusive of hunting mortalities, and exclusive of natural mortalities. Excluding, or censoring hunting mortalities, provided estimates of natural survival rates, while censoring natural mortalities but including hunting mortalities provided estimates of hunting removal rates calculated as $\hat{r}$ = (1 - $\hat{s}$), with ($\hat{s}$) being survival rate with natural mortalities censored. Chi-square contingency tests were initially used for comparing calf survival (alive or dead categories) between sexes, years, and DAUs (White and Garrott 1990, SAS 1988 PROC FREQ). Parameter estimates were expressed as means ± 95% confidence limits unless otherwise noted.

Elk dying of suspected captured-induced trauma were censored from survival estimates. Deaths of calves or adults occurring within 1 week of capture were likely to be classed as capture-induced deaths unless field evidence strongly suggested a natural cause of death independent of capture. Capture-induced trauma could affect animals for up to 2-4 weeks post-capture so we routinely attempted to assess whether deaths were potentially capture-induced. We also censored elk having telemetry collars that electronically failed or slipped-off the elk (White and Garrott 1990). Elk with failed or slipped collars were censored for an entire seasonal time interval for binomial survival estimates and will be censored on the date they were last known alive based on telemetry signals in Kaplan-Meier estimates of survival. Elk whose telemetry signals disappeared during hunting seasons continued to be monitored for several subsequent months over large geographic areas until such time these elk were judged to have likely been removed during hunting seasons. Radioed elk that disappeared during hunting seasons were assumed to be legally harvested.

Reproductive Collections

Fecundity of adult female elk (age $\geq$1 year) was estimated by examining reproductive organs of antlerless elk harvested during limited-entry late-hunting seasons that occurred from mid-November through December in portions of GMUs 54, 55, and 66. About 2-3 weeks prior to the beginning of seasons, we mailed permitted hunters collection packets explaining procedures for obtaining reproductive organs and incisor teeth (for dental cementum aging) from harvested elk as done previously in Colorado (Freddy 1992). Additionally, we asked hunters to collect kidneys with associated fat from these elk to allow calculation of kidney-fat indices and estimates of percent total fat to better assess body condition of adult females in relation to reproductive status (Kohlmann 1999, Cook et al. 2001a, 2001b). Hunters were instructed to place samples in collection bags and leave specimens in protected containers that kept samples cool at several drop-off sites within the Gunnison Basin from which samples were picked-up almost daily by project personnel. Dental cementum aging was completed by the CDOW research laboratory.

Pregnancy status of elk was determined as: pregnant was uterus with embryo, fetus or fetal membranes; not pregnant was no evidence of fetus, no active uterine tissue, and no active corpora lutea of pregnancy; suspected pregnant was active corpora lutea, apparently active uterine tissue but no visible embryo or fetus; and unknown was either incomplete sample or no sample available. Fresh fetuses were sexed, weighed, and measured (Armstrong 1950, Morrison et al. 1959). Fetuses and questionable uteri were stored in 10% buffered formalin for reference examination.

Morrison et al. (1959) graphically presented a logarithmic relationship between fetal crown-rump length (Y, dependent variable) and known fetal-age in days (X, independent variable) but did not present a standardized equation. To develop a standardized arithmetic equation for predicting fetal age, traditionally the unknown variable of interest, from fetal crown-rump length, traditionally the variable measured, we first used Morrison et al. data in MS-Excel® curve-fitter to develop 2 predictive polynomial equations. These equations were: (a) $Y_{(\text{fetal crown-rump mm})} = 0.0085X^2_{(\text{fetal age days})} + 1.7603X - 57.034$, $r^2 = 0.9969$, for the complete 8 data points presented by Morrison et al. (1959), and (b) $Y_{(\text{fetal crown-rump mm})} = 0.0194X^2_{(\text{fetal age days})} + 0.2521X - 17.51$, $r^2 = 0.9987$, for 7 Morrison et al. (1959) data points with their late March data point excluded. We found equation (b) reduced the error in predicted crown-rump measurements by $\geq$50% over equation (a) when predicted crown-rump lengths were compared with Morrison et al. actual crown-rump lengths, especially for the critical 60-90 day fetal-age stage that was associated with fetal collections occurring in November-December.

Because fetal age in days is what is estimated from measured crown-rump values, we input polynomial equations (a) and (b) into program DERIVE® to solve for fetal-age days (X) in terms of crown-rump measurements (Y). These DERIVE® equations were: for polynomial equation (a) $X_{(\text{fetal age days})} = \{[\sqrt{}(3400000*Y_{(\text{fetal crown-rump mm})} + 503781209) - 17603] / 170\}$, and for polynomial equation (b) $X_{(\text{fetal age days})} = \{[\sqrt{}(7760000*Y_{(\text{fetal crown-rump mm})} + 142256321) - 2521] / 388\}$. We used DERIVE® equation (b) to estimate elk fetal ages from crown-rump measurements. Fetal age in days was subtracted from date of hunter collection and then converted to calender and Julian dates of estimated conception.

We measured total kidney fat mass and trimmed kidney fat mass after Riney (1955), Kohlmann (1999), and Cook et al. (2001a,b). We calculated modified total and trimmed kidney fat indices after Anderson et al. (1990), Kohlmann (1999), and Cook et al. (2001a,b). We estimated percent total body fat from measurements of kidney fat using simple linear equations that predicted percent body fat from kidney total fat mass (TFM), full kidney fat index (TF-KFI), and trimmed kidney fat index (TRF-KFI) presented by Cook et al. (2001a). We commonly received only 1 kidney fat mass submitted with reproductive samples so for those elk for which we received both kidney masses, we averaged kidney fat measurements to produce 1 value per elk (Cook et al. 2001a). Although TFM was potentially the best predictor of percent body fat of the measurements we made (see Cook et al. 2001a) we had no control on how well hunters collected all fat associated with kidneys so we conservatively viewed percent body fat estimates derived from trimmed kidney fat might be more accurate because we standardized the amount of fat measured among samples. All reproductive measurements were compiled in MS-Excel® and analyzed with SAS (1988, PROC FREQ, PROC UNIVARIATE, PROC REG, PROC GLM[ANOVA], PROC LOGISTIC).

General Elk Movements

During aerial flights to monitor survival status of elk, we interpreted signal strength and direction to judge general locations of telemetry signals for each elk as to primary drainages or topographic features to describe general movements of elk to and from seasonal ranges. Elk that made large or unique movements, such as across main highways or DAU boundaries, were located relatively precisely from the airplane with the radius of location error likely <1,000 m. This location data was not gathered to assess specific habitats used but rather to describe the major movement patterns of these elk. Data will be summarized in future reports using ArcView 3.2®.

RESULTS AND DISCUSSION

Capture

In 2000, we radio-collared 78 calves, of which 38 were males and 40 were females, and 39 adult females age ≥2 years. Frequency of age classes for adult females were: 2-4 years = 3, 5-9 years = 30, and >9 years = 6. We achieved our objective of capturing 13 adult females and 26 calves in each DAU and nearly balanced sex ratios among calves in each DAU (Table 1). Elk were captured at 20 different sites representing a broad geographic area in the Gunnison Basin (Figure 1, Appendix A). There were no acute deaths of calves during capture but 2 adult females died while being blindfolded and hobbled prior to radio-collaring. Upon necropsy, both adults had extensive hemorrhaging in the thoracic cavity but no hemorrhaging in the abdominal cavity and no obvious indications of cervical injuries. We surmised that the heart-lung complex received extensive shock from capture. In neither case did we believe the animals had experienced extreme physical exertion nor aspiration of rumen contents. At time of capture, snow depths were about 25 cm and chase times appeared reasonable while ambient temperatures were -15 C and -2 C. Therefore, of 41 adult females captured and handled, 2 or 5% died of capture-induced injuries. Both adult elk were donated for human consumption. Subsequent to capture and radio-collaring, 1 male and 1 female calf died likely within 7 days of capture and were classified as capture-induced deaths and censored from the radioed-collared population of calves. Histopathology confirmed capture-myopathy in the male calf which had been killed by a mountain lion (Appendix B). At capture, rectal temperatures were 106.6 F (41.4 C) for the male and 105.5 F (40.8 C) for the female calves. Therefore, of 78 calves captured and handled, 2 or 2.6% died of capture-induced injuries resulting in a net sample of 76 radio-collared calves at the beginning of winter 2000.

In 2001, we captured 80 calves, 40 males and 40 females, and 12 adult females age ≥2 years. Frequency of age classes for adult females were: 2-4 years = 0, 5-9 years = 10, and >9 years = 2. We achieved our objectives of 26 calves of nearly balanced sex ratios in each DAU and maintained ≥13 radio-collared adult females in each DAU (Table 1). Elk were captured at 19 new and 3 previously used sites (Figure 1, Appendix A). There were no acute deaths of adult females or calves during capture. However, 2 female calves caught from the same group in trap-zone E and radio-collared died within 48-hours of capture and were classified as capture-induced deaths (Appendix C). One calf became entangled in a fence about 1 km from the capture site and the second calf was euthanized by gun-shot about 0.5 km from the capture site because of obvious weakness following capture. At time of capture, snow depths were about 20 cm and capture chase times were < 1 minute at an ambient temperature of -4 C. Rectal temperatures of these calves at capture were 106.7 F (41.5 C) and 105.4 F (40.8 C), respectively. Two additional replacement female calves were captured from the same area prior to completing all capture activities. An additional male calf died within 3 days of capture and was classified as a capture-induced death even though a mountain lion had probably killed the calf (Appendix C). At capture, rectal temperature of the male calf was 103.8 F (39.9 C), capture chase time seemed reasonable, and snow depths were about 20 cm. All 3 calves were censored from the collared population of calves. Therefore, of 80 calves captured and handled, 3 or 3.8% died of capture-induced injuries resulting in a net sample of 77 radio-collared calves at the beginning of winter 2001. For both years, capture-induced deaths occurred in 3.2% of the calves and 3.8% of the adult females that were captured and handled.

Collar Failures

We experienced pre-mature expansion of 14 calf collars, 13 males and 1 female, that resulted in collars slipping off calves causing us to censor calves during winter-spring or as yearlings during summer-fall time periods. For calves collared in December 2000, 5 males slipped collars between 30 April and 7 June 2001 and 3 males successfully recruited as yearlings, slipped their collars between 20 June and 20 July 2001. For calves collared in December 2001, 2 males slipped collars between 20 May and 3 June 2002, 3 males recruited as yearlings slipped their collars between 18 June and 17 July 2002, and 1 female recruited as a yearling, slipped her collar between 17 July and 22 August 2002.

Evidence suggested that amber latex tubing (3/8" O.D., 3/16" I.D, 3/32" wall thickness) used as a break-away component to allow collar expansion pre-maturely deteriorated and broke allowing collars to expand and slip over the heads of calf and yearling elk. This calf collar design using the same or similar components had been previously used on 280 calves on the Grand Mesa, Colorado (Freddy 1997) where only 1 5-month-old male calf, 1 13-month-old male yearling, and 2 23- to 26-month-old females slipped collars of which none were due to pre-mature breakage of latex tubing. On Grand Mesa, evidence indicated that latex tubing deteriorated as planned 10 to 18 months post-application after males had grown spike antlers or heads of either sex had grown to retard collars from slipping over heads. Deterioration of tubing apparently occurred sooner in the Gunnison Basin, maybe because of colder temperatures or slightly higher effective UV light levels, and males were much more prone than females to slip collars. We also speculated that antlers of yearling males in Gunnison might possibly be shorter than Grand Mesa yearling males during early summer thus allowing collars to slip more readily in Gunnison. After 2000-01, we changed brands of latex tubing and maintained the same size of tubing for 2001-02 but the problem persisted to a lesser degree. In the future, we will change to a thicker latex tubing on male collars of either 1/8" or 3/16" wall thickness to reduce the problem of pre-mature expansion and the need to censor calves or yearlings from survival estimates but still maintain expansion capability so collars will adequately fit adult elk.

We used radio-collar telemetry frequencies between 172 and 176 MHz and found an increasing problem with white-noise interference at frequencies >175 MHz. At times, interference prevented hearing radio-collars except at relatively close distances, especially during aerial surveys when radio-collars or interference could be heard over several kilometers of distance. Interference was most commonly associated with human developments but likely sources could not be identified. We therefore caution project leaders to assess potential interference problems when selecting collar frequencies >175 MHz.

Weather

Although official NOAA weather data has not been summarized as yet, winter-spring snow depths and summer-fall precipitation for both 2000-01 and 2001-02 were well below average for the entire Gunnison Basin. Both years were considered to represent drought conditions, not only for the Gunnison Basin, but most of southwestern Colorado. On most segments of winter range, snow depths generally did not exceed 30 cm during either winter with 2001-02 having shallower average snow depths than 2000-01. During both winters, snow had melted from primary winter ranges by late-March to mid-April. Snow depths and persistence of snow cover varied greatly in the Basin. Snow depths tended to decrease from west to east and north to south such that the deepest snow occurred in E-25 (GMU 66), E-41(GMU 54), and E-43 (GMU 55) and the shallowest snow in E-25 (GMU 67) and in E-43 (GMU 551) (Figure 1). Winter temperatures were generally mild for the Gunnison Basin with daily minimums seldom below -26 C and generally >-18 C and daily maximums often >-6 C.

Calf Survival

Survival rates of all calves pooled among 3 DAUs during winter-spring were 0.89 ± 0.08 (± CL, $n = 71$), 0.83 ± 0.09 ($n = 75$), and 0.86 ± 0.06 ($n = 146$) for 2000-01, 2001-02, and both years combined, respectively (Table 2). Survival of all calves was not different between years ($P = 0.2965$, Table 4). Male calves had lower survival (0.78) than female calves (0.97) in 2000-01 ($P = 0.0105$) but not in 2001-02 or when years were combined ($P \geq 0.1463$, Tables 2, 4). The greatest discrepancy between sexes occurred in DAU E-25 where survival of males and females was 0.71 and 0.93, respectively (Table 3). In comparison, yearly calf winter-spring survival on Grand Mesa was 0.86 to 0.92 ($n = 69$-73) and averaged 0.89 ($n = 280$) during 4 consecutive winters (1993-94 - 1996-97) with no differences in survival among years or between sexes (Freddy 1997).

Among the 3 DAUs, survival of all calves tended to be lower in E-41 (0.78) compared to E-25 (0.84) and E-43 (0.94) ($P = 0.0737$, Tables 3, 4). In paired comparisons between DAUs, calf survival was lower in E-41(0.78) than E-43 (0.94) ($P = 0.0213$, Tables 3, 4).

During winter-spring, calves died due to predation, malnutrition, suspected predation or malnutrition, accidents, and of unknown causes. In 2000-01, 8 calves died with proximate causes of deaths being 37.5% predator-related and 62.5% malnutrition-related. In 2001-02, 13 calves died with proximate causes of death being 62% predator-related, 15% accidents, and 23% unknown causes. For years combined, 21 calves died with proximate causes of death being 53% predation-related, 24% malnutrition-related, 9% accidents, and 14% unknown causes (Figure 2). On average then, for each 100 calves entering the population on 15 December, we would expect 86 to survive to the following 15 June with 7 deaths predation-related, 4 deaths malnutrition-related, and 3 deaths from other causes. Mountain lions and black bears predated elk calves and coyotes were suspected predators in one death. Accidental deaths were associated with a haystack collapsing and trapping a calf while elk were feeding on hay and a calf apparently slipped off a deep snow-trail used by elk and became trapped upside down among dead-fall trees. In comparison, estimated causes of calf mortalities ($n = 31$) on Grand Mesa were 65% predation-related, 26% malnutrition-related, and 9% of unknown causes (Freddy 1997).

Calf mortalities tended to occur later and primarily after 16 March in the winter-spring of 2000-01 than in 2001-02 (Figure 3, A & B). Timing of deaths in 2000-01 was consistent with deaths directly associated with malnutrition or predation-related deaths of malnourished calves as winter progressed. In contrast, predation-related deaths occurred from January through May in 2001-02 with no deaths directly attributed to malnutrition in 2001-02 (Figures 2, 3). In comparison, calves died on Grand Mesa from January into late May but the majority died in March and April (Freddy 1997).

Femur marrow fat of dead calves was 34% ± 25 (SD, $n = 8$) in 2000-01 and marginally lower ($P = 0.11$, *t*-test) than the 59% ± 35 (SD, $n = 10$) in 2001-02. In general, most calves dying from any cause had femur fat < 50% in 2000-01 and >55% in 2001-02 (Figure 4). For deaths attributed directly to predation, femur fat averaged 16% ($n = 3$) in 2000-01 and 91% ($n = 4$) in 2001-02. In 2001-02, all deaths considered predation-related had femur fat >60% ($n = 7$), even deaths occurring in mid-May (Figure 4). In contrast, both accidental deaths in 2001-02 had femur fat <5% and likely represented calves already extremely malnourished prior to the end of February (Table 5). Importantly, Cook et al. (2000a) noted that femur fat values <85% in adult female elk were associated with total percent body fat < 5% indicating that nearly any loss of femur fat suggested an animal in poor physical condition.

Although there were limited sample sizes both years, data suggested a different dynamic between years of mild winters. In 2000-01, calf survival appeared more influenced by nutrition and relative body condition, possibly representing either the previous summer or winter forage production. Predation appeared more compensatory related. In 2001-02, predation appeared more additive than compensatory because calves that died were possibly not predisposed by malnutrition. In both years, overall calf survival remained high regardless of the proximate cause of mortality. We must also caution that predation-related deaths in early January 2002 could not be totally separated from possible capture-induced deaths as deaths likely occurred <2 weeks post-capture.

Adult Survival

Survival rates for adult females age ≥2 years were 1.00 during winter-spring as no deaths occurred during 2000-01($n = 39$) and 2001-02 ($n = 48$). During summer-fall 2001, survival was 0.92 ± 0.08 ($n = 39$) when natural (1) and hunting deaths (2) were included. The one natural death occurred about July 1 of unknown causes in a female age 19 years based on dental cementum resulting in a natural summer-fall survival rate of 0.97 ± 0.05 ($n = 37$) (Table 6, Appendix D). Annual survival rates were 0.92 ± 0.08 ($n = 39$) including all causes of death and 0.97 ± 0.05 ($n = 37$) including only natural deaths (Table 6). In comparison, natural survival of adult females was ≥0.97 in winter-spring and summer-fall during 7 consecutive years on Grand Mesa (1993-94 - 1999-2000) (Freddy 2000).

Yearling Survival

Survival rate for yearling female elk, age 12-17 months, was 0.89 ± 0.10 (*n* = 38) during summer-fall 2001 and because all 4 deaths were hunting-related, natural survival during summer-fall was 1.00 (*n* = 34). Survival of the same cohort of yearling males was 0.86 ± 0.15 (*n* = 22) during summer-fall when natural (2) and hunting deaths (1) were included. Two yearling males died in July 2001 of suspected predation (Appendix D) resulting in a natural summer-fall survival rate of 0.90 ± 0.13 (*n* = 21) (Table 7). Survival of all females age ≥12 months during summer-fall was 0.91 ± 0.07 (*n* = 77) inclusive of natural (1) and hunting deaths (6) and natural survival for these females was 0.99 ± 0.03 (*n* = 71, Table 6).

Survival rates for both yearling female and male elk, age 18-23 months, was 1.00 (*n* = 34 F, *n* = 19 M) during winter-spring as no deaths occurred during 2001-02 (Table 7). Survival of all females age ≥18 months during winter-spring 2001-02 was 1.00 (*n* = 82) as no deaths occurred (Table 6).

Harvest Removal

Harvest removal rates ($\hat{r}$) during summer-fall 2001 were 0.05 for adult females, 0.11 for yearling females, 0.08 for all adult females age ≥12 months, and 0.06 for yearling males. Hunting mortalities for adult females consisted of 3 legally harvested (2 regular rifle, 1 late rifle) and 3 wounding losses (1 archery/muzzleloading, 2 regular rifle). Wounding loss thus equaled the legal harvest in this small sample situation. The one yearling male hunting mortality represented an illegal harvest that occurred during a late-season in December 2001 (Appendix D). With observed calf and adult female natural survival rates, computer models suggest that removal rates for adult females age ≥12 months in the Gunnison Basin would need to be ≥15% per year to stabilize the population.

Calf Body Size

Calf body mass averaged 99.1 ± 2.2 kg and ranged from 52.0 to 133.0 kg for all calves and years (Table 8) with 7% of the calves having mass <80 kg (Figure 5). There were no effects of capture year, calf sex, or year-sex interaction on body mass ($P \geq 0.259$) although calves were 2.6 kg smaller in mass in 2001 and males were 1 kg larger than females. However, calf mass was different among management DAUs ($P = 0.003$). In simultaneous paired comparisons, calves were larger in E-41 (104.4 kg) than in E-43 (96.8 kg) and E-25 (95.9kg) with no differences between E-43 and E-25. Calf mass was reasonably consistent within trapzones within DAUs, with mass tending to be larger in trapzones I and J (E-41) than in D (E-25) and F (E-43) ($P = 0.090$). Similar trends among years, sex, DAUs and trapzones occurred for calf total body length and hind-foot measurements with both measurements supporting that E-41 calves were largest ($P < 0.002$) (Table 8).

Calf mortalities occurred across the range of calf body mass classes (Figure 5). Predation-related mortalities occurred in the most frequent mass classes between 80 and 119 kg, suggesting predators were taking calves with no particular selectivity. Except in one case, malnutrition-related mortalities occurred in calves < 99 kg in size. Calves <80 kg did not necessarily perish, although 2 of the 3 calves <60 kg died of malnutrition or accident (Figure 5). Survival of calves tended to be lower in E-41 ($P = 0.0737$), where calf mass was largest, compared to survival in E-25 and E-43 (Tables 3, 4, 8). In E-41, mortalities were predator-related (45%), malnutrition-related (36%, including 1 accident where calf femur marrow was < 2%), and unknown (18%). On Grand Mesa, the larger mass of male calves also did not necessarily translate to higher survival rates compared to smaller female calves (Freddy 1997).

In the Gunnison Basin, male and female calves were 15% and 7% smaller, respectively than their counterparts captured and radio-collared on Grand Mesa 1993-94 - 1996-97. On Grand Mesa, body mass was 115 ± 2.5 kg for males (*n* = 138) and 106 ± 2.3 kg for females (*n* = 136) with an overall range in size of 60 to 141 kg (Freddy 1997). Furthermore, unlike Gunnison, males were significantly larger (8%) than females on the Grand Mesa. Unfortunately, we cannot distinguish whether differences in mass reflect population or year effects.

Elk Reproduction Samples

Participation by successful hunters in providing biological samples from adult female elk harvested during late-seasons was disappointing. Of the estimated 665 adult females harvested during 2000-2001, we received some of the requested biological samples from 19% of the elk with reproductive organ and kidney fat samples representing only 13% of the elk. Importantly, rates of participation by hunters harvesting elk declined from 28 to 12% from 2000 to 2001 despite attempts to improve collection instructions and packets sent to hunters in 2001 (Table 9). Providing an incisor tooth from harvested elk was the most common biological sample collected by hunters. For many data summaries and analyses, reproductive data from both years was combined because 65% of the samples were obtained in 2000. Furthermore, approximately 80% of the samples came from elk harvested in GMU 66 and 20% from elk harvested in GMUs 41 and 55. Therefore, data summaries were inherently weighted to year 2000 and GMU 66.

Ages of adult female elk harvested ranged from 1 to 20 years with 63% estimated to be age 3 to 10 years. Yearlings (≈age 17-18 months) and females age ≥15 each represented 5% of the harvest. Because hunter selectivity and animal behavior may bias vulnerability of different elk age classes to harvest, the distribution of harvested age classes may biasly represent the age structure of the elk population (Table 10).

Pregnancy Rates and Conception Dates

Pregnancy rate for all adult females age ≥1 year was 85% (*n* = 89, Table 11). Pregnancy rate was 92-100% for female age classes 3 to 14 years. Pregnancy rate was 67% in females age 2 and 50% in females age ≥15. Pregnancy rates across age classes were highly similar to rates measured in the Forbes-Trinchera elk population of south-central Colorado (Freddy 1993b). The 100% pregnancy rate in yearlings could be questionable because pregnancy status was unknown in 67% of the submitted yearling samples. For age classes 2 and 3-4, pregnancy status was unknown in up to 44% of the animals. We might expect that in these younger age classes, uteri may be small, in-active and non-pregnant or in the early stages of pregnancy, creating more difficult circumstances for hunters to find and collect specimens. In comparison, for age classes ≥ age 5, ≤27% of the specimens were of unknown pregnancy status. Thus, there is the possibility that pregnancy rates for young elk age 1 to 4 could be overestimated due to collections biased against non-pregnant elk.

Estimated conception dates followed an expected asymmetrical pattern (Flook 1970, Freddy 1993b,Noyes et al. 1996). Mode, median, and mean days of conception were 23, 26, and 29 September, respectively (*n* = 72, Figure 6). Conceptions spanned 68 days with 75% occurring in the 26-day interval from 8 September to 3 October. This conception pattern strongly suggested that most adult females conceived during their first estrus cycle at the expected time of year. Females conceiving after 10 October (*n* = 12, 17%) may have had a delayed first estrus or conceived during their second estrus cycle. Patterns and dates of conception were quite similar to estimates obtained for Forbes-Trinchera elk where post-season mature bull:cow rations commonly exceeded 35:100 (Freddy 1993b). The mirror-image asymmetrical distributions for conception dates (Figure 6) and calf body mass (Figure 5) indirectly suggest that smaller calves (7% < 80 kg) may be associated with adult females conceiving later in the fall (17% after 10 October).

Females conceiving after 10 October were comprised of 9% yearlings, 18% age 3-4, 45% age 5-7, and 27% age ≥15 years. All pregnant females ≥ age 15 conceived after 16 October (*n*= 3). Later breeding by youngest and oldest age classes would not be unexpected but later conception by females age 5-7 may indicate some nutritional or disturbance stress affecting timing of breeding in about 8%of the population. Overall, conception date was not dependent on adult female age ($r^2 = 0.014$, $P = 0.173$, $n = 66$).

Pregnancy status was associated with ovarian mass of both ovaries combined. Total ovarian mass (g) was 5.37 ± 0.28 (CL, $n = 59$) and larger in pregnant than the 3.36 ± 1.60 ($n = 5$) in non-pregnant elk ($P = 0.025$). Larger ovarian mass reflected the presence of active corpora lutea of pregnancy.

Fetal Rates, Sex, Age, and Size

Litter size was 1 fetus in uteri with detectable fetuses ($n = 69$). Fetal sex favored females (37F:21M) for years combined which differed from a 50:50 ratio ($\chi^2 = 4.414$, $df = 1$, $P = 0.036$). Female fetuses also dominated within each year (24F:15M, 2000; 13F:6M, 2001) but such yearly ratios were not different from 50:50 ($P \geq 0.108$). Fetal sex could be determined in those fetuses near ≥70 mm crown-rump length based on external genitalia as also found by Morrison et al. (1959) and Kohlmann (1999). In general, fetal sex could not be determined in fetuses estimated to have been conceived after 10 October.

Fetal sex tended to be dependently associated with adult female grouped age class (Figure 7 [Right], $\chi^2 = 10.885$, $df = 5$, $P = 0.054$). Male fetuses predominated in adult females age 8-10 while females fetuses were most common within age classes 3-4, 5-7, and 11-14. Fetal sex ratio was equal in 2-year-old females which may have been conceiving for the first time. Male fetuses were also more predominate in elk age ≥8 years in the Forbes-Trinchera elk (Freddy 1993b). Kohlmann (1999) found male fetuses were more common in adult females having high kidney fat levels, and thus good body condition, and that adult females in good body condition conceived earlier in the breeding season. We could speculate that adult females age 8-10 had male fetuses because they were in better body condition at conception than other age classes due to their age and inherent larger body size that allowed them to withstand the rigors of a previous pregnancy and calf rearing and maintain access to better matriarchal habitats (Clutton-Brock et al. 1982). In 2-year-old females, male fetuses may have been more common because these females likely had not gone through a previous pregnancy and subsequent calf-rearing prior to conception and thus were in better body condition. Although male fetuses predominated in those adult females conceiving 16-20 September just prior to the peak of conception, a pattern favoring male fetuses during early conceptions was not clearly evident (Figure 7 [LEFT]).

Estimated fetal age averaged 69 and 76 days in 2000 and 2001and was not different between years ($P = 0.139$). We found that fetal age predictive equation (b) (see METHODS) provided estimated dates of conception that occurred about 3-days earlier than equation (a) (paired t-test, $P < 0.001$).

Fetal size compared favorably with fetuses measured in the Forbes-Trinchera elk population and appeared to be within an acceptable range of weight and skeletal dimensions (Freddy 1993b). There was a general pattern of fetuses in 2001 being slightly larger in crown-rump ($P < 0.080$), hind-leg ($P < 0.033$), and hind-foot ($P < 0.070$) dimensions but not in body mass ($P < 0.138$) (Table 12). Fetal size is highly dependent on date of collection so absolute comparisons between years or among elk populations must include corrections for date of collection.

Body Fat Condition and Reproduction

Total fat kidney fat index values (TF-KFI) for adult females age ≥1 year averaged 106 and ranged from 29 to 306 ($n = 84$) which were similar to values for Oregon elk (Kohlmann 1999) (Table 13, Figure 8[LEFT]). The 25% quantile value was 63 which was slightly higher than the 50 reported by Kohlmann (1999). Other kidney fat values in Table 13 were presented for reference as these measurements were the basis for estimating percent total body fat (Cook et al. 2001a), or body condition, in adult female elk. TF-KFI for calves averaged 44 ($n = 6$).

Estimates of percent body fat for all adult females age $\geq$1 year based on the 3 kidney fat measurements, TF-KFI, TRF-KFI, and TFM, averaged between 11.1 and 12.1% with a combined range of 5.4 to 18.5% (Table 14, Figure 8 [RIGHT]). Percent body fat of all adult females tended to be 1-2% higher in 2001 than 2000 for all estimators of body fat ($P \leq 0.073$, Table 14). For yearling females, specifically, percent body fat estimates averaged 10.7 to 13.0% with minimum-maximums of 9 and 14% ($n = 4$) while body fat in calves was 4-7% (see Table 14 cautionary foot-note).

Based on estimates of percent total body fat, about 65% of the adult females age $\geq$1 year were in moderate, 30% in low, and <5% in very low or very good body condition, and 0% in excellent condition (Figure 8 [RIGHT]). Relative condition class ratings were very low = <7% body fat, low = 7-10%, moderate = 10-15%, very good = 15-20%, and excellent = 20-25% (Cook, J. G. 2001 unpublished data). Kidney fat measurements provide the best predictive accuracy of percent total body fat at moderate levels of body condition and less accuracy at very high or very low levels of body condition (Cook et al. 2001a) so that our ability to detect outliers in body condition status may have been limited by measuring only kidney fat. Furthermore, percent total body fat levels in the excellent category may be rarely found in wild elk as these values were associated optimum nutrition in captive elk and likely represent the physiological maximums attainable by elk (Cook J. G., 2001 unpublished data).

Probability of an adult female elk age $\geq$1 year being pregnant was dependent on estimated percent total body fat when body fat was based on TFM (g): *(logit (Pregnancy))* = -2.2835 + 0.3704*(X-percent body fat); $P = 0.033$, $n = 68$). Pregnancy probability was predicted to be $\geq$0.90 when percent total body fat was $\geq$12%, or $\geq$ moderate body condition (Figure 9). Similar dependent relationships (*logit P*) could not be detected between pregnancy status and percent total body fat based on TF-KFI ($P = 0.130$) and TRF-KFI ($P = 0.099$), or on direct TF-KFI ($P = 0.206$) values. Cook et al. (2001a) indicated that TFM was the superior predictor of body condition within the kidney fat measurement alternatives. Kohlmann (1999), however, did find that probability of pregnancy (*logit P*) increased with increasing TF-KFI values in Oregon elk ($n = 1152$). Similarly, Cook et al. (2001c) documented that low quality nutrition prior to breeding prevented or delayed conception in adult female elk and, furthermore, high pregnancy rates could be associated with marginally deficient nutritional conditions.

Standard ANOVA results were consistent with logistic regression results. Estimated percent body fat was higher for pregnant than non-pregnant elk for body fat estimates based on TFM ($P = 0.038$) but not for body fat estimates based on TF-KFI and TRF-KFI ($P \geq 0.112$, Table 14). All estimates of percent body fat were not different among pregnant, non-pregnant and pregnancy status-unknown adult females ($P \geq 0.149$, Table 14). Furthermore, using linear regression, all estimates of percent body fat were not dependent on adult female age within pregnant ($r^2 \leq 0.014$, $P \geq 0.315$, $n = 54$) or non-pregnant elk ($r^2 \leq 0.008$, $P \geq 0.543$, $n = 8$).

Probability of conceiving before or after the median date of conception was not dependent on percent total body fat based on TFM: (*logit (Before) P* =0.221, $n = 53$), indicating there was no detectable increased probability to conceive before the median date based on percent total body fat. Using linear regression, conception date was not dependent on percent body fat based on TF-KFI, TRF-KFI, or TFM ($r^2 \leq 0.025$, $P > 0.141$, $df = 49$) or dependent on 2-variable combinations of adult female dental cementum age and percent body fat ($R^2 \leq 0.031$, $P > 0.178$, $df = 49$). Estimates of body fat for adult females conceiving after 10 October was about 11.1% for all 3 estimates of body fat.

Overall, measured population performance of elk in the Gunnison Basin generally followed the predictions of proposed performance models for adult female elk in moderate or low body fat condition (B and C, below; Cook J.G. 2001 unpublished data).

The measured performance of elk in the Gunnison Basin could be summarized as:

> Pregnancy rates were 85%, about 17% of the females conceived after 10 October, adult female survival during mild winters was 100%, average mass of 6-month old calves was 99 kg with 7% of the calves weighing <80 kg and 21% weighing >110 kg, and survival of calves during mild winters was >83%;

and compared to:

> Model A: If adult females in very good body fat condition, then we should expect: Pregnancy rates >90%, significant early breeding, high adult survival in harsh winters, >110 kg calves in November; *<5% of adult female Gunnison elk were classified in very good body fat condition.*
>
> Model B: If adult females in moderate body fat condition, then we should expect: Pregnancy rates ≥90%, some delayed breeding, with high adult winter survival depressed somewhat in harsh winters, 90-110 kg calves in November; *65% of adult female Gunnison elk were classified in moderate body fat condition.*
>
> Model C: If adult females in low body fat condition, then we should expect: Pregnancy rates ≥70-90%, more delayed breeding, with markedly lower adult winter survival in harsh winters, 70-100 kg calves in November; *30% of adult female Gunnison elk were classified in low body fat condition.*
>
> Model D: If adult females in very low body fat condition, then we should expect: Pregnancy rates ≤70%, delayed breeding up to 6 weeks, with low adult winter survival in harsh winters, 60-90 kg calves in November; *<5% of adult female Gunnison elk were classified in very low body fat condition.*

General Movements of Elk

Insights into the general distribution and movements of elk in Gunnison Basin DAUs (see PN Figure 1,) were obtained from approximate locations of radio-collared elk obtained during 44 aerial survey flights between December 2000 and June 2002. Maps of elk distribution are in process so only verbal descriptions will be presented at this time.

Elk wintered in segments of winter range near where they were trapped in December as elk did not usually make large movements during winter. Movement from winter areas towards summer ranges began in April, proceeded in earnest in mid-May after snow had melted at higher elevations, and ended with elk arriving on highest elevation summer ranges in July after calving and subsequent to snow melting on alpine ranges. Movements from summer to winter ranges began in early September and continued through November with rates of movement most likely affected by hunting season activities and increasing snow depths.

Elk essentially did not cross U.S. Highway 50 (Hy50) which separated the south (trap-zones A-E) and north (trap-zones F-J) (Figure 1) portions of the Gunnison Basin. Only 2 elk were known to cross this highway: an adult female in September 2001 moved from the Tomichi Dome area (trap-zone F) southwest to Sawtooth Mountain; and, a 24-month-old male in June 2002 moved from Tomichi Dome area (trap-zone F) to the southeast onto Sargents Mesa and then proceeded south over the La Garita Mountains to Alder Creek in the Rio Grande River drainage near South Fork, Colorado.

Elk did move beyond the boundaries of the Gunnison Basin during winter and summer but only 2, at this time, have likely dispersed from the Gunnison Basin; an 18-month-old female moved from trap-zone H north to Paonia Reservoir in November 2001 and a 24-month-old male moved trap-zone F south into the Rio Grande River drainage during June 2002. During summer, radioed elk were commonly found along the higher elevation divides associated with the boundaries of the Gunnison Basin DAUs, often in sub-alpine or alpine habitats from which they vacated in September while moving towards their winter ranges within the Gunnison Basin. These boundary areas included: upper and lower Cimarron and Little Cimarron rivers (west of trap-zone A); upper Rio Grande river in Rat Creek and near Continental and Rio Grande reservoirs (south of trap-zones A, B, C); Saguache Park (east of trap-zone D); Sargents Mesa-Cameron Park (east of trap-zone E); upper Chalk creeks (northeast trap-zone F); upper forks of North Fork of Cottonwood, Lake Fork, Clear, and Castle creeks (east-northeast of trap-zone G); Anthracite creeks, Snowshoe and Cliff creeks, Coal Creek Basin, and Willow and Minnesota creeks (north of trap-zones H, I, J); and, upper Smith Fork, Dyer, and Crystal creeks (west-northwest of trap-zone J). The greatest overlap of Gunnison Basin elk with elk from other management DAUs occurred during summer in the Big Blue Wilderness (west trap-zone A), in the upper Rio Grande River near Slumgullion-Spring Creek Pass and west of Continental Reservoir (south trap-zones A, B, C), and in the West Elk Wilderness (north trap-zones I, J). During winter, only a few elk remained outside of the Gunnison Basin DAUs, mainly in lower Cimarron creeks (west trap-zone A), just east of North Pass and Old Cochetopa passes (east of trap-zone E), near Paonia Reservoir (north trap-zone I, J), and in Smith Fork and Doug creeks near Crawford, Colorado (west trap-zone J).

Some consideration should be given to re-aligning elk management DAUs in the Gunnison Basin based on observed movements of elk. There was a continuum of elk interchange among trap-zones on an west to east basis, especially during summer and to a lessor degree in winter. South of Hy50, elk in trap-zones A through E interacted with elk in adjacent trap-zones such that there was no clear demarcation of separate elk sub-populations across this area (Figure 1). Similarly, north of Hy50, elk in trap-zones J through F interacted with elk in adjacent trap-zones such that there was no clear demarcation of separate elk sub-populations across this area, although elk in trap-zones G and F only interacted with elk from trap-zone H in areas near Gothic, Colorado in the upper East and Slate rivers (Figure 1). Therefore, all areas south of Hy50 from Monarch pass on the east to the Cimarron Divide on the west (GMUs- part 551, 67, 66, and adding 65) could be treated as one DAU. Likewise, all areas north of Hy50 from Monarch Pass on the east to at least the Curecanti divide on the west (GMUs- part 551, 55, 54, and potentially adding 53 and 63) could be treated as one DAU. Elk that winter in GMUs 53 and 63 to the northwest of the Gunnison Basin likely have high interchange with elk from GMU 54 during summer in the West Elk Wilderness.

SUMMARY

In the Gunnison Basin, Colorado during winter-spring 2000-01 and 2001-02, survival rates of calves averaged 83-89% and tended to vary among elk management DAUs while survival rates of all age classes of adults were 100%. During summer-fall, survival rates were $\geq$97% for adult females, 100% for yearling females, and 90% for yearling males when hunting deaths were excluded. Survival rates were comparable to survival rates previously estimated for elk inhabiting the Grand Mesa, Colorado. Harvest removal rates during summer-fall 2001 were 5% for adult females, 11% for yearling females, 8% for all adult females age $\geq$12 months, and 6% for yearling males. Measures of reproductive and survival parameters were consistent with predictions of performance outcomes for adult female elk having low to moderate body condition status during fall. More than likely, marginally deficient levels of seasonal nutrition were depressing optimal reproductive performance of adult female elk. Consideration should be given to re-aligning management DAUs with observed distribution and movements of radioed elk.

LITERATURE CITED

Anderson, A.E., D.C. Bowden, and D.E. Medin. 1990. Indexing the annual fat cycle in a mule deer population. Journal of Wildlife Managment 54:550-556.

Anderson, C.R., Jr., D.S. Moody, B.L. Smith, F.G. Lindzey, and R. P Lanka. 1998. Development and evaluation of sightability models for summer elk surveys. Journal of Wildlife Management 62:9933991055-1066.

Armstrong, R.A. 1950. Fetal development of northern white-tailed deer. American Midland Naturalist 43:650-666.

Bartholow, J. 1999. POP-II system documentation Windows™ Version 1.0. Fossil Creek Software, Fort Collins, Colorado USA.

Bear, G.D., G.C. White, L.H. Carpenter, R.B. Gill, and D.J. Essex. 1989. Evaluation of aerial mark-resighting estimates of elk populations. Journal of Wildlife Management 53:908-915.

Carpenter, L.H., R. B. Gill, D. L. Baker, and N.T. Hobbs. 1984. Colorado's big game supplemental winter feeding program. Colorado Division of Wildlife, Fort Collins, Colorado USA.

Cogan, R.D., and D.R. Diefenbach. 1998. Effect of undercounting and model selection on a sightability-adjustment estimator for elk. Journal of Wildlife Management 62:269-279.

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

Cook, R..C., J.G. Cook, D.L. Murray, P. Zager, B.K. Johnson, and M.W. Gratson. 2001b. Nutritional condition models for elk: which are the most sensitive, accurate, and precise? Journal of Wildlife Management 65: 988-997.

Cook, R.C., D.L. Murray, J.G. Cook, P. Zager, and S.L. Monfort. 2001c. Nutritional influences on breeding dynamics in elk. Canadian Journal of Zoology 79:845-853.

Clutton-Brock, T.H., F.E. Guinness, and S.D. Albon. 1982. Red deer behavior and ecology of two sexes. University of Chicago Press, Chicago, Illinois, USA.

Eberhardt, L.L., R.A. Garrott, P.J. White, and P.J. Gogan. 1998. Alternative approaches to aerial censusing of elk. Journal of Wildlife Management 62:1046-1055.

Flook, D.R. 1970. Causes and implications of observed sex differential in the survival of wapiti. Canadian Wildlife Service Report Series 11. Ottawa, Ontario, Canada.

Freddy, D.J. 1992. Effect of elk harvest systems on elk breeding biology. Colorado Division of Wildlife Research Report July:45-70. Fort Collins, Colorado, USA. July:45-70.

Freddy, D.J. 1993. Program Narrative for Estimating survival rates of elk and developing techniques to estimate population size. Colorado Division of Wildlife Research Report July:83-117. Fort Collins, Colorado, USA.

Freddy, D.J. 1993b. Effects of elk harvest systems on elk breeding biology. Colorado Division of Wildlife Research Report July:50-65. Fort Collins, Colorado, USA.

Freddy, D.J. 1997. Estimating survival rates of elk and developing techniques to estimate population size. Colorado Division of Wildlife Research Report July:47-73. Fort Collins, Colorado, USA.

Freddy, D.J. 1998. Estimating survival rates of elk and developing techniques to estimate population size. Colorado Division of Wildlife Research Report July:177-206. Fort Collins, Colorado, USA.

Freddy, D.J. 2000. Estimating survival rates of elk and developing techniques to estimate population size. Colorado Division of Wildlife Research Report July (2):239-258. Fort Collins, Colorado, USA.

Freddy, D.J., D.L. Baker, R.M. Bartmann, and R.C. Kufeld. 1993. Deer and elk management analysis guide, 1992-1994. Colorado Division of Wildlife Division Report 17, Fort Collins, Colorado USA.

Haigh, J.C., and R.J. Hudson. 1993. Farming wapiti and red deer. Mosby, Saint Louis, Missouri, USA, pages 187-192.

Kohlmann, S.G. 1999. Adaptive fetal sex allocation in elk: evidence and implications. Journal of Wildlife Managment 63:1109-1117.

Lewis, R.J., G.A. Chalmers, M.W. Barrett, and R. Bhatnagar. 1977. Capture myopathy in elk in Alberta, Canada: a report of three cases. Journal of The American Veterinary Medical Association 171:927-932.

Morrison, J.A., C.E. Trainer, and P.L. Wright. 1959. Breeding seasons in elk as determined from known-age embryos. Journal of Wildlife Management 23:27-34.

Nelson, L.J., and J.M. Peek. 1982. Effect of survival and fecundity on rate of increase of elk. Journal of Wildlife Management 46:535-540.

Noyes, J.H., B.K. Johnson, L.D. Bryant, S.L. Findholt, and J.W. Thomas. 1996. Effects of bull age on conception dates and pregnancy rates of cow elk. Journal of Wildlife Management 60:508-517.

Roath, R., L. Carpenter, B. Riebsame, and D. Swift. 1999. Gunnison Basin habitat assessment project-Final Report March 1999. Colorado State University, Department of Range Science, Fort Collins, Colorado USA.

Riney, T. 1955. Evaluating condition of free ranging red deer (*Cervus elaphus*), with special reference to New Zealand. New Zealand Journal of Sciene and Technology 36:429-463.

Samuel, M.D., E.O. Garton, M.W. Schlegel, and R. G. Carson. 1987. Visibility bias during aerial surveys of elk in northcentral Idaho. Journal of Wildlife Management 51:622-630.

SAS. 1988. SAS/STAT user's guide, release 6.03. SAS Institute, Inc. Cary, North Carolina USA.

Spraker, T.R. 1982. An overview of the pathophysiology of capture myopathy and related conditions that occur at the time of capture of wild animals. Pages 82-118 *in* L. Nielsen, J.C. Haigh, and M.E. Fowler, editors. Chemical immobilization of North American Wildlife. Wisconsin Humane Society, Inc., Milwaukee, Wisconsin, USA.

Unsworth, J.W., L. Kuck, and E.O. Garton. 1990. Elk sightability model validation at the National Bison Range, Montana. Wildlife Society Bulletin 18:113-115.

Wade, D.A., and J.E. Browns. 1982. Procedures for evaluating predation on livestock and wildlife. Texas- Agricultural Experiment Station Publication B-1429.

White, G.C. 1991. DEAMAN database manager and population modeling procedures; Colorado Division of Wildlife User's manual and reference. Colorado State University, Fort Collins, Colorado USA.

White, G.C. and R.A. Garrott. 1990. Analysis of wildlife radio-tracking data. Academic Press, Inc., San Diego, California USA

Table 1. Number of male (M) and female (F) calf and adult female elk radio-collared in each DAU and trap-zone in the Gunnison Basin, December 2000 and 2001.

		Calf Elk Collared									Adult Female Elk			Total Elk	
		2000			2001			2000-01			Collared			Collared	
DAU-(GMUs)	Trapzone	M	F	Total	M	F	Total	M	F	Total	2000	2001	2000-01	2000	2001
E-25 (66, 67)	A - Lake Fork	4	7	11	2	4	6	6	11	17	5	1	6	16	7
	B - Cebolla	3	4	7	2	0	2	5	4	9	3	2	5	10	4
	C - Huntsman	4	1	5	6	6	12	10	7	17	3	2	5	8	14
	D - Sawtooth	2	1	3	2	4	6	4	5	9	2	1	3	5	7
subtotals E-25		13	13	26	12	14	26	25	27	52	13	6	19	39	32
E-43 (55, 551)	E - Razor	1	2	3	1	5[a]	6	2	7	9	2	1	3	5	7
	F - Tomichi	4	1	5	3	3	6	7	4	11	3	0	3	8	6
	G - Almont	7	11	18	11	5	16	18	16	34	8	2	10	26	18
subtotals E-43		12	14	26	15	13	28	27	27	54	13	3	16	39	31
E-41 (54)	H - Flat Top	2	4	6	3	3	6	5	7	12	4	1	5	10	7
	I - Beaver	4	6	10	3	4	7	7	10	17	4	0	4	14	7
	J - West Elk	7	3	10	7	6	13	14	9	23	5	2	7	15	15
subtotals E-41		13	13	26	13	13	26	26	26	52	13	3	16	39	29
Totals	All Subtotals	38	40	78	40	40	80	78	80	158	39	12	51	117	92

[a] Includes 2 female calves that died of capture-induced causes within 24 hours of capture for which 2 additional female calves were captured from the same area and radio-collared prior to completing capture of all elk. The net beginning sample size was therefore11 female calves for estimating survival rates in DAU E-43 in 2001.

Table 2. Survival rates of elk calves age 6-11 months for males, females, and sexes combined from 15 December to 14 June in the Gunnison Basin, Colorado, 2000, 2001, and years pooled. Binomial estimator used to calculate survival rates and confidence limits for calves combined among DAUs E-25, E-41, and E-43.

	Elk Calves			Elk Calves			All Elk Calves		
	15 Dec 2000 - 14 June 2001			15 Dec 2001 - 14 June 2002			15 Dec - 14 June 2000 - 2002		
	Males	Females	All	Males	Females	All	Males	Females	All
Survival Rate	0.78	0.97	0.89	0.84	0.82	0.83	0.81	0.90	0.86
Lower 95% CL	0.63	0.92	0.81	0.71	0.69	0.74	0.72	0.83	0.80
Upper 95% CL	0.93	1.00	0.96	0.96	0.94	0.91	0.91	0.97	0.91
n Collars	32	39	71	37	38	75	69	77	146
Collars Deployed	38	40	78	40	40	80	78	80	158
Collars Censored	6[a]	1[b]	7	3[c]	2[d]	5	9	3	12
Died	7	1	8	6	7	13	13	8	21
Non-hunting Deaths	7	1	8	6	7	13	13	8	21
Hunting Deaths	0	0	0	0	0	0	0	0	0

[a] Male calves censored: for post-capture induced mortality 173.082/00 on 12/29/00; for slipped-collars, 173.269/00 on 4/30/01, 173.170/00 on 5/7/01, 173.250/00 on 5/25/01, 173.151/00 on 6/7/01, and 173.220/00 on 6/7/01.

[b] Female calves censored: for post-capture induced mortality 172.379/00 on 12/26/00.

[c] Male calves censored: for post-capture induced mortality 174.720/01 on 12/19/01; for slipped-collars, 174.099/01 on 5/20/02, and 175.221/01 on 6/3/02.

[d] Female calves censored: for post-capture induced mortality 173.429/01 on 12/16/01 and 173.740/01 on 12/16/01.

Table 3. Survival rates of elk calves age 6-11 months for males, females, and sexes combined from 15 December to 14 June for DAUs E-25, E-41, and E-43 in the Gunnison Basin, Colorado, 2000-01 and 2001-02 combined. Binomial estimator used to calculate survival rates and confidence limts.

	Elk Calves - DAU E-25			Elk Calves - DAU E-43			Elk Calves - DAU E-41		
	15 Dec - 14 June 00-01, 01-02			15 Dec - 14 June 00-01, 01-02			15 Dec - 14 June 00-01, 01-02		
	Males	Females	All	Males	Females	All	Males	Females	All
Survival Rate	0.71	0.93	0.84	0.92	0.96	0.94	0.77	0.80	0.78
Lower 95% CL	0.47	0.82	0.73	0.82	0.88	0.87	0.60	0.63	0.67
Upper 95% CL	0.94	1.00	0.95	1.00	1.00	1.00	0.94	0.97	0.90
n Collars	17	27	44	26	25	51	26	25	51
Collars Deployed	25	27	52	27	27	54	26	26	52
Collars Censored	8	0	8	1	2	3	0	1	1
Died	5	2	7	2	1	3	6	5	11
Non-hunting Deaths	5	2	7	2	1	3	6	5	11
Hunting Deaths	0	0	0	0	0	0	0	0	0

Table 4. Comparisons of calf survival between years, sexes, and among DAUs in the Gunnison Basin, Colorado, 2000-01 through 2001-02 based upon chi-square (χ^2) contingency tests.

Calf Survival Rate Comparisons	χ^2 Value	χ^2 Probability	Likelihood Ratio	Ratio χ^2 Probability	*df*
Calf Sexes & DAUs Pooled 2000-01 vs 2001-02	1.09	0.2965	1.10	0.2942	1
Calf Male vs. Female All Years & DAUs pooled	2.11	0.1463	2.12	0.1456	1
Calf Male vs. Female in 2000-01 with DAUs pooled	6.56	0.0105	7.07	0.0078	1
Calf Male vs. Female in 2001-02 with DAUs pooled	0.06	0.8009	0.06	0.8008	1
Calf Sexes Pooled DAU E-25 vs E-43 vs E-41 & Years Pooled	5.21	0.0737	5.71	0.0577	2
Calf Sexes Pooled DAU E-25 vs E-43 & Years Pooled	2.52	0.1123	2.56	0.1098	1
Calf Sexes Pooled DAU E-25 vs E-41 & Years Pooled	0.49	0.4827	0.50	0.4808	1
Calf Sexes Pooled DAU E-41 vs E-43 & Years Pooled	5.30	0.0213	5.59	0.0181	1

Table 5. Percent femur marrow fat in elk calves dying from estimated causes of mortality during winter-spring 15 December to 14 June, 2000-01 and 2001-02 in the Gunnison Basin, Colorado.

	Estimated Mortality Causes											
	Predation		Malnutrition		Suspected Predation		Suspected Malnutrition		Accidents		Unknown	
	12/15/00-06/14/01	12/15/01-06/14/02	12/15/00-06/14/01	12/15/01-06/14/02	12/15/00-06/14/01	12/15/01-06/14/02	12/15/00-06/14/01	12/15/01-06/14/02	12/15/00-06/14/01	12/15/01-06/14/02	**12/15/00-06/14/01**	**12/15/01-06/14/02**
Samples	15.8	90.7	42.8			68.6	48.7			1.6		27.1
	45.3	94.4				60.0	27.5			5.3		
	13.2	83.6				75.6	0.0					
		78.5					77.7					
Average Fat	24.8	86.8	42.8			68.1	38.5			3.5		27.1
n - samples	3.0	4.0	1.0	0.0	0.0	3.0	4.0	0.0	0.0	2.0	0.0	1.0
SD	17.8	5.5				7.8	24.4			2.6		
SE	10.3	2.7				4.5	12.2			1.8		
Min	13.2	83.6	42.8			60.0	0.0			1.6		27.1
Max	45.3	94.4	42.8			75.6	48.7			5.3		27.1

Table 6. Survival rates for winter-spring (WS), summer-fall (SF), and annual (Ann) seasonal intervals from 15 December 2000 to 14 June 2002 for adult female elk age ≥2 years ≥1 year radio-collared in December 2000 and 2001 in the Gunnison Basin, Colorado. Binomial estimator used to calculate survival rates and confidence limts for elk combined among DAUs E-25, E-41, and E-43.

	Adult Female Elk Seasonal Interval and Dates			
	WS	SF	Ann	WS
	12/15/00 - 06/14/01	06/15/01- 12/14/01	12/15/00- 12/14/01	12/15/01- 06/14/02
FEMALES (≥2 yrs old)				
Survival Rate	1.00	0.92	0.92	1.00
Lower 95% CL		0.84	0.84	
Upper 95% CL		1.00	1.00	
n Collars	39	39	39	48[b]
Collars Deployed	39	39	39	48
Collars Censored	0	0	0	0
Died	0	3[a]	3	0
Non-hunting Deaths	0	1	1	0
Hunting Deaths	0	2	2	0
FEMALES (≥1 yr old)				
Survival Rate	1.00	0.91		1.00
Lower 95% CL		0.84		
Upper 95% CL		0.97		
n Collars	39	77[c]		82
Collars Deployed	39	77		82
Collars Censored	0	0		0
Died	0	7		0
Non-hunting Deaths	0	1		0
Hunting Deaths	0	6		0

[a] Adult female deaths: 172.758/00 about 7/1/01, 174.478/00 legal rifle harvest, and 172.030/00 archery/muzzleloading wounding loss.

[b] Includes 12 additional adult females radio-collared 16-20 December 2001.

[c] Includes 38 yearling females that survived as radio-collared calves.

Table 7. Survival rates for winter-spring (WS) and summer-fall (SF) seasonal intervals from 15 December 2000 to 14 June 2002 for the cohort of 6-month old elk calves radio-collared in December 2000 in the Gunnison Basin, Colorado. Binomial estimator used to calculate survival rates and confidence limits for elk combined among DAUs E-25, E-41, and E-43.

	Elk Age (months) and Seasonal Interval and Dates						
	6-11 mos	12-17 mos	18-23 mos		6-11 mos	12-17 mos	18-23 mos
	WS	SF	WS		WS	SF	WS
MALES	12/15/00 - 06/14/01	06/15/01- 12/14/01	12/15/01- 06/14/02	FEMALES	12/15/00 - 06/14/01	06/15/01- 12/14/01	12/15/01- 06/14/02
Survival Rate	0.78	0.86	1.00	Survival Rate	0.97	0.89	1.00
Lower 95% CL	0.63	0.71		Lower 95% CL	0.92	0.79	
Upper 95% CL	0.93	1.00		Upper 95% CL	1.00	0.99	
n Collars	32	22	19	*n* Collars	39	38	34
Collars Deployed	38	25	19	Collars Deployed	40	38	34
Collars Censored	6	3[a]	0	Collars Censored	1	0	0
Died	7	3	0	Died	1	4	0
Non-hunting Deaths	7	2	0	Non-hunting Deaths	1	0	0
Hunting Deaths	0	1[b]	0	Hunting Deaths	0	4[c]	0

[a] Yearling males censored: slipped collars, 173.091/00, 173.391/00, and 173.510/00 between 6/22/01and 7/20/01.

[b] Yearling male illegally wounded and died about 12/10/01 during late-season for antlerless elk.

[c] Yearling females 172.619/00 and 174.360/00 wounded during regular rifle seasons and 174.560/00 173.589/00 disappeared during regular rifle and late rifle seasons respectively, and assumed to be legally harvested.

Table 8. Body mass (kg), total body length (cm), and hindfoot length (cm) of elk calves captured and radio-collared in mid-December 2000 and 2001 in the Gunnison Basin, Colorado. Summaries include only those calves contributing to estimates of survival during winter from 15 December to 14 June and exclude calves dying from capture-induced causes. Values represent average weight (Mean), sample size (*n*), standard error of the mean (SE), confidence interval of the mean (CI), minimum (Min), and maximum (Max).

Calf Groupings	Mass (kg)						Total Body Length (cm)						Hindfoot Length (cm)					
Gunnison	Mean	*n*	SE	95% CI	Min	Max	Mean	*n*	SE	95% CI	Min	Max	Mean	*n*	SE	95% CI	Min	Max
All Females	98.6	74	1.54	95.5 - 101.7	57.5	121.5	179.0	77	1.15	176.7 - 181.3	143.5	196.0	56.0	77	0.22	55.6 - 56.4	49.0	61.5
All Males	99.6	74	1.64	96.3 - 102.8	52.0	133.0	178.2	76	1.12	176.0 - 180.4	146.0	196.0	56.4	76	0.30	55.8 - 57.0	47.5	65.0
All Calves	99.1	14	1.12	96.9 - 101.3	52.0	133.0	178.6	153	0.80	177.0 - 180.2	143.5	196.0	56.2	15	0.19	55.8 - 56.6	47.5	65.0
Females 2000	99.9	37	2.14	95.6 - 104.3	57.5	119.0	178.6	39	1.62	175.3 - 181.9	143.5	194.5	55.9	39	0.33	55.2 - 56.5	49.0	59.5
Males 2000	100.8	37	2.56	95.6 - 106.0	52.0	124.5	180.2	37	1.81	176.4 -183.8	146.0	196.0	56.1	37	0.47	55.2 - 57.1	47.5	60.5
All 2000	100.4	74	1.66	97.1 - 103.7	52.0	124.5	179.3	76	1.20	176.9 - 181.7	143.5	196.0	56.0	76	0.28	55.4 - 56.6	47.5	60.5
Females 2001	97.3	37	2.22	92.8 - 101.8	57.5	121.5	179.5	38	1.66	176.1 - 182.9	151.5	196.0	56.2	38	0.30	55.5 - 56.8	51.5	61.5
Males 2001	98.3	37	2.05	94.2 - 102.5	78.5	133.0	176.3	39	1.30	173.7 - 179.0	163.0	193.5	56.6	39	0.39	55.8 - 57.4	52.5	65.0
All 2001	97.8	74	1.50	94.8 - 100.8	57.5	133.0	177.9	77	1.06	175.8 -180.0	151.5	196.0	56.4	77	0.25	55.9 - 56.9	51.5	65.0
DAU E25 All Calves	95.9	48	1.67	92.5 - 99.3	64.5	118.0	176.6	50	1.25	174.0 - 179.1	151.5	194.5	55.4	50	0.30	54.8 - 56.0	49.0	59.0
DAU E43 All Calves	96.8	50	2.10	92.6 - 101.0	52.0	119.0	175.4	52	1.43	172.5 - 178.3	143.5	193.5	56.3	52	0.37	55.5 - 57.0	47.5	65.0
DAU E41 All Calves	104.4	50	1.81	100.8 - 108.1	57.5	133.0	184.0	51	1.15	181.6 - 186.3	157.0	196.0	56.9	51	0.25	56.4 - 57.4	52.0	60.5
E25 All Calves Trapzone A	97.6	17	2.47	92.4 - 102.9	81.0	118.0	179.6	17	1.98	175.4 - 183.8	166.0	194.5	55.8	17	0.50	54.7 - 56.8	51.5	59.0
E25 All Calves Trapzone B	96.2	7	3.27	88.2 - 104.2	86.0	109.0	177.1	7	1.66	173.0 - 181.1	170.5	181.5	56.2	7	0.73	54.4 - 58.0	53.0	59.0
E25 All Calves Trapzone C	95.1	15	3.94	86.7 - 103.6	64.5	117.0	175.8	17	2.38	170.8 - 180.9	153.0	189.0	54.9	17	0.58	53.7 - 56.2	49.0	58.5
E25 All Calves Trapzone D	93.7	9	3.41	85.8 - 101.5	73.0	105.0	171.8	9	3.23	164.4 - 179.3	151.5	182.0	54.9	9	0.66	53.4 - 56.5	51.5	57.5
E43 All Calves Trapzone E	100.4	6	4.68	88.4 - 112.5	87.5	117.0	178.6	7	2.62	172.2 - 185.0	167.5	188.0	55.9	7	0.38	55.0 - 56.9	55.0	58.0
E43 All Calves Trapzone F	93.1	10	6.17	79.1 - 107.1	52.0	117.0	170.8	11	3.90	162.1 - 179.5	146.0	185.5	56.8	11	1.36	53.8 - 59.8	47.5	65.0
E43 All Calves Trapzone G	97.3	34	2.41	92.4 - 102.1	57.5	119.0	176.2	34	1.68	172.8 - 179.6	143.5	193.5	56.1	34	0.37	55.4 - 56.9	49.0	59.5
E41 All Calves Trapzone H	100.1	11	6.37	86.0 - 114.4	57.5	133.0	181.6	11	3.56	173.7 - 189.5	157.0	193.5	56.3	11	0.71	54.7 - 57.9	52.0	60.0
E41 All Calves Trapzone I	104.9	17	2.60	99.4 - 110.5	85.5	121.5	185.0	17	1.86	181.0 - 188.9	167.0	196.0	57.3	17	0.40	56.5 - 58.2	54.5	60.0
E41 All Calves Trapzone J	106.1	22	1.79	102.4 - 109.8	89.0	124.5	184.3	23	1.39	181.5 - 187.2	169.0	196.0	56.9	23	0.33	56.3 - 57.6	54.0	60.5

Table 9. Numbers of adult female elk harvested during late-seasons in the Gunnison Basin, Colorado, November-December 2000 and 2001 with numbers and percent (%) of harvested adult females from which hunters provided any of the requested biological samples, reproductive organ samples, and kidney fat samples. Samples received for kidney fat expressed as fat with 1 kidney, fat with 2 kidneys; and elk with at least 1 kidney fat sample. Estimates of adult females harvested obtained from CDOW statewide harvest surveys.

Late Season Year	Adult Females Harvested	Adult Females With Any Requested Samples Submitted	Adult Females With Reproductive Organs Submitted	Adult Females With Kidney Fat Samples Submitted 1 kidney; 2 kidneys; ≥1 kidney
2000	291 (100)	81 (28)	58 (19)	17 (6); 40 (14); 57 (20)
2001	374 (100)	46 (12)	31 (8)	22 (6); 5 (1); 27 (7)
All	665 (100)	127 (19)	89 (13)	39 (6); 45 (7); 84 (13)

Table 10. Frequency (%) of dental cementum ages of adult female elk harvested in the Gunnison Basin, Colorado, November-December 2000 and 2001 based on useable incisor tooth samples submitted by hunters.

	Age Class of Adult Female Elk Based on Dental Cementum (years)							
Year	1	2	3-4	5-7	8-10	11-14	15-20	All
2000	5	7	12	20	10	14	6	74
2001	1	7	15	8	9	4	0	44
All	6 (5)	14 (12)	27 (23)	28 (24)	19 (16)	18 (15)	6 (5)	118 (100)

Table 11. Pregnancy rates (%) by age class of adult female elk in the Gunnison Basin, Colorado, November-December 2000-2001 based on samples submitted by hunters for years combined. Age of elk based on dental cementum. Pregnancy rates based only on numbers of known pregnant and non-pregnant elk per age class.

	Age Class of Adult Female Elk Based on Dental Cementum (years)								
Pregnancy Status	1	2	3-4	5-7	8-10	11-14	15-20	Unknown Adult	All
Non- Pregnant	0	3	1	0	1	1	3	4	13
Pregnant	2 (100)	6 (67)	14 (93)	21 (100)	13 (93)	12 (92)	3 (50)	5(56)	76 (85)
Unknown	4	5	12	7	5	5	0	0	38
Total	6	14	27	28	19	18	6	9	127

Table 12. Measurements of elk fetal size in the Gunnison, Basin, Colorado during November-December 2000 and 2001. Values represent average size ($\bar{X}$, mean), sample size (n), standard deviation of the mean (SD), confidence interval of the mean (CI), and minimum (min) and maximum (max) values.

	November-December 2000				November-December 2001			
Measurements	$\bar{X}$ (n)	SD	95% CI	min-max	$\bar{X}$ (n)	SD	95% CI	min-max
Mass (g)								
Male	64.7 (15)	51.0	36.5-92.9	12.4-167.0	119.3 (6)	95.9	18.7-219.9	46.4-289.1
Female	86.8 (24)	97.8	45.5-128.0	12.3-425.5	111.0 (13)	85.5	59.4-162.7	22.1-310.5
Unknown Sex	4.3 (7)	3.7	0.8-7.7	2.0-12.6	4.9 (3)	3.2	0.0-12.7	1.8-8.1
Crown-Rump (mm)								
Male	114.5 (15)	30.4	97.7-131.4	73.6-165.0	138.6 (6)	31.0	106.1-171.2	111.6-186.5
Female	125.6 (24)	39.5	108.9-142.3	68.5-223.0	139.5 (13)	37.7	116.7-162.2	87.9-202.0
Unknown Sex	33.9 (8)	18.6	18.4-49.4	0.5-69.0	44.7 (3)	12.6	13.5-75.9	32.3-57.4
Hind-Leg (mm)								
Male	44.9 (15)	16.6	35.7-54.0	23.8-73.9	60.6 (6)	15.0	44.9-76.4	47.0-83.4
Female	50.7 (24)	20.3	42.2-59.3	23.6-103.9	59.4 (13)	19.0	47.9-70.9	36.1-91.2
Unknown Sex	24.0 (1)				17.4 (1)			
Hind-Foot (mm)								
Male	29.2 (15)	10.6	23.3-35.0	14.9-48.1	40.4 (6)	13.4	26.3-54.5	29.4-61.4
Female	34.7 (24)	16.5	27.7-41.6	14.8-79.9	39.8 (13)	14.8	30.8-48.7	21.4-64.6
Unknown Sex	13.9 (1)				11.5 (1)			

Table 13. Summary values for total fat kidney fat index (TF-KFI), trimmed fat kidney fat index (TRF-KFI), kidney total fat mass (TFM g), and kidney trimmed fat mass (TRFM g) for adult female elk in the Gunnison Basin during November-December 2000-2001. Kidney mass one and two could represent either the left or right kidney masses with kidney mass two associated with elk for which both kidney masses were collected by hunters during late antlerless-only hunting seasons. Values represent average size ($\bar{X}$, mean), sample size (*n*), standard deviation of the mean (SD), confidence interval of the mean (CI), and minimum (min) and maximum (max) values.

	Kidney Mass One				Kidney Mass Two			
Fat Value	$\bar{X}$ (*n*)	SD	95% CI	Min-Max	$\bar{X}$ (*n*)	SD	95% CI	Min-Max
TF-KFI	105.8 (84)	54.5	93.9-117.6	29.1-306.1	91.0 (45)	37.5	79.8-102.3	33.4-165.3
TRF-KFI	78.4 (84)	35.5	70.7-86.1	29.1-212.8	70.3 (45)	26.5	62.3-78.3	30.4-136.1
TFM (g)	218.7 (84)	103.9	196.1-241.2	57.0-551.0	202.4 (45)	90.6	175.2-229.6	72.0-486.0
TRFM (g)	163.6 (84)	70.4	148.4-178.9	48.0-383.0	156.8 (45)	66.3	136.9-176.7	69.0-388.0

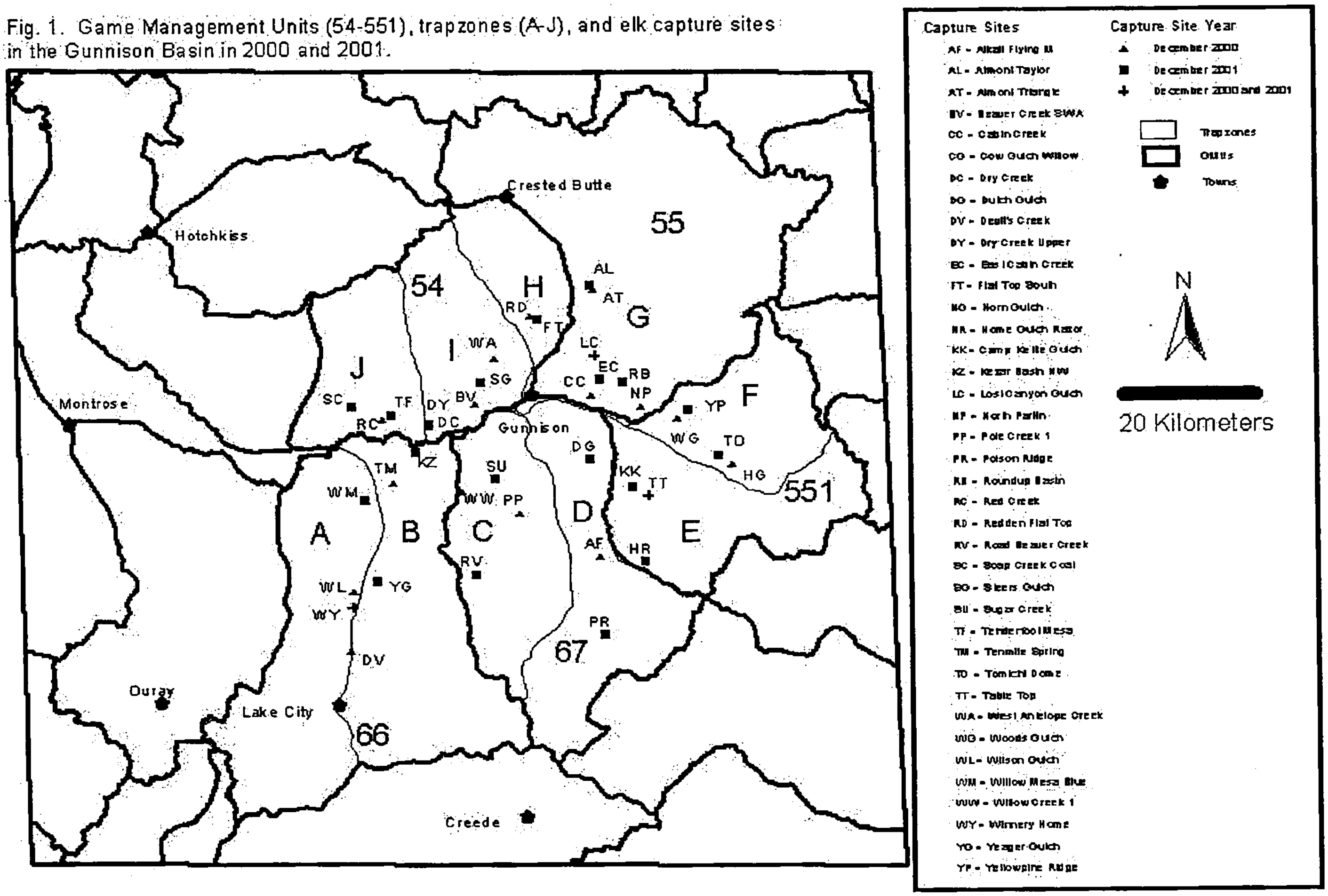
Table 14. Estimates of percent total body fat in adult female elk by pregnancy status and calf elk (sexes combined) in the Gunnison Basin, Colorado during November-December 2000-2001. Percent body fat based on total fat kidney fat index (TF-KFI), trimmed fat kidney fat index 9TRF-KFI), and total kidney fat mass (TFM g) after Cook et al 2001a. Comparisons among mean values shown by *P*-values (ANOVA). Values represent average size ($\bar{X}$, mean), sample size (*n*), and confidence interval of the mean (CI).

	% Body Fat TF-KFI		% Body Fat TRF-KFI		% Body Fat TFM		Percent Body Fat	
	$\bar{X}$ (*n*)	95% CI	$\bar{X}$ (*n*)	95% CI	$\bar{X}$ (*n*)	95% CI	Min[b]	Max[b]
Adult Females								
Pregnant	11.2 (57)	10.6-11.8	12.1 (57)	11.5-12.8	11.3 (57)	10.8-11.9	7.0 (TF)	18.5 (TRF)
Non-Pregnant	10.2 (11)	8.8-11.5	10.9 (11)	9.5-12.2	9.9 (11)	8.9-10.9	8.3 (TFM)	14.8 (TRF)
Pregnancy Status Unknown	11.8 (16)	10.4-13.1	12.6 (16)	11.1-14.1	11.1 (16)	9.6-12.5	5.4 (TFM)	15.3 (TRF)
Pregnant vs. Non-Pregnant	$P = 0.143$		$P = 0.112$		$P = 0.038$			
Pregnant vs. Non-Pregnant vs. Unk.	$P = 0.193$		$P = 0.198$		$P = 0.149$			
All Adult Females	11.2 (84)	10.7-11.7	12.1 (84)	11.5-12.6	11.1 (84)	10.6-11.6	5.4 (TFM)	18.5 (TRF)
Adult Females 2000	10.7 (57)	10.2-11.3	11.6 (57)	11.0-12.2	10.8 (57)	10.2-11.4	5.4 (TFM)	18.5 (TRF)
Adult Females 2001	12.1 (27)	11.1-13.1	13.1 (27)	12.1-14.1	11.7 (27)	10.8-12.6	7.3 (TF)	17.0 (TRF)
2000 vs. 2001	$P = 0.009$		$P = 0.010$		$P = 0.073$			
All Calves[a]	7.1 (6)	4.1-10.1	7.3 (6)	4.1-10.4	4.1 (6)	1.1-7.0	0.2 (TFM)	10.4 (TF)
Calves 2000	7.4 (2)	0.3-14.5	7.7 (2)	0.0-23.4	3.8 (2)	0.0-8.2	3.4 (TFM)	9.0 (TRF)
Calves 2001	7.0 (4)	1.2-12.8	7.0 (4)	1.1-10.3	4.2 (4)	0.0-9.9	0.2 (TFM)	10.4 (TF)

[a] Estimates of percent body fat in calves should be viewed with caution as calibration equations developed by Cook et al. 2001 were based only on adult female elk.

[b] Minimum and maximum estimates of percent body fat obtained from either *TF*-KFI, *TRF*-KFI, or *TFM* estimators.

Fig. 1. Game Management Units (54-551), trapzones (A-J), and elk capture sites in the Gunnison Basin in 2000 and 2001.



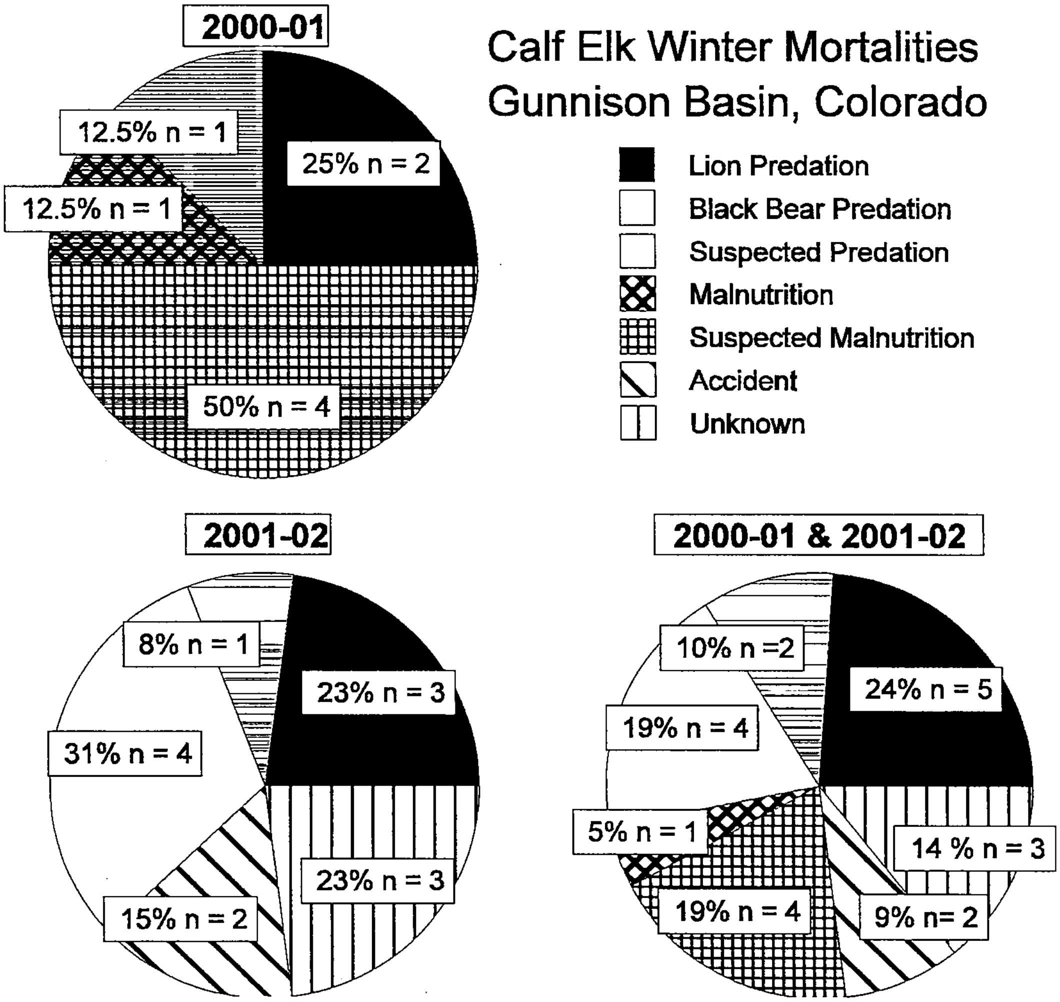


Figure 2. Estimated causes of calf elk mortalities during winter from 15 December through 14 June in the Gunnison Basin, Colorado, 2000-01, 2001-02, and years combined.

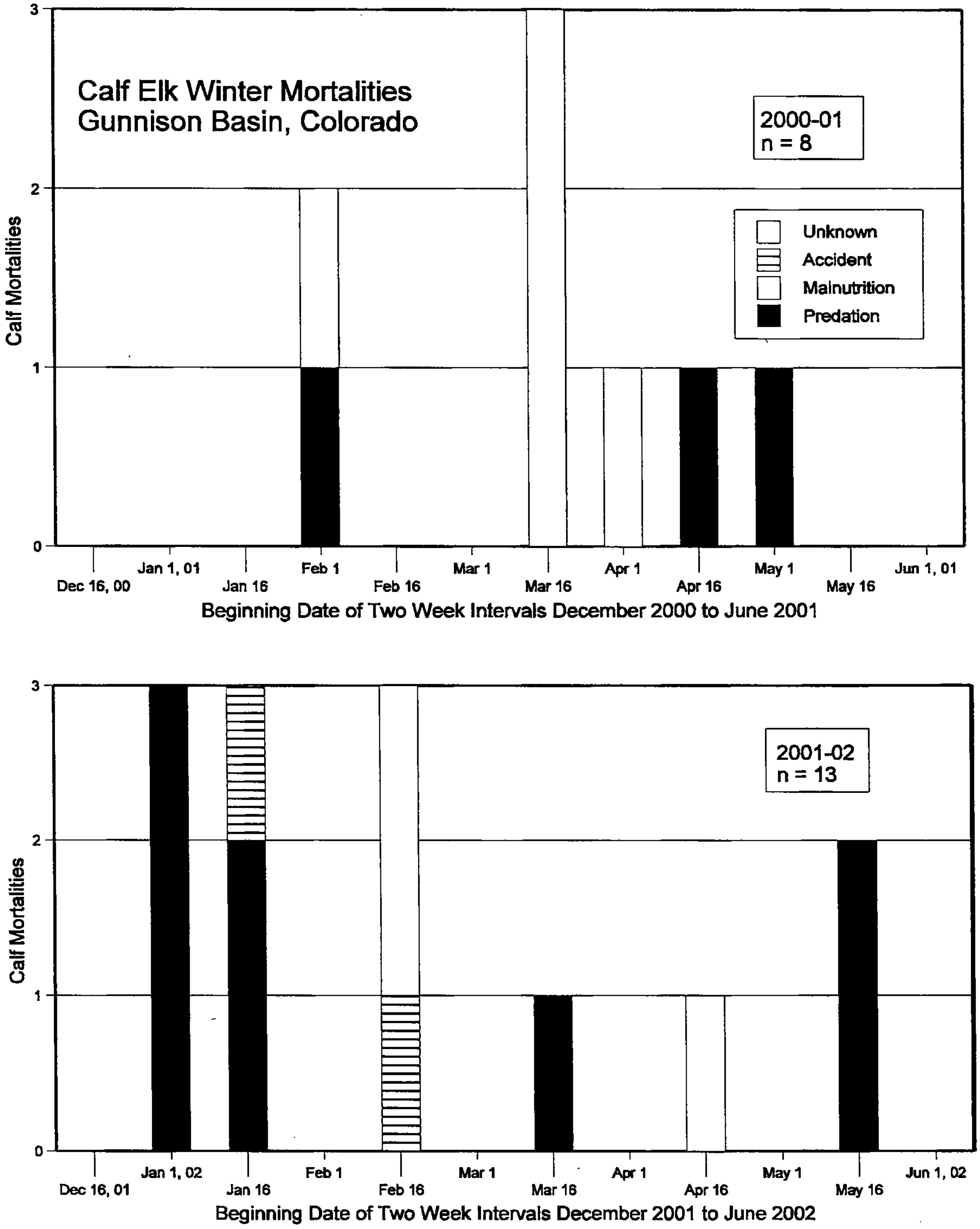


Figure 3. Timing and estimated causes of calf elk mortalities during winter from 15 December through 14 June in the Gunnison Basin, Colorado, 2000-01 and 2001-02.

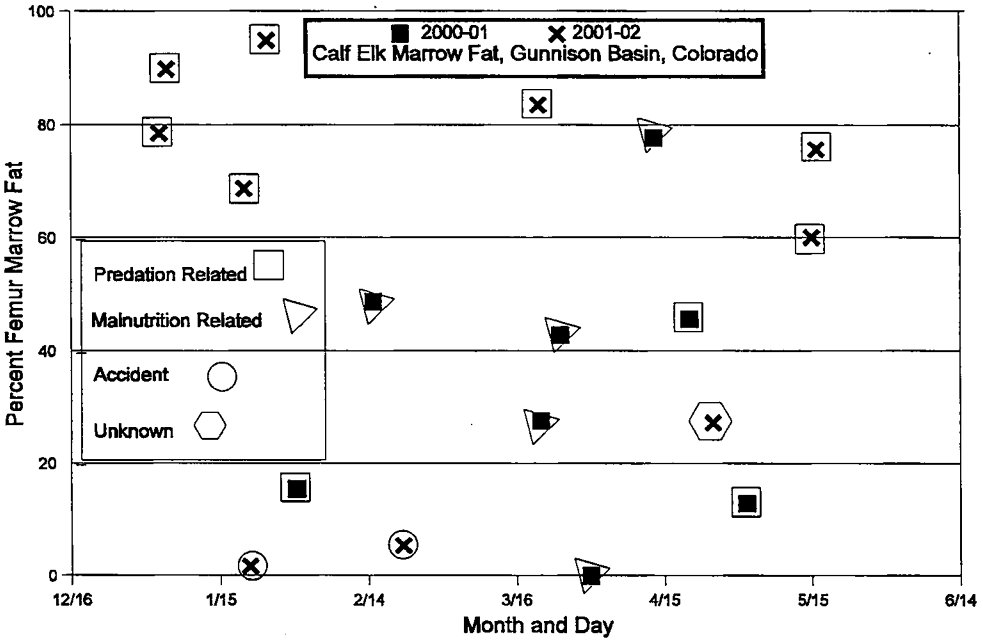


Figure 4. Percent femur marrow fat in calf elk mortalities by estimated cause and timing of deaths during winter from 15 December to 14 June in the Gunnison Basin, Colorado, 2000-01 and 2001-02.

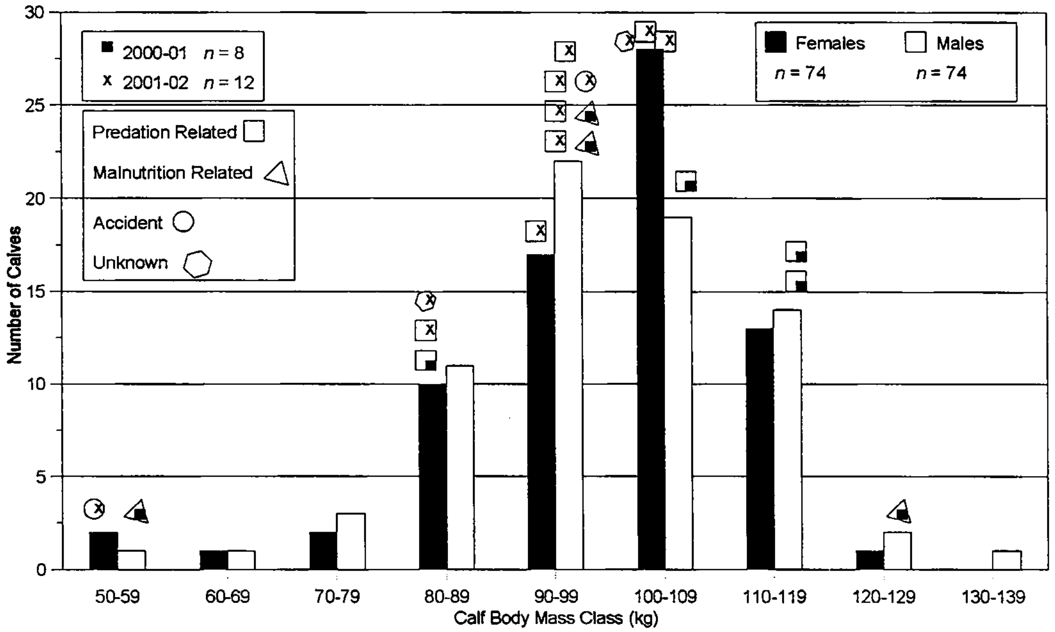


Figure 5. Distribution of male and female calf body masses and occurrence of calf mortalities by mass class, calf sex, and estimated cause of death during winter from 15 December to 14 June, Gunnison Basin, Colorado, 2000-01 and 2001-02.

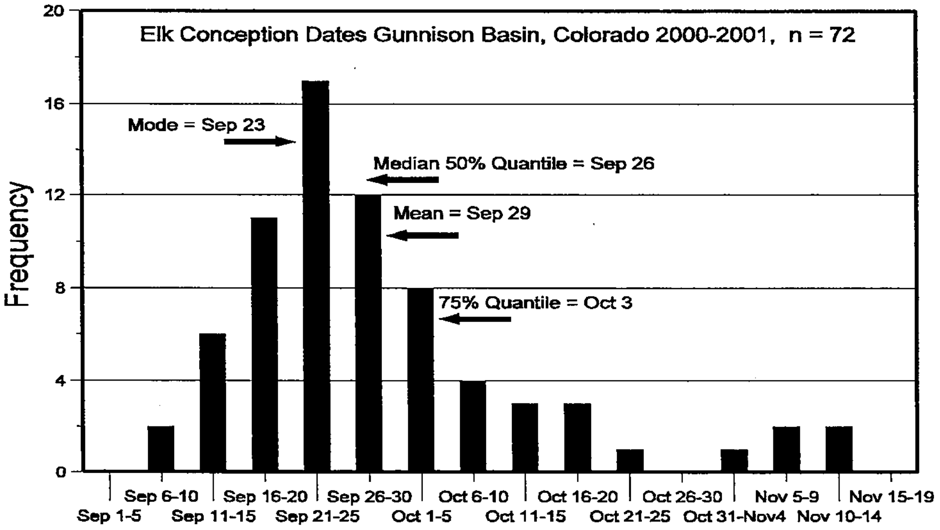


Figure 6. Frequency of estimated conception dates in 5-day intervals for elk fetuses in the Gunnison Basin, Colorado, 2000-2001.

Figure 7. Proportions of male elk fetuses per conception date interval (LEFT) and per adult female age class (RIGHT), Gunnison Basin, Colorado, 2000-2001.

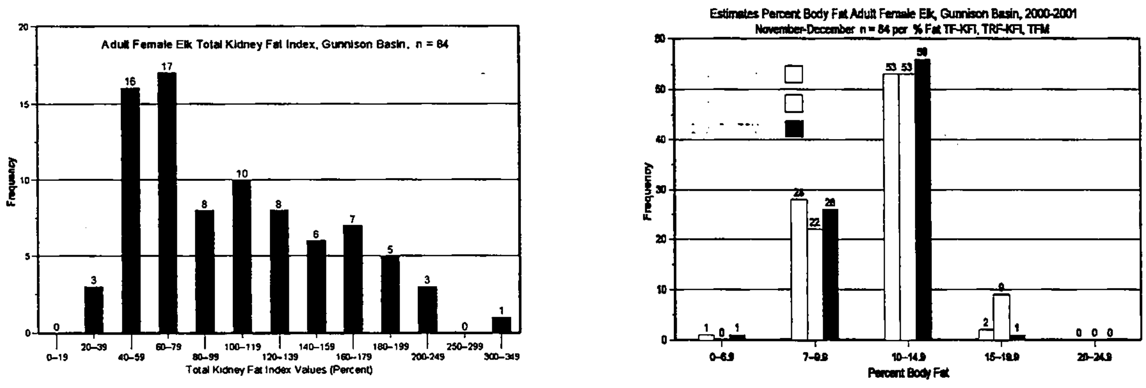


Figure 8. Frequency of total kidney fat index values (TF-KFI) (LEFT) and percent total body fat estimates (RIGHT) for adult female elk age ≥1 year during November-December, Gunnison Basin, Colorado, 2000-2001. Body fat estimates based on TF-KFI, trimmed kidney fat index (TRF-KFI), and total kidney fat mass (TFM g), respectively, after Cook et al. 2001a. Percent body fat classes 0-6.9, 7-9.9, 10-14.9, 15-19.9, and 20-24.9 represent body condition classes very low, low, moderate, very good, and excellent, respectively, after Cook J.G. (2001 unpublished data).

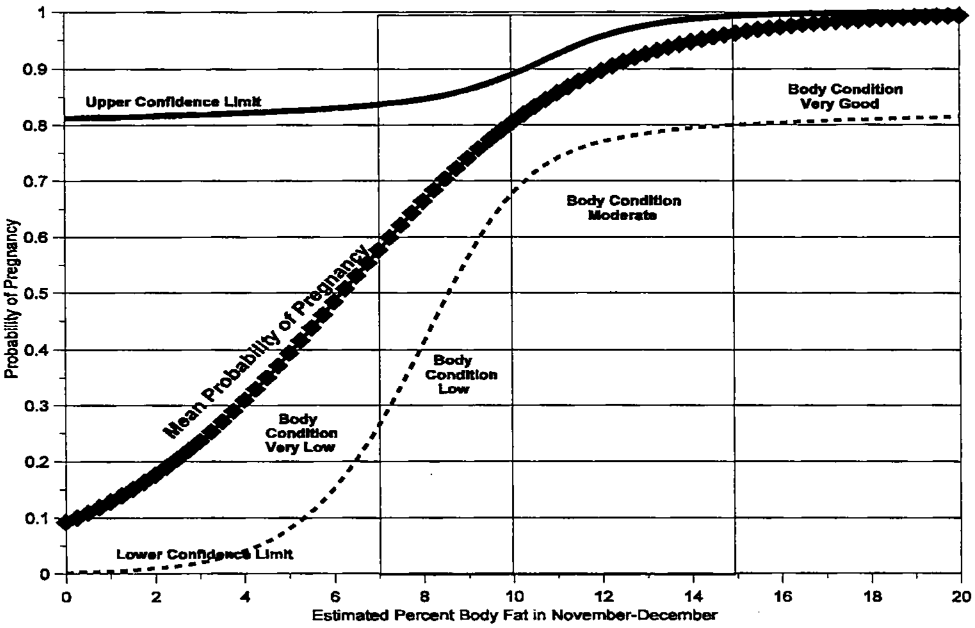


Figure 9. Probability of adult female elk age ≥1 year being pregnant as predicted from percent total body fat based on total kidney fat mass (TFM g) measured in November-December, Gunnison Basin, Colorado, 2000-2001. Probablility curve bracketed by approximate 95% confidence limits. Relative body condition rating classes from Cook J.G. (2001 unpublished data). Logistic regression was: *logit* (*P*) = -2.2835 + 0.3704 *(X-percent body fat); regression slope significant $P = 0.033$).

Appendix A. Locations of elk capture sites in the Gunnison Basin during December 2000 and 2001. All UTM coordinates are referenced to NAD 27 datum projection.

Site Code	Trap Site	Trap-zone	Capture UTMx	Capture UTMy	Capture UTMZone	Capture 2000	Capture 2001
WY	WINNERY HOME	A	299842	4229298	13	2000	2001
WL	WILSON GULCH	A	299987	4232163	13	2000	
WM	WILLOW MESA BLUE	A	302286	4248791	13	2000	
DV	DEVILS CREEK	B	299507	4221245	13	2000	
TM	TENMILE SPRING	B	307088	4252151	13	2000	
WW	WILLOW CK 1	C	319409	4250445	13	2000	
PP	POLE CK 1	C	329616	4246431	13	2000	
AF	ALKALIFLYING M	D	343809	4238265	13	2000	
TT	TABLE TOP	E	352655	4249609	13	2000	2001
HG	HORN GULCH	F	367555	4255415	13	2000	
WG	WOODS GULCH	F	357804	4263648	13	2000	
CC	CABIN CK	G	342564	4267804	13	2000	
NP	NORTH PARLIN	G	351341	4265757	13	2000	
LC	LOST CANYON GULCH	G	343419	4275048	13	2000	2001
AL	ALMONT TAYLOR	G	343020	4287228	13	2000	
RD	REDDEN FLATTOP	H	331774	4282420	13	2000	
WA	WEST ANTELOPE CK	I	325259	4274696	13	2000	
BV	BEAVER CK SWA	I	321816	4266364	13	2000	
DC	DRY CREEK	I	313617	4262208	13	2000	
RC	RED CREEK	J	305342	4263542	13	2000	
CG	COW GULCH WILLOW	A	302170	4248762	13		2001
YG	YEAGER GULCH	B	304088	4233715	13		2001
KZ	KEZAR BASIN NW	B	311114	4257470	13		2001
RV	ROAD BEAVER CK	C	321992	4235039	13		2001
SU	SUGAR CREEK	C	325267	4252487	13		2001
PR	POISON RIDGE	D	344624	4223850	13		2001
DG	DUTCH GULCH	D	342179	4256150	13		2001
HR	HOME GULCH RAZOR	E	351874	4237208	13		2001
KK	CAMP KETTLE GULCH	E	349729	4250925	13		2001
TO	TOMICHI DOME	F	365097	4256608	13		2001
YP	YELLOWPINE RIDGE	F	359615	4264943	13		2001
AT	ALMONT TRIANGLE	G	342507	4287754	13		2001
EC	EAST CABIN CREEK	G	344065	4270540	13		2001
RB	ROUNDUP BASIN	G	348075	4270061	13		2001
FT	FLATTOP SOUTH	H	333051	4281590	13		2001
SG	STEERS GULCH	I	323101	4270141	13		2001
DY	DRY CREEK UPPER	I	313563	4262643	13		2001
TF	TENDERFOOT MESA	J	306929	4264206	13		2001
SC	SOAP CREEK COAL	J	299839	4265834	13		2001

Appendix B. Summary of calf elk mortalities in the Gunnison Basin, 15 December to 14 June, 2000-01.

No	Elk ID	Sex	Mass	Trap-zone	Death Date	Recovered	Femur Marrow Fat	Tissue Samples	Parasites	Carcass Status	Death Cause	Death Location		
												UTMx	UTMy	Drainage
1	173.082/00	M	92	B	12/29/00-1/4/01	5-Jan-01	WhiteCreamy 38.7%	Yes CM	n/a	Nearly Complete	Capture Related / Lion	303163	4253981	Lake Gulch
2	172.379/00	F	127	H	12/19-26/00	3-Jan-01	WhiteFirm 94.7%	n/a	n/a	Scavenged	Capture Related	335406	4282773	Flat Top
3	173.640/00	F	82	A	2/1-7/01	7-Feb-01	RedJelly 15.8%	No CM	Moderate sarcocysts	Partially Scavenged	Lion Predation	304608	4243376	Lake Fork
4	172.959/00	M	125	J	2/15/01	15-Feb-01	WateryPink 48.7%	No CM	Moderate sarcocysts	Carcass Complete	Unk.-Suspect Starvation	304753	4261110	Red Ck.
5	173.351/00	M	52	F	3/21/01	24-Mar-01	RedJelly 27.5%	No CM	Normal sarcocysts	Scavenged	Unk.-Suspect Starvation	360867	4262422	Yellow Pine
6	173.160/00	M	94	A	3/25/01	26-Mar-01	Red Jelly 42.8%	No CM	Moderate sarcocysts/NI	Carcass Complete	Stravation	298132	4230866	Dwyer Gulch
7	173.300/00	M	112	I	3/31/01	1-Apr-01	Red Jelly 0.0%	No CM	Severe sarcocysts/NI	Carcass Complete	Unk.-Suspect Starvation	308379	4263917	Dry Gulch
8	173.041/00	M	97	I	4/13-14/01	15-Apr-01	Red Jelly 77.66%	No CM	Severe sarcocysts/NI	Nearly Complete	Unk.-Suspect Starvation	320104	4270341	Beaver Ck.
9	173.949/00	M	107	A	4/20/01	26-Apr-01	RedCreamy 45.27%	No CM	Normal sarcocysts	Scavenged	Lion Predation	311827	4245467	Cebolla Ck.
10	173.011/00	M	113	J	4/28-5/10/01	23-May-01	Red Jelly 13.15%	n/a	n/a	Scavenged	Bear Predation	300715	4268428	E. Coal Ck.

Mass = Weight of calf (kg) at capture; CM = capture myopathy; NI = no evidence of inflamation around sarcocysts; n/a = samples not available.

Appendix C. Summary of calf elk mortalities in the Gunnison Basin, 15 December to 14 June, 2001-02.

No	Elk ID	Sex	Mass	Trap-Zone	Death Date	Recovered	Femur Marrow Fat	Tissue Samples	Parasites	Carcass Status	Death Cause	Death Location		
												UTMx	UTMy	Drainage
1	173.429/01	F	100	E	12/18/ 2001	20-Dec-01	Firm core, pink;87.45%	No CM	unremark-able	Carcass Complete	Capture Related Fence Kill	351433	4245033	Prosser Ck
2	173.740/01	F	101	E	12/21/ 2001	21-Dec-01	Firm core, pink;66.5%	Mild CM	n/a	Carcass Complete	Capture Related euthanized	353050	4250600	E. TableTop Mt
3	174.720/01	M	101	B	12/21-23/2001	26-Dec-01	Soft core, pink;88.87%	No CM	Low Sarcosysts	Partially Scavenged	Capture Related / Lion	302744	4230958	Skunk Ck.
4	173.269/01	M	98	J	01/2-12/2002	14-Jan-02	n/a	n/a	n/a	Totally Scavenged	Unk-suspect lion predation	300102	4267074	Pearson Pt.
5	172.350/01	F	86	H	01/3-7/2002	8-Jan-02	Firm core, pink;78.50%	No CM	unremark-able	Partially Scavenged	Bear Predation	334033	4282350	Flat Top Mtn
6	173.852/01	F	101	I	1/4-9/ 2002	10-Jan-02	Firm core, pink;90.71%	No CM	Low Sarcosysts	Partially Scavenged	Lion predation	321888	4275810	W.Antelope Ck
7	175.181/01	M	91	A	1/15-2/5 /2002	6-Feb-02	Firm, red; 68.56%	n/a	n/a	Scavenged heavily	Unk-suspect coyote predation	297064	4231180	Dwyer Gulch
8	172.170/01	F	58	H	1/20-21/ 2002	23-Jan-02	Jelly, red: 1.57%	No CM	broncho-pnuemonia	Carcass Complete	Accident-Haystack collapse	330243	4280937	Redden's
9	173.861/01	F	102	J	1/25-28/ 2002	29-Jan-02	Firm core, pink:94.36%	No CM	Moderate sarcocysts	Partially Scavenged	Lion predation	299250	4267725	Pearson Pt.
10	174.770/01	M	92	A	2/21-28/ 2002	4-Mar-02	Soft core, red; 5.27%	No CM	Moderate sarcocysts	Carcass Complete	Accident-fell, trapped	294622	4227200	Elk Ck.
11	172.379/01	F	81	G	2/25-3/6 /2002	7-Mar-02	n/a	n/a	n/a	Totally Scavenged	Unknown	342715	4288645	AlmontTriangle
12	173.300/01	M	none	J	2/27-3/6 /2002	9-Mar-02	n/a	n/a	n/a	Not Found-Snow	Unknown	299323	4268454	N.Pearson Pt.
13	173.632/01	F	96	C	3/20-25 /2002	26-Mar-02	Firm core, pink: 83.60%	No CM	Moderate sarcocysts	Partially Scavenged	Lion predation	322925	4232867	RoadBeaver Ck.
14	173.780/01	F	108	J	4/25-4/30 /2002	1-May-02	Firm core, pink; 27.08%	n/a	n/a	Totally Scavenged	Unknown	306109	4267739	Red Ck.
15	175.240/01	M	100	C	5/15-20 /2002	21-May-02	Red, firm core;60.02%	n/a	n/a	Totally Scavenged	Unk-suspect lion predation	325443	4235881	N. RoadBeaver Ck.
16	174.180/01	M	95	E	5/15-20/ 2002	22-May-02	Firm core, pink;75.63%	n/a	n/a	Totally Scavenged	Unk-suspect lion predation	351363	4240438	Home Gulch

Mass = Weight of calf (kg) at capture; CM = capture myopathy; n/a = samples not available

Appendix D. Summary of adult elk mortalities in the Gunnison Basin 15 December 2000 to 14 June 2002.

No	Elk ID	Age @ Death	Sex	Trap-zone	Death Date	Recovered	Femur Marrow Fat	Tissue Samples	Para-sites	Carcass Status	Death Cause	Death Location		
												UTMx	UTMy	Drainage
1	172.758/00	19 yrs	F	H	>06/22<7/21/01	21-Jul-01	n/a	n/a	n/a	Decomposed	Unknown Mortality	321262	4294461	S. Carbon Mtn.
2	173.330/00	12 mos	M	G	>06/22<7/24/01	24-Jul-01	77.46%	n/a	n/a	Scavenged	Unk-Suspect Predation	354289	4290527	Summerville Ck.
3	173.340/00	12 mos	M	G	>6/22<7/20/01	16-Aug-01	n/a	n/a	n/a	Heavily Scavenged	Unk-Suspect Predation	384766	4303460	N. Cottonwood Ck.
4	172.030/00	6 yrs	F	C	>9/25<10/18/01	19-Oct-01	white,solid 97.31%	n/a	n/a	Heavily Scavenged	Archery/Muzzle wound loss	322980	4227638	Swinehart Gulch
5	172.619/00	16 mos	F	J	>10/13<10/18/01	20-Oct-01	pink,crum-bles 85.18%	n/a	n/a	Complete	Rifle wound loss 1st season	299161	4275164	Cow Ck.
6	174.478/00	5-9 yrs	F	G	10/13/2001	17-Oct-01	n/a	n/a	n/a	Hunter Kill	Rifle 1st season Legal	341000	4242650	Rock Ck.
7	174.360/00	17 mos	F	G	>11/8 <11/16/01	17-Nov-01	white/gray, solid 95.18%	n/a	n/a	Complete	Rifle 4th season wound loss	346979	4279939	E. Beaver Ck.
8	174.140/00	18 mos	M	C	>12/5 <12/28/01	29-Dec-01	white/pink, firm 86.27%	n/a	n/a	Scavenged	Late rifle wound/illegal loss	308573	4242145	Lake City Cut-Off
9	173.589/00	18 mos	F	B	>12/28/01<1/3/02	n/a	n/a	n/a	n/a	n/a	Disappear Late Rifle season Legal	n/a	n/a	Low Cebolla Ck.
10	174.560/00	17 mos	F	J	>10/30/01<12/31/ 01	n/a	n/a	n/a	n/a	n/a	Disappear 3rd rifle season Legal	n/a	n/a	West Elk Ck.

Age estimated using dental cementum or known age as elk collared as calf.

APPENDIX I
PROGRAM NARRATIVE
STUDY PLAN FOR RESEARCH FY 2000-01 - FY 2003-04

State of: Colorado	Cost Center 3430
Project No.: W-153-R-14	Mammals Research Program
Work Package: 3002	Elk Conservation
Study No.: 3	Estimating Calf and Adult Survival and Pregnancy Rates of Gunnison Basin Elk Populations

ESTIMATING CALF AND ADULT SURVIVAL AND PREGNANCY RATES OF GUNNISON BASIN ELK POPULATIONS

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STUDY PLAN APPROVAL

Prepared by: ______________________ Date: ____________

Submitted by: ______________________ Date: ____________

Reviewed by: ______________________ Date: ____________

______________________ Date: ____________

______________________ Date: ____________

Approved by: ______________________ Date: ____________
Biometrician

______________________ Date: ____________
Research Leader

PROGRAM NARRATIVE
STUDY PLAN

State of:	Colorado	Cost Center 3430
Project No.:	W-153-R-14	Mammals Research Program
Work Package:	3002	Elk Conservation
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A. NEED

Elk (*Cervus elaphus nelsoni*) are a high-profile and highly valued resource throughout much of Colorado because elk provide recreation for persons who hunt, watch, and photograph wildlife (Freddy et al. 1993). The elk resource has many benefits but frequent social, political, and economic conflicts suggest elk can reach "social" if not "biological" carrying capacities. Recent controversy surrounding management of elk in the Gunnison Basin of Colorado (Roath et al.1999) exemplifies conflicting social and biological agendas regarding appropriate numbers of elk.

The core of conflict in elk management often centers on establishing management objectives for numbers of elk that are agreeable to competing interests and then monitoring elk populations to demonstrate that objectives are achieved. This type of conflict is paramount in Colorado Division of Wildlife (CDOW) elk population Data Analysis Units (DAUs) E-25, E-41, and E-43 in the Gunnison Basin (Fig. 1) where a combination of resource carrying capacity objectives for elk on winter ranges and difficulties associated with knowingly achieving those objectives has fostered argumentative distrust among public groups and management agencies. Accomplishing management by population objective can depend on reliably estimating elk population size. Estimating population size is expensive and intensive (Samuel et al. 1987, Bear et al. 1989, Unsworth et al. 1990, Anderson et al. 1998, Cogan and Diefenbach 1998, Eberhardt et al. 1998, Freddy 1998) and these factors often preclude routinely using tested inventory methodologies.

Alternatively, population size and trend can be estimated using computer models that incorporate harvest, age and sex ratios, and survival rates (White 1992, Bartholow 1999). Model outputs are extremely sensitive to estimates of survival rates such that, reliable measurements of survival can greatly enhance the quality of models (Nelson and Peek 1982). Thus, estimating survival rates is fundamental to modeling elk populations in the absence of routine measurements of population size.

Estimating calf and adult female survival during winter and annual rates of survival for adult females are higher priorities than estimating adult male survival primarily because most males are harvested when they reach legal age and contribute little to long-term problems of population growth or decline. Models having valid estimates of survival along with currently obtained precise estimates of harvests and population composition would provide more defensible estimates of population size.

Although small changes in adult female survival can have major effects on population growth or decline if compounded for several years, calf survival is likely more variable among years. The ability to detect changes in calf survival should be greater than detecting smaller, but important changes in adult female survival (White et al. 1987, Bartmann et al. 1992, Freddy 1998). Estimates of calf survival in Colorado during winter are limited to the Grand Mesa in west-central Colorado where yearly average survival varied between 0.86 and 0.92 from 1993-1996 (Freddy 1998, $n \geq 67$ calves/year). Applying these survival rates to other Colorado elk populations, especially those populations using winter ranges higher in elevation, colder, and more prone to significant snow depths such as in the Gunnison Basin, may or may not be appropriate. Rates of survival on the Grand Mesa were higher than expected and considerably greater than 0.70-0.72 survival rate estimated for elk calves during winter in Yellowstone National Park (Houston 1982, Singer et al. 1997).

Estimates of annual survival for radio-collared adult female elk in Colorado averaged 0.95 and ranged from 0.94-0.99, excluding hunting mortalities, for several populations inhabiting widely differing ecosystems (Petersburg and White 1998, Freddy 1999; $n > 1{,}250$ adult female-years). Because of the availability of these adult survival estimates, the need to estimate adult female survival is therefore less than the need to obtain additional estimates of calf survival, but ideally we would measure both calf and adult survival simultaneously to document relative differences in survival.

A recent evaluation of existing population models for elk in the Gunnison Basin and subsequent development of new population models using estimates of calf and adult survival measured in Colorado altered population trajectories and relative size (Freddy 2000). Consequently, management objectives for Gunnison elk were amended to continue reducing numbers of elk in all DAUs. Controversy surrounding new models and management decisions reinforced the need to obtain measurements of elk survival specific to the Gunnison Basin.

B. OBJECTIVE

This project will obtain estimates of population parameters for elk in the Gunnison Basin. Major objectives are:

1) Estimate survival rates of elk calves during winter from 15 December-14 June within ±15% of the true survival rate at the 95% confidence interval for 3 consecutive years and identify probable sources of mortality.
2) Estimate winter (15 Dec-14 Jun) and yearly (15 Dec-14 Dec) survival rates of adult females for 3 consecutive years to assess whether the true survival rate is likely ≥0.95 and identify probable sources of mortality.
3) Estimate pregnancy rates of adult female elk harvested during November-December late hunting seasons for 3 consecutive years if late hunting seasons are scheduled.
4) Estimate hunting removal rates for adult females, yearling males, and when possible, adult males for 3 consecutive years.
5) Evaluate Gunnison elk population models using newly acquired survival rates.

C. EXPECTED RESULTS OR BENEFITS

This project will provide estimates of survival rates for calf and adult female elk and estimates of hunting removal rates for adult elk in the Gunnison Basin DAUs E-25, E-41, and E-43 for 3 consecutive years. These estimates will immediately assist the CDOW in refining population models for Gunnison elk and provide estimates of survival/removal that may be applicable to modeling other elk populations inhabiting similar habitats. In the process of estimating survival rates, probable causes of mortality will be identified which may provide insight into relative health status of elk. Additionally, estimates of pregnancy rates will provide documentation on the fecundity of these elk in relation to other elk populations in Colorado and other states.

D. APPROACH

EXPERIMENTAL DESIGN

SURVIVAL RATES

Radio-telemetry Equipment

Survival rates will be estimated by marking elk with radio-telemetry collars that emit a mortality pulse code when collars remain motionless for 4-6 hours (White et al.1987, Freddy 1993). Radios provide the ability to know the fate of individual animals (alive or dead) over discrete periods of time (White and Garrott 1990). Radio-collaring does not likely bias estimates of survival by jeopardizing or enhancing the welfare of individuals when radio-collars weigh <0.8% of an ungulate's body weight (Garrott et al. 1985, White et al. 1987).

Radio-collars similar to those previously designed and successfully used for calf and adult elk on the Grand Mesa, Colorado will be used in this project (Freddy 1993, Appendix I). Collars for male and female calves will allow for expansion to adult size while adult female collars will be of fixed circumference and fitted to each individual. Calf collars weigh 840 gm and represent <1% of expected calf body weight while adult collars weigh 1.1 kg and represent <0.5% of expected body weight. Collars will be white in color, have a unique black colored number/symbol embossed on bright yellow plastic material (Ritchey Manufacturing, Brighton, CO) attached to the dorsal surface of collar to enhance visual identification from helicopters (Appendix II), have unique frequencies between 172-176MHz, and a battery life of ≥4 years.

Animal Capture

We assume survival of those elk captured provides an unbiased estimate of population survival rates recognizing that individual behavior, social behavior, trapping methods and distribution of trapping effort all potentially bias those individuals actually marked (White et al. 1982). Recognizing these problems, elk will be captured with the intent of systematically marking elk throughout the distribution of elk in the Gunnison Basin.

Each of the 3 DAUs, will be divided into trap-zones having multiple trap-sites. Capture quotas for calves and adults in trap-zones within each DAU will be proportional to expected elk density as estimated from yearly sex and age ratio classification flights conducted each January throughout the Gunnison Basin. Trap-zones will be initially defined as: 1) for DAU E-25: Big Blue Creek to Gunnison River (TzA), Gunnison River to Cebolla Creek (TzB), Cebolla Creek to Gold Basin Creek (TzC), and Gold Basin Creek to Cochetopa Creek (TzD), 2) for DAU E-43: Cochetopa Creek to Tomichi Creek (TzE), Tomichi Creek to Quartz Creek (TzF), Quartz Creek to East River (TzG), and 3) for DAU E-41: East River to Ohio Creek (TzH), Ohio Creek to Dry Creek (TzI), and Dry Creek to Curecanti Creek (TzJ).

Elk will be captured using a Hughes 500 helicopter and net-guns (contracted services) (Freddy 1994). We will attempt to collar equal numbers of male and female calves. Helicopter trapping will occur in mid-December each year. Capture and handling procedures will follow protocols used to capture 257 calves and 46 adult females on the Grand Mesa (Freddy 1993-1996) and previously approved by CDOW Animal Care and Use Committee (Appendix III).

Survival Monitoring

Radioed elk will be monitored daily from the ground and bimonthly with aerial surveys (Cessna 185 or equivalent) to determine life/death status of elk. During hunting seasons, aerial surveys will be occur bimonthly in September and weekly during October and November. RADIOS database program will be used to maintain animal records.

Suspected mortalities will be confirmed using ground searches. Criteria for assigning probable cause of death will include body position, presence of bite or claw marks and sub-dermal hemorrhaging, tracks, drag marks, and tissue samples if available (Wade and Browns 1982, Freddy 1998). Potential causes of death include starvation, accidental trauma, plant poisoning, predation by black bears, mountain lions, coyotes, and domestic dogs, and legal and illegal hunter harvest (Freddy 1997).

Survival Sample Sizes and Tests

Each year we will radio-collar 78 calves (39 male, 39 female) with 26 calves marked in each DAU and during the initial year, 39 adult females will be radio-collared with 13 in each DAU (Table 1). We anticipate >20 radioed female calves will be recruited to yearling adults each year resulting in >50 radioed adult females in the population to estimate adult survival in subsequent years. However, by not collaring known adult females each year, we run the risk of having biased estimates of adult female survival because the age structure of collared adult females will progressively be biased to younger aged females recruited from marked calves. An alternative would be to mark enough adult females in each subsequent year to replace those adult females marked in year 1 that had died the previous year. We anticipate needing to replace 15-20 older adult females per year to achieve this goal which will be dependent on future funding. If adult females could be replaced yearly, we would be able to separate year effects from age effects on survival rates. Approximately 30 yearling males will be available each year, 2001-2003, to estimate percent of yearling males illegally removed under a hunting system using antler-point regulations to protect yearlings. Approximately 30, ≥2-year-old males will be available each year, 2002-2004, to estimate percent of branch-antlered males removed with a hunting system using antler-point regulations.

We chose to mark 78 calves per year and 39 adult females during the initial year because we will have acceptable confidence intervals about mean estimates of survival each year for all DAUs pooled into 1 elk population, have the potential to detect major differences in survival between years due to changes in winter severity when all 3 DAUs are pooled, and be able to detect major differences in survival between DAUs when data are pooled within DAUs for 3 years. The ability to detect differences between DAUs within years is desirable but economically prohibitive due to numbers of collared elk required (>47 per DAU per year).

We anticipate yearly calf survival to be 0.70 to 0.90 and adult survival, exclusive of hunting-related deaths, to be 0.95 to 0.99. If calf survival is ≥0.70 (n = 78 calves), 95% confidence intervals (Zar 1984, 378) will be ≤ ±15% of the yearly mean survival rate. If adult female survival is ≥0.95 (n ≥ 39 adults), 95% confidence intervals will be ≤ ±10% of the yearly mean survival rate. Additionally, if adult female survival = 0.95 we expect to estimate yearly survival within ±5% of the true survival rate at alpha = 0.10 when n ≥ 50 adult females.

Table 1. Elk calves (6 months old) and adult females (≥12 months old) captured and radio-collared for Gunnison elk DAUs E-25, E-41, and E-43, December 2000-2002 (shaded cells). Adult females captured only during initial year, 2000. Numbers of radioed adult males and females in December years 2001-05 estimated by assuming survival rates between years: adult females net rate = 0.7, male and female calves to yearling adult age net rate = 0.8, yearling males to adult males net rate = 0.9, adult males net rate = 0.3.

	DAU E-25				DAU E-41				DAU E-43				ALL DAUs				
	Calves		Adults		Calves		Adults		Calves		Adults		Calves		Adults		Totals
Year	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	All
2000	13	13	0	13	13	13	0	13	13	13	0	13	39	39	0	39	117
2001	13	13	10	19	13	13	10	19	13	13	10	19	39	39	30	57	165
2002	13	13	13	23	13	13	13	23	13	13	13	23	39	39	39	69	186
2003			14	26			14	26			14	26			42	78	120
2004			4	18			4	18			4	18			12	54	66
2005			1	13			1	13			1	13			3	39	42
ALL	39	39	42[a]	112[a]	39	39	42[a]	112[a]	39	39	42[a]	112[a]	117	117	126[a]	336[a]	696[a]

[a] Represents elk-years and not necessarily numbers of individual radioed adult elk as adults survive between years.

Number of collars deployed in combination with actual survival rates determines our ability to detect differences in survival among years, DAUs, or geographic areas. When survival rates are near 0.50, variance, or precision, about the mean survival estimate is largest, and thus the sensitivity to detecting differences in survival rates is least (Zar 1984). As survival rates approach 0.0 or 1.0, precision improves for a fixed sample size of collars, and sensitivity to detecting differences in survival increases. Given our assumptions about expected average survival rates and potential higher calf survival in DAU E-25 based on computer modeling (Freddy 2000), we estimated the statistical power (Snedecor and Cochran 1967; 113, 221, 269; pers. comm. D. Bowden) to detect differences in mean survival rates given specific hypotheses. We consider detecting differences in survival of 0.20 with statistical power of 0.80 at an alpha = 0.10 to be acceptable.

Generalized hypotheses (S = survival rate) and power for detecting major differences in survival among years, DAUs, age and sex classes, and geographic areas.

(1) H_O: $S_{\text{calves year1}} = S_{\text{calves year2}} = S_{\text{calves year3}}$ **for DAUs pooled each year.**
H_A: $S_{\text{calves year1}} \neq S_{\text{calves year2}} \neq S_{\text{calves year3}}$ **for DAUs pooled each year.**
Power = 0.80 at alpha = 0.10 to detect differences in yearly survival of 0.15 between pairs of years given 78 collars per year and expected survival rates of 0.90 and 0.75.
Power = 0.80 at alpha = 0.10 to detect differences in yearly survival of 0.15 between 1 year with lower survival and the average higher survival of the other 2 years given 78 collars per year and expected survival rates of 0.75 and 0.90.

(2) H_O: $S_{\text{calves DAU1}} = S_{\text{calves DAU2}} = S_{\text{calves DAU3}}$ **for years pooled for each DAU.**
H_A: $S_{\text{calves DAU1}} \neq S_{\text{calves DAU2}} \neq S_{\text{calves DAU3}}$ **for years pooled for each DAU.**
Power = 0.80 at alpha = 0.10 to detect a difference in 3-year average survival of 0.15 between pairs of DAUs given 26 collars per year per DAU and expected yearly survival rates of 0.90 and 0.75.

Power = 0.90 at alpha = 0.10 to detect difference in 3-year average survival of 0.15 between 1 DAU with higher survival and the average lower survival of the other 2 DAUs given 26 collars per year per DAU and expected yearly survival rates of 0.90 and 0.75.

Power = 0.90 at alpha = 0.10 to detect difference in 3-year average survival of 0.15 between 1 DAU with higher survival and the average lower survival of the other 2 DAUs given 26 collars per year per DAU and expected yearly survival rates of 0.90 and 0.80 and 0.70 among DAUs.

(3) H_O: $S_{\text{male calves}} = S_{\text{female calves}}$ **for years pooled for each sex.**
H_A: $S_{\text{male calves}} \neq S_{\text{female calves}}$ **for years pooled for each sex.**

Power = 0.90 at alpha = 0.10 to detect difference in 3-year average survival of 0.15 between sexes of calves given 35 collars per year per calf sex and expected survival rates of 0.75 for one sex and 0.90 for the other sex.

(4) H_O: $S_{\text{adultfemales year1}} = S_{\text{adultfemales year2}} = S_{\text{adultfemales year3}}$ **for DAUs pooled each year.**
H_A: $S_{\text{adultfemales year1}} \neq S_{\text{adultfemales year2}} \neq S_{\text{adultfemales year3}}$ **for DAUs pooled each year.**

Power = 0.80 at alpha = 0.10 to detect difference in survival of 0.15 between pairs of years given 56 collars per year and expected survival rates of 0.95 and 0.80.

Power = 0.80 at alpha = 0.10 to detect differences in yearly survival of 0.15 between 1 year with lower survival and the average higher survival of the other 2 years given 50 collars per year and expected survival rates of 0.80 and 0.95.

(5) H_O: $S_{\text{calves}} = S_{\text{adult females}}$
H_O: $S_{\text{calves}} \neq S_{\text{adult females}}$

Power = 0.80 at alpha = 0.10 to detect difference of 0.15 between calf and adult female survival within each year given 56 collars per year per age class and expected survival rates of 0.80 for calves and 0.95 for adult females.

Power = 0.90 at alpha = 0.10 to detect difference in 3-year average survival of 0.10 between calves and adult females given 51 collars per year per age class and expected survival rates of 0.85 for calves and 0.95 for adult females.

(6) H_O: $S_{\text{calves Gunnison}} = S_{\text{calves Grand Mesa}}$ **for years pooled within each area.**
H_A: $S_{\text{calves Gunnison}} \neq S_{\text{calves Grand Mesa}}$ **for years pooled within each area.**

Power = 0.80 at alpha = 0.05 to detect difference in a 3-year average survival of 0.10 between calf survival in the Gunnison Basin and calf survival on the Grand Mesa given 66 collars per year per area and expected survival of 0.80 in the Gunnison Basin and 0.90 on the Grand Mesa.

Survival will be estimated for calves and adults during winter-spring (15 Dec -14 Jun), for adults during summer-fall (15 Jun-14 Dec), and for adults during the year (15 Dec - 14 Dec). The yearly time period, or biological year, initiates with capture and release of marked elk into the population (White et al. 1987). Capture of elk will occur in mid-December instead of early December as on the Grand Mesa (Freddy 1993-1997) to accommodate capture services on other projects. We expect this change in capture dates to have minimal effects on estimates of survival as no natural deaths of calves or adults occurred during December on the Grand Mesa (Freddy 1999).

We will use a staggered entry Kaplan-Meier analysis to estimate survival rates (SAS 1988, White and Garrot 1990, Bartmann et al. 1992). We will compare survival rates using chi-square analyses and conduct pair-wise comparisons using log-rank tests to compare survival of calves and adults among years for DAUs combined, between DAUs for years combined, between male and female calves, and between calves and adults. We will assess whether calf survival can be predicted from sex, body weight, hind foot length, total body length, and mean monthly snow depths and temperature using logistic regression (SAS 1988). Additionally, we will test for differences in survival of calf and adult elk between the Gunnison Basin and the Grand Mesa (Freddy 1998) potentially using beta-binomial distribution approaches outlined by Unsworth et al. 1999. Tests will be significant at alpha $P \leq 0.10$.

PREGNANCY RATES

Fecundity of adult female elk will be determined by examining reproductive organs of antlerless elk harvested during hunting seasons from mid-November through December. Initially, late seasons are scheduled to occur in 2000, but may continue in subsequent years depending upon population management objectives. Numbers of hunters will be controlled by limited permits issued each year. During 2000, we anticipate >650 hunters will provide ≥200 useable reproductive tracts from antlerless elk harvested in portions of DAUs E-25, E-41, and E-43.

Hunters will be mailed packets explaining procedures for collecting reproductive organs and incisor teeth from harvested elk as done previously in Colorado for Middle Park and Forbes-Trinchera elk collections (Freddy 1992, pers. comm. C. Wagner, CDOW). Additionally, we will ask hunters to collect kidneys and associated fat from harvested elk to allow calculation of kidney-fat indices to better assess body condition of adult females in relation to reproductive status (Kohlmann 1999). Hunters will be directed to leave collected organs at drop-off sites in Lake City, Colorado, Gunnison CDOW Service Center, Gunnison commercial meat-processors, and at CDOW Roaring Judy Hatchery.

Fetuses will be sexed, weighed, and measured (Armstrong 1950) with conception dates estimated from fetal measurements (Morrison et al.1959). Pregnancy status, fetal age, fetal sex, and conception dates will be related to female dental cementum age and kidney fat indices using regression analyses (SAS 1988). Additionally, comparisons to reproductive measurements on elk from Middle Park and Forbes-Trinchera will be made.

POTENTIAL ADDITIONAL EXPERIMENTS AND APPLICATIONS

Management of elk in the Gunnsion Basin has contentiously focused on population status of elk, impacts of elk on plant communities, long-term carrying capacities for wild and domestic ungulates and seasonal patterns of habitat use (Carpenter et al. 1980, Roath et al. 1999). Expanding our understanding of these general topics can be greatly enhanced by effectively utilizing the radio-collared elk that will be available because of this project. Investigations regarding these topics could be initiated with additional funding, personnel, and agency cooperation.

Potential investigations could address:

a). Management objectives as of 1999 are to reduce elk populations in DAUs E-25, E-41, and E-43. Reductions are projected to be most severe in DAU E-25 and approach 50% over the next 5 years based on computer models. Reductions in DAUs E-41 and E-43 are projected to be <25% and completed in 2-3 years. If elk are indeed at biological carrying capacity and if reductions proceed in E-25, there may be the opportunity to conduct management experiments to assess whether calf survival and/or fecundity increase in response to lowered density. Radio-collaring and monitoring additional calves each year would be required. Estimated additional costs could approach $50,000.

b). Population reductions may also create an opportunity to apply sampling systems developed to estimate elk density, including mark-resight estimators (Freddy 1998), to verify modeled population status and achievement of populations goals. Estimated additional costs would be in helicopter hours ($40,000) and additional radio-collared elk ($40,000) for mark-resight surveys. Additionally, sampling systems to estimate sex ratios could be implemented and evaluated in E-25 with reallocation of existing survey monies plus an additional $10,000.

c). Patterns of habitat use and forage removal could be investigated utilizing intensive measurements on selected range sites and monitoring of radioed elk and their associates. This would be a major project and possibly approach $100,000 per year including additional personnel.

d). Seasonal movements and patterns of spatial use to document seasonal behavior of elk would require additional personnel and aerial fixed-wing costs of $40,000 per year.

PROJECT SCHEDULE

Fiscal Year	Activity/Objective	Period
2000-01	Complete study plan; purchase radio-collars;	Jul-Nov
	Estimate pregnancy/fetal rates;	Nov-Dec
	Trap and radio-collar elk and estimate survival.	Dec-Jun
2001-02	Estimate survival and hunting removal rates;	Jul-Dec
	Estimate pregnancy/fetal rates;	Nov-Dec
	Trap and radio-collar elk and estimate survival.	Dec-Jun
2002-03	Estimate survival and hunting removal rates;	Jul-Dec
	Estimate pregnancy/fetal rates;	Nov-Dec
	Trap and radio-collar elk and estimate survival; assess potential for mark-resight estimates of elk density.	Dec-Jun
2003-04	Estimate survival and hunting removal rates; complete data analyses, initiate manuscripts.	Jul-Jun

Estimated Annual Costs

FTE Requirements	Budget Category	Costs
PFTE = 1.00	(01) Personal Services	$102,000
TFTE = 0.83	(21) Operating Supplies and Services	84,000
TOTAL = 1.83	(21) Utilities	0
	(28) Travel Expenses	1,000
	(31) Capital Outlay	0
	Total Costs	$187,000

Costs anticipated to increase 5% each year in 2001-02, 2002-03, 2003-4 for inflation.

Personnel Program Responsibilities

David J. Freddy: Wildlife Researcher, Principal Investigator responsible for final project design, organizing field personnel, obtaining and organizing data, data analyses, financial control, and coordinating publications.

R. Bruce Gill: Wildlife Research Leader, provides administrative support, input for study design, and liaison with other administrative sections within the Division of Wildlife.

Rick Kahn, John Ellenberger, Jim Olterman, Don Masden, Jim Young: Provide coordination and support of Terrestrial managers and biologists and Area management staff and facilities.

Gary C. White: Provide input for study design and statistical protocol, conduct data analyses, and provide software support.

David C. Bowden: Provide input for study design and statistical protocol.

E. LOCATION

The Gunnison Basin in south-central Colorado was selected for this project (Fig. 1). The Basin encompasses the entire headwaters of the main Gunnison River and the centrally located town of Gunnison. Between 12-16,000 elk and 8-10,000 mule deer (*Odocoileus hemionus*) are thought to exist within the Basin. Elk are managed as 3 populations representing DAUs E-25 (Game Management Units [GMU] 66, 67), E-41 (GMU 54), and E-43(GMUs 55, 551). The 3 DAUs encompass about 9,291 km^2 of which 3,648 km^2 are considered winter range for elk (CDOW WRIS database). DAUs are contiguous with no major geographic barriers separating DAUs that would prevent interchange of elk among DAUs.

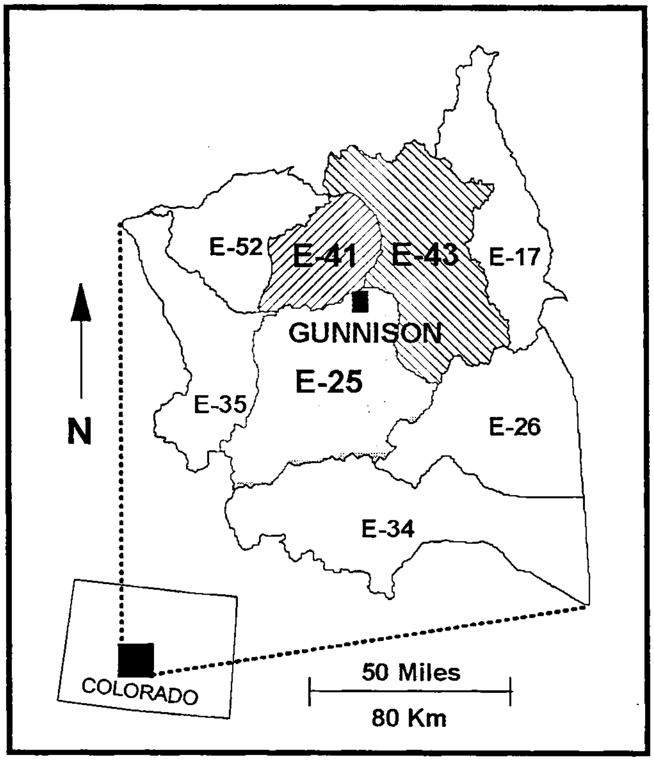

Fig. 1. Location of the Gunnison Basin and elk Data Analysis Units E-25, E-41, and E-43 within Colorado.

The Basin represents a high altitude, cold winter range for both elk and mule deer which is similar to ecosystems in North Park, Middle Park, and the San Luis Valley, Colorado. The sagebrush steppe winter ranges (2,250- 2,700 m elevation) can receive extreme snow depths and cold temperatures that cause severe mortality among ungulates (Carpenter et al. 1984) while the conifer-alpine summer ranges (3,000 - 4,200 m elevation) can be subjected to drought. Overall, these ranges collectively are thought to be less productive and nutritious for elk than the milder climate oakbrush-pinyon-juniper winter ranges of the Grand Mesa where elk survival was measured from 1993-99.

We anticipate dependable access to both private and public lands to conduct research activities and there is local, Area, and Regional CDOW support for conducting the project in this area. Additional financial and logistical support may be available from the Gunnison Habitat Partnership Committee. The airport and other businesses in Gunnison will provide readily accessible support services.

F. RELATED FEDERAL AID PROJECTS

Calf and adult elk survival rates were measured on the Grand Mesa, Colorado from 1993-99 under Federal Aid Research Project W-153-R (Freddy 1994-1999).

G. LITERATURE CITED

Anderson, C.R., Jr., D.S. Moody, B.L. Smith, F.G. Lindzey, and R. P Lanka. 1998. Development and evaluation of sightability models for summer elk surveys. Journal of Wildlife Management 62:1055-1066.

Armstrong, R.A. 1950. Fetal development of northern white-tailed deer. American Midland Naturalist 43:650-666.

Bartholow, J. 1999. POP-II system documentation Windows™ Version 1.0. Fossil Creek Software, Fort Collins, Colorado USA.

Bear, G.D., G.C. White, L.H. Carpenter, R.B. Gill, and D.J. Essex. 1989. Evaluation of aerial mark-resighting estimates of elk populations. Journal of Wildlife Management 53:908-915.

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

Carpenter, L.H., D.L. Baker, and R.B. Gill. 1980. Tests of a nutritionally based big game habitat evaluation system. Colorado Division of Wildlife Unpublished Report. Colorado Division of Wildlife, Fort Collins, Colorado, USA.

Carpenter, L.H., R. B. Gill, D. L. Baker, and N.T. Hobbs. 1984. Colorado's big game supplemental winter feeding program. Colorado Division of Wildlife, Fort Collins, Colorado USA.

Conner, M.M. 1999. Elk movement in response to early-season hunting in the White River Area, Colorado. Dissertation, Colorado State University, Fort Collins, Colorado, USA.

Cogan, R.D., and D.R. Diefenbach. 1998. Effect of undercounting and model selection on a sightability-adjustment estimator for elk. Journal of Wildlife Management 62:269-279.

Eberhardt, L.L., R.A. Garrott, P.J. White, and P.J. Gogan. 1998. Alternative approaches to aerial censusing of elk. Journal of Wildlife Management 62:1046-1055.

Freddy, D.J. 1992. Effect of elk harvest systems on elk breeding biology. Colorado Division of Wildlife Research Report July: 45-70. Fort Collins, Colorado, USA. July:45-70.

Freddy, D.J. 1993. Program Narrative for Estimating survival rates of elk and developing techniques to estimate population size. Colorado Division of Wildlife Research Report July:83-117. Fort Collins, Colorado, USA.

Freddy, D.J. 1994. Estimating survival rates of elk and developing techniques to estimate population size. Colorado Division of Wildlife Research Report July: 27-42. Fort Collins, Colorado, USA.

Freddy, D.J. 1995. Estimating survival rates of elk and developing techniques to estimate population size. Colorado Division of Wildlife Research Report July: 63-79. Fort Collins, Colorado, USA.

Freddy, D.J. 1996. Estimating survival rates of elk and developing techniques to estimate population size. Colorado Division of Wildlife Research Report July: 87-108. Fort Collins, Colorado, USA.

Freddy, D.J. 1997. Estimating survival rates of elk and developing techniques to estimate population size. Colorado Division of Wildlife Research Report July: 47-73. Fort Collins, Colorado, USA.

Freddy, D.J. 1998. Estimating survival rates of elk and developing techniques to estimate population size. Colorado Division of Wildlife Research Report July: 177-206. Fort Collins, Colorado, USA.

Freddy, D.J. 1999. Estimating survival rates of elk and developing techniques to estimate population size. Colorado Division of Wildlife Research Report July: (in press). Fort Collins, Colorado, USA.

Freddy, D.J. 2000. Modeling elk populations in the Gunnison Basin, Colorado using POPII and POPMOD software (draft in process). Colorado Division of Wildlife Special Report No.??, Fort Collins, Colorado USA.

Freddy, D.J., D.L. Baker, R.M. Bartmann, and R.C. Kufeld. 1993. Deer and elk management analysis guide, 1992-1994. Colorado Division of Wildlife Division Report 17, Fort Collins, Colorado USA.

Garrott, R.A., R.M. Bartmann, and G.C. White. 1985. Comparison of radio-transmitter packages relative to deer fawn mortality. Journal of Wildlife Management 49:758-759.

Houston, D.B. 1982. The northern Yellowstone elk, ecology and management. Macmillan Publishing Company, Inc. New York, New York, USA.

Kohlmann, S.G. 1999. Adaptive fetal sex allocation in elk: evidence and implications. Journal of Wildlife Management 63: 1109-1117.

Morrison, J.A., C.E. Trainer, and P.L. Wright. 1959. Breeding seasons in elk as determined from known-age embryos. Journal of Wildlife Management 23:27-34.

Nelson, L.J., and J.M. Peek. 1982. Effect of survival and fecundity on rate of increase of elk. Journal of Wildlife Management 46:535-540.

Petersburg, M., and G. White. 1998. Kaplan-Meier survival estimates for cow elk. Colorado Division of Wildlife Terrestrial Section Unpublished Memorandum, Fort Collins, Colorado USA.

Phillips, G.E. 1998. Effects of human-induced disturbance during calving season on reproductive success of elk in the upper Eagle River Valley, Colorado. Dissertation, Colorado State University, Fort Collins, Colorado, USA.

Quimby, D.C., and J.E. Gaab. 1957. Mandibular dentition as an age indicator in Rocky Mountain elk. Journal of Wildlife Management 21:134-153.

Roath, R., L. Carpenter, B. Riebsame, and D. Swift. 1999. Gunnison Basin habitat assessment project-Final Report March 1999. Colorado State University, Department of Range Science, Fort Collins, Colorado USA.

Samuel, M.D., E.O. Garton, M.W. Schlegel, and R. G. Carson. 1987. Visibility bias during aerial surveys of elk in northcentral Idaho. Journal of Wildlife Management 51: 622-630.

SAS. 1988. SAS/STAT user's guide, release 6.03. SAS Institute, Inc. Cary, North Carolina USA.

Snedecor, G.W., and W.G. Cochran. 1967. Statistical methods, sixth edition. Iowa State University Press, Ames, Iowa, USA.

Singer, F.J., A. Harting, K.K. Symonds, and M.B. Coughenour. 1997. Density dependence, compensation, and environmental effects on elk calf mortality in Yellowstone National Park. Journal of Wildlife Management 61:12-25.

Unsworth, J.W., L. Kuck, and E.O. Garton. 1990. Elk sightability model validation at the National Bison Range, Montana. Wildlife Society Bulletin 18:113-115.

Unsworth, J.W., D.F. Pac, G.C. White, and R.M. Bartmann. 1999. Mule deer survival in Colorado, Idaho, and Montana. Journal of Wildlife Management 63:315-326.

Wade, D.A., and J.E. Browns. 1982. Procedures for evaluating predation on livestock and wildlife. Texas Agricultural Experiment Station Publication B-1429.

White, G.C. 1992. DEAMAN database manager and population modeling procedures; Colorado Division of Wildlife User's manual and reference. Colorado State University, Fort Collins, Colorado USA.

White, G.C. and R.A. Garrott. 1990. Analysis of wildlife radio-tracking data. Academic Press, Inc., San Diego, California USA.

White, G.C., D.R. Anderson, K.P. Burnham, and D.L. Otis. 1982. Capture-recapture and removal methods for sampling closed populations. Los Alamos National Laboratory LA-8787-NERP, Los Alamos, New Mexico, USA.

White G.C., R.A. Garrott, R.M. Bartmann, L.H. Carpenter, and A.W. Alldrege. 1987. Survival of mule deer in northwest Colorado. Journal of Wildlife Management 51: 852-859.

Zar, J.H. 1984. Biostatistical analysis, second edition. Prentice-Hall, Englewood Cliffs, New Jersey, USA.

APPENDIX I
SPECIFICATIONS FOR RADIO-COLLARS

Manufacturer: Lotek, Inc.
Pulse Rate Normal: 60-65 ppm
Pulse Rate Mortality: 120-130 ppm
Motion Sensor Delay: 4-6 hrs
Batteries: 4+ year life, 1 lithium D-cell calf collars
Antenna: External whip, pvc coated
Collar Material: 7.6 cm (3") wide white colored smooth surfaced conveyor belting, 2 layers sewn together, 0.64 cm (1/4") total thickness
Additional Material: Bright yellow with black core Ritchie All-Flex plastic material for identification symbol/number placed as a sleeve over top portion of collar (Ritchey Manufacturing, Inc., Brighton, CO).
Collar Size: 61-81 cm (24-32") adult females, individually fitted; 56-69 cm (22-27") expandable for female calves; 57-89 cm (22.5-35") expandable for male calves.
Collar Weight: 820 gm female calves; 840 gm male calves; 1.1 kg adult females.

APPENDIX II
VISUAL IDENTIFICATION SYSTEM FOR RADIO-COLLARS

Numbers, symbols, and letters will be used in ordered combinations to quickly allow identification of individual elk primarily during aerial surveys. No more than 2 characters will be used to identify an individual. Characters will be ordered and read from left to right on the collar from the perspective of looking down on the elk from the rear of the animal when approached by an observer in a helicopter.

Numbers to be Used (8): 0, 1, 2, 3, 4, 5, 6, and 7
Symbols to be Used (5): solid circle ●, solid square ■, solid triangle ▲, solid hourglass ⧗, plus sign ✚, (solid diamond potentially ◆)
Letters to be Used (9): A, C, F, H, J, K, N, P, X (T, V, Y potentially)

Identification Combinations:

Number combinations represent 56 individuals
10, 20, 30, 40, 50, 60, 70
11, 21, 31, 41, 51, 61, 71
12, 22, 32, 42, 52, 62, 72
13, 23, 33, 43, 53, 63, 73
14, 24, 34, 44, 54, 64, 74
15, 25, 35, 45, 55, 65, 75
16, 26, 36, 46, 56, 66, 76
17, 27, 37, 47, 57, 67, 77

Each Symbol paired with each Number represents 16 identification codes when ordered symbol-number and then number-symbol. Five symbols paired with 8 numbers represents 80 individuals. Examples: 7●and ●7.

Each Letter paired with each Number represents 16 identification codes when ordered letter-number and then number-letter. Nine letters paired with 8 numbers represents 144 individuals. Examples: A7 and 7A.

Each Letter paired with each Symbol represents 10 identification codes when ordered letter-symbol and then symbol-letter. Nine letters paired with 5 symbols represents 90 individuals. Examples: A● and ●A.

Therefore, a minimum of 370 different animals can be individually marked using this system.

APPENDIX III
HELICOPTER NET-GUNNING CAPTURE PROTOCOL FOR ELK

Background: Helicopter net-gunning has been successfully and safely used to capture and radio-collar elk in Colorado during both winter and summer. This success has been in part due to following accepted protocols for handling elk (Colorado Division of Wildlife Animal Care and Use Committee Reviews and Approvals). Helicopter capture of elk on the Grand Mesa, Colorado during December 1993-1996, resulted in no acute or post-capture related deaths in 46 adult females and 1 acute death (broken neck, 0.4%) and 2 post-capture myopathy deaths (0.7%) in 258 calves captured and handled (Freddy 1996, 1997). During early December 1994-96 near Vail, Colorado, 2.2% of 185 adult females died from effects of helicopter capture (Phillips 1998). In the White River, Colorado, <1% of 95 adult female elk captured during July and 4% of 32 adult females captured during August near Vail, Colorado died from effects of helicopter capture (Conner 1999, pers. comm. M. Conner, 1999, Phillips 1998).

Capture Protocol: Capture of elk will follow procedures successfully used on the Grand Mesa (Freddy 1995). David J. Freddy is the principal investigator and will coordinate capture of elk. All persons involved in the capture operation, including the helicopter net-gunning crew, will be instructed on proper care and handling of elk to reduce stress and injury to elk.

Capture Timing and Conditions: Elk are scheduled to be captured during mid-December in the Gunnsion Basin but there remains the possibility that capture could occur in early January depending on availability of contract helicopter services. During either month, cool ambient temperatures and moderate snow depths (<60cm) contribute to successfully capturing elk by reducing threats of hyperthermia potentially induced by capture chases. We anticipate capturing elk when ambient temperatures are -18 - 3°C. Temperatures < -18°C (0° F) may restrict human efficiencies while temperatures >3°C (38° F) may induce hyperthermia in elk.

No-fly Zones: Pursuit and capture of elk will not occur within 1,000m (0.5 miles) of human residences or other cultural developments such as well traveled roads, reservoirs, etc..

Notification of Affected Parties: Local residents and federal, state, and local agencies will be notified of the time and general area of capture activities. Notification will be via newspaper articles, public meetings, and other informal verbal communications.

Emergency Services: Capture personnel will be instructed that the nearest medical and emergency services are located at the Gunnison Valley Hospital in Gunnison. Capture crews will have communications radio contact to CDOW service centers and emergency Colorado State Patrol.

Radio Collars/Ear Tags: Expandable collars will be placed on male and female calves to accommodate neck growth as animals become adults (Appendix I). Collar design was previously used on 285 elk calves on the Grand Mesa with no known cases of expandable collars inducing trauma for up to 4 years of age on males and 7 years of age on females (Freddy 1999). Collars of fixed size will be placed on each adult female and individually fitted usually to 69-74 cm (27-29 in). Fixed collar design was previously used on 82 adult females with no known cases of trauma (Freddy 1999). No ear-tags will be used.

Command Post: The principal investigator and handling crew will establish mobile command /handling sites that will be near actual locations of capture. The handling crew will be ferried by the capture helicopter as needed. At these command posts, elk calves will be weighed, measured, collared and released while adult female elk will be captured and released at the point of capture. This will facilitate efforts of the principal investigator to remain in contact with the helicopter net-gunning crew and make all decisions regarding care and welfare of captured elk.

Chase Time: The helicopter crew will locate groups of elk and determine if calves and adult females are present. If the group is >20 animals, the helicopter will splinter the group into smaller groups within 1-2 minutes of detecting the initial group. The helicopter will then spend <5 minutes maneuvering a smaller group to a suitable capture site. Once a target animal is selected it will be actively pursued for ≤1 minute or until active panting is observed at which time the pursuit is terminated. Total time spent disturbing the initial group and target animal should be <10 minutes. No more than 2-3 animals will be taken from an initial group to avoid unnecessary chase time of non-target animals. Care will be taken by the helicopter crew to avoid chasing animals into fences, roads, rivers, or unfavorable terrain.

Animal Care and Handling: Elk calves will be hobbled and blindfolded at the point of capture and then slung under the helicopter, one calf per ferry, to a nearby command/handling site where they will be measured, weighed, collared, and released at that site. Capture locales will be within 1-2 minutes of flying time or <3,000m (2 miles) of command/handling sites. Adult females will be blindfolded, hobbled, collared, aged, and then released at the point of capture by the net-gunning crew. Adult females will be assigned to an age class based on relative wear and height of incisors: yearling, 2-4 years, 5-9 years, and >9 years (Quimby and Gaab 1957). At the handling site, 3-4 persons will handle and release calves. Calves will be gently lowered to the ground by the helicopter near the handlers at which time handlers will check calf for injuries, remove netting, and check blindfold and hobbles for proper function. Rectal temperature will then be measured using a digital thermometer (°F) while measurements of total body length (cm), hind foot length (cm) are being obtained. If rectal temperature is ≥41.9°C (107.4°F) and heavy panting evident, the calf will be only collared and released and not weighed to reduce handling time. Previous experience on the Grand Mesa indicated calves survive when rectal temperatures briefly approach 42.2°C (108°F) (Freddy, unpubl. data). The 2 cases of capture myopathy on the Grand Mesa were males with rectal temperatures of 42.2 and 41.5°C (100th and 90th quantiles, respectively), ambient air temperatures -2.2 and 3.9°C (<50th and 90th quantiles, respectively), and below average body weights <108kg. Assuming acceptable body temperature, the calf will be weighed (kg) by gently sliding the calf into a weigh-bag which will support the entire weight of the calf while the calf is hoisted by a pulley and suspended from a scale affixed to a portable steel quad-pod. Care will be taken to always support the spine and neck of the calf during the weighing process. Once weighed, calves will be lowered to the ground, slid out of the bag, radio-collared, hobbles removed, blindfold removed, and released towards the direction from which they were ferried by the helicopter. Previous experience on the Grand Mesa indicated calves readily find and join elk groups after being released. Total time to process and release calves should be ≤8 minutes. If ambient air temperature exceeds 3.3°C (38 °F), capture activities will likely be halted, especially if snow is not present to help cool captured elk.

Injured Animals: We expect <3% serious injury/mortality rate. Capture techniques will be constantly monitored and changed if necessary to insure that minor injuries to animals do not chronically occur. However, any debilitating injury or mortality of a captured elk will cause at least temporary suspension of capture activities to assess the cause of injury and if further injuries can be prevented. Animals having a broken leg, neck, pelvis, or other debilitating wound will be euthanized with a gunshot to the head (0.357 or larger caliber pistol) following euthanasia protocols of the Colorado Division of Wildlife Animal Care and Use Committee. The principal investigator will make decisions regarding euthanasia but all persons involved in capture will be trained to properly euthanize appropriate animals. The helicopter net-gunning crew and the handling crew will both have ready access to pistols needed for euthanasia. Euthanized animals will be processed for human consumption and donated to social service agencies.

Release of Animals: While still blindfolded, hobbled, and prior to release, elk will again be examined for injuries. Superficial injuries such as abrasions and small cuts will be treated with antibiotic ointment. The release sequence will be to place elk in sternal recumbency with head pointed towards direction of capture, remove hobbles, remove blindfold, physically hold elk until elk regains eyesight and orientation, at which time handlers release elk and help elk maintain its balance and upright position. Elk will then be observed for any signs of injury while moving away from handlers. Care will be taken to avoid releasing elk towards fences or unfavorable terrain.

Post-Capture Monitoring: All radioed elk will be monitored for their life/death status ≥2 times within 10 days of capture. If a mortality occurs, the carcass will be located, necropsy performed, and cause of death estimated if possible. If available, muscle tissue samples will be collected and sent to Colorado State University Veterinary Diagnostic Laboratory to detect evidence of capture myopathy.

Colorado Division of Wildlife
Wildlife Research Report
July 2001 and July 2002

PROGRESS REPORT

State of Colorado : Division of Wildlife – Mammals Research

Work Package No. 3003 : Predatory Mammals Conservation

Task No. 3 : Pilot Study – Evaluation of GPS Technology in Measuring Chronic Wasting Disease Prevalence Among Deer Preyed upon by Puma

Period Covered: January 1, 2001 – December 31, 2001

Author: C. E. Krumm, T.D.I. Beck, M. W. Miller.

Personnel: C. E. Krumm, T.D.I. Beck, M. W. Miller

Interim Report – Preliminary Results

This work continues, and precise analysis of data has yet to be accomplished. Manipulation or interpretation of these data beyond that contained in this report should be labeled as such and is discouraged.

ABSTRACT

A prospectus for a pilot study to ascertain the efficacy and feasibility of using Global Position Systems (GPS) technology to measure chronic wasting disease prevalence among puma prey, as well as in other studies of puma, was developed. Objectives of the pilot study are to:

1) Evaluate the potential utility of Televilt Positioning GPS collars in studies of selective predation in puma under field conditions; and
2) Develop and assess the adequacy of field sampling techniques for studying selective predation on CWD-infected mule deer.

Two adult puma are to be captured and fitted with GPS collars for the pilot study.

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PILOT STUDY

Evaluation of new GPS technology in measuring chronic wasting disease prevalence among deer preyed upon by mountain lions

C. E. Krumm, T. D. I. Beck, and M. W. Miller

Background

As a pilot study to test a new technology in Global Positioning Systems (GPS) and its application to studies of predator-prey relationships, we plan to capture and collar two free-ranging puma (*Puma concolor*) in the foothills west of Ft. Collins in early April of 2001. Our pilot study will evaluate new GPS technology, as well as the potential utility of data collected with this system in testing hypotheses about selective predation; specifically, we will evaluate the ability to compare chronic wasting disease prevalence among puma-killed deer to prevalence among harvested deer.

Chronic wasting disease (CWD) is a naturally occurring spongiform encephalopathy of captive and free-ranging deer and elk. CWD has become a concern in managing deer herds in northeastern Colorado. Studies conducted the past several years have provided important data on prevalence of CWD (Miller et al. 2000) and the potential effects of selective population control on affected populations (Gross and Miller 2001). It follows that processes fostering selective removal of affected individuals, like test-and-slaughter or predation, should be closely evaluated in the context of disease management.

New technology in GPS tracking of animals by Televilt Positioning (Lindesberg, Sweden) allows location data to be downloaded remotely without retrieval of collars. Testing the effectiveness and accuracy of these collars will benefit a suite of studies that are being planned across Colorado to examine the selectivity of puma for prey animals (specifically mule deer) of varying condition. These studies will help to answer a fundamental ecological question: Do puma selectively prey on debilitated or compromised animals rather than healthy ones?

Objectives

Our specific objectives are to:

1. evaluate the potential utility of Televilt Positioning GPS collars in studies of selective predation in puma under field conditions; and
2. develop and assess the adequacy of field sampling techniques for studying selective predation on CWD-infected mule deer.

Study Design

Because this is a pilot study, we will capture and collar only two adult puma to evaluate equipment and sampling techniques. We regard two individuals as the fewest needed to adequately assess all aspects of equipment use and performance, sampling techniques, and other logistical facets of larger prospective studies.

Capture Methods and Handling

We plan to capture adult puma for this study using methods described in Shaw (1979). Briefly, a tracker with experience in tracking and handling mountain lions will be hired to facilitate capture and will use trained dogs to track and tree or bay each mountain lion. Field anesthesia will be supervised by an attending veterinarian. Anesthetic drugs will be administered intramuscularly via projectile syringe using a gas-powered projector. For capture, puma will be anesthetized with ketamine (10-11mg/kg) and xylazine HCl (1.8-2mg/kg) or ketamine (2 mg/kg) and medetomidine (0.075 mg/kg) (Shaw 1979, Kreeger 1996). We will observe darted puma for signs of sedation (salivation, unsteadiness of head and body, and a wide-eyed expression). If the puma is treed, then people and dogs will be removed from the immediate area to give the animal a chance to descend before becoming completely anesthetized. If the puma remains in the tree until almost completely anesthetized, then someone wearing climbing gear will climb to the puma and attach either a chest harness (preferred) or hind leg noose and quickly lower the animal before it falls; others will hold a taut net below to break the puma's fall should it slip before a harness or rope can be secured. If signs of anesthesia are inapparent after 15 minutes, then a second full injection will be given.

Upon first approach of an apparently anesthetized puma, a 4-5 foot stick will be used to gently prod the paws and muzzle of the animal; if there is no response (i.e. snarling or biting), then we will assume anesthesia is sufficient for handling. Once anesthetized, we will apply eye ointment and a blindfold to reduce visual stimuli, place gauze pads in the puma's ears to reduce auditory stimuli, and restrain its legs with nylon belts or hobbles. A GPS-Simplex collar (Televilt Positioning; maximum weight 600 g) will be fastened around the puma's neck. The leg restraints will be quickly removed, and the puma will be allowed to recover from the sedation either naturally or with the aid of an antagonist; when prescribed, yohimbine HCl (0.125 mg/kg IV) will be used to antagonize xylazine sedation and atipamezole (0.3 mg/kg) will be used to antagonize medetomidine sedation.

Postcapture Monitoring

According to the manufacturer, the locations of collared animals can be retrieved and plotted several times a day without removing the collars. Up to 2000 satellite positions can be stored in the memory, allowing us to closely monitor the puma's movement on a daily basis. If a puma remains in one location for several hours, we will assume that it has made a kill. Based on data from studies elsewhere (e.g., Hornocker 1970, C. Anderson, personal communication), we anticipate that each collared animal will make an ungulate kill every 7 to 11 days on average. We will locate the prospective kill site using the GPS-Simplex system. We will evaluate whether using this system allows us to locate kill sites quickly enough to retrieve a suitable tissue sample to test for CWD. If the animal killed is a deer, the presence of suitable diagnostic samples (brain stem and tonsil tissues) and overall carcass condition will be noted, and tissues will be taken to test for CWD when available. To evaluate the effect of carcass sampling activities on puma behavior, we will alternate taking the entire head of the kill with sampling only the necessary tissues in the field to compare the effect on the puma's return to the kill. The animals will be monitored closely after the kill has been sampled to ensure our handling does not interfere with their return to the kill site. Generally, researchers' presence at and inspection of a kill site does not dissuade a puma from returning to that site (T. Beck, unpublished data). However, if it becomes apparent that one technique is more disruptive than the other, then we will adopt the least disruptive sampling technique for the remainder of the study.

Both puma will remain collared for a period of no less than one month unless the collars appear to be adversely affecting them. We will monitor each animal for changes in behavior like decreased kill rates or mobility that may be attributed to the collars. If the collars seem to have no adverse effects on the puma, then they will remain in place until the batteries must be replaced (about 3-4 mo, depending on final programming configuration). If the collars need to be removed for any reason, the same capture and handling methods as described above will be used for recapture.

Data from this pilot study will be used in designing more comprehensive studies of puma-deer relationships in Colorado, and may be of use in other studies of predator-prey ecology.

Literature Cited

Gross, J. E., and M. W. Miller. 2001. Chronic wasting disease in mule deer: A model of disease dynamics, control options, and population consequences. J. Wildl. Manage. *In press*.

Hornocker, M. G. 1970. An analysis of mountain lion predation upon mule deer and elk in the Idaho Primative Area. Wildlife Monographs 21.

Kreeger, T. J. 1996. Handbook of wildlife chemical immobilization. International Wildlife Veterinary Sciences, Inc. Laramie, Wyoming, USA.

Miller, M. W., E. S. Williams, C. W. McCarty, T. R. Spraker, T. J. Kreeger, C. T. Larsen, and E. T. Thorne. 2000. Epizootiology of chronic wasting disease in free-ranging cervids in Colorado and Wyoming. Journal of Wildlife Diseases 38:676-690.

Shaw, H.G. 1979. Mountain lion field guide. Fourth edition. Arizona Game and Fish, Phoenix, Arizona, USA.

Colorado Division of Wildlife
Wildlife Research Report
July 2001 and July 2002

PROGRESS REPORT

State of Colorado : Division of Wildlife – Mammals Research

Work Package No. 3004 : Other Ungulate Conservation

Task No. : Annual Winter Count of Middle Park Pronghorn

Period Covered: July 1, 2000 - June 30, 2001

Authors: Thomas M. Pojar

Personnel: CDOW – T.M. Pojar, R. Firth, J.Claassen, M. Crosby, K. Holinka, T. Kroening, R. Thompson, C. Wagner. Others – C. Cesar (BLM). Volunteers – B. Kraft, R. Nutter, D. O'Sullivan, M. Palowoda.

MIDDLE PARK PRONGHORN
WINTER 2000-01 COUNT

Tom Pojar, February 13, 2001

The annual winter count of the Middle Park pronghorn herd was conducted during February 9 through February 12, 2001. The major effort was done on February 9th when several observation crews from Area 9 assisted and the largest pronghorn groups were counted. The smaller, more isolated groups were counted during subsequent days.

Division of Wildlife personnel from Area 9 that participated in the count were: Jerry Claassen, Mike Crosby, Kris Holinka, Tom Kroening, Jim Liewer, Bob Thompson, and Chuck Wagner. Chuck Cesar of BLM assisted as well as the following volunteers: Ben Kraft, Ron Nutter, Dan O'Sullivan, and Marie Palowoda.

This year's count was made more interesting with the infusion of animals into the population from the Blue Valley Ranch transplant. The purpose of this transplant was to expand the range of the Middle Park population to wintering areas south of the Colorado River. Throughout the years of habitation, the pronghorn have only wintered north of the Colorado River. BVR pronghorn were released from enclosures they were held in during winter 1999-00 around June 1, 2000. At this point they were free to select the summer, and subsequently, the winter range they found desirable. Of 50 BVR pronghorn radioed, 39 survived to the winter of 2000-01. Twenty-six of these are wintering south of the Colorado River; 15 west of BVR headquarters west of the Blue River, 2 west of Jim Yust's (west of the Blue River), and 9 east of Junction Butte, which is east of the Blue River. Thirteen of the BVR radioed animals are wintering north of the Colorado River with groups of the "native" pronghorn.

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Count North of the Colorado River

AREA	COUNT
Back Troublesome	176
Starr Gulch	221
NE Red Mt.	138
Pinto Ranch	4
TOTAL	**539**

Count south of the Colorado River

AREA	COUNT
Junction Butte – east	13
Blue Valley Ranch – west	28
Jim Yust's ranch – west	2
TOTAL	**43**

GRAND TOTAL = 582

The conclusion from this count is that there are at least 582 pronghorn wintering in Middle Park during winter 2000-01. A spreadsheet population model has been maintained for this herd since it was first being tracked in 1986. The projected winter population has corresponded with the actual count quite closely through the years with a mean deviate count of 17. This year, the model projects a population of 675 for the largest discrepancy ever encountered – 93 animals. The model was adjusted for the infusion of BVR animals with the fawn to doe ratio applied to all mature females in the entire Middle Park population.

There are several possible scenarios to explain the apparent undercount for this year. No new radios have been deployed on the population north of the Colorado River since 1998. Population growth, radio failure, and harvested radioed animals have contributed to dilution of the proportion of radioed animals. This year about 5% of the population north of the river are carrying working radios. As this percentage decreases the probability of having a group of animals without at least one radio in it to allow detection increases. Finding pronghorn groups with winter conditions featuring a mottled background of snow and sagebrush can be very difficult. Radios are crucial to locating pronghorn groups during winter. All of the radios that were presumed to be working were located except 3. Although these radios were located earlier in the fall during the herd structure survey they may have failed since then or it is possible we missed detecting them during the winter count. The Antelope Creek, Antelope Pass, Cow Gulch, Wolford Mountain, Sulphur Gulch, and Corral Creek areas were searched and radio scanned for these 3 radios. The fact that these radios were not found does not eliminate the possibility that a group (or groups) of pronghorn were missed.

Winter conditions are mild thus far this year. The winter began with a much colder than normal November and some snow. However, milder conditions prevailed during December, January, and so far in February. Snow depth where the pronghorn are wintering ranges from 4-10 inches with clear south facing slopes and adequate wind-blown ridges. In brief, the pronghorn should come through this winter in very good condition barring any severe late winter weather.

Colorado Division of Wildlife
Wildlife Research Report
July 2001 and July 2002

JOB PROGRESS REPORT

State of Colorado : Mammals Research

Work Package No. 1A : Multispecies Investigations

Task No. 5 : Consulting Services for Mark-Recapture Analysis

Federal Aid Project No. W-153-R-2 : Research and Development

Period Covered: July 1, 2000 - June 30, 2001

Author: G. C. White, Ph.D.

Personnel: C. Bishop, R. B. Gill, D. C. Bowden, R. M. Bartmann, D. J. Freddy, T. M. Shenk, M. M. Conner, M. Post Vieira, A. Dharman, B. Lubow

ABSTRACT

Progress towards the objectives of this job include:

Consulting assistance to CDOW on harvest surveys, terrestrial inventory systems, and population modeling procedures was provided. Estimates of spring and fall turkey, spring snow goose, sharp-tailed and sage grouse, chukars, ptarmigan, Abert's squirrels, and general small game harvest were computed from survey data, and programs and harvest estimates provided to CDOW via email and CD ROM. Input on the design and analysis of the Harvest Information Program was provided on several occasions.

The DEAMAN software package for the storage, summary, and analysis of big game population and harvest data was revised further as a Windows 95/98/NT/2000/ME program. The capability to incorporate data on radio-collared animals to estimate survival with the Kaplan-Meier estimator and display movement data was added, and distributed to terrestrial biologist via the WWW at http://www.cnr.colostate.edu/~gwhite/deaman.

A 1-day workshop was conducted with NE region personnel in the use of DEAMAN and population modeling procedures, mainly to instruct region personnel on the use of spreadsheet models for ungulate population dynamics. In addition, numerous questions were answered via meetings with biologists, and via email.

A preliminary analysis of the survival rates from the mule deer monitoring data was completed. However, I have not received final data from some of the biologists, so have not been able to complete this analysis.

A paper, coauthored with Bruce Lubow, was submitted for publication to the Journal of Wildlife Management on past efforts to develop a realistic mule deer population model based on data collected with current CDOW procedures. Data from the Piceance Basin were used to illustrate the modeling

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technique. In addition, a book chapter on modeling big game populations appeared in print: White, G. C. 2000. Modeling Population Dynamics. Pages 84-107 *in* S. Demarais and P. R. Krausman, eds. Ecology and Management of Large Mammals in North America. Prentice-Hall, Upper Saddle River, New Jersey, USA.

A paper on optimal allocation of resources to sample Colorado mule deer populations was published in the Journal of Wildlife Management: Bowden, D. C., G. C. White, and R. M. Bartmann. 2000. Optimal allocation of sampling effort for monitoring a harvested mule deer population. Journal of Wildlife Management 64:1013-1024.

A paper on trends in Colorado mule deer age and sex ratios was published in the Journal of Wildlife Management: White, G. C., D. J. Freddy, R. B. Gill, and J. H. Ellenberger. 2001. Effect of adult sex ratio on mule deer and elk productivity in Colorado. Journal of Wildlife Management 65:436-444.

Assistance in the design and analysis of candidate systems to estimate deer abundance in GMU 10 was provided.

A research study to examine the impact of nutrition on the decline of mule deer fecundity during the last 20 years was initiated. I have provided input on estimation of the number of deer on the feed sites, and developed an estimator of fawn survival rates based on radio-collared does and fall and spring fawn:doe ratios.

Data were collected and analyzed on spatial distribution, movement of radio-collared animals, and population sizes related to estimating the spread and impacts of chronic wasting disease in deer populations. A report summarizing these findings was provided to CDOW personnel involved with the study.

A final report on the response of elk to lower numbers of archery licenses in the White River Data Analysis Unit was prepared and submitted to CDOW personnel involved with the project. A paper reporting results of the earlier experiment to detect elk response to the opening of archery season has been accepted for publication in the Journal of Wildlife Management: Conner, M. M., G. C. White, and D. J. Freddy. 2001. Elk movement in response to early-season hunting in Colorado. Journal of Wildlife Management 65. In Press.

A graduate research project to evaluate the movements of Preble's meadow jumping mouse populations away from riparian areas was completed. A final report of this project was submitted to CDOW personnel involved with the project.

In cooperation with CDOW personnel, I developed an analysis of survival of lynx released as part of the reintroduction program.

An analysis to estimate the effort required to estimate the percent of eastern Colorado inhabited by black-tailed prairie dogs was completed and results provided to CDOW personnel involved with the effort.

CONSULTING SERVICES FOR MARK-RECAPTURE ANALYSES

G. C. White

P. N. OBJECTIVES

Design a sampling scheme to estimate the area of black-tailed prairie dog colonies in eastern Colorado.

SEGMENT OBJECTIVES

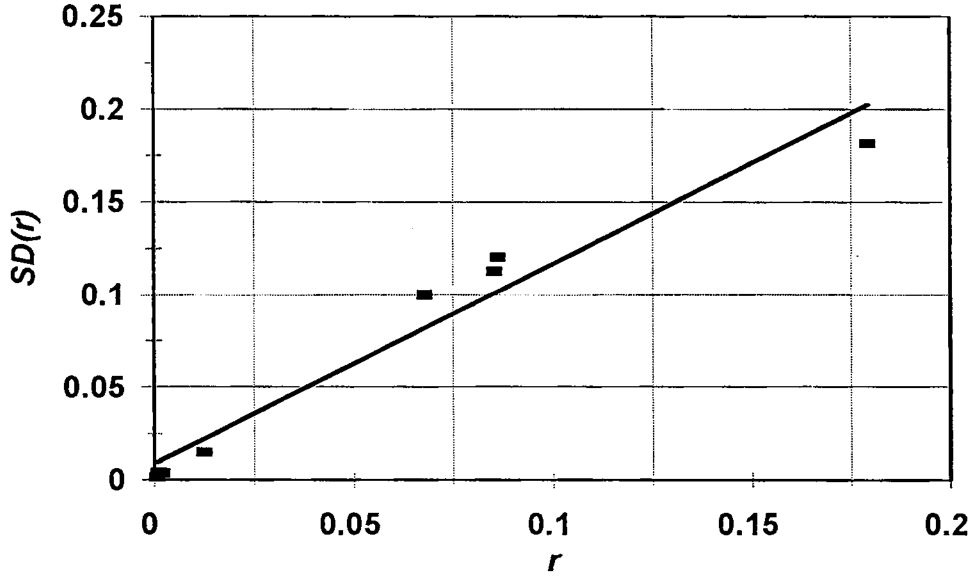
1. Develop a sampling scheme to estimate the area of black-tailed prairie dog colonies in eastern Colorado.
2. Develop estimates of the cost of this sampling scheme as a function of the expected precision.

RESULTS AND DISCUSSION

Area of black-tailed prairie dog colonies in Wyoming, North and South Dakota, and Nebraska have been sampled successfully with aerial line intercept sampling techniques (Sidle et al. In Press). CDOW is interested in applying this technique to eastern Colorado, and obtaining estimates of the areas occupied by prairie dogs by county. However, there are concerns regarding the cost of the survey and expected precision. In the following, I present an analysis of the expected cost as a function of the precision of the estimates of area of black-tailed prairie dog colonies.

To compute the expected precision as a function of the cost of the aerial survey for black-tailed prairie dogs, I went through the following steps.

> I assumed that the lines to be flown would be stratified by county. Because an infinite number of lines can be flown for each county, the sampling scheme can be viewed as sampling with replacement, and hence, no finite population correction is allowed. Further, I treated each line as providing an estimate of the proportion of the county area in active prairie dog towns, and not as a ratio estimator. Sidle et al. (In Press) compared both types of estimators, and developed a composite of the 2. However, design of a new survey seemed easier to conceptualize with the approach taken. This approach allowed the use of the formulas on pages 341-342 of Thompson et al. (1998), ignoring the finite population correction. Other pertinent references are Thompson (1992) and Cochran (1997).
>
> From the area of each county and the estimated area of prairie dog towns within the county provided by the EDAW survey, I predicted the proportion of the line in each county that would intersect dog towns (r) as:
>
> $$r = \frac{\text{Active Towns Area}}{\text{County Area}} = \frac{\text{C}}{\text{A}} .$$
>
> From Table 1 of Sidle et al. (In Press) I computed the relationship between the standard deviation of r [SD(r)] and the value of r. To compute SD(r) from Table 1 of Sidle et al., I got the number of lines flown for each of the 8 surveys from Douglas Johnson, Northern Prairie Wildlife Research Center, USGS. A linear relationship of $\text{SD}(r) = 0.0087 + 1.0804r$ was found to provide a decent fit to the data (Figure 1).



I assumed that each county was to be estimated with some relative precision (e) such that the 95% confidence interval for each county would be ± eC, where C is the estimated acres of active towns. This approach is not the optimal for the estimate of the total active town area in the state, but would provide good estimates (i.e., estimates of quality e) for each county. For each county, the standard error of the estimate of the active prairie dog town area [SE(C)] was computed based on the SD(r) and the estimated number of lines (n) to be flown, where $\mathrm{SE}(r) = \mathrm{SD}(r)/\sqrt{n}$, and $\mathrm{SE}(C) = A^2\mathrm{SE}(r)$. Given the desired level of precision, I computed the number of lines to fly in a county as:

$$n = \left(\frac{1.96 \ A \ \mathrm{SD(r)}}{\mathrm{e \ C}} \right)^2 .$$

Because some counties had values of $C = 0$ (and hence the above equation is undefined), and others have very small values, I assumed that all counties had at least 0.5% area in active towns to compute these samples sizes, although the actual value of r was used to compute the standard deviation.

The total length of the lines to be flown in the county is the square root of the county area multiplied by the number of lines to be flown.

Cost of the survey for a county was figured as the length of line to be flown plus 2 times the square root of county area in miles (to account for ferry time), all divided by a flight speed of 90 mph, times $180 per hour of flight time.

The total acreage of prairie dog towns (C_T) is the sum of the county estimates, with the variance computed as the sum of the variances across the counties.