WILDLIFE RESEARCH REPORTS

JULY 2009 – AUGUST 2010

AVIAN PROGRAM

COLORADO DIVISION OF WILDLIFE
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Colorado Division of Wildlife
July 2009 – August 2010

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COLORADO DIVISION OF WILDLIFE - AVIAN RESEARCH PROGRAM
PROGRESS REPORT
September 2010

TITLE: Demography and Dispersal of Gunnison sage-grouse (*Centrocercus minimus*)

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PROJECT PERSONNEL: Colorado Division of Wildlife: R. DelPiccolo, J Wenum; Colorado State University: A. Davis, P. Doherty, P. Street

Period Covered: December 1, 2008 - August 1, 2010

ABSTRACT

In 2005, the Colorado Division of Wildlife (CDOW) initiated a research project to evaluate the demography and movement patterns in two Gunnison sage-grouse (GUSG) populations. The objective is to develop population and landscape models that will be used in the development and refinement of management plans for GUSG and to update the population viability analysis used in the Gunnison Sage-grouse Rangewide Conservation Plan. Acquiring more precise estimates of demographic rates (and their variances) will enable us to evaluate the relative importance of various environmental and demographic factors that potentially influence population abundance, dynamics and persistence of GUSG. There are seven GUSG populations distributed across southwestern Colorado and southeastern Utah. Six of the populations are relatively small (with < 100 males counted on leks and < 100,000 acres of sagebrush habitat) compared to the Gunnison Basin (with 750-1,000 males counted on leks and > 500,000 acres of sagebrush). We chose to contrast the demography and movement patterns of GUSG in one of the small populations in San Miguel County with the large population in Gunnison County. The population in San Miguel County is one of the more complex of the smaller populations with approximately 6 isolated communities. Gunnison Basin and San Miguel are the only populations in which long distance movements of hens from the point of capture to a nesting area has been documented (Apa 2004). We currently lack information on the role of landscape features (e.g., the composition and fragmentation of sagebrush habitat) on the movement patterns and demography of GUSG. This report represents the fifth year of field work on this project (including 2 years of pilot and baseline data in Gunnison Basin). This is the final field season for this project.

DEMOGRAPHY AND DISPERSAL OF GUNNISON SAGE-GROUSE (*Centrocercus minimus*)
Progress Report, December 1, 2008 - August 1, 2010
Michael L. Phillips

PROJECT OBJECTIVES

1. Acquire current estimates of nest success, juvenile survival, and adult survival with estimates of temporal and spatial process variation for 2 populations of Gunnison sage-grouse (GUSG).
2. Record movement patterns and dispersal behaviors of GUSG and use the information to develop landscape use and movement models and spatial models of demographic parameters.
3. Use the above estimates to update and refine a population viability analysis (PVA) model developed for the GUSG Rangewide Conservation Plan (Gunnison Sage-grouse Rangewide Steering Committee. 2005) and to develop a spatially-explicit population model (SEPM) for GUSG.
4. Use estimates of demographic parameters and model output to develop and evaluate the projected consequences of alternative management plans.

SEGMENT OBJECTIVES

1. Capture and radio-mark 30 adult females in the Gunnison Basin population and 10 females in the San Miguel population each year to determine nest success and survival of adults and juveniles.
2. Capture and radio-mark 40 chicks in the Gunnison Basin population and 10-15 chicks in the San Miguel population each year to determine survival and movement patterns of juvenile GUSG.
3. Record locations of radio-marked GUSG every 1-3 days during April–September each year to determine movement patterns in the 2 populations.
4. Record locations of radio0marked GUSG once a month during October–March each year to record winter movements and survival of adults and juveniles.

INTRODUCTION

Our ability to conserve GUSG will depend on our ability to restore and manage a biologically relevant mosaic of habitats. PVA and SEPM are 2 analytical tools increasingly used by conservation biologists to evaluate the relative effects of demographic rates and changing landscape structure on the viability of populations. Before such models can be constructed, there is a need for reliable estimates of demographic and behavioral data for GUSG. We currently lack information on how productivity, recruitment and movement patterns of GUSG may be a function of landscape features. Information on movement patterns and dispersal is necessary before constructing a useful SEPM. We need to determine how far and under what conditions GUSG move and disperse, and how these behaviors are influenced by landscape features and how the landscape feature in turn influence demographic parameters (e.g., nest success, and survival). Developing valid models of population viability and population dynamics will require information on the effect of landscape features (e.g., changes in the composition and fragmentation of sagebrush habitat) on dispersal patterns and demographic rates (and their variances) in the Gunnison Basin in contrast with at least one of the smaller populations. The Gunnison Basin has the largest GUSG population (750-1,000 males counted on leks in the last 5 years) and the largest amount of relatively homogeneous sagebrush habitat (> 500,000 acres) of the 7 GUSG populations. In contrast, the sagebrush communities in the other 6 populations are smaller (< 100,000 acres of sagebrush habitat), potentially more fragmented and fewer individuals (< 100 males counted on leks).

The GUSG population in the San Miguel Basin is one of the more complex of the smaller populations with approximately 6 isolated communities. Movement by a few individuals between these sagebrush communities has been observed in the San Miguel Basin (T. Apa and J. Stiver, *pers. comm.*).

Furthermore, Gunnison Basin and San Miguel are the only populations in which long distance movements of hens from the point of capture to a nesting area have been documented (Apa 2004).

Because little demographic data for GUSG was available, the PVA developed for the GUSG Rangewide Conservation Plan (RCP) relied largely on information available for greater sage-grouse (*Centrocercus urophasianus*). Results from this study will be used to refine the PVA in the GUSG RCP, and will also be used to develop a SEPM designed specifically for GUSG. Acquiring more precise estimates of demographic rates (and their variances) will enable us to develop more reliable models of population viability, as well as evaluate the relative importance of various landscape and demographic factors that potentially influence population abundance, dynamics and persistence of GUSG. Development of relevant management strategies for GUSG will depend on modeling efforts derived from reliable estimates of demographic rates and behavioral patterns (e.g., movement and dispersal).

A refined PVA model will allow more realistic projections of persistence time and a more rigorous evaluation of the relative demographic and environmental factors influencing the viability of GUSG. The PVA developed for the GUSG RCP indicated that juvenile mortality and female productivity have significant impacts on population growth. If these conclusions withstand scrutiny using demographic data specific to GUSG, then management actions should be developed that will directly influence these parameters. Furthermore, the population targets reported in the GUSG RCP may need to be revised if there are significant differences in species-specific demographic and behavioral data.

A SEPM will be a valuable tool that will allow researchers and managers to develop and evaluate alternative management plans specifically for GUSG. A SEPM will allow land managers to evaluate the relative merits of proposals for land acquisition and easements based on spatially explicit demographic and behavioral data (e.g., what is the potential for sage-grouse to use a specific land parcel and what effect may it have on the local population persistence). A SEPM will be a valuable tool to evaluate potential linkages between GUSG populations that are proposed in the GUSG RCP. Currently we do not have the movement and dispersal data necessary to prioritize the proposed linkages. Furthermore, a SEPM would be used to refine the Theobold model of risk assessment of residential development used in the GUSG RCP.

The development of a PVA and a SEPM are valuable tools for evaluating the relative threats to GUSG; however, the models do not automatically indicate which management strategies will have the greatest impact on minimizing the threats. Therefore, species-specific data and modeling results acquired in this study will ultimately be used to develop a decision analysis approach to evaluating alternative management programs. Decision analysis is an analytical approach to evaluate the relative outcomes of alternative management actions. Using the approach, managers can assess alternative strategies by incorporating the probability of an event occurring (given a particular strategy) and the probabilities of several potential outcomes as a result of that event. In this manner the consequences of management strategies can be evaluated more quantitatively (in a probabilistic framework) than qualitatively.

STUDY AREA

There are seven GUSG populations distributed across southwestern Colorado and southeastern Utah. Six of the populations are relatively small (with < 100 males counted on leks and < 100,000 acres of sagebrush habitat) compared to the Gunnison Basin (with 750-1,000 males counted on leks and >500,000 acres of sagebrush). The Gunnison Basin is an intermontane basin that includes parts of Gunnison and Saguache Counties, Colorado. Elevation ranges from 7,500-9,000 feet. Steep sloped mesas are scattered throughout the basin. Uplands are divided by permanent or intermittent drainages. Big sagebrush (*Artemisia tridentata* spp.) dominates upland vegetation. Habitat along major stream drainages has been converted to hay and pastureland.

The San Miguel population is located in Montrose and San Miguel Counties, Colorado. Sagebrush habitat in the San Miguel population is one of the more complex with fragmentation into approximately 6 isolated communities (GUSG RCP).Elevation ranges from 6,300-9,000 feet. Habitat varies from a patchy Big sagebrush (*Artemisia tridentata* spp.) distribution with sparse grass and forb understory in the Dry Creek community to more diverse sagebrush stands of Big sagebrush (*Artemisia tridentata* spp.), Low sagebrush (*Artemisia arbuscula*) and Black sagebrush (*Artemisia nova*) and a more abundant grass and forb understory in the other San Miguel communities.

METHODS

Trapping and Radiomarking

Animal Care and Use Committee approval (project # 02-2005) was granted February 2005 and updated August 2008 with an addendum to include collaboration with Colorado State University.

Adult and yearlings.-- We focus our radiomarking efforts on females since two key demographic parameters of the current project are nest success and juvenile survival. GUSG were captured using spot-lighting techniques (Giesen et al. 1982, Wakkinen et al. 1994). Spring trapping began mid-March and ended in early May. Fall trapping began in late August and continued into September (avoiding spot-lighting during the fall hunting season). Spring spot-lighting efforts were centered initially in areas near leks with increasing effort further away from leks. We did not search or trap on leks. The search effort during both periods was opportunistic. Areas where grouse are more likely to be located (e. g., open areas near sagebrush and along adjacent ridge tops) were searched more thoroughly.

Each captured individual was radio-marked. Using radio-marked individuals provides a valid, although intensive, method for estimating demographic parameters (White and Garrott 1990, White et al. 2002). We used necklace-mounted radio transmitters (Advanced Telemetry Systems or Holohil Systems, Inc.). The transmitters (17 g) were equipped with a 4-hour mortality circuit and have a nominal battery life of 18 months. The transmitter weight is < 2% of the body weight of an adult female, and < 1% body weight of an adult male GUSG. An aluminum band (size 14 female; size 16 male) was attached to each individual. We recorded body weight, age and sex of each individual (Crunden 1963, Dalke et al. 1963, Beck et al. 1967). We located females with broods 6 days each week, females without broods 3-4 times each week and males 2-3 times each week. All trapping and handling procedure followed the CDOW Sage-grouse Trapping and Handling Protocol previously approved by the Animal Care and Use Committee.

Juveniles.-- We used radiotelemetry to estimate juvenile survival and movement patterns. The status of nests was monitored daily. Immediately after hatching, we located the brooding hen either early in the morning or at dusk (i.e., during periods when the juveniles are most likely to be closely brooded by the female), visually located juveniles, estimated brood size, then flushed the female off her brood and captured the entire brood by hand or with a light-weight hand-held mesh net. Trapping juveniles was not attempted in inclement weather (e.g., rain or snow) or during extreme cold temperatures (< 20° F). We randomly selected approximately half of the juveniles from the brood and fitted them with a 1.0 g transmitter with a nominal battery life of 18 days (Advanced Telemetry Systems). GUSG juveniles weighed 25-30 g at birth (Phillips, preliminary CDOW data). The 1.0 g transmitters are < 5.0% body weight of a juvenile GUSG. Procedures for attaching light-weight transmitters to juveniles have been developed for juvenile greater sage-grouse (Aldridge 2000, Burkpile et al. 2002) and juvenile ruffed grouse (Larsen et al. 2001). The transmitter is attached to a juvenile by suturing it to the interscapular region of the juvenile. There were no reported mortalities or overt signs of stress for juveniles during attachment of transmitters to greater sage-grouse. Juveniles were handled as quickly as possible to minimize stress. The brood was released where they were originally captured. We estimated Universal Transverse Mercator (UTM) location, using triangulation, for each radio-marked juvenile every 2 days.

We recaptured juveniles after 18 days to replace the 1.0 g transmitter with a 4.0 g transmitter with a nominal battery life of 6 months (Advanced Telemetry Systems) by suturing it to the interscapular region (as described above). A 4.0 g transmitter is < 3.0% body weight of an 18-day old GUSG (Phillips, preliminary CDOW data). In the fall (August-September) we recaptured juveniles to attach an adult 17g transmitter if the juvenile weighs > 800 g and is in good condition. If the juvenile is < 800 g and in good condition then the 4.0 g transmitter was replaced with another 4.0 g transmitter. These individuals will be recaptured the following spring and refitted with a 17 g transmitter (only if they weigh > 800 g when recaptured). The sex of each juvenile was estimated using primary feather and molting sequence (Beck et al. 1967), but will not be confirmed until following spring using behavioral (mating behavior at leks) and plumage characteristics.

Radiotelemetry

Following release, radiotelemetry locations of radio-marked individuals were estimated on the ground using hand-held Yagi antennas once every 2-3 days (from date of capture through September) to monitor status (dead or alive) and movement patterns. UTM locations and appropriate measurement error were estimated by triangulation using the program LOCATE II (Nams 1990) using ≥ 3 bearings. During fall and winter (October-March), all radio-marked individuals were located 1-2 times per month using either ground or aerial telemetry to document movement patterns and seasonal habitat use.

Vegetation sampling

Vegetation characteristics were measured at all nest locations using established techniques (Connelly et al. 2003). Microhabitat data has the potential of being an important covariate in estimating nest survival. After a hen left a nest (whether successful or unsuccessful), a 30 m transect was placed along a north-south direction bisected by the nest. The nest shrub species and height were measured. Canopy cover of the shrub species was determined using line-intercept (Canfield 1941). Shrub canopy cover were measured separated into 3 categories: *Artemisia tridentata* spp., other sagebrush species and non-sagebrush shrubs (e.g., antelope bitterbrush). Height of a sagebrush shrub within 1 m of the transect line was measured every 5 m along the transect. The percent of grass cover, forb cover, bare ground, and litter was estimated using 20 x 10 cm Daubenmire frame along the line transect (Daubenmire 1959). Grass height, number of grass species, forb height and number of forb species were measured within the Daubenmire frame at 5 m intervals along the line transect.

Analyses

Nest initiation, estimates of nest (and renesting) success and nest survival were determined by locating and monitoring nests of radio-marked females. We will record and compare estimates of annual and seasonal survival probabilities for all age and sex classes using either log-rank or likelihood ratio tests depending on rate of censured data and sample size (Allison 1995, Kalbfleisch and Prentice 2002). However, since fates of individuals are being recorded using radiotelemetry, we will calculate survival probabilities using the Kaplan-Meier product limit estimator (Kaplan and Meier 1958) with staggered entry design (Pollock et al. 1989a, Pollock et al. 1989b). If there is significant movement and dispersal within a population then survival estimates will include transition probabilities between spatially isolated areas (Hestbeck et al. 1991, Brownie et al. 1993). Variation in survival estimates can be generated using either bootstrapped estimates from different populations over time (which may confound spatial and temporal variability and artificially increase the variance around the estimate) or by using a covariate of survival such as size and weight measured at time of capture (White 2000); however there are no studies that have demonstrated a correlation between survival in grouse with any environmental covariate.

Estimates of demographic rates and their variance will be used to develop a PVA model specifically for GUSG. PVA models are typically constructed as matrix models incorporating information on age- and/or sex-specific parameters, however, matrix models may lead to misleading inferences about sensitivity of some parameters (Lande 1988, Caswell 2001). After evaluation of the model, it may be necessary to construct an individually-based, stochastic model for prediction and sensitivity analysis.

Movement and dispersal metrics will include information on distance, rate, and spatial orientation. These metrics will be evaluated using a GIS to assess the effect of landscape features (e.g., habitat composition, configuration of landscape features, barriers, etc.) on movement and dispersal patterns (McGarigal and Marks 1995, White and Garrott 1990, Turchin 1998). These metrics will be critical in the development of landscape model and a SEPM. These analyses will require an accurate GIS database.

RESULTS AND DISCUSSION

Gunnison Basin

In 2009, we captured 30 females and 2 males. We tracked 65 females. This included 35 females caught in previous field seasons. We tracked 5 males. This included 3 males trapped in previous field season. Two of the males dropped their collar shortly after capture. The remaining three males were killed by predators by the end of the field season in September. There were seven mortalities and 5 missing adult females during the breeding season. Six females were separated from this study and used for the CDOW capture breeding project. We collected the eggs from the nests of these 6 females and transported the eggs to the CDOW Foothills Wildlife Research Facility to hatch in captivity. Three of these females renested. Two of those nests hatched successfully. The remaining forty-seven females were tracked during nesting season. Forty of the 47 females (85%) initiated nests. Twenty of the 40 females successfully hatched a brood. We captured and radio-marked 50 chicks from the 20 broods. By March 2010, 5 of the chicks were alive, with 39 mortalities and 11 missing chicks. The temporal pattern of mortality is similar to previous field seasons (Fig. 1).

During March-May 2010, we captured and radiomarked 32 female and 5 male GUSG. By the end of our trapping season we had 78 birds on the air: 5 males and 73 females. This total included individuals radio-marked in previous field seasons. We radiotracked 58 of the females. Fifteen females were either missing or their transmitter failed. Eight-one percent of the females attempted to nest (47/58). Forty-one were adult and the other 6 were yearling females. Twenty of the nests were successful (43%). Twenty-six were destroyed by predation and one was abandoned. Half of the yearling nests hatched, while 42% of the adult nests hatched (17/41). Twenty-three adult nests were destroyed by predation and one was abandoned. Of the 20 nests that hatched we radiomarked 51 chicks. Four chicks were radiomarked for the CDOW captive breeding research project. However, the chicks were not incorporated into the captive breeding project so they were added to the demography / dispersal project, bringing the total number of chicks to 55. To date, 16% (9/55) of the chicks are alive, 60% (33/55) are mortalities and the remaining 24% (13/55) are missing. These estimates are consistent with trends in previous field seasons (Fig.1).

San Miguel

In 2009, we captured 2 females and 2 males. We tracked 7 GUSG, 5 were adult females. This included individuals radio-marked in previous seasons. There were 24 males counted on leks in the Miramonte Reservoir area. Using the formula from the GUSG Rangewide Conservation Plan, there were approximately 90-100 individuals in this area of the population. The 7 radio-marked individuals represented 7-8% of the population. Four of the 5 females initiated a nest. All 4 nests were destroyed by predators. Three females renested and 2 of females successfully hatched broods (8 chicks in one brood and 4 in the other). We radio-marked 4 chicks from the 2 broods. All chicks were killed by a predator within 5 days after hatch. Three were killed after 2 days (2 transmitters were found in the same coyote scat a few days later) and the other killed after 5 days.

We began the 2010 field season in San Miguel with 12 GUSG: 8 females and 4 males. Nineteen males were counted on leks near the Miramonte Reservoir. Therefore, approximately 15% of the GUSG were radiomarked in this portion of the San Miguel population. We observed 4 mortalities (2 females and 2 males) from February - May. This is above average adult mortality for this time period. Normal annual adult survival for GUSG in San Miguel is 70-80%. Four of the six females attempted to nest. Three nests were destroyed by predation and one was abandoned. Three of the females attempted to renest. All of these nests were also destroyed by predation. They did not attempt any further nests. No chicks were produced by the radiomarked females.

A preliminary survival analysis using a nonparametric product-limit estimator illustrates similar temporal trends in juvenile survival in the Gunnison Basin (Fig. 1); however, no statistical difference was detected with these samples (Table 1). Juveniles radio-marked after 24 hours after hatch (n=6) were not added to this analysis.

SUMMARY

The demographic parameters recorded in the Gunnison have shown consistent patterns with previous field seasons. The increased mortality during the winter of 2007-2008 is the exception. During January-March 2008, we observed 10 mortalities out of 38 GUSG being tracked in the Gunnison Basin population. In the San Miguel population we observed 4 mortalities out 20 GUSG being tracked (8 near the Miramonte Reservoir area and 12 in Dry Creek Basin). Three of the mortalities were in the Miramonte Reservoir area and only 1 mortality was in Dry Creek Basin. This illustrates the potential for significant spatial variation in demographic rates among GUSG that has not been previously documented among GUSG.

The impact of predation in the San Miguel population is of concern. Low nest success and no juvenile survival indicate little or no recruitment of young into the population. Lek counts have been declining in the San Miguel population since 2006. For the last 2 years, lek counts have been at, or below, 30% of the target population. It was recommended in the GUSG Rangewide Conservation Plan that this threshold should trigger thorough consideration of conservation actions (pp. 198ff and 256; GUSG RCP). The lek counts are at the threshold of 25% of the target population (pp. 134ff and 243ff) that warrants an evaluation of predator control (see also Research, Objective #4, p. 250). The demographic data collected in the Miramonte Reservoir area suggests there has been no recruitment of young since 2006. Adult mortality (with no juvenile recruitment) appears to account for the decline in lek counts (Table 2). A predator control project is being evaluated for this population.

Future Plans

Field work will continue through the spring of 2011. The intensive radiotelemetry will be completed by the end of September 2010, while monthly radiotelemetry locations will be recorded throughout the winter. In 2009, Amy Davis joined the project as a graduate student at Colorado State University under the mentorship of Dr. Paul Doherty. Analyses and production of reports, publications, and a Ph.D. dissertation will continue through 2012.

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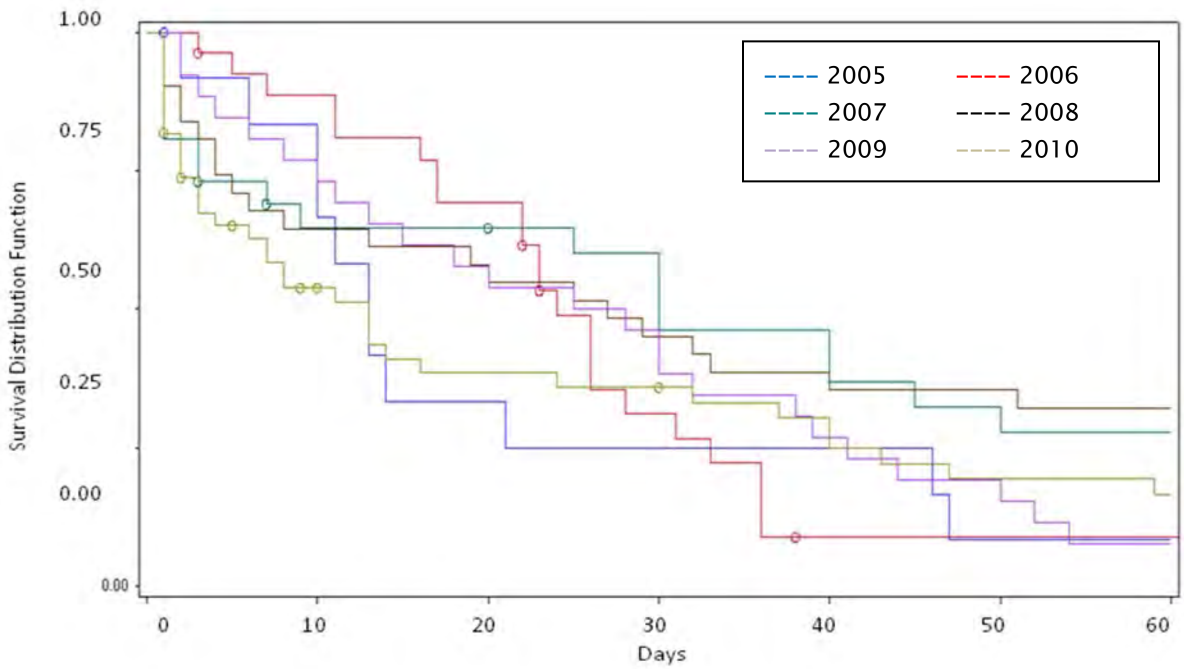
Table 1. Comparison of juvenile survival rates in the Gunnison Basin in 2005-2010.

Test	X^2	DF	$Pr > X^2$
Log-Rank	12.7529	5	0.0758
Wilcoxon	7.1477	5	0.2099
-2Log(LR)	9.9133	5	0.0777

Table 2. High male counts (HMC) at the Miramonte & Summer Camp leks (San Miguel population). We began collecting demographic rates in this area in 2007. The annual survival estimates are from March-February each year. The survival rate ($\hat{S}$) for 2007 is estimated based on annual survival rates from 2009-2010. The survival estimate for 2011 is based on data collected from March-July 2010. Estimated lek counts (E(HMC)) are calculated from the HMC and adult survival for the previous year (e.g., 2006 HMC= 62 x 0.8 ($\hat{S}$ [adult]) = 49.6, the E(HMC) for 2007). The E(HMC) assumes no recruitment of chicks (marked or unmarked).

Year	$\hat{S}$ [adult]	$\hat{S}$ [chick]	E(HMC)	HMC	
2006				62	
2007	*0.8*	0	49.6	50	
2008	0.63	0	31.5	29	[= winter of 2007-2008]
2009	0.8	0	23.2	24	
2010	0.8	0	19.2	19	
2011	*0.75*		*14.3*		

Figure 1: Preliminary product-limit estimates of juvenile survival in the Gunnison Basin in 2005 - 2010.



COLORADO DIVISION OF WILDLIFE - AVIAN RESEARCH PROGRAM
Progress Report
September 2010

TITLE: Gunnison Sage-grouse Captive-Rearing

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

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ABSTRACT

Gunnison sage-grouse (*Centrocercus minimus*, hereafter GUSG) is a species of concern in Colorado. Two conservation issues addressed in the Gunnison Sage-grouse Rangewide Plan (RCP) are the population persistence of GUSG (especially the small populations) and the relatively low genetic diversity among GUSG. Augmenting small GUSG populations is a potentially useful management tool to address these conservation concerns. Five alternative techniques to transplanting yearling or adult individuals are discussed in the RCP, including use of captive-reared GUSG. Researchers at the U.S.D.A. National Wildlife Research Center (NWRC) in Fort Collins, CO were able to maintain 18 yearling greater sage-grouse (*C. urophasianus*, hereafter GRSG) in captivity for 8 months. Recent Colorado Division of Wildlife (CDOW) research on GRSG has evaluated different aspects of captive-rearing techniques. The objectives for this project segment are to: 1) collect 70 GUSG eggs, 2) artificially incubate and hatch eggs, 3) develop captive breeding techniques for GUSG,4) determine if captive GUSG can initiate incubation and rear a brood in captivity, 5) augment wild surrogate broods with domestically-reared chicks at 1-, 3-, 5-, and 7- weeks of age. Female GUSG were captured using spot-lighting techniques. Females were radio-marked and monitored to assist in locating nesting females. Eggs were collected from laying and incubating females. Eggs were transported from the Gunnison Basin to the CDOW Foothills Wildlife Research Facility (FWRF) in Fort Collins and placed in an incubator in a newly constructed building until an external pip was observed (25-26 days) and then they were moved to a hatcher. Twenty-three females were captured in Kezar Basin and Sapinero Mesa to serve as surrogate females for captive-reared chick augmentation. Three females were selected from the Gunnison Basin to intensively track and locate nests for egg collection. Twenty-two eggs were collected from 3 females. Six eggs were collected during laying from one female and 16 were collected from 3 incubating females. Hatching began on 22 May and continued through 13 June. Hatching success was 78% (46/59). After hatching, chicks were weighed, banded, and fed an invertebrate dominated diet. Initial post-hatch survival appeared low with 7 mortalities. Bacterial infections, as in 2009, were present which resulted in the mortality of 13 chicks. Preliminary necropsies suggest *Klebsiella spp* and *E. coli* as the cause of the bacterial infections. Fourteen captive-reared chicks have been introduced to augmented wild broods in 5 separate introductions. The overall adoption rate is 79% with 12 more chicks to introduce. We propose that captive-rearing efforts should continue for at least one additional year to gain additional knowledge on the source of bacterial infections and to increase sample sizes of augmented chicks.

GUNNISON SAGE-GROUSE CAPTIVE-REARING
Progress Report, December 1, 2009 – June 30, 2010
Anthony D. Apa, Michael L. Phillips, and Lief Wiechman

PROJECT OBJECTIVES

1. Evaluate various husbandry techniques and develop protocols for hatching and maintaining juvenile and adult GUSG in captivity.
2. Compare chick survival and growth rates for chicks raised with and without adult female brood hens.
3. Compare the behavior and reproduction (mating and nesting effort) between captive-reared and wild grouse.
4. Test and modify husbandry techniques developed for greater sage-grouse at the National Wildlife Research Center (NWRC).
5. Use the results to develop management plans that incorporate captive-breeding as a technique for conserving Gunnison sage-grouse (GUSG) populations.

SEGMENT OBJECTIVES

1. Collect 70 GUSG eggs from wild and captive females (combination of laid and incubated eggs).
2. Artificially incubate and hatch eggs.
3. Develop captive breeding techniques for adult GUSG in captivity.
4. Determine if captive GUSG females will initiate a nest and rear a brood in captivity.
5. Augment wild surrogate broods with domestically-reared chicks at 1-, 3-, 5-, and 7- weeks of age.

INTRODUCTION

Gunnison sage-grouse (*Centrocercus minimus*) is a recently described species (Young et al. 2000) that is a species of concern in Colorado. It has been proposed that the geographical distribution of Gunnison sage-grouse (GUSG) has decreased significantly in the past century along with a dramatic decline in the amount of sagebrush (*Artemisia* spp.) in the landscape (Schroeder et al. 2004). There are seven GUSG populations distributed across southwestern Colorado and southeastern Utah. The populations are described in the Gunnison Sage-grouse Rangewide Conservation Plan (RCP) as 1) Cerro Summit / Cimarron / Sims Mesa, 2) Crawford, 3) Dove Creek / Monticello (Utah), 4) Gunnison Basin, 5) Pinyon Mesa, 6) Poncha Pass, and 7) San Miguel Basin. Six of the populations are relatively small (with < 100 males counted on leks and < 100,000 acres of sagebrush habitat) compared to the Gunnison Basin (with 750-1,000 males counted on leks in the last 5 years and more than 500,000 acres of sagebrush).

Two of the conservation issues addressed in the RCP are population persistence of GUSG (especially the small populations) and the relatively low genetic diversity among GUSG. Conservation biologists assume that variation in demographic rates (due to environmental and demographic stochasticity) can greatly influence population dynamics and has a greater impact on small populations by significantly reducing persistence time (Shaffer 1987, Lande 1988, Ruggiero et al. 1994; Caughley 1994). There is lower genetic diversity among GUSG than Greater sage-grouse (*C. urophasianus*; GRSG) (Oyler-McCance et al. 1999) with the majority of genetic diversity existing in the Gunnison Basin (Oyler-McCance et al. 2005). The relatively low genetic diversity among GUSG populations may affect population persistence by reducing the effective population size of GUSG and increasing the potential for negative impacts of inbreeding depression (Oyler-McCance, et al. 2005; Stiver et al., 2008).

Augmenting GUSG populations is a potentially useful management tool to address these conservation concerns. A population viability analysis (PVA) was developed Dr. Philip Miller (IUCN /

SSC Conservation Breeding Specialist Group) for GUSG in the RCP using VORTEX software (Lacy et al. 2003). The PVA used the best demographic data available to estimate population persistence times and to estimate the number and rate of transplants needed to maintain 50% of the initial population size (that ranged from 100-300 GUSG). The augmentation of 10-40 GUSG 3-9 times over a 50-year time frame effectively reduced population extinction probabilities to zero and retained most of the genetic diversity in the original populations. This analysis demonstrated the potential positive effects of augmentation for the conservation of GUSG. However, population augmentation by transplanting yearling or adult GRSG has been only moderately successful, possibly due to the site fidelity and inexperience of transplanted sage-grouse (Musil et al. 1993, Reese and Connelly 1997). The Gunnison Basin has been the source population for transplanting yearling and adult GUSG into two host populations, Poncha Pass and San Miguel. The Gunnison Basin population is considerably larger than all others and has the greatest genetic diversity (Oyler-McCance et al., 2005). Over 100 GUSG have been transplanted to the Poncha Pass and San Miguel populations since 2000. We have observed ≥ 50% mortality within the first year after release. Average annual mortality of radio-marked adult sage-grouse is approximately 20%. Future transplants are reviewed annually by the CDOW Trap and Transplant Committee.

Five alternative techniques to transplanting yearling or adult individuals are discussed in the RCP, including: 1) transplanting eggs from radio-marked hens from a source to a host population, 2) incubating eggs in captivity from either the source or host population and release either eggs or chicks to brooding hens to reduce mortality from nest predation, 3) supplement wild-reared broods with young raised in captivity, 4) raise grouse in captivity and release to populations as needed, and 5) maintain a captive flock as a genetic diversity bank. These proposed techniques require the ability to either hatch chicks, or raise individuals, in captivity. An early attempt at developing a captive-rearing program for GRSG in Idaho was relatively successful (Pyrah 1963, 1964). However, many captive birds died of diseases such as salmonellosis, *Pseudomonas aeuginosa*, and aspergillosis. The majority of chick mortality was due to disease and vitamin E deficiency.

Researchers at the U.S.D.A. National Wildlife Research Center (NWRC) in Fort Collins, CO were able to maintain 18 yearling GRSG in captivity for 8 months before exposing them to West Nile virus (Oesterle et al. 2005). They allowed the GRSG to move about freely in a large aviary. They observed aggressive behavior among individuals that was mitigated by barriers placed in the aviary that seemed to act as a refuge for subordinate individuals. The larger aviary seemed to also aid in establishing a proper diet by allowing feeding without interference from other individuals. Several females exhibited breeding behavior and laid 13 eggs. None of the hatched chicks survived. They observed a mortality rate of 16.7% among the yearlings before testing exposure to the West Nile virus.

Recent CDOW research projects on GRSG have evaluated different aspects of captive rearing techniques. Huwer (2004) was able to collect eggs from GRSG nests and hatch them in captivity. The chicks were imprinted on humans to evaluate the effect of forb communities on chick development. Thompson et al. (2007) were also able to collect eggs from GRSG nests and hatch them captivity. The chicks were held in captivity for 1-7 days before being released to wild radio-marked hens with broods. The hens accepted the captive-raised chicks. Survival of captive-raised chicks (0.21; 95% CI = 0.16-0.28) was similar to that of wild chicks. However, they also observed deformities in 7% of the captive-raised chicks that hatched (e.g., splayed legs, curled toes, seizures and curved backs). They proposed that the deformities may be due to a combination of inadequate nutrition, poor thermoregulation, and stress from handling. Further research is required to better understand these problems with captive-rearing techniques. Continued research with GUSG by the CDOW has improved our knowledge on captive-rearing of GUSG (Phillips and Apa 2009a, 2009b). Research on captive-rearing of the endangered Atwater's prairie chicken illustrates many of the potential problems that need to be evaluated for GUSG (Jurries et al. 1998). Researchers observed toe and leg deformities, digestive tract abnormalities that may have been due to improper diet, and diseases (avian pox, avian reticuloendotheliosis, and infectious enteritis) in captive prairie-chicken chicks (Smith 1993).

Although detailed information is not available, diets of GUSG are assumed to be similar to those of GRSG and we have confirmed those diets with current research on GUSG (Phillips and Apa 2009a, 2009b). The diet of juvenile GRSG chicks is primarily composed of invertebrates with increasing using of forbs (Klebenow and Gary 1968, Peterson 1970; Huwer 2004). The survival and growth is correlated with the quantity of invertebrates in the diet of GRSG chicks (Johnson and Boyce 1990). Invertebrates make up the majority of food items consumed by GRSG chicks in their first week after hatch and decreases over the following 2-3 months until plants dominate their diet (Huwer 2004). Protein has an important function in juvenile development in gallinaceous birds (Savory 1989). Sagebrush is the predominate food item of adult sage-grouse throughout most of the year (Rasmussen and Griner 1938; Patterson 1952; Barber 1968; Wallestad et al. 1975; Schroeder et al. 1999). Adult GRSG in captivity were fed a variety of plant items, such as items such as, sagebrush, yarrow (*Achillea millefolium*), mixed vegetables (lettuce, spinach, and beet greens), chopped apples, green peas, alfalfa hay, dandelions, and clover (Oesterle et al. 2005) and a similar diet in captivity was provided to GUSG in 2009 (Phillips and Apa 2009a, 2009b).

STUDY AREAS

Our study occurred in three areas, the Gunnison Basin (GB), Kezar Basin/Sapinero Mesa (KBSM) areas on the western end of the Gunnison Basin, and in Fort Collins (FTC), Colorado. KBSM was allocated to the capture of surrogate females and broods while we used females captured in other areas of the GB for collecting eggs. GB is an intermontane basin that includes parts of Gunnison and Saguache Counties, Colorado. Elevations in the area range from 2,290 to 2,900 m. FTC is located in Larimer County on the eastern slope of Colorado. Grouse were hatched in a newly constructed incubation building (provides egg storage, incubation, and hatching) (Fig. 1A) and raised at the CDOW Foothills Wildlife Research Facility (FWRF) in FTC and moved to the NWRC in FTC and raised to an introduction treatment age.

METHODS

Our methods for husbandry of eggs and chicks followed techniques already established in previous CDOW research projects (Huwer, 2004; Thompson et al. 2007) as well as the implementation of successful techniques learned in the first year of this project (Phillips and Apa 2009a, 2009b). Previous research projects were approved by the CDOW and the University of Idaho and Colorado State University Animal Care and Use Committee (ACUC): Huwer (CSU ACUC # 02-023A-01; Thompson et al (U. Idaho ACUC # 2005-45). This current project received CDOW ACUC approval (ACUC #03-2009) and ACUC review and approved from the NWRC (# QA-1625).

Six temporary staff were hired for the project. Two technicians were stationed in GB to conduct trapping, telemetry, and brood augmentation in GB and KBSM. Three additional staff were hired and stationed in Fort Collins to conduct husbandry of GUSG as well as captive-rearing protocols. One technician was hired to support GUSG husbandry in FTC, transport captive-reared chicks from FTC to KBSM, as well as assist with nest searching, brood capture and domestic chick introduction in GB and KBSM. Field work was initiated on 15 March.

Winter Diet and Husbandry

The winter diet of GUSG consisted of big sagebrush (*Artemisia spp.*) leaves, Purina Game Bird Maintenance Chow® (chow) (12.5% protein), and superworms. Water was provided *ad libitum* throughout the winter. GUSG were provided superworms twice daily and chow was supplemented twice daily. Big sagebrush plants were provided *ad libitum*. Big sagebrush was obtained from two sources, wild harvested and nursery potted plants. Harvested big sagebrush was distributed throughout the aviary. Potted plants were also distributed throughout the aviary although some were planted and others remained in pots. The plants that remained in pots were collected after grouse defoliated the plant. They were subsequently placed in a greenhouse to encourage refoliation in an attempt to reduce costs associated with the purchase of new plants.

Invertebrate Husbandry

Invertebrate husbandry included mealworms, flightless fruit flies, house crickets and superworms following the husbandry protocols outlined by Apa et al. (2010).

Captive Breeding

The winter captive flock consisted of 5 males (3 captive-reared and 2 wild-reared) and 9 females (8 captive-reared and 1 wild-reared). In order to control when breeding occurred we separated the males and females on 1 February into two aviaries. We attempted to synchronize breeding activity in FTC with observed breeding activity the GB and KBSM.

Two wild males, captured in October 2009, were allowed access to all nine females at sunrise to approximately 0800. Three of the males were yearlings from the 2009 project and were not allowed to breed with any of the captive females because they were siblings of 5 of 8 domestically-reared females. Those males were kept in a separate enclosure (8.2-m x 15.0-m x 15.7-m; 61.7-m^2) within the male aviary throughout breeding activity with no access to the females.

Once breeding activity was observed in the GB and KBSM, females were given access to the male aviary by opening the netting that divided the two aviaries. As in the wild, if weather conditions were not conducive to breeding activity (precipitation, heavy winds, etc.) males and females remained separated. All breeding activity was documented from a blind approximately 15 m from the female-male access point. Observers documented breeding behaviors (displays, aggression, copulations) using binoculars.

All females and males had unique colored leg bands to allow for individual identification used for behavioral observations and paternity assignment. As breeding activity subsided in the GB and KBSM and all captive females were laying eggs, females were no longer allowed access to males. The yearling males were released into the larger male aviary following the cessation of breeding activity.

Surrogate Female Capture

Female GUSG were captured in the KBSM and GB using the spot-lighting technique and long-handle hoop nets (Giesen et al. 1982, Wakkinen et al. 1994) in 2010 and 2008-2009, respectively. Spring trapping began in mid-March and ended in late April. Spot-lighting efforts were centered initially on or around leks with increasing effort further away from leks. The search efforts were opportunistic rather than strictly random. Trapped females were radio-marked with a 17-g necklace-mounted radio transmitter (Advanced Telemetry Systems). Transmitters were equipped with a 4-hour mortality circuit and have a nominal battery life of 18 months. The transmitter weight is < 2% of the body weight of an adult female. A 30 cm antenna lies between the wings and down the back of the grouse.

Females were aged as yearling or adult by examining the condition of the outer primaries (Patterson 1952, Dalke et al. 1963). We recorded body mass, as well as age of each female (Crunden 1963, Dalke et al. 1963, Beck et al. 1967). Mass was recorded by placing the restrained individual on an electronic balance. Individuals were restrained using a Velcro strap wrapped around the body to restrain both wings. An aluminum band (size 14: appropriate for female sage-grouse) was attached to a leg for individual identification. The females were released at the point of capture. All trapping and handling procedure followed the CDOW Sage-grouse Trapping and Handling Protocol previously approved by the ACUC. Birds were released by placing them under a sagebrush or in adjacent cover.

Nest Monitoring

Marked female movements and nesting activity were monitored every 1 – 2 days between the hours of 0800 and 1100. Locations were obtained using a hand-held Yagi antenna and collecting UTM coordinates ≤ 30 m from the female. Females were not approached closely to minimize disturbance during nesting activity and prevent nest abandonment. When a female was observed under a shrub, and nesting was suspected, we returned the following day to confirm nest initiation.

KBSM. -- We returned to the nest location the following day at a different time to confirm the presence of the female. Once nesting was confirmed, we monitored nest fate from >75 m from the nest every 3-5 days. Following incubation activity, we ascertained nest fate.

GB. -- Since eggs were collected in the GB, the status of the female nesting behavior (nest building or egg-laying stage) was critical. Once a female was confirmed nesting, if the nest had ≥ 7 eggs, we assumed the female was incubating. If the exact date of nest initiation was unknown, it was estimated based on previous locations. If there were < 7 eggs in the nest bowl, and the female was off of the nest periodically, we classified the female as laying. The nest site was recorded with a GPS location as well as the error of the estimate. Females of abandoned nests (forced or not) were monitored to determine renesting activity.

Egg Production and Collection

GB.-- Egg-laying females had eggs collected depending on the current clutch size. We replaced collected eggs with artificial sage-grouse eggs (manufactured by Jerry Craig, *pers. comm.*). Artificial eggs are made of latex casting resin and colored to mimic sage-grouse eggs. Artificial eggs were used to reduce the probability of female abandonment due to perceived depredation of the nest. We returned to the nest 2-3 days later to recheck the status of the nest and collected additional eggs which were replaced with artificial eggs.

For incubating females, the entire clutch was collected as early in incubation as possible to force abandonment and encourage a renesting effort. All eggs were weighed and individually marked to identify maternity. For eggs previously incubated, both fresh mass (mass of the egg after being laid) and set mass (mass prior to incubation) were estimated.

NWRC. -- Following breeding activity each morning, staff searched the aviary for eggs. All laid egg locations were identified on an aviary map. Second and third searches were conducted mid-day and in the evening before feeding, respectively. Eggs not found in an established nest bowl were immediately collected and individually marked. Eggs were transported to the CDOW FWRF where they were stored in a cooler at 10-15° C (50°-60° F), for < 7 days prior to being placed in the incubator. The date of incubation initiation was previously determined to synchronize the age of chick augmentation and wild female clutch hatch dates.

To examine whether captive females would initiate and incubate a nest, we monitored the development of nest bowls. If eggs were observed in a nest bowl, we monitored additional egg laying in that nest. If more eggs were laid, maternity was assigned to the female that exhibited egg-laying behavior. If no additional eggs were laid, we removed the egg and effectively ―depredated" the nest. If any nests were created within 5 m of an existing nest, the nest was ―depredated" so that the initial nest was not disturbed. Eggs were individually labeled and the date and time were recorded.

Egg Storage and Incubation

Eggs collected at the egg-laying stage were placed in a container (egg cartons secured in a padded box) and transported to the CDOW FRWF. The eggs were stored in a cooler at 10-15° C (50°-60° F) and turned twice/day (Harvey 1993). Incubators and hatchers were set up at the CDOW FWRF and CDOW staff monitored the incubators 24 hours/day for incubator failure or electricity issues. All eggs were transferred to an incubator to synchronize egg hatching.

Eggs collected from incubating females were transported in a temporary incubator (maintained at 35-37.5° C; GQF Manufacturing; Foam Hova-Bator) and immediately transferred to an incubator at the CDOW FWRF. The cabinet incubator (Model 1502, Sportsman Company) was maintained at 37.5° C, 58% relative humidity. Eggs were turned automatically every 4 hours during the first 25-26 days of incubation (Huwer 2004; Thompson et al. 2007) or when an internal pip was observed from egg candling (J. Azua, *pers. com.*). Eggs were examined and weighed 3 times/week to determine mass loss and development (Huwer 2004). Humidity was monitored and adjusted to achieve 11-12% egg-mass loss (Harvey 1993).

Eggs were transferred to a hatcher (Model 1550 Sportsman Company) and stored at 37.2 ° C and 80% humidity 1-3 days before hatching (or dependent on embryo development determined by egg candling). Date of hatch was estimated at 27 days after the eggs were transferred to the incubator. For eggs collected while incubating, we estimated the date of hatching as 27 - y_i days after collection, where y_i is the number of days from the last recorded location of the female and the date of collection.

Egg Hatching

After hatch, chicks were weighed, banded, and had their umbilicus swabbed with iodine. Chicks remained in the hatcher for up to 24 hours to dry. Chicks were individually marked with bandettes (Dunlap Hatchery, Caldwell, ID). The bandettes range in size from 4-6 (approximately 6 – 9 mm – (1/4 - 3/8") diameter) with smaller bandettes replaced by larger bandettes as the chick aged. If a chick had curled toes, they were given 24 hours to correct themselves. If the toes did not straighten, we applied tape on top of and underneath the toes to assist in straightening them. Tape remained on the toes for up to 24 hours.

Chick Brooding

After chicks dried, they were placed in small brooder pens (1.3 m^2) and observed for any sign of behavioral abnormalities (e.g., do not feed, unstable locomotion, isolation from other chicks, etc.). Each pen had a decoy female and wing placed in the center (Apa *et al.* 2010). Each wing had a heat lamp mounted in the back of the wing and a heating pad fixed to the inside ceiling of the wing (Apa *et al.* 2010). A heat lamp was also placed in the corner of the pen to provide additional heat. As ambient temperature increased, supplemental heat sources were shut off. Chicks were placed in a small hut (coop) at night. Feather dusters provided a simulated female at night and supplemental heat was provided by a heat pad and lamp. Two feather dusters were provided to allow for adequate spacing of chicks.

Chicks were provided a diet of invertebrates (crickets of various ages/sizes, mealworms, flightless less fruit flies, waxworms, chopped forbs, and a mixture of 1/3 Purina Game Bird Startena® [30% protein], 1/3 Purina Game Bird Breeder Layena® [20% protein], and 1/3 Purina Game Bird Maintenance Chow® [12.5% protein], and water supplemented with a vitamin supplement, Vitamax®, *ad libitum* in the brooder pen. Forbs (alfalfa, yarrow, white sweet clover, dandelion), were fed as much as the chicks showed interest. The diet consisted primarily of invertebrates for the first 10 days. We recorded the quantity provided at every feeding on the hour, although consumption of various foods is very difficult to precisely ascertain. Chicks were fed every 1-2 hours from sunrise to sunset (0600 to 2000).

Brood Augmentation

Wild females with broods were located approximately one hour before sunset. The female was flushed from the brood and all wild chicks were captured. Chicks were placed in a containment apparatus and kept warm. Three wild chicks in the brood were marked with 1.1 gram transmitters (Burkepile et al. 2002) to monitor survival and brood movements. We designated surrogate broods based on their hatch date, location, and brood size. In order to minimize a possible negative effect on brood survival, we did not increase a brood size beyond 10 chicks. Depending on the mass of the captive-reared chicks, introductions were matched with surrogate broods the same age, or up to 4 days younger.

Once a surrogate brood was identified and captive-reared chicks were assigned, the chicks were transported via ground transportation to KBSM. Chicks were transported approximately five hours and given 2 – 3 hours to rest/feeding prior to introduction. Chicks were transported in the early afternoon, and then provided rest/food/water in a temporary holding pen before a dusk augmentation. Two challenges associated with introducing older chicks (>14 days) are their ability to fly, and the potential that the maternal female may no longer be brooding the entire brood because of chick body size and ambient temperature.

There were four Treatments for brood augmentation:

1. Treatment I (1 week of age) augmentation was conducted at dusk. After all chicks were weighed and marked, we held the wild brood along with the domestic-reared chicks for ≤15 minutes before releasing them at the capture location.
2. Treatment II (3 weeks of age) brood capture occurred after dusk using telemetry and spotlighting techniques (Giesen et al. 1982, Wakkinen et al. 1994) to locate the brood. Once the brood was located, we released 2-3 domestic-reared chicks ≤ 15 m of the brood. We then slowly moved away from the release location. Wild and captive-reared chicks were checked within 12 hours to assess the success of the augmentation. The augmentation was considered successful if the captive-reared chicks were associated with the rest of the brood. To assist in providing for a successful augmentation an artificial brooder wing was placed at the introduction site. When released, captive-reared chicks were placed under the wing to provide shelter and warmth until sunrise.
3. Treatment III (5 weeks of age) methods were the same as in Treatment II, but using older chicks.
4. Treatment IV (7 weeks of age) will occur during dusk and/or night as discussed earlier. There may be opportunities to focus on broods in or near areas of heavy brood use and/or concentration. At 7 weeks old, chicks may be independent of the maternal female, and may be able to gather or associate with any grouse in the immediate area.

RESULTS AND DISCUSSION

Winter Diet and Husbandry

Fourteen grouse (9 F and 5 M) were kept and fed over the winter. Three wild adults (2 M and 1 F) captured in October 2009 were kept in a separate aviary through 1 February 2010. Potted big sagebrush plants were purchased from local nurseries and big sagebrush plants were harvested from Bureau of Land Management land in North Park, Colorado. After 1 December 2009, 540 potted and 360 harvested big sagebrush plants were fed to GUSG. Through the winter, a total of 1,012 big sagebrush plants (215 planted, 437 potted, and 360 harvested) were fed to captive GUSG.

From 1 December 2009 through 31 January 2010, the 3 wild-reared GUSG were provided an average of 220 g (range 100 – 400 g) of large superworms daily. Nearly all of the superworms were consumed (215 g of 220 g provided). Eleven captive-reared domestic grouse were provided 150 g of large superworms daily and nearly all of the superworms were consumed. Captive-reared grouse were also provided Purina Game Bird Maintenance Chow® (chow) daily. Captive-reared GUSG were provided

500 g of chow daily and consumed 90% of the chow provided. Chow was also provided to the wild-reared GUSG, but they did not consume any measureable amount of chow.

On 1 February 2010, when the males and females were separated, the female diet was changed to reflect the on-set of the breeding season. Females were provided an average of 140 g of superworms daily (range 125 – 225 g). Additionally they were provided 300 g of a 1:1 mix of Purina Game Bird Breeder Layena® and Purina Gamebird Maintenance Chow® formulations. They consumed an average of 240 g daily (range 66 – 300 g). Prior to breeding, males were fed and consumed 150 g daily a chow mixture that was the same as the female mixture. The males were also provided and consumed 125 g of superwoms daily.

After 10 April 2010, wild- and captive-reared males were fed separately. They were provided and consumed 25 g/male of superworms daily. The captive-reared males were provided 150 g (range 32 – 150 g) of chow daily and consumed 83% of the chow. Wild-reared males were provided 50 g/male (range 18 – 50 g) and 90% was consumed.

Invertebrate Husbandry

We cultivated a population of house crickets, mealworms, and flightless fruitflies. This effort was undertaken in an attempt to reduce costs associated with the purchase of invertebrates from outside vendors and to determine if invertebrate husbandry was feasible. All 3 cultures maintained a small population that provided a minimal source of food. House crickets yielded the most food in the fastest turn-a-round time.

The lack of space and climate control was an issue. Crickets and mealworms require abundant space (shelf space for differing stages of the life cycle) to successfully breed and maintain low densities because high densities can result in excessive mortality. Additionally, temperature control is needed because facility temperatures need to be consistently above 21° C (70° F). A larger space needs to be dedicated exclusively towards invertebrate husbandry if increased quantities or a consistent supply of CDOW produced invertebrates are desired.

Captive Breeding

Although the captive-reared males began to display in late-January and the wild males began to display in February, we delayed breeding interaction with the females until 10 April to reflect lek and nesting activity observed in the GB. Nine females were allowed access to 2 wild males for a total of 16 days between 10 April and 30 April for ≥ 1.5 hours each day ($\bar{x}$ = 93 minutes) (Table 1).

We observed a dominant male prior to female interaction, but on the second day of breeding (11 April), both males engaged in a wing fight. The dominant male (Wild-Left) suffered a torn hamstring and internal injuries. This injury impeded subsequent breeding efforts and Wild-Left eventually died from injuries sustained in the wing fight as well as another fight 2 days later. After the initial wing fight, male Wild-Right assumed dominance (Table 2). A 17 April 2010 necropsy by Dr. Karen Fox (CSU) found that the cause of death of Wild-Left was —…cardiac tamponade (the sac around the heart was filled with fluid) that caused ascites (fluid in the abdomen) and pulmonary edema (fluid in the lungs). This was caused by a tear in the atrium."

When females did not enter the male aviary, males would pursue females into the female aviary. On those occasions the males were returned to the male aviary later in the morning (Table 3). In a couple of instances, females would enter the male aviary, and illustrate breeding —interest" (precopulatory postures) but was never observed copulating (Table 1). At the cessation of all breeding, male Wild-Right was radio-marked and returned to the GB and released near his fall 2009 capture location. As of the writing of this progress report Wild-Right was still alive.

Surrogate Female Capture

Twenty-three females were captured and radio-marked in the KBSM. Captures occurred over 12 trapping nights with 1–2 trapping crews. Adult female mass was 1,199 ± 34 ($\bar{x}$ ± SE) (n=8) and was higher ($t_{2,12}$ = 2.18; P = 0.023) than yearling females at 1,097 ± 20 g (n=13) (Table 4). These females were available to become surrogate brood hens for the captive-rearing study.

Nest Monitoring

GB.-- Female movements were monitored daily to establish nesting behavior. Three females (#804, #820, #805) were monitored for egg collection. All three females established nests. Renesting was documented for 33% (n = 1/3) of the females. Female #804 had an unsuccessful renesting attempt.

KBSM.-- Female movements were monitored daily to establish nesting behavior. Of the 23 grouse captured, 16 were available as surrogates (6 grouse left study area, 1 was depredated prior to documenting any nesting attempt). Fourteen of 16 females (87.5%) initiated nests (Table 5). Five of 14 females had successful (35.7%) nests. We did not document a renesting attempt for the 9 remaining unsuccessful females but small clutch sizes for 1 yearling (4), and an adult (6), may indicate an original nesting attempt was not detected and these could be renests.

Egg Production and Collection

GB.--Nesting behavior was documented on or about 27 April with incubation starting on approximately 25 April. Twenty-two GUSG eggs were collected from 3 females. All females were adults. Eight eggs were collected from a incubating female (#804), 6 eggs were collected from female #805 during egg laying and 1 egg while she was incubating. The last 7 eggs were collected from female #820 during incubation (Table 6). Eggs were transported to the CDOW FWRF on 27 April, 29 April, and 7 May.

NWRC.--Thirty-eight of 56 eggs laid were collected (Table 7). We allowed 5 of 8 nests created to persist to determine whether females would incubate, hatch clutches and raise broods in captivity. Eggs laid in those nests were labeled when found and the date was recorded (Table 8). During the breeding season, we removed 2 of the 5 nests because it became apparent that, based on female nesting behavior (lack of attendance at the nest), they would have low hatchability before incubation started. In the 3 nests that persisted we had exchanged real eggs with artificial eggs thus reducing the number of eggs in the nest but guaranteeing some eggs from captive females would be hatched, either in the nest or in the incubator.

Of the 3 incubated nests, 1 female abandoned her nest after 2-3 days of incubation. We suspect that her nest location (within 5 m of the net dividing male and female aviary) and the continued strutting behavior of the males disturbed the female to the point of abandonment. The two remaining females incubated for 28 days, and each hatched 3 of 4 eggs (Table 9). These chicks remained in the flight pens to be raised by the maternal females.

Each nest had its logistical issues. We had 2 females (#1199-09 and #1193-09) that alternated the incubation of a nest. After 7 days, and each having incubated 2 times, one female removed an egg from the nest bowl and began to incubate it next to the original nest (<15 cm). Later that day and we moved the secondary female (#1193-09) to the adjacent aviary with the rest of the non-nesting females.

A gopher snake (*Pituophis catenifer sayi*) entered the aviary, flushed an incubating female (# 1198-09) off of her nest and attempted to depredate the nest. The snake was removed, the egg was returned to the nest, and the female returned to incubate her clutch.

We documented numerous movements and behaviors, as well as which female was on a nest. From that information, we assigned ownership of nests to individual females, and the rest of the females were removed from the female aviary. They were moved to a third aviary and were not allowed contact with the males. However, assigning ownership proved to be difficult. It was difficult to observe the female on the nest while laying; several females spent time on several nests or even maintaining (moving grass, sticks, covering eggs) more than one nest in a day.

On 28 April, after six nest bowls had been established, we observed multiple eggs laid in a nest bowl in the same day (morning and/or afternoon). We observed a clutch increasing from 0 eggs to 2, and another from 3 eggs to 5 eggs in a 24 hour period. We suspect that because of the limited space and relatively high density of females, that we created an opportunity for females to dump eggs in nests.

Egg Storage and Incubation

Mass of eggs collected from wild females (42.73 ± 0.48) was heavier ($t = 2.02_{2,41}$; P < 0.0000) than eggs collected from captive-reared females (39.81 ± 0.34) (Fig. 1). The percent of egg mass loss varied during incubation. Although egg mass differed between eggs collected in the wild versus eggs collected in captivity, the percent mass loss during incubation did not differ ($t = 2.03_{2,33}$; $P = 0.0993$) (Fig. 2). The percent mass loss for eggs collected in the wild was 10.53 ± 0.14 while the percent mass loss for eggs collected in the wild was 11.11 ± 0.31 (Fig. 2). The combined mean percent mass loss was 10.88 ± 0.18 (95% CI = 8.31 – 13.39).

In 2010, hatched chick mass varied by egg origin, either produced in the wild and hatched in captivity (wild-produced) or produced in captivity and hatched in captivity (captive-produced). Wild-produced chick mass at hatch was 32.07 ± 0.49 g ($\bar{x} \pm$ SE) (Fig. 3) which was heavier ($t = 2.02_{2,40}$; $P =$ 0.0016,) than captive-produced chick mass which was 29.95 ± 0.39 g. (Fig. 3). Hatched chick mass from eggs collected in the wild and hatched in captivity did not differ ($t = 2.02_{2,39}$; $P = 0.1095$) between 2009 (31.06 ± 0.37) and 2010 (32.07 ± 0.49) (Fig. 3). Therefore, 2009 and 2010 chick mass was pooled. As a result, there was a difference ($t = 2.01_{2,52}$; $P = 0.0026$) between wild-produced chick mass (31.51 ± 0.31) and captive-produced chick mass (29.95 ± 0.39).

Egg Hatching

Hatching of collected eggs started on 22 May and continued through 17 June. Overall hatch success was 78% (n = 46/59) (Table 10). One egg was not incubated. It was found and collected on 25 May covered in mold. We determined the hatchability of the egg was low, and the mold could create bacterial problems with existing eggs in the incubators. Hatch success of eggs removed from incubating females was 94% (n = 15/16). Hatch success of eggs removed from laying females was 72% (n = 31/43). Twenty-six eggs were left in the female aviary and were laid in 4 of 8 nest bowls. One nest was determined to be ―abandoned" (not incubated) and they were removed from the aviary. Three nests were created next to other nests and if it was determined they would hinder the success of a nearby nest, the eggs were removed. Because of logistical issues 5 eggs were not removed for ≤ 15 days. During that time span, temperatures ranged from approximately 0^{o} to 23^{o} C with heavy frost and snow that consisted of 5 cm of accumulation.

Chicks were weighed everyday for the first 10 days (Table 11). After day 10, chicks were weighed opportunistically, and at day-14, -17, -21, -28, and -35 if possible (Fig. 4). Chicks were also weighed when they were transported to the GB for introduction.

Chick Brooding

Initially, post-hatch mortality of chicks appeared to be relatively low (Table 12). Through the 1st day post-hatch, we experienced 7 mortalities. Six of the mortalities were related to developmental/birth deformations (splayed legs = 5, crooked neck = 1), 3 of which died within hours, and 3 were euthanized

(Table 13). One of those chicks tested positive for bacteria that would ultimately be the cause of 13 mortalities. The remaining post-hatch mortality was an accident. A chick died of suffocation as it became entangled in the feather dusters. All chicks with crooked toes either corrected themselves or were successfully corrected with the use of tape on the toes. This resulted in 39 chicks that hatched and appeared to be healthy at 1 day of age. All chicks were eating well and gaining weight. All chicks remained separated in predetermined broods, assigned by hatch date and limiting brood sizes to no more than 10 chicks.

We used separate food and water dishes for each brood and each set was cleaned daily. Latex gloves were used to handle all chicks, and no equipment was used from one brood to another to prevent cross-contamination.

The first chick mortality caused by problems associated with bacterial infections occurred on 26 May (Table 14). On 27 May, Dr. Lisa Wolfe (CDOW) prescribed an antibiotic (Baytril®) to be administered orally to every chick for 7 days (which coincided with the amount of time the chicks are at the CDOW FWRF, prior to being moved to the NWRC). The most common symptoms were pulmonary edema (stemming from fibrin and fluid in the coelomic cavity). Fluid in the coelomic cavity could be a result of an infected umbilicus. The infected umbilicus can be the product of a partially absorbed yolk sac. Dr. Karen Fox (CSU) conducted necropsies for chick mortalities. Preliminary diagnoses based on the necropsy results showed a presence of *Klebsiella spp.* and *Escheriachia coli (E. coli)*. Cause-specific mortalities are listed in the appendix (Table 15). On 23 June, another antibiotic (sulfamethoxazole) was prescribed by Dr. Lisa Wolfe to be administered in the chicks' water (30ml /3.78L). The antibiotic was administered for 7 days to all chicks. Test results showed that the bacteria were resistant to the sulfamethoxazole. At the writing of this progress report other options are being explored.

The following results were gleaned from various websites to assist in describing the bacteria cultured from chick necropsies:

Klebsiella spp. is a Gram-negative bacteria. *Klebsiella* organisms can lead to a wide range of disease states, notably pneumonia, urinary tract infections, and septicemia. *Klebsiella* species are ubiquitous in nature.

Escheriachia coli are a gram negative bacterium that is commonly found in the lower intestine of warm-blooded organisms. Most *E. coli* strains are harmless, but some, such as serotype O157:H7, can cause serious food poisoning in humans. The harmless strains are part of the normal flora of the gut, and can benefit their hosts by producing Vitamin K or by preventing the establishment of pathogenic bacteria within the intestine. *E. coli* was found in tissue samples from chick necropsies. Other bacteria were found in tissue samples for the liver and/or lung and included *Proteus vulgaris*, *Enterococcus spp*., *Klebsiella terrigena*, and *Clostridium perfringens*.

Burkholderia spp. is used for agricultural purposes (such as biodegradation, biocontrol and as plant-growth-promoting rhizobacteria). It can have pathogenic effects in immuno-compromised humans. *Burkholderia spp.* has antibiotic resistance and exhibits a high mortality rate from their associated diseases.

Staphylococcus spp. includes thirty-three species. Most are harmless and reside normally on the skin and mucous membranes of humans and other organisms. Found worldwide, they are a small component of soil microbial flora.

Proteus vulgaris is a gram negative bacterium that inhabits the intestinal tracts of humans and animals. It can be found in soil, water and fecal matter. It is known to cause urinary tract infections.

Enterococcus spp. are Gram-positive cocci that are difficult to distinguish from *Streptococci*. Two species are common commensal organisms in the intestines of humans.

Clostridium perfringens is a Gram-positive bacterium. *C. perfringens* is ubiquitous in nature and can be found as a normal component of decaying vegetation, marine sediment, the intestinal tract of humans and other vertebrates, insects, and soil.

Brood Augmentation

Two wild broods have been augmented with 14 captive-reared chicks over 5 separate introductions (Table 16). Overall adoption rate (defined as successful if the chick are with the surrogate brood 24-36 hours post-introduction) was 79% (*n* = 11/14). Two introductions (3 chicks each), were conducted for Treatment I (chicks were1 week old). Adoption rate for Treatment I was 100% (*n* = 6/6). Two introductions (2 chicks each), were conducted for Treatment II (chicks were 3 weeks old). Adoption rate for Treatment II was 50% (n=2/4). One introduction (4 chicks) was conducted for Treatment III (chicks were 5 weeks old), with a 75% adoption rate (*n* = 3/4). Apparent survival of all introduced chicks is 29% (*n* = 4/14; 2 chicks are missing and presumed dead) which is comparable to wild chicks of the same age (Phillips, Progress Report for GUSG Demography and Dispersal, 2010).

Current Status

Currently, we have 12 chicks at the NWRC (Table 17). Nine of the chicks are being held in two enclosures with mosquito proof netting (Fig. 5) to protect them potential exposure to West Nile virus (WNv). Four more introductions will take place over the next 3 weeks (we have no results at this time, but they will be present in the next progress report). Brood and chick survival will be monitored through the fall. The captive GUSG flock of 8 females and 3 males will be held at the NWRC through at least 2011. Options for retaining a captive flock at the NWRC as well as building a new facility are being explored.

SUMMARY

Although chick survival in captivity was less than desirable, we continued to build on our knowledge of captive-rearing and husbandry of Gunnison sage-grouse. Bacterial infections continued to result in higher than desired chick mortality post-hatch, although we eliminated the issue of the brooding substrate as potential source of the bacteria as proposed in 2009. The bacterial infections continue to present themselves from unknown sources, although we are continuing discussions and possible solutions with CDOW veterinary staff and CSU poultry scientists.

Other aspects of the captive-rearing project have gone exceedingly well. We have found that captive-reared and wild grouse brought into captivity will breed and produce viable eggs in captivity. Females will also nest and successfully raise chicks in captivity to seven weeks of age. Due to space limitations, females confined in a single aviary will exhibit egg dumping behavior.

The construction of a new incubation and hatching facility (Fig. 6) was critical to the success of the project. It allowed us to establish protocols that will ultimately help in isolating the source of the bacterial infections. It is also helpful to limit personnel access to one facility to prevent unintentional cross contamination of any bacteria or other diseases.

Invertebrate husbandry has been successful for all species raised. In contrast, a new facility specifically dedicated for invertebrate husbandry will be needed if operational quantities of invertebrates are desired. At least 4 months of advance time is required to start producing operational quantities of invertebrates in a dedicated facility. Otherwise, outside vendors will be needed to obtain adequate supplies of invertebrates.

To date, captive-chick augmentation to wild brooding females appears successful although sample sizes are extremely small the number of brooding females was limited.

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Table 1. Captive Gunnison Sage-grouse female breeding history at the National Wildlife Research Center, Fort Collins, Colorado, USA, 2010.

Female ID	Band ID	Access to Males (Days)	Access Time (min.)	Number of Males Copulated	Total Copulations
2972-09	Red-Orange	16	93	1	5 (10)
1195-09	Red-Blue	16	93	2	3
1197-09	Red-White	16	93	2	2
1200-09	Red-Green	16	93	1	2
N/A	Unk	16	93	1	2
1193-09	Pink	16	93	1	1
1199-09	Orange	16	93	1	1
1198-09	Green	16	93	1	1
1196-09	Blue	16	93	1	1

Table 2. Captive Gunnison Sage-grouse female breeding occasions at the National Wildlife Research Center, Fort Collins, Colorado, USA, 2010.

Female ID	Band ID	Date	Time	Male
2972-09	Red-Orange	11-Apr	0645	Wild Left
2972-09	Red-Orange	11-Apr	0649	Wild Left
1195-09	Red-Blue	11-Apr	0653	Wild Left
2972-09	Red-Orange	11-Apr	0654	Wild Left
1197-09	Red-White	11-Apr	0703	Wild Left
2972-09	Red-Orange	12-Apr	0555	Wild Left
2972-09	Red-Orange	12-Apr	0601	Wild Left
1193-09	Pink	14-Apr	0546	Wild Right
1198-09	Green	15-Apr	0550	Wild Right
1199-09	Orange	15-Apr	0555	Wild Right
1195-09	Red-Blue	15-Apr	0600	Wild Right
2972-09	Red-Orange*	15-Apr	0615	Wild Left
1196-09	Blue	16-Apr	0529	Wild Right
2972-09	Red-Orange**	16-Apr	0600	Wild Left
1197-09	Red-White	19-Apr	0532	Wild Right
1200-09	Red-Green	25-Apr	0715	Wild Right
1195-09	Red-Blue	26-Apr	0527	Wild Right
1200-09	Red-Green	26-Apr	0614	Wild Right
Unk	Unk	27-Apr	0525	Wild Right
1199-09 or 1193-09	Orange or Pink	30-Apr	0515	Wild Right

* Attempted two copulations, but Wild Left male could not mount because of the leg injury
** Attempted three copulations, but Wild Left male could not mount because of the leg injury

Table 3. Captive Gunnison Sage-grouse male breeding history at the National Wildlife Research Center, Fort Collins, Colorado, USA, 2010.

Male ID	Female Access (Days)	Access Time (min.)	Different Females Bred	Total Copulations
Wild Right	16	93	7	11
Wild Left	6	94	3	7*

* Five copulation attempts were made but could not mount because of the leg injury

Table 4. Capture information for female Gunnison Sage-grouse captured in KBSM; Colorado, USA, 2010.

Female ID	Capture Date	Lek of Capture	Sex	Age[1]	Weight (g)
1001	4/3	KEZAR	F	Y	1147
1002	4/3	KEZAR	F	A	1101
1003	4/4	KEZAR	F	Y	1119
1004	4/4	KEZAR	F	Y	1102
1005	4/4	KEZAR	F	A	1231
1006	4/4	KEZAR	F	A	1248
1007	4/5	KEZAR	F	A	1105
1008	4/5	KEZAR	F	Y	947
1009	4/5	KEZAR	F	Y	1206
1010	4/7	KEZAR	F	Y	1071
1011	4/14	SAPINERO	F	A	1371
1012	4/14	SAPINERO	F	Y	1131
1013	4/16	SAPINERO	F	Y	1133
1014	4/17	KEZAR	F	A	1187
1015	4/17	KEZAR	F	Y	1118
1016	4/19	SAPINERO	F	Y	977
1017	4/20	SAPINERO	F	Y	1055
1018	4/20	SAPINERO	F	A	1247
1019	4/21	SAPINERO	F	Y	1172
1020	4/24	SAPINERO	F	Y	1095
1021	5/6	SAPINERO	F	A	1103
1022	6/9	HARTMAN	F	A	N/A
1033	4/18	SOUTH BEAVER	F	A	1074

[1]A = Adult, Y = Yearling

Table 5. Gunnison Sage-grouse female nest success in KBSM; Colorado, USA, 2010.

Female ID	Age	Initiation Date[1]	Hatch Date	Nest Fate[2]	Total Eggs Laid	Eggs Hatched
1011	A	4-May	31-May	S	7	6
1019	Y	4-May	31-May	U	6	0
1015	Y	4-May	31-May	U	6	0
1033	Y	7-May	6-Jun	S	6	6
1018	A	9-May	5-Jun	U	5	0
1021	A	10-May	6-Jun	U	6	0
1020	Y	13-May	9-Jun	U	5	0
1001	Y	16-May	12-Jun	U	7	0
1017	Y	17-May	11-Jun	S	4	4
1008	Y	17-May	13-Jun	U	Unk	0
1006	A	23-May	19-Jun	S	6	5
1012	Y	Laying	N/A	U	3	0
1013	Y	Laying	N/A	U	5	0
1022	A	Unk	Unk	S	Unk	Unk

[1] Unk = Unknown
[2] S = Successful, U = Unsuccessful

Table 6. Number and allocation of eggs collected in the GB, Colorado, USA, 2010.

Location	Female ID	Age	# of Eggs	Incubating or Laying	Date Collected	Renested[1]	Renest Fate
S. Parlin	804	Adult	8	Incubating	27-Apr	Y	Unsuccessful
S. Parlin	805	Adult	6	Laying	29-Apr	N	n/a
S. Parlin	805	Adult	1	Incubating	7-May	N	n/a
S. Parlin	820	Adult	7	Incubating	29-Apr	N	n/a
Total			22				

[1] Y = Yes, N = No

Table 7. Number of captive females and eggs laid at the National Wildlife Research Center, Fort Collins, Colorado, USA, 2010

Captive Females	Eggs Laid	Eggs Collected	Eggs Incubated
9*	56	38	37

* One female died during breeding season

Table 8. Captive Gunnison Sage-grouse female incubation at the Foothills Wildlife Research Facility, Fort Collins, Colorado, USA, 2010.

Captive Females*	Captive Nests**	Eggs Incubated	Captive Nests Incubated	Successful Captive Nests	Eggs Hatched	Chicks Yielded
9	8	15	3	2	6	2

* One female died during breeding season

** Number of nest bowls initiated

Table 9. Captive nest incubated in female aviary at the National Wildlife Research Center, Fort Collins, Colorado, USA, 2010.

Nest ID	Eggs Laid	Eggs Removed	Eggs Destroyed	Eggs Incubated	Eggs Hatched	Chicks Yielded	
CN-1	10	4	2	4	3	0	
CN-2	7	3	0	4	3	2	
CN-3	7	0	0	7	0	0	Abandoned
Total	24	7	2	15	6	2	

Table 10. Total Gunnison Sage-grouse egg artificial incubation at the Foothills Wildlife Research Facility, Fort Collins, Colorado, USA, 2010.

Captive Females	Eggs Collected	Eggs Incubated	Eggs Hatched	Eggs 'Dead in Shell'	Possible Infertile Eggs	Chicks Yielded
9*	60	59	46	10	3	27

* One female died during breeding season

Table 11. Chick masses for domestically hatched Gunnison Sage-grouse chicks at hatch, days 1, 2, 3, 7, and 14, Fort Collins, Colorado, USA, 2010.

	Mean Chick Mass (g)						
Egg Origin	Hatch (n=46)	Day 1 Loss	Day 1 (n=39)	Day 2 (n=34)	Day 3 (n=36)	Day 7 (n=18)	Day 14 (n=14)
Wild	32.07	0.90	31.17	33.50	35.56	59.04	109.62
Captive	29.95	1.45	28.50	30.40	33.90	55.38	106.32

Table 12. Apparent Gunnison Sage-grouse chick survival (to 5, 7, and 10 days) at the National Wildlife Research Center, Fort Collins, Colorado, USA, 2010.

	5 Days of Age		7 Days of Age		10 Days of Age		Mean Time from External Pip To Hatch	
Chicks	Number of Chicks	Apparent Survival	Number of Chicks	Apparent Survival	Number of Chicks	Apparent Survival	Hours	Days
46	37	80.43%	31	67.39%	20	58.70%	42.89	1.79

Table 13. Gunnison Sage-grouse chick mortality totals at the Foothills Wildlife Research Facility, Fort Collins, Colorado, USA, 2010

Trauma / Accidental	Splayed Leg	Euthanized	Bacteria	Unknown	Total Morts
3	3	3	13	2	24*

*Includes 4 chicks hatched/reared by captive females.

Table 14. Gunnison Sage-grouse chick mortalities at the Foothills Wildlife Research Facility, Fort Collins, Colorado, USA, 2010

Chick ID	Hatch	Mortality Date	Time of Death	Age at Death (days)	Gross Diagnosis	Hours Between External Pip and Hatch[3]	Days between Ext. Pip and Hatch	Assisted Hatch
D-38-10	6/4	6/4	1900	2 hrs	Crooked Neck[2]	55.15	2.30	Yes
D-25-10	5/28	5/29	1100	2 hrs	Splayed Legs[2]	37.33	1.56	No
D-42-10	6/8	6/8	1000	3 hrs	Splayed Legs[2]	59.00	2.46	Yes
D-19-10	5/27	5/28	1040	6 hrs	Splayed Legs	28.25	1.18	No
D-45-10	6/13	6/14	0940	16 hrs	Splayed Legs / Bacterial[1]	46.66	1.94	No
D-7-10	5/23	5/24	1530	23 hrs	Splayed Legs	61.50	2.56	Yes
D-2-10	5/22	5/23	1730	1	Suffocation	34.25	1.43	No
D-26-10	5/28	5/30	0100 - 0530	2	Bacterial[1]	52.00	2.17	No
D-5-10	5/22	5/26	1030	4	Bacterial[1]	46.00	1.92	No
D-4-10	5/22	5/27	2000 - 0630	5	Bacterial[1]	43.50	1.81	No
D-3-10	5/22	5/27	0745	5	Bacterial[1]	43.50	1.81	No
D-18-10	5/27	6/1	1430	5	Bacterial[1]	28.25	1.18	No
D-11-10	5/25	6/1	1800 - 1815	7	Bacterial[1]	42.00	1.75	No
D-13-10	5/26	6/2	2230 - 0455	7	Bacterial[1]	52.50	2.19	No
D-39-10	6/5	6/12	2300 - 0445	7	Bacterial[1]	47.33	1.97	No
D-16-10	5/26	6/4	2000 - 0545	9	Bacterial[1]	62.33	2.60	Yes
D-23-10	5/27	6/5	1215	9	Bacterial[1]	28.75	1.20	No
D-46-10	6/13	6/22	1900 - 0600	9	Bacterial[1]	45.66	1.90	No
D-12-10	5/26	6/5	1900 - 0600	10	Bacterial[1]	45.00	1.88	No
D-9-10	5/25	6/11	1600	17	Trauma	36.66	1.53	No

[1] = Bacterial mortality caused by a combination of pulmonary edema, stemming from fibrin and fluid in the coelomic cavity. Fluid in the coelomic cavity could be a result of an infected umbilicus. The infected umbilicus can be the product of a partially absorbed yolk sac.

[2] = Chick was euthanized via cervical dislocation.

[3] = Hours between external pip and hatch - Measured from the time when the external pip was first seen (may have some variability if pipped in the middle of the night), until the chick was seen out of the shell. On average, there could be up to an hour of variability on both ends, if happened during our normal day shifts.

Table 15. Cause specific Gunnison Sage-grouse chick mortalities, 2010 (* Fresh and/or Set weights were estimated. ** Days on the ground are estimated under the assumption that we found all eggs within 24 hours of being laid).

Egg ID	Chick ID	Hatch	Mortality Date	Time of Death	Age (days) at death	Gross Diagnosis	est. DAYS egg was laid (prior to collection)	DAYS egg was in cooler / aviary	Final Measured Weight Loss %	Final Projected Weight Loss %	HOURS between external pip and hatch[2]	DAYS between ext. pip and hatch	Assisted Hatch
CU-41	D-38-10	6/4	6/4	1900	2 hrs	Crooked Neck	<1	5.71			55.15	2.30	Yes
CU-47	D-42-10	6/8	6/8	1000	3 hrs	Splayed Legs	<1	5.58	6.80%	7.02	59	2.46	Yes
CU-55	D-45-10	6/13	6/14	940	16 hrs	Splayed Legs	15	0	12.35%	12.83	46.66	1.94	No
804-17	D-7-10	5/23	5/24	1530	23 hrs	Splayed Legs	unk	0	8.58% *	9.77	61.5	2.56	Yes
805-30	D-19-10	5/27	5/28	1040	1	Splayed Legs	unk	0	9.90%	10.29	28.25	1.18	No
CU-5	D-25-10	5/28	5/29	1100	1	Splayed Legs	<1	6.07	10.42%	10.70	37.33	1.56	No
BIRTH DEFECTS	**** (summary 6 total) ** 2 wild eggs - 4 domestic eggs - 3 assisted hatches - 3 Euthanized - 3 Died naturally**												
CN1-d	D-47-10	6/4	6/4	~1415	1	Bacterial[1]	N/A	8**	N/A	N/A	N/A		N/A
CU-6	D-26-10	5/28	5/30	0100 - 0530	2	Bacterial[1]	<1	6.07	8.82%	9.07	52	2.17	No
804-14	D-5-10	5/22	5/26	1030	4	Bacterial[1]	unk	0	8.57% *	9.76	46	1.92	No
804-19	D-4-10	5/22	5/27	2000 - 0630	5	Bacterial[1]	unk	0	8.59% *	9.78	43.5	1.81	No
804-15	D-3-10	5/22	5/27	745	5	Bacterial[1]	unk	0	8.55% *	9.73	43.5	1.81	No
805-33	D-18-10	5/27	6/1	1430	5	Bacterial[1]	unk	0	10.17%	10.56	28.25	1.18	No
820-23	D-11-10	5/25	6/1	1800 - 1815	7	Bacterial[1]	unk	0	11.52% *	11.93	42	1.75	No
820-28	D-13-10	5/26	6/2	2230 - 0455	7	Bacterial[1]	unk	0	11.32% *	11.73	52.5	2.19	No
CU-45	D-39-10	6/5	6/12	2300 - 0445	7	Bacterial[1]	<1	4.75	10.12%	10.43	47.33	1.97	No
CU-1	D-16-10	5/26	6/4	2000 - 0545	9	Bacterial[1]	<1	6.15	12.10%	12.87	62.33	2.60	Yes
805-32	D-23-10	5/27	6/5	1215	9	Bacterial[1]	unk	0	10.05%	10.44	28.75	1.20	No
CU-59	D-46-10	6/13	6/22	1900 - 0600	9	Bacterial[1]	8	0	13.25%	13.76	45.66	1.90	No
820-27	D-12-10	5/26	6/5	1900 - 0600	10	Bacterial[1]	unk	0	10.68% *	11.06	45	1.88	No
BACTERIAL	**** (summary 13 total) ** 8 wild eggs - 3 domestic eggs - 1 captive nest egg - 1 assisted hatches - 0 Euthanized**												

Table 15 (continued). Cause specific Gunnison Sage-grouse chick mortalities, 2010 (* Fresh and/or Set weights were estimated. ** Days on the ground are estimated under the assumption that we found all eggs within 24 hours of being laid).

Egg ID	**Chick ID**	**Hatch**	**Mortality Date**	**Time of Death**	**Age (days) at death**	**Gross Diagnosis**	**est. DAYS egg was laid (prior to collection)**	**DAYS egg was in cooler / aviary**	**Final Measured Weight Loss %**	**Final Projected Weight Loss %**	**HOURS between external pip and hatch[2]**	**DAYS between ext. pip and hatch**	**Assisted Hatch**
804-13	D-2-10	5/22	5/23	1730	1	Suffocation	unk	0	9.44% *	10.72	34.25	1.43	No
CN1-e	D-48-10	6/4	6/6	~1350	2	Trauma	N/A	8**	N/A	N/A	N/A		N/A
820-22	D-9-10	5/25	6/11	1600	17	Trauma	unk	0	10.04% *	10.41	36.66	1.53	No
TRAUMA	**** (summary 3 total) ** 2 wild eggs - 1 domestic eggs - 1 accidental - 1 brood hen cause - 1 suffocation**												
CN5-d	D-50-10	6/4	6/5	~1100	1	Unknown	N/A	8**	N/A	N/A	N/A		N/A
CN1-a	D-49-10	6/4	6/8	~1800	3	PENDING	N/A	15**	N/A	N/A	N/A		N/A
UNKNOWN	**** (summary 2 total) ** 2 captive nest eggs**												

[1] **BACTERIAL** - Mortality caused by a combination of pulmonary edema, stemming from fibrin and fluid in the coelomic cavity. Fluid in the coelomic cavity could be a result of an infected umbilicus. The infected umbilicus can be the product of a partially absorbed yolk sac.

[2] **HOURS between external pip and hatch** - Measured from the time when the external pip was first seen (may have some variability if pipped in the middle of the night), until the chick was seen out of the shell. On average, there could be up to an hour of variability on both ends, if happened during our normal day shifts.

Table 16. Domestically reared Gunnison Sage-grouse chick introduction history, 2010 (*chick found w/ surrogate brood 36 hours post introduction).

Chick ID	Introduction Date	Introduction Weight (g)	Introduction Age (days)	Surrogate Female / Brood ID	# of Chicks in the Surrogate Brood Before Introduction	Brood Size at Capture / Introduction	Brood Size After Introduction	Number of Domestic Chicks w/ Surrogate 24 hrs post Intro	Successful Adoption (y/n)	Chick Status as of July 1 (Alive, Dead, MIA)	Date of Mort / MIA	Age at Death (days)	Cause of Death
D-17-10	6/2	55.7	6	SAP-11-10	6	6	9	3	Y	MIA			
D-20-10	6/2	55	6	SAP-11-10	6	6	9	3	Y	A	N/A	N/A	N/A
D-21-10	6/2	51.5	6	SAP-11-10	6	6	9	3	Y	M	6/22		Mammalian
D-34-10	6/9	51.4	6	GB-33-10	6	4 (6)	7 (9)	3	Y	M	6/14	11	Unk
D-35-10	6/9	50	6	GB-33-10	6	4 (6)	7 (9)	3	Y	MIA			
D-37-10	6/9	41	4	GB-33-10	6	4 (6)	7 (9)	3	Y	M	6/14	9	Unk
D-33-10	6/20	101	18	GB-33-10	1	1	3	2	N	M	6/23	21	Unk (Avian?)
D-36-10	6/20	124	16	GB-33-10	1	1	3	2	N	M	6/23	19	Unk (Exposure?)
D-22-10	6/16	191	20	SAP-11-10	4	4	6	2 (3)	Y	M	6/18	22	Unk
D-24-10	6/16	148.9	19	SAP-11-10	4	4	6	2 (3)	Y	M	6/19	23	Unk
D-8-10	6/29	341	34	SAP-11-10	3	3	6	0 (1)	N	M	7/1	37	Unk
D-10-10	6/29	273.1	34	SAP-11-10	3	3	6	0 (1)*	Y	A	N/A	N/A	N/A
D-14-10	6/29	341.1	35	SAP-11-10	3	3	6	0 (1)*	Y	A	N/A	N/A	N/A
D-15-10	6/29	273.1	35	SAP-11-10	3	3	6	0 (1)*	Y	A	N/A	N/A	N/A

Table 17. Egg specific information related to, hatch, fate, current status, and exposure of each egg collected, 2010 (*Chick may have externally pipped or hatched over night, potentially adding up to 6 hrs to hatching time. In those cases, the midpoint was used).

EGG ID	HATCH[1]	CHICK ID	HATCH DATE	HATCH TIME	EXT. PIP DATE	EXT. PIP TIME	HATCHING TIME (hrs)	HATCHING TIME (days)	HATCH WEIGHT (grams)	PROJECTED WT. LOSS PERCENTAGE (27 days)	STATUS as of 7/1 (Alive, Dead, Introduced)	AGE as of 7/1 (days)	MORT DATE	MORT TIME	AGE at DEATH / STOP in EGG DEVELOPMENT (days)	MORT CAUSE
804-12	Y	D-1-10	5/22	1200	5/20	2230	37.50	1.56	31.8	9.79	Alive	40				
804-13	Y	D-2-10	5/22	1315	5/21	600*	34.25	1.43	31	10.72	Dead		5/23	1730	1	Suffocation
804-14	Y	D-5-10	5/22	2030	5/20	2230	46.00	1.92	31.3	9.76	Dead		5/26	1030	4	Bacterial
804-15	Y	D-3-10	5/22	1800	5/20	2230	43.50	1.81	33.1	9.73	Dead		5/27	745	5	Bacterial
804-16	Y	D-6-10	5/23	1630	5/21	830	56.00	2.33	32.3	9.67	Alive	39				
804-17	Y	D-7-10	5/23	1630	5/21	600*	61.50	2.56	29	9.77	Dead		5/24	1530	23 hrs	Splayed Legs
804-18	N														16	Infertile
804-19	Y	D-4-10	5/20	1800	5/22	2230	43.50	1.81	33.1	9.78	Dead		5/27	2000 - 0630	5	Bacterial
CU-1	Y	D-16-10	5/26	1750	5/24	630*	62.33	2.60	25.7	12.87	Dead		6/4	2000 - 0545	9	Pending
CU-2	Y	D-14-10	5/26	1245	5/24	630*	54.25	2.26	27.3	9.94	Introduced	36				
CU-3	N														28	Malpositioned
820-22	Y	D-9-10	5/25	1610	5/24	630*	36.66	1.53	30.1	10.41	Dead		6/11	1600	17	Trauma
820-23	Y	D-11-10	5/25	2130	5/24	630*	42.00	1.75	30.7	11.93	Dead		6/1	1800 - 1815	7	Bacterial
820-24	Y	D-15-10	5/26	1745	5/24	630*	59.25	2.47	29.7	11.34	Introduced	36				
820-25	Y	D-8-10	5/25	945	5/23	1900	38.75	1.61	32.8	10.35	Introduced	Mort	7/1	unk	37	Unknown
820-26	Y	D-10-10	5/25	2025	5/24	1015	34.17	1.42	30.6	10.87	Introduced	37				
820-27	Y	D-12-10	5/26	0715	5/24	1015	45.00	1.88	29.6	11.06	Dead		6/5	1900 - 0600	10	Bacterial
820-28	Y	D-13-10	5/26	0800	5/24	630*	52.50	2.19	30.3	11.73	Dead		6/2	2230 - 0455	7	Bacterial
805-29	Y	D-22-10	5/27	1215	5/25	2020	39.92	1.66	34.8	10.60	Introduced	Mort	6/18	unk	22	Unknown
805-30	Y	D-19-10	5/27	0500*	5/25	1845	28.25	1.18	36	10.29	Dead		5/28	1040	1	Splayed Legs
805-31	Y	D-17-10	5/27	0035	5/25	1845	29.83	1.24	35.8	10.53	Introduced	MIA				
805-32	Y	D-23-10	5/27	1400	5/26	915	28.75	1.20	35.7	10.44	Dead		6/5	1215	9	Bacterial
805-33	Y	D-18-10	5/27	0200	5/25	1845	28.25	1.18	32.1	10.56	Dead		6/1	1430	5	Bacterial

Table 17 (continued). Egg specific information related to, hatch, fate, current status, and exposure of each egg collected, 2010 (*Chick may have externally pipped or hatched over night, potentially adding up to 6 hrs to hatching time. In those cases, the midpoint was used).

EGG ID	HATCH[1]	CHICK ID	HATCH DATE	HATCH TIME	EXT. PIP DATE	EXT. PIP TIME	HATCHING TIME (hrs)	HATCHING TIME (days)	HATCH WEIGHT (grams)	PROJECTED WT. LOSS PERCENTAGE (27 days)	STATUS as of 7/1 (Alive, Dead, Introduced)	AGE as of 7/1 (days)	MORT DATE	MORT TIME	AGE at DEATH / STOP in EGG DEVELOPMENT (days)	MORT CAUSE
805-34	Y	D-20-10	5/27	1110	5/25	1845	40.42	1.68	34.6	10.67	Introduced	36				
CU-4	Y	D-24-10	5/28	0430	5/26	1930	33.00	1.38	28.4	10.90	Introduced	Mort	6/19	unk	23	Unknown
CU-5	Y	D-25-10	5/28	0850	5/26	1930	37.33	1.56	31.3	10.70	Dead		5/29	1100	1	Splayed Legs
CU-6	Y	D-26-10	5/28	2330	5/26	1930	52	2.17	29.7	10.07	Dead		5/30	0100 - 0530	2	Bacterial
CU-7	N														16	Dead in Shell
805-54	Y	D-21-10	5/27	1215	5/25	945	50.66	2.11	29.1	11.14	Introduced					
CU-8	N														11-Apr	Dead in Shell
CU-9	Y	D-28-10	5/30	900	5/28	1300	44	1.83	29.8	8.31	Alive	32				
CU-10	Y	D-27-10	5/30	530*	5/28	1300	40.5	1.69	29.4	10.56	Alive	32				
CU-11	Y	D-29-10	5/30	1445	5/28	1300	49.75	2.07	29.7	11.64	Alive	32				
CU-20	Y	D-32-10	6/1	956	5/30	2045	37.18	1.55	29.4	12.02	Alive	30				
CU-21	Y	D-31-10	6/1	940	5/30	1315	44.42	1.85	31.1	10.81	Alive	30				
CU-35	Y	D-30-10	6/1	0550*	5/30	2045	33.12	1.38	31.4	13.67	Alive	30				
CU-52	N														25	
CU-36	N														9-Apr	
CU-37	Y	D-33-10	6/2	2030	6/1	1300	31.5	1.31	29.6	11.58	Introduced	Mort	6/23	unk	21	Unknown
CU-38	Y	D-35-10	6/3	1045	6/1	1300	45.75	1.91	31.8	10.89	Introduced	MIA				
CU-39	Y	D-34-10	6/3	0530*	6/1	1300	40.5	1.69	32.1	10.43	Introduced	Mort	6/14	unk		
CU-40	N														23	Malposition
CU-41	Y	D-38-10	6/4	1655	6/2	945	55.15	2.3	32.4	10.5	Dead		6/4	1900	2 hrs	Crooked Neck
CU-42	Y	D-36-10	6/4	1014	6/2	1200	46.25	1.93	27.1	11.77	Introduced	Mort	6/23	unk	19	Unk (Exposure)
CU-43	N														22	Unknown
CU-44	Y	D-37-10	6/4	1430	6/3	1225	26.07	1.09	27.3	11.74	Introduced	Mort	6/14	unk	9	Unknown

Table 17 (continued). Egg specific information related to, hatch, fate, current status, and exposure of each egg collected, 2010 (*Chick may have externally pipped or hatched over night, potentially adding up to 6 hrs to hatching time. In those cases, the midpoint was used).

EGG ID	HATCH[1]	CHICK ID	HATCH DATE	HATCH TIME	EXT. PIP DATE	EXT. PIP TIME	HATCHING TIME (hrs)	HATCHING TIME (days)	HATCH WEIGHT (grams)	PROJECTED WT. LOSS PERCENTAGE (27 days)	STATUS as of 7/1 (Alive, Dead, Introduced)	AGE as of 7/1 (days)	MORT DATE	MORT TIME	AGE at DEATH / STOP in EGG DEVELOPMENT (days)	MORT CAUSE
CU-45	Y	D-39-10	6/5	1145	6/3	1225	47.33	1.97	31	12.97	Dead		6/12	2300 - 0445	7	??
CU-46	N														24	Unknown
CU-47	Y	D-42-10	6/8	0624*	6/5	1620	59	2.46	33.4	7.02	Dead		6/8	1000	3 hrs	Splayed Legs
CU-48	N														15-Apr	Dead in Shell
CU-49	N														24	Dead in Shell
CU-50	Y	D-41-10	6/7	915	6/5	1215	45	1.88	28.9	10.05	Alive	24				
CU-51	Y	D-40-10	6/6	1350	6/4	2035	31.25	1.3	28.3	10.13	Alive	25				
CU-53	Y	D-43-10	6/10	1405	6/8	2045	41.33	1.72	29.5	10.14	Alive	22				
CU-55	Y	D-45-10	6/13	1700	6/11	1921	46.66	1.94	31.7	12.83	Dead		6/14	940	16 hrs	Splayed Legs / Bacterial
CU-56	N														9	
CU-57	Y	D-44-10	6/13	0445*	6/11	600*	46.75	1.95	29.7	12.58	Alive	18				
CU-58	N														9	Infertile
CU-59	Y	D-46-10	6/13	1700	6/11	1921	45.66	1.9	32.7	13.76	Dead		6/22	1900 - 0600	9	Bacterial
AVERAGE			5/29	20:48	5/28	3:39	42.89	1.79	30.92	10.85						

[1] Y = Yes, N = No

Figure 1. Mass ($\bar{x} \pm$ SE) of eggs collected from wild females in the GB and captive-reared females in FTC, Colorado, USA, 2010.

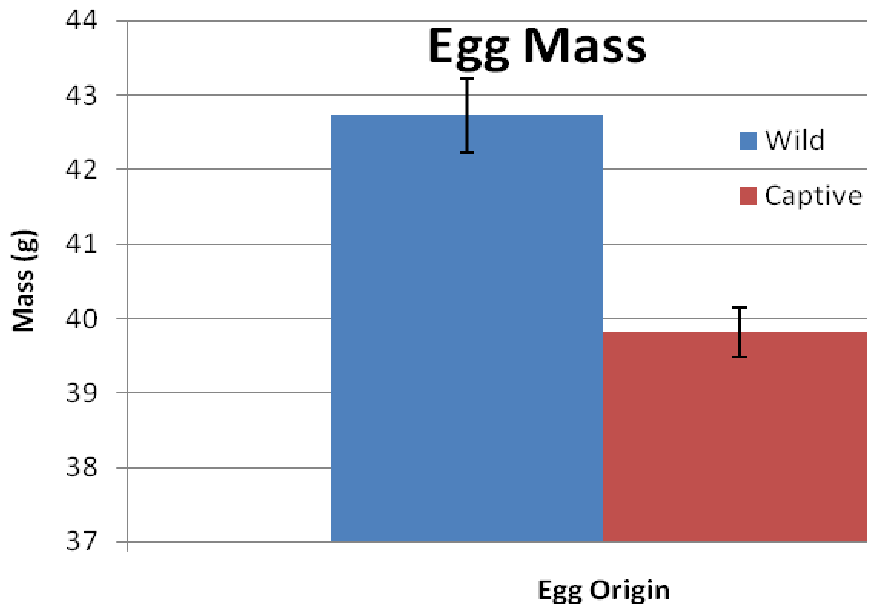

Figure 2. Percent mass loss of wild and captive-produced eggs during incubation at the Foothills Wildlife Research Center, Fort Collins, Colorado, USA, 2010.

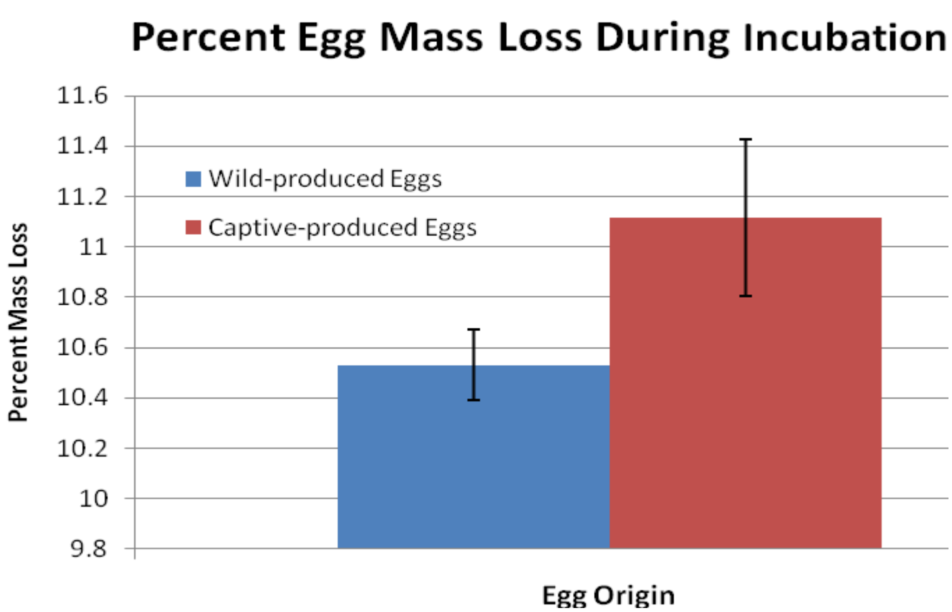

Figure 3. Hatched chick mass of wild and captive-produced eggs, 2010.

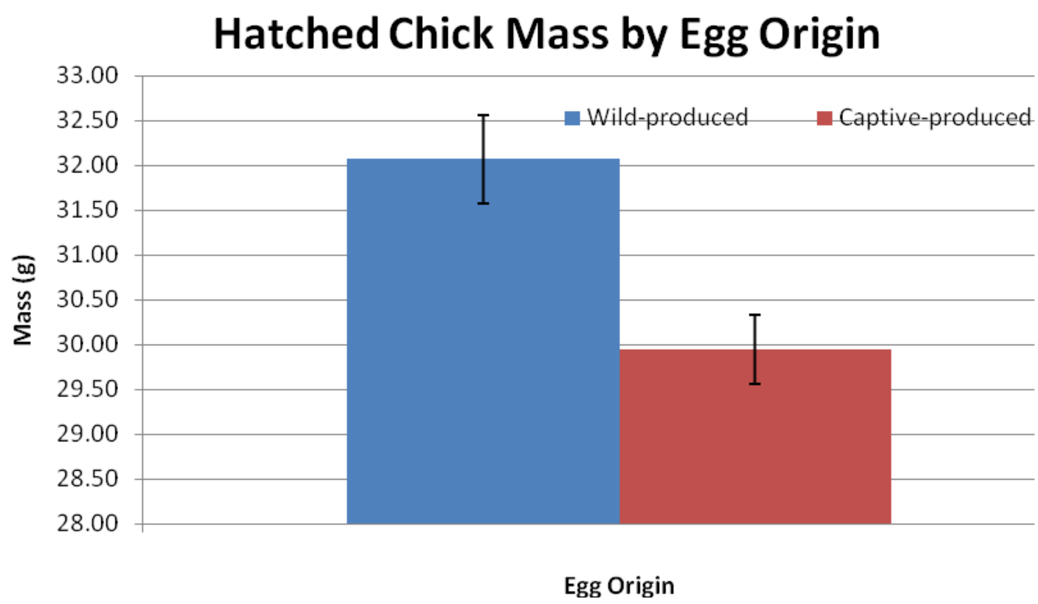

Figure 4. Individual captive-reared chick mass gain for the first 35 days of life in Fort Collins, Colorado, USA, 2010.

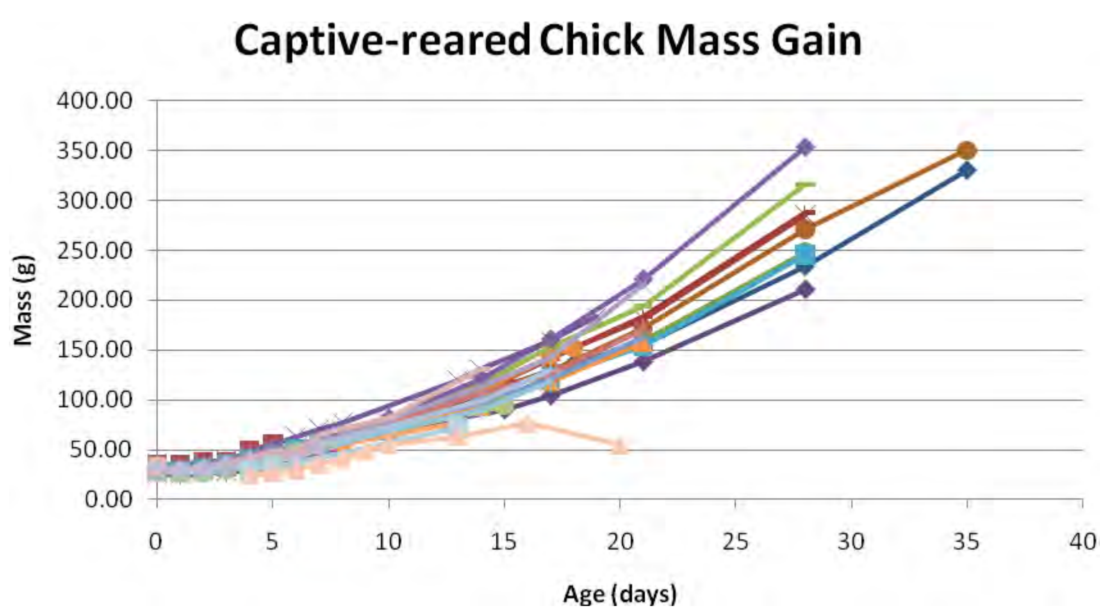

Figure 5. West Nile virus / Mosquito exclosure.

Figure 6. CDOW Foothills Wildlife Research Facility incubation building. In February, 2010, we built a facility (A) to house all of the egg incubation and hatching operations. The building allowed us to better control temperature and humidity as well as have a clean work space to help prevent bacteria growth. The building is 3.7-m x 6.1-m x 2.4-m (W x L x H). The building electricity was wired to have separate breakers for each of the incubators and hatchers (B). The building also had a heating and air conditioning unit as well as a sink and water heater. Brooder pens and coops (A) were also provided at the facility.

COLORADO DIVISION OF WILDLIFE - AVIAN RESEARCH PROGRAM
Progress Report
September 2010

TITLE: Baseline habitat monitoring for Gunnison sage-grouse in the Gunnison Basin, Colorado

AUTHOR: Anthony D. Apa, Michael L. Phillips, and James H. Gammonley

PROJECT PERSONNEL: A. Hild and M. I. Williams, University of Wyoming, Laramie, WY

Period Covered: March 1, 2005 – August 31, 2010

ABSTRACT

The Gunnison sage-grouse (*Centrocercus minimus*) has been a candidate species under the Federal Endangered Species Act (ESA) and is a Colorado Species of Special Concern. There is little scientific data linking domestic livestock grazing practices to sage-grouse population levels; however, one of the continuing questions facing western land management agencies is the potential influence of livestock grazing on sagebrush dominated habitats and sage-grouse populations. Structural habitat guidelines have been established for Gunnison sage-grouse. However, additional research is needed to provide a better understanding of the guidelines as they apply to the population dynamics of sage-grouse, and how methods used by land management agencies (Bureau of Land Management, Natural Resource Conservation Service) to assess rangeland condition, health, and ecological trajectories are related to habitat characteristics of importance to sage-grouse. In 2008, the grazing subcommittee of the Gunnison Sage-grouse Strategic Committee requested that a research proposal be developed to address the issue of livestock grazing and sage-grouse management. As an initial step in addressing this issue, the Colorado Division of Wildlife (CDOW) partnered with the University of Wyoming to conduct a one-year field effort to intensively monitor and assess current habitat conditions in sage-grouse study sites in Gunnison County. The results will allow the investigators to compare relationships between general rangeland monitoring programs based on ecological site descriptions and assessments of sage-grouse habitat conditions. This baseline habitat assessment will also provide information necessary to design future experimental studies to examine the impact of domestic livestock grazing on Gunnison sage-grouse populations, and the grazing treatments that are appropriate for each study site. Field work was initiated in June. Several large study sites were identified based on existing locations of radio-marked Gunnison sage-grouse in the Gunnison Basin. The study sites were further stratified based on soils, elevation, and other ecological site information, and field plots were selected in each study site. A sampling approach was used that allowed for statistically representative and reliable sampling approach to describe vegetation conditions at the grazing allotment scale. Field crews are currently measuring vegetation information at selected plots, including species composition, cover and height. Field work will be completed in fall 2010. A final report will be completed by February 2011.

COLORADO DIVISION OF WILDLIFE - AVIAN RESEARCH PROGRAM
Progress Report
September 2010

TITLE: Greater Sage-grouse natal dispersal and brood augmentation with captive-reared chicks

AUTHOR: Anthony D. Apa

PROJECT PERSONNEL: T. Thompson and K. P. Reese, University of Idaho, Moscow, ID

Period Covered: March 1, 2005 – August 31, 2010

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ABSTRACT

In response to population declines, recent research on greater sage-grouse (*Centrocercus urophasianus*) has focused on the population ecology, habitat relationships, and response to management practices by this species. However, the mechanisms, patterns, and consequences of movements between seasonal habitats, especially by juveniles during natal dispersal, and the effects of this movement on survival, recruitment, the redistribution of individuals, as well as the population dynamics within and between populations remains largely unknown. Quantifiable data and information on juvenile dispersal and survival in the greater sage-grouse is one of the least understood aspects of this species' life history. Dispersal patterns and recruitment processes of juvenile sage-grouse, as well the landscape characteristics that influence and contribute to these movements remain lacking. Knowledge of the dispersal ecology (timing, distances moved, frequency and rate of movement, immigration and emigration rates within and between populations, and juvenile survivorship) will provide better information on how to manage this species at the landscape level, as well as within and between populations. This information will be useful in attempting to improve and plan for the conservation of this species as its habitat becomes more fragmented and altered. The objectives of our study are to 1) determine the sex-specific movement patterns of juvenile sage-grouse during natal dispersal including timing, duration, rate of movement, distances moved and recruitment rate, 2) determine the effects of these dispersal patterns on survival rates and causes of mortality, 3) determine how landscape structure influences both the movement patterns and survival of juveniles during this period, 4) verify and evaluate the mechanisms and conditions of adoption in wild broods through the introduction of domestically-hatched chicks and observation of natural adoption rates, 5) assess the movement patterns and survivorship of successfully adopted domestically-hatched 2 and 7 day-old chicks from the natal area of the surrogate brood to chick independence and brood break-up (approximately 10 weeks of age), and 6) compare the movement patterns and survivorship of domestically-hatched chicks with the movement patterns and survivorship of wild-hatched chicks in mixed and unmixed broods from the natal area of the surrogate brood to chick independence and brood break-up. The study areas were located in the Axial Basin and Cold Springs Mountain in northwestern Colorado. During 2005-2007 we radio-marked 281 females and 625 chicks from approximately 200 broods. Of those females, 352 nests were monitored. Field work was completed in spring 2008 when we monitored the dispersal movements and survival of chicks produced and radio-marked in 2007. A total of 208 eggs were collected and 166 chicks were hatched for the brood augmentation portion of the study. The project field research is complete and all dissertation chapters of the student will be completed by late-September with a defense scheduled in late-December 2010.

COLORADO DIVISION OF WILDLIFE - AVIAN RESEARCH PROGRAM
PROGRESS REPORT
September 2010

TITLE: Modeling the probability of greater sage-grouse presence across its distribution in Colorado

AUTHOR: M. B. Rice

PROJECT PERSONNEL: K. Eichhoff, B. Petch

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

ABSTRACT

Detailed maps of the distribution of a species are valuable for conservation planning and for communication with private landowners and partner agencies. With a recent decision of ―warranted but precluded” for listing under the Endangered Species Act, there is increased interest in identifying key habitat areas for greater sage-grouse (*Centrocercus urophasianus*). The Colorado Division of Wildlife has compiled a large database of greater sage-grouse locations from numerous radio-telemetry studies conducted on different subpopulations during 1997-2008, that can be used to develop models of habitat associations and predictive maps of sage-grouse distribution in Colorado. I overlaid the occupied range of greater sage-grouse in northwestern Colorado with a 1-km^2 grid; presence or absence of sage-grouse locations in grid cells were counted as the response variable. I used a generalized linear mixed model (GLMM) in program R using habitat variables, age, sex, and season as fixed effects and subpopulation as a random effect to predict greater sage-grouse location counts. In a preliminary model, differences among the 6 subpopulations accounted for 52.6% of the variability in sage-grouse locations. In the overall model, locations were highly associated with sagebrush and most other vegetation types had minor effects on sage-grouse locations. The resulting map of the probability of greater sage-grouse presence was consistent with existing information on greater sage-grouse distribution in Colorado. In particular, the model predicted a high probability of sage-grouse presence in North Park, where the second-largest population of greater sage-grouse in Colorado occurs, but where no location data were available for use in developing the model. The initial model will be further refined and validated with field data that is currently being collected. Maps produced from the final model should serve as a useful tool for managers in greater sage-grouse conservation.

MODELING THE PROBABILITY OF GREATER SAGE-GROUSE PRESENCE ACROSS ITS DISTRIBUTION IN COLORADO

Progress Report, July 1, 2009 – June 30, 2010

Mindy B. Rice

PROJECT OBJECTIVES

The objective of this study is to provide managers and biologists with a comprehensive map of greater sage-grouse (*Centrocercus urophasianus*) habitat in Colorado using a consistent and repeatable methodology at multiple scales.

SEGMENT OBJECTIVES

1. Use locations of radio-marked greater sage-grouse collected during 1997-2008 and GIS habitat layers to develop biologically relevant models to predict the probability of greater sage-grouse presence in Colorado.

INTRODUCTION

Managers and biologists need detailed, accurate maps of where species are predicted to occur across the landscape, for conservation planning and for communication with private landowners and partner wildlife professionals. For greater sage-grouse, habitat mapping often revolves around leks which are only available during the breeding season and often represent unique habitat used for a short period during the year (Doherty et al. *in press*). The Colorado Division of Wildlife has a large database of greater sage-grouse telemetry locations that have been collected for various studies in recent years from various portions of the species' range in the state (Table 1), and will continue to acquire location data from radio-marked greater sage-grouse in future years. These data can be used to provide a more detailed analysis of greater sage-grouse distribution across seasons and populations by incorporating the variability that exists across time and space. Both local and landscape scale habitat features influence habitat use by greater sage-grouse especially when both scales are incorporated in the same model (Doherty et al. 2010).

One problem with incorporating multiple scales into one model is that autocorrelation between observations can exist across scales (e.g. an individual observation at the fine scale will be incorporated into the variable at the broader scale). In addition, the relationship between variables can be obscured by other variables at different scales (McMahon and Diez 2007). Using mixed effects models, also called hierarchical or multilevel models, permits correlations that often exist within grouped data to be modeled (Buckley et al. 2003). Spatialized generalized linear mixed models (GLMM) are generalized linear models that allow random effects where within-group errors can be spatially autocorrelated (Dormann et al. 2007).

In Colorado, greater sage-grouse are distributed in multiple populations that are separated geographically and may exhibit regional differences in habitat preferences. A current trend in habitat mapping is to use the detailed information collected on individual animals while also predicting distributions at a broader scale using less resolute data (Klar et al. 2008). By incorporating random effects in the model, it is possible to investigate the variation that may exist among genotypes, populations, species, regions or time periods (Bolker et al. 2008). By accounting for differences among populations and subpopulations as well as incorporating more detailed information on individual birds, we can provide a more accurate and valid assessment of the probability of presence of greater sage-grouse across its range in northwestern Colorado.

STUDY AREA

Greater sage-grouse occur in Eagle, Garfield, Grand, Jackson, Moffat, Rio Blanco, and Routt counties in northwestern Colorado (Fig. 1). Within this area, several distinct populations are recognized (Fig. 2). The Northwest Population (NM) occurs in Moffat, Rio Blanco, and Routt counties; the NW population is further separated into several subpopulations or zones. The Parachute/Piceance/Roan (PPR) population is located in Rio Blanco and Garfield counties, the Meeker/White River population is in Rio Blanco County, the North Eagle/South Routt (NESR) population is in Eagle and Routt counties, the Middle Park (MP) population is in Grand County, and the North Park (NP) population is in Jackson County; a small population that historically occurred in the Larimie River Basin in Larimer County was not included in this assessment.

METHODS

Greater sage-grouse telemetry locations were compiled from 1997 to 2008 from a series of 11 studies in the NW, NESR, MP, and PPR populations (Table 1, Fig. 2). Only individuals that had more than 3 telemetry locations were included and only studies that used VHF transmitters were incorporated into the original model (recent data using GPS transmitters were not used). All locations were projected to NAD83 UTM 13 and cross-checked with the original data. Each location was associated with information on the population, sex, age, date of location, year, season, and coordinates. Seasons were classified as follows: breeding habitat was March through July, summer/fall was July through September, and winter was October through February. Populations were separated based on management zones as well as clustering (Figure 2).

I included elevation, slope, proportion of sagebrush, proportion of pinyon- juniper, proportion of shrubland, proportion of urban, proportion of alpine, proportion of riparian, proportion of grassland, proportion of forest, proportion of bare ground, and proportion of greasewood as variables in the model. I checked correlations between variables using the Pearson correlation coefficient and removed urban and alpine due to lack of data. All other variables were not correlated. The vegetation data were obtained from the Colorado Division of Wildlife‘s Basinwide vegetation layer with a resolution of 30m. The elevation and slope data were from the USGS DEM which is also a 30 m resolution. All variables were centered which can help alleviate convergence issues (Bolker et al. 2008). Elevation and slope were log transformed in order to alleviate scale issues within the data. I overlaid a 1-km^2 grid on the study area counties. I used the number of sage-grouse locations in each grid cell as the response variable with the environmental variables as well as age, sex, and season as fixed effects.

The initial model consisted of a generalized linear model with all the variables using glm in program R. We then used a generalized linear mixed model (GLMM) with random effects to investigate whether there was variance that could be explained by group differences in the GLM. Because of the occurrence of overdispersion I used the quasi-poisson distribution with a log link (Zuur et al. 2009). Due to lack of convergence when seasons were included in the model, I ran 3 separate seasonal models for comparison purposes. I then added population and individual bird as random variables using the lme4 library and the lmer function in program R. Using individual birds as a random grouping resulted in a lack of convergence which resulted in population being the only random effect for our model. I compared the two models to determine if grouping based on population or season increased the power of the model. Significance tests between models were based on the change in deviance which was compared to the χ^2 distribution. In this preliminary analysis, only the full model with all variables included as fixed effects was investigated.

RESULTS AND DISCUSSION

There were 19534 radio-telemetry locations from 1072 birds from 1997-2008 available for use in this model (Table 1, Figure 3). Seventy percent of the individual sage-grouse and 94% of the locations were in the NW populations (particularly in zones NW_1, NW_3, and NW_5). Overall, sagebrush vegetation dominated the landscape of greater sage-grouse with an average of 68% of bird locations in this habitat (Table 2). MP and NW_3 had the highest proportions of sagebrush in their regions (Table 2). Values for grassland, greasewood, pinyon-juniper, forest, bare ground, and riparian were low for all populations (Table 2).

There was no seasonal random effect, but population accounted for 52.6% of the variation in the data (Table 3). This means that for each population a different intercept helped explain the association of sage-grouse locations in that population to the environmental variables. Greater sage-grouse location counts were positively associated with sagebrush, shrubland, riparian, and elevation variables (Table 3). Counts were negatively associated with greasewood, forest, and slope. Other variables in the model were found to not be significantly correlated with sage-grouse location counts.

The resulting preliminary map indicated that all Colorado populations of greater sage-grouse were ranked high on the probability of sage grouse locations (Figure 4). The map also corresponded to the radio-telemetry locations across the state, as well as predicting extensive presence of greater sage-grouse in NP, where no data were available for developing the model (Figure 5). In fact, the NP area was predicted to have a higher probability of sage-grouse presence than the NW area, considered to be the healthiest population in Colorado.

The seasonal models indicated that sage-grouse locations were more associated with sagebrush and shrubland vegetation during the winter (Table 4). The breeding season model resembled the full overall model except for a negative association with bare ground. All of these models are preliminary and need to be further investigated to distinguish seasonal differences in greater sage-grouse locations. The next step in this project will be to eliminate variables and test hypotheses in order to determine the best model for predicting greater sage-grouse locations. It appears that some model results may be driven by elevation as this variable feature is present across the prediction map. The fact that the model predicted high sage-grouse presence in an area occupied by a large sage-grouse population without including locations from that area (NP) in the model building is encouraging.

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Table 1. Summary of datasets used from the Colorado Division of Wildlife from 1997-2008 for compiling location data for radio-marked greater sage-grouse in Colorado.

Investigator	Number of location records	Number of individual sage-grouse	Period of data collection	Sex data	Age data	Population
B. Miller	1907	92	4/2006 to 1/2008	yes	yes	Parachute/Piceance/Roan
S. Huwer	1047	92	3/2000 to 8/2002	yes	yes	Middle Park
J. Beck	343	23	4/1997 to 12/1998	yes	yes	Parachute/Piceance/Roan
M. Cowardin	616	55	2/2001 to 3/2002	some	some	Middle Park
L. Rossi	1438	63	10/2003 to 9/2007	some	some	North Eagle/South Routt
T. Apa	8604	279	5/2001 to 5/2007	yes	yes	Northwest Zone 5
T. Apa	2466	83	4/2001 to 12/2006	yes	yes	Northwest Zone 1
T. Apa	1842	131	3/2001 to 5/2006	yes	yes	Northwest Zone 3
T. Apa	1666	70	4/2006 to 1/2008	yes	yes	Northwest
T. Thompson	3691	158	4/2000 to 2/2008	no	no	Northwest
B. Walker	179	26	12/2007 to 7/2008	yes	yes	Northwest Zone 1
TOTAL	19534	1072				

Table 2. Mean values for variables used in model development for greater sage-grouse habitat model for 6 population segments in Colorado (MP=Middle Park, NESR=North Eagle/South Routt, NW_5=northwest zone 5, NW_1=northwest zone 1, NW_3=northwest zone 3, PPR=Parachute/Piceance/Roan). All vegetation values are expressed as proportions.

Variable	MP	NESR	NW_5	NW_1	NW_3	PPR	Overall
Sagebrush	0.77	0.69	0.68	0.72	0.86	0.56	0.68
Agriculture	0.07	0.09	0.02	0.00	0.01	0.00	0.02
Grassland	0.04	0.04	0.06	0.00	0.03	0.08	0.05
Shrubland	0.02	0.06	0.14	0.21	0.06	0.26	0.15
Greasewood	0.01	0.00	0.02	0.00	0.01	0.00	0.01
Pinyon-juniper	0.00	0.01	0.07	0.01	0.02	0.02	0.04
Forest	0.01	0.08	0.01	0.03	0.00	0.06	0.02
Bare ground	0.05	0.01	0.00	0.01	0.00	0.02	0.01
Riparian	0.02	0.03	0.01	0.02	0.00	0.00	0.01
Elevation	2425.08	2553.12	2039.04	2444.50	2005.40	2470.50	2224.40
Slope	11.19	10.44	11.08	8.86	7.43	23.47	12.53

Table 3. Results of the full model for the generalized linear mixed model with a quasi-poisson distribution.

(a) Fixed effects for the full model.

Term	Coefficient	SE	t-test	P-value
Intercept	3.020	12.62	0.24	
Sagebrush	1.418	0.74	1.92	0.03
Grassland	0.661	0.66	1.14	0.60
Greasewood	-3.170	1.94	-1.63	0.05
Shrubland	1.819	0.79	2.31	0.01
Pinyon-juniper	-1.007	0.96	-1.05	0.15
Forest	-3.775	1.32	-2.87	0.002
Bare ground	1.097	2.28	0.48	0.32
Riparian	3.306	1.23	2.68	0.004
Elevation	0.002	0.004	5.51	<0.001
Slope	-0.050	0.009	-5.58	<0.001
Age	0.016	0.06	0.25	0.40
Sex	-0.128	0.12	-1.08	0.14

(b) Variance components and standard errors for the random effect.

Term	Variance component	Standard deviation
Population	795.95	28.213
Residual	718.05	26.796

(c) Intercepts for the greater sage-grouse population random effect.

Population	Intercept term
Middle Park	-1.622
North Eagle South Routt	-0.340
Northwest Zone 5	1.573
Northwest Zone 1	-0.082
Northwest Zone 3	-0.539
Parachute/Piceance/Roan	1.010

Table 4. Seasonal models for greater sage-grouse habitat in Colorado for breeding (March through July), summer (July through September), and winter (October through February).

Variable	Breeding		Summer		Winter	
	Estimate	SE	Estimate	SE	Estimate	SE
Intercept	3.01	9.89	2.87	11.07	2.28	10.59
Sagebrush	1.17	0.71	1.73	1.26	3.59	2.40
Grassland	0.57	1.14	0.34	1.92	2.36	2.94
Greasewood	-3.73	2.02	1.28	4.70	-4.19	4.61
Shrubland	1.58	0.77	2.53	1.40	3.42	2.46
Pinyon-juniper	-1.48	0.97	1.38	2.85	0.71	1.87
Forest	-2.41	1.30	-2.29	2.20	-2.35	3.00
Bare ground	-1.79	2.42	6.68	4.83	7.47	3.36
Riparian	3.07	1.11	4.09	1.88	4.12	1.27
Elevation	0.0017	0.0004	0.003	0.001	-0.0001	0.0002
Slope	-0.05	0.01	-0.07	0.02	-0.01	0.01

Figure 1. Counties where greater sage-grouse reside in Northwestern Colorado and those counties included in the overall model.

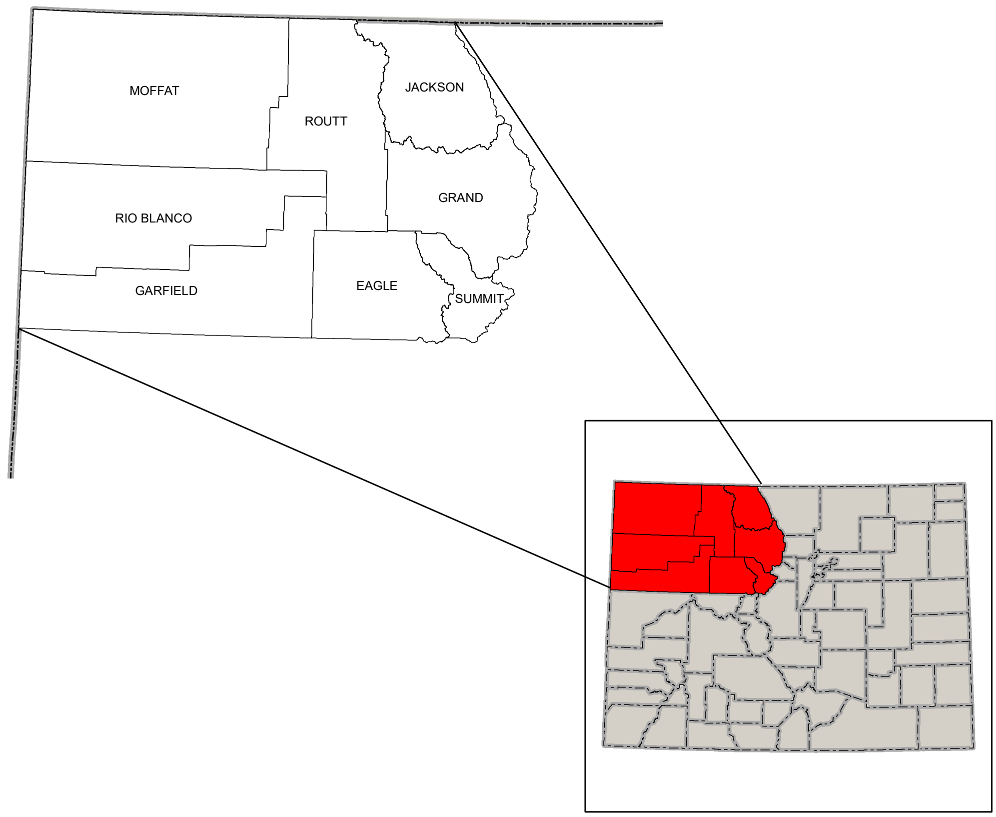


Figure 2. The seven populations of greater sage-grouse in Colorado and their associated labels used in the model. North Park is not included in the initial model as no data was collected from this population at the time of this report.

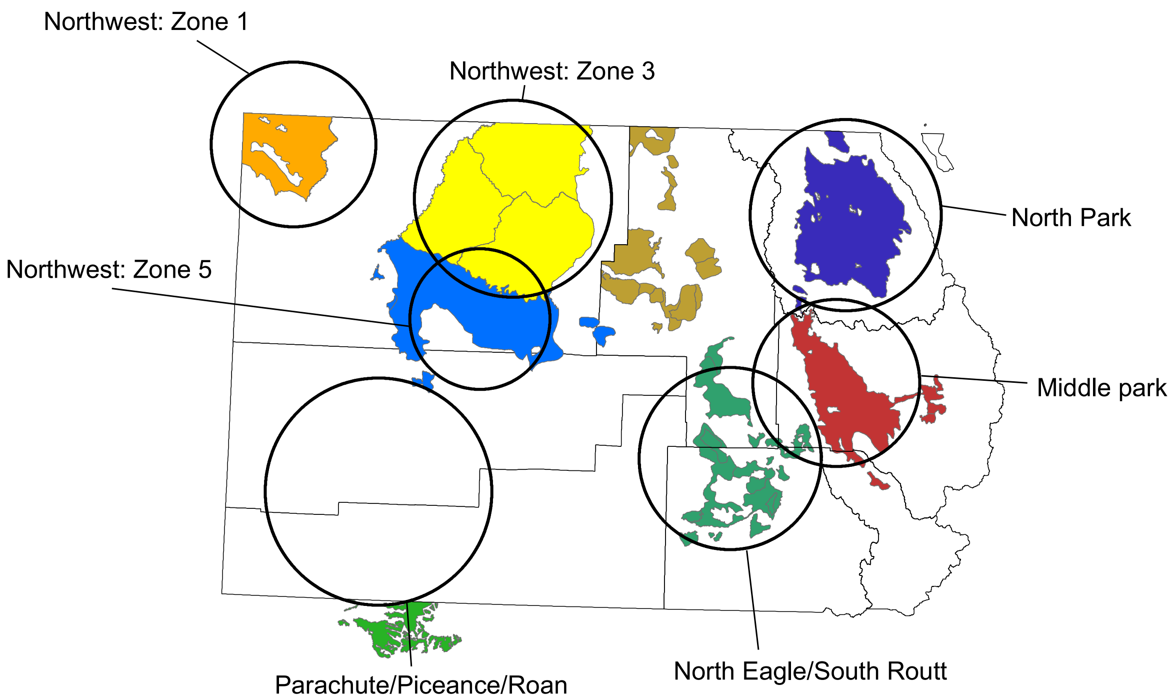


Figure 3. Distribution of locations of radio-marked greater sage-grouse in Colorado collected from 1997-2008.

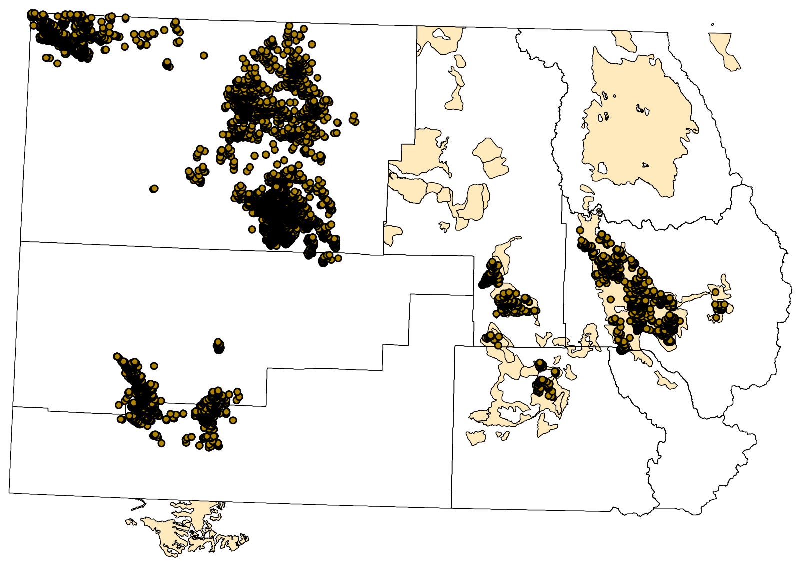


Figure 4. Initial map that included the full model of variables across the Northwestern range of greater sage Grouse in Colorado. Red indicates prime habitat while blue indicates habitat that is not prime.

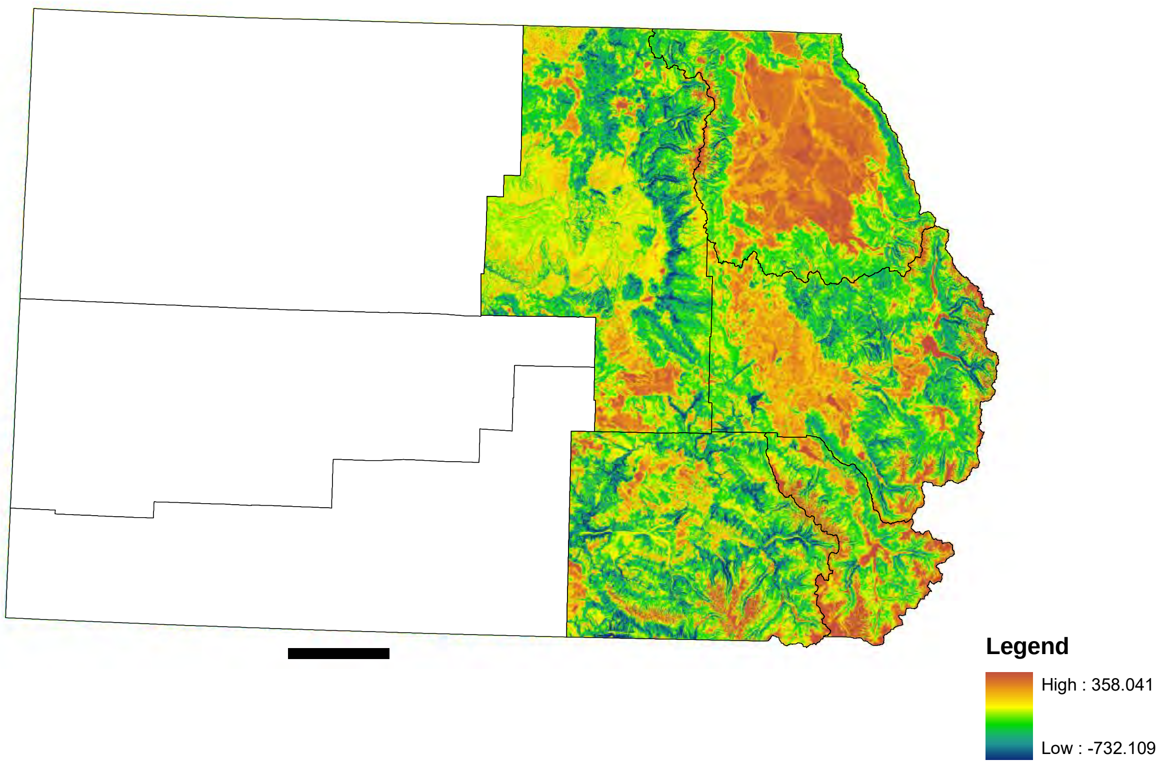
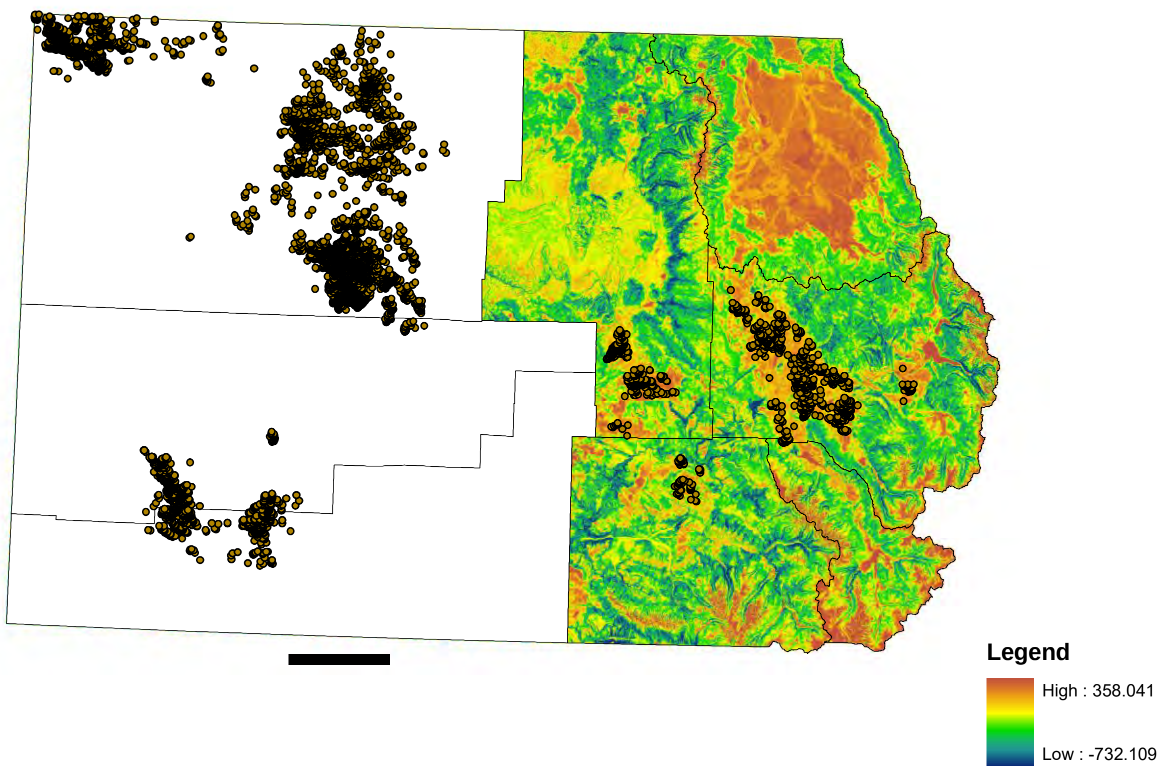


Figure 5: Map using the full model along with the original telemetry data from greater sage-grouse in Colorado.



COLORADO DIVISION OF WILDLIFE - AVIAN RESEARCH PROGRAM
PROGRESS REPORT
September 2010

TITLE: Greater sage-grouse seasonal habitat use and demographics in North Park

AUTHORS: A. D. Apa, L. Rossi, and M. B. Rice

PROJECT PERSONNEL: Colorado Division of Wildlife: J. Haskins, Area 10 Wildlife Manager; J. Broderick, Northwest Region Senior Terrestrial Biologist, B. Petch, Northwest Region Wildlife Conservation Manager; Bureau of Land Management Kremmling Field Office; North Park Greater Sage-Grouse Local Working Group

Period Covered: July 1, 2009 – August 10, 2010

ABSTRACT

Rangewide declines and recent energy development within sagebrush habitat has led to concern for conservation of greater sage-grouse (*Centrocercus urophasianus*) (GRSG) populations across Colorado, including in North Park, which supports approximately 20% of the state‘s GRSG. Breeding, summer/fall, and winter habitat has been described at the local scale across the GRSG range and in Colorado, but it is important to understand how these local scale use patterns are juxtaposed at the landscape level. These habitats have not been comprehensively and explicitly mapped in Colorado. GRSG habitat use is known to be influenced by both landscape-scale factors, such as extent of sagebrush habitat and topography, and by local factors, however, the relative importance of local vs. landscape scale variables in habitat selection remains unknown. In addition, information on survival and reproductive effort obtained both before and during energy development, and compared with similar areas where development is not occurring, is needed to evaluate population-level responses of GRSG to energy development.

Spatially explicit, high-resolution maps depicting seasonal habitat areas within larger landscapes across the range of GRSG in Colorado would be particularly useful for agencies and industry to make informed decisions for conservation and mitigation. Additionally, linking spatially explicit habitat use models with updated measures of crucial demographic parameters can help guide successful conservation and management. On-the-ground efforts to map GRSG habitat within proposed oil and gas fields are expensive, time-consuming, and by necessity, limited in geographic scope. However, uniformly-applied mitigation buffers may include areas with non-critical habitat in which spatial and temporal restrictions on development could be relaxed. Conversely, uniform buffers may not adequately protect all required seasonal habitats because GRSG use a variety of seasonal habitats. The proposed EOG Resources Energy Development (EOG RED) project encompasses most of the southwestern portion of North Park. The project area is also within occupied range of GRSG and includes 10 active GRSG leks as well as 2 active leks adjacent to the EOG RED project area. The objectives of this research project are to: 1) generate high-resolution digital maps showing seasonal GRSG seasonal habitat throughout North Park, the proposed EOG RED oil field and across the distribution of GRSG in Colorado, 2) evaluate a hierarchical modeling approach to mapping GRSG seasonal habitat in North Park and across the distribution of GRSG in Colorado; 3) provide current estimates of key demographic parameters (nest initiation rates and success rates, and juvenile, yearling, and adult survival) inside and outside the EOG RED areas as well as

seasonal movement patters inside and outside the EOG RED area; and provide managers with estimates of local habitat variables in relation to established guidelines. To accomplish these objectives we radio-marked 95 female GRSG in April 2010. We plan to continue tracking these GRSG through spring 2011. We are also collecting habitat measurements at used and unused locations.

GREATER SAGE-GROUSE SEASONAL HABITAT USE AND DEMOGRAPHICS IN NORTH PARK

Progress Report, July 1, 2009 – August 10, 2010

Anthony D. Apa, Liza Rossi, Mindy B. Rice

PROJECT OBJECTIVES

The goal of this study is to obtain detailed, current information on GRSG habitat use and demography in North Park. Specific objectives include:

1. Generate high-resolution digital maps showing GRSG seasonal habitat throughout North Park and across the distribution of GRSG in Colorado;
2. Evaluate a hierarchical modeling approach to mapping GRSG seasonal habitat in North Park and across the distribution of GRSG in Colorado using physical and vegetation variables;
3. Provide current estimates of critical demographic parameters inside and outside the EOG RED areas as well as seasonal movement patterns inside and outside the EOG RED area;
4. Provide managers with estimates of local habitat variables in relation to established guidelines (CDOW 2009).

SEGMENT OBJECTIVES

1. Radio-mark female GRSG in North Park in spring 2010 and monitor movements, survival, nest success, and brood success.
2. Monitor absence sites for seasonal habitat model development.

INTRODUCTION

The greater sage-grouse (*Centrocercus urophasianus*) (GRSG) is a species of conservation concern due to historical population declines and range contraction (Schroeder et al. 2004), and there have been repeated attempts to list the species under the Endangered Species Act of 1973 (DOI 2005). Rapid, widespread energy development within sagebrush habitats of the western U.S. has raised additional concerns, as several recent studies have documented demographic impacts to GRSG in areas with active gas development (Lyon and Anderson 2003, Holloran 2005, Kaiser 2006, Aldridge and Boyce 2007, Walker et al. 2007). Extensive efforts have been made by industry and federal and state agencies to avoid, minimize, and mitigate impacts of energy development on GRSG (CDOW 2008). Such efforts include wildlife surveys, environmental planning, alternative siting, and adherence to spatial and timing restrictions designed to minimize impacts to GRSG. However, the effectiveness of these efforts in reducing impacts on GRSG populations needs to be evaluated, and industry and agencies need better information to use in planning energy development activities.

North Park (Jackson County) is an important area for GRSG in Colorado, supporting approximately 20% of the statewide population (CDOW 2008). The proposed EOG Resources Energy Development (EOG RED) project encompasses most of the southwestern portion of North Park. The project area is also within occupied range of GRSG and includes 7 active GRSG leks as well as two active leks adjacent to the project area. The Colorado Division of Wildlife (CDOW) is interested in developing information that will assist in avoiding impacts to GRSG through development planning for the EOG RED, and in better understanding GRSG response to energy development in North Park.

GRSG require sagebrush throughout the year. Specific habitat requirements, however, may differ among breeding, summer brood-rearing, fall, and winter seasons, and the juxtaposition of suitable areas of these different habitats determine the seasonal movements and distribution of GRSG throughout the year (Connelly et al. 2000). Current patterns of seasonal habitat use by GRSG across the landscape in North Park are not well-documented. Sage-grouse habitat requirements at the local scale are generally well-known, but to date no study has simultaneously addressed the influence of both landscape- and local-scale factors on GRSG habitat use. For example, soil type has never been included in habitat analyses. In other sagebrush-obligate species, specific soil types are key predictors of occupancy and abundance because of the direct influence of soil on the structure and composition of sagebrush (Vander Haegen et al. 2000). More research is needed to understand the full range of biotic and abiotic (i.e., current and historic energy development) factors influencing GRSG habitat selection.

Addressing wildlife requirements can be costly because it can result in delays in permitting, disruption of drilling and construction activities, seasonal lay-offs, and repeated revisions to maps and planning documents. On-the-ground efforts to identify important seasonal GRSG habitats within proposed oil and natural gas fields are expensive, time-consuming, and due to logistical constraints, limited in area. Moreover, fixed mitigation or avoidance buffers around critical seasonal habitats may include areas of non-critical habitat in which restrictions could be relaxed with little impact to GRSG populations, thereby reducing costs of planning and mitigation. Conversely, fixed buffers also may not adequately protect all seasonal habitats, or impacts to habitats and populations may be severe enough that areas suitable for off-site mitigation need to be identified over a larger landscape. Thus, there is a need to identify and delineate important seasonal habitats for GRSG on a landscape scale prior to energy development.

Recent advances in modeling using high-resolution satellite imagery now allow researchers to more effectively classify and map seasonal habitat over large scales. These techniques provide spatially explicit information at a resolution sufficient to undertake detailed planning, mitigation, and conservation efforts. This approach also allows for the delineation of seasonal habitats at local and landscape levels using a hierarchical (individual-population-statewide range) modeling approach. The approach allows external validation of selected models against independent datasets to ensure that findings are robust (Boyce et al. 2002, Johnson et al. 2006). There are 6 major populations of sage grouse in Northwestern Colorado including the North Park, Middle Park, Meeker/white river, North Eagle/South Routt, Northwest, and Parachute/Piceance/Roan populations (Figure 1). Currently, there are just under 20,000 sage grouse telemetry locations in Northwestern Colorado, but none of the locations are in the North Park population (Figure 2). The absence of data in North Park, which accounts for 20% of the state population, would bias a statewide habitat model as the variability within North Park would not be captured or included.

A preponderance of recent research on oil and gas development impacts on GRSG has been conducted in actively developing fields (Lyon and Anderson 2003, Holloran 2005, Kaiser 2006, Aldridge and Boyce 2007, Walker et al. 2007, Walker 2008). Assuming that oil and gas development will occur in the near future, North Park presents the unique opportunity for the CDOW to collect baseline demographic data prior to substantial development. There has been little or no information collected through either long-term research or retrospective analyses, on the long-term response of GRSG to historic development, where fields are in the production phase and sites have largely been reclaimed. North Park provides a unique opportunity to retrospectively assess the response of GRSG to historic development that occurred over 30 years ago.

In addition to quantifying accurate and precise estimates of habitat use at the local and landscape level, quantifying precise and accurate estimates of demographic parameters (survival rates, recruitment rates, etc.) is critical to successful conservation and management (Skalski et al. 2005) of GRSG. In a recent GRSG population viability analysis (CDOW 2008), juvenile and adult female survival were found to be crucial to population viability. There are no recent estimates of these demographic parameters for North Park and some demographic estimates were reported over 30 years ago. Current estimates of survival and reproduction of GRSG in North Park will provide a baseline for future monitoring and management, and allow comparison of demographic rates between the EOD RED project area and areas in North Park where development is not occurring, as well as comparison to historic estimates.

STUDY AREA

The study area includes the currently mapped occupied range of GRSG in North Park, Jackson County, Colorado. This study area includes the EOG RED project boundary, as well as adjacent areas in North Park that have proposed leases to facilitate modeling and increase our ability to make inferences to the entire North Park population of GRSG (Figs. 1 and 2).

METHODS

GRSG were captured and radio-marked during April 2010 using spot-lighting techniques (Giesen et al. 1982, Wakkinen et al. 1994), and a CODA net launcher. All GRSG captured were weighed (±1 g) using an electronic scale and marked with uniquely numbered aluminum leg bands. The age and gender of each GRSG was determined using wing (Dalke et al. 1963) and other plumage or morphological characteristics.

VHF transmitters were 17-g necklace-mounted radio transmitters with a 30 cm antenna lying between the wings and down the back of the grouse. Transmitters have a minimum battery life of 18 months and a 4-hour mortality circuit. The radio transmitter package was 0.8% and 0.56% of the body weight of a yearling and adult male, and 1.0% or 1.2% of the body weight for adult and yearling females, respectively.

Data Collection and Analysis

Following release, the movements and survival of all radio-marked GRSG were monitored 1-2 times/week. GRSG general locations were determined by triangulation and radio-tagged birds were not flushed. Hand-held Yagi antennas, attached to a receiver/scanner, were used to locate radio-marked grouse. The loudest-signal method was used to locate grouse/transmitters (Springer 1979). Monitoring efforts were distributed equally among 3 diurnal periods; morning (< 4 hours following sunrise), midday (> 4 hours after sunrise) and evening (< 4 hours before sunset). All grouse were circled at a 50 – 100 m radius (Apa 1998) to determine habitat type use. A precise Universal Transverse Mercator (UTM) location was not possible at the time of location (the bird will not be flushed). To obtain more precise use locations, the observer selected a location approximately 50 m in one of the 4 cardinal directions from the estimated location of the bird. The observer took a Global Positioning System (GPS) location, and then manually correct the UTM location. VHF collars allowed field crews to collect real-time local-scale data while in the field (i.e., snow depth, flock size and composition, etc.). A fixed-wing aircraft assisted to locate any grouse not located by ground monitoring or lost during ground monitoring efforts. General locations were identified aerially and ground locations will be identified within 48 hours.

When a female is incubating, the nest location was determined using binoculars as described by Apa (1998). Once a female is identified as incubating, she was not disturbed. Diagrams of the nest location was drawn to assist in nest location after the completion of nesting. The precise UTM location was collected following the cessation of nesting (successful or unsuccessful). A nest was considered successful if ≥ 1 egg hatches (Rearden 1951). At all nest sites four 10-m transects were placed in the cardinal directions intersecting at the nest bowl. The nest shrub species and height were measured. The height of the lowest live and dead nest bush branch above the nest bowl were measured from the edge of the nest bowl. Canopy cover (foliar intercept) of the shrub species overstory was determined using line-intercept (Canfield 1941) (Fig. 6). The intercept by the lowest possible taxa was measured. Height of the of the nearest nest bush type shrub within 1 m of the transect line was measured at 2.5 m, 5 m, and 10 m.

Grass and forb height was measured for the nearest, tallest grass/forb part at the point where the edge of the nest bowl and the transect intercected, and at the 1 m point on each transect.

The percent of forbs and grass cover, bare ground, and litter horizontal understory cover was estimated using 50 x 50 cm microplots (Daubenmire 1959). Eleven cover classes will be used and delineated as follows: Trace: 0-2%, 1: 3-9%, 2: 10-19%, 3: 20-29%, 4: 30-39%, 5: 40-49%, 6: 50-59%, 7: 60-69%, 8: 70-79%, 9: 80-89%, 10: 90-100%. The first 2 microplots were located on opposing sides of the nest bowl. Subsequent plots were placed systematically along the transects at 2.5, 5, and 10 m. In addition, the distance to nearest visible roadways, telephone poles, powerlines, and fence posts were determined.

The same vegetation data collection techniques were applied to at least one random location for each nest. Random locations were obtained by using randomly selected UTM coordinates located in cells considered ―unused" in the study area based on a spatially balanced random design.

Females with broods, unsuccessful females, and males were located 1-2 times per week. At each location, date, time, UTM coordinates, slope and aspect were recorded. Unsuccessful females were located in the same manner as females with broods. When females with broods are circled, the intersection point of flags placed in the cardinal directions were used to identify the center of the brood location. Microhabitat variables were measured at a minimum of 20% of unsuccessful female use locations.

RESULTS AND DISCUSSION

A total of 95 female GRSG were radio-marked throughout the study area in April 2010 (Fig. 4). As of August 11, 2010 there were 13 birds dead with 82 birds still alive. There have been 80 hens nesting with 86 total nests (Figure 5). There were 45 nests depredated, 41 nests that were successful (47% apparent nest success), and 6 hens that renested (51% hen success). Approximately 1400 sage grouse locations were collected through 10 August (Figure 3). The crew has completed 82 nest vegetation plots and 87 non-use vegetation plots. We have not analyzed the vegetation data or the demography data as these are still being collected in the field. Brood data is starting to be collected and we will continue radio-tracking birds through the winter and possibly next spring/summer.

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Figure 1. North Park study area showing land ownership, oil and gas leases, existing and active oil and gas wells, and GRSG core areas.

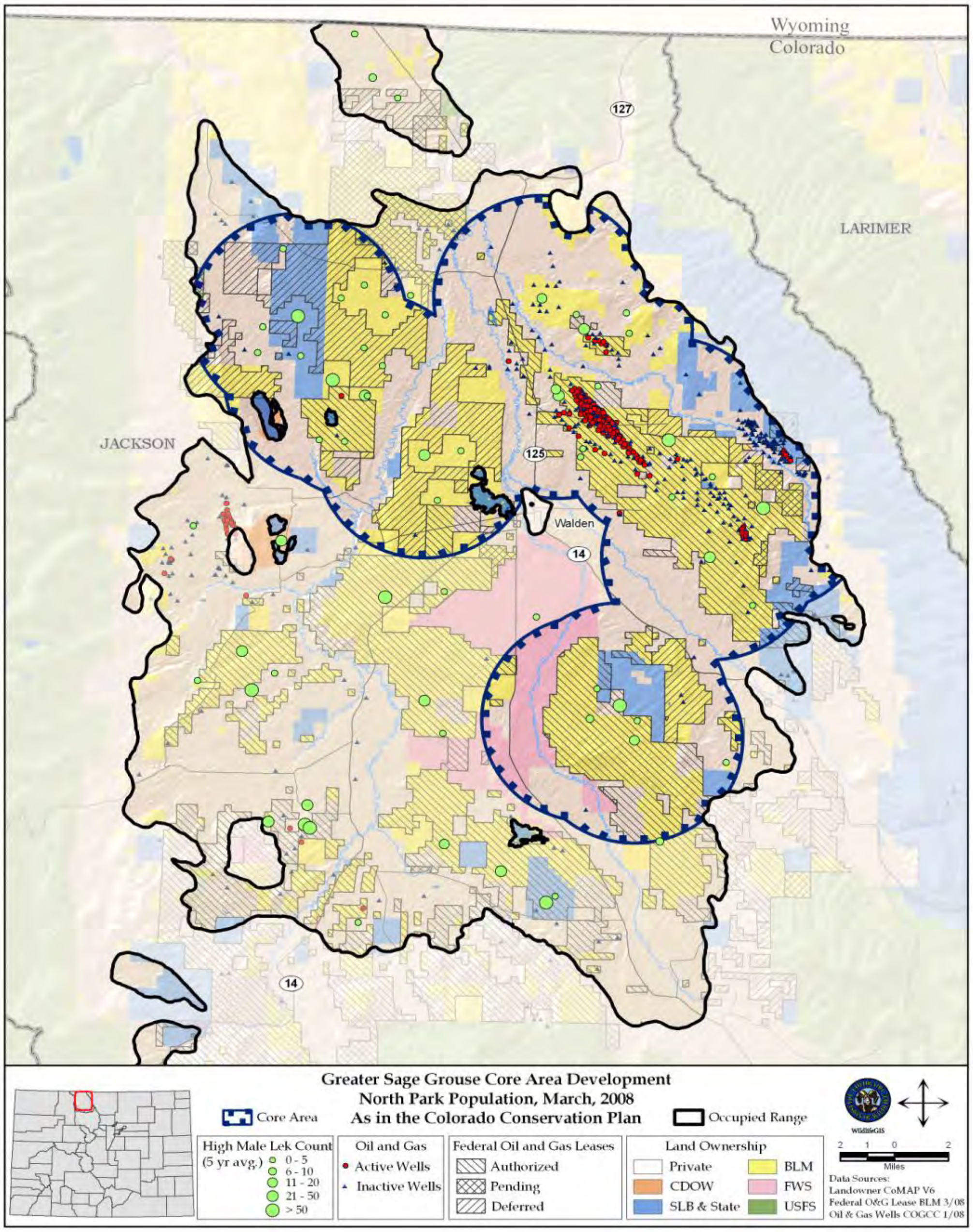


Figure 2: North Park study area showing active and inactive leks as well as EOG interest areas and GRSG core areas.

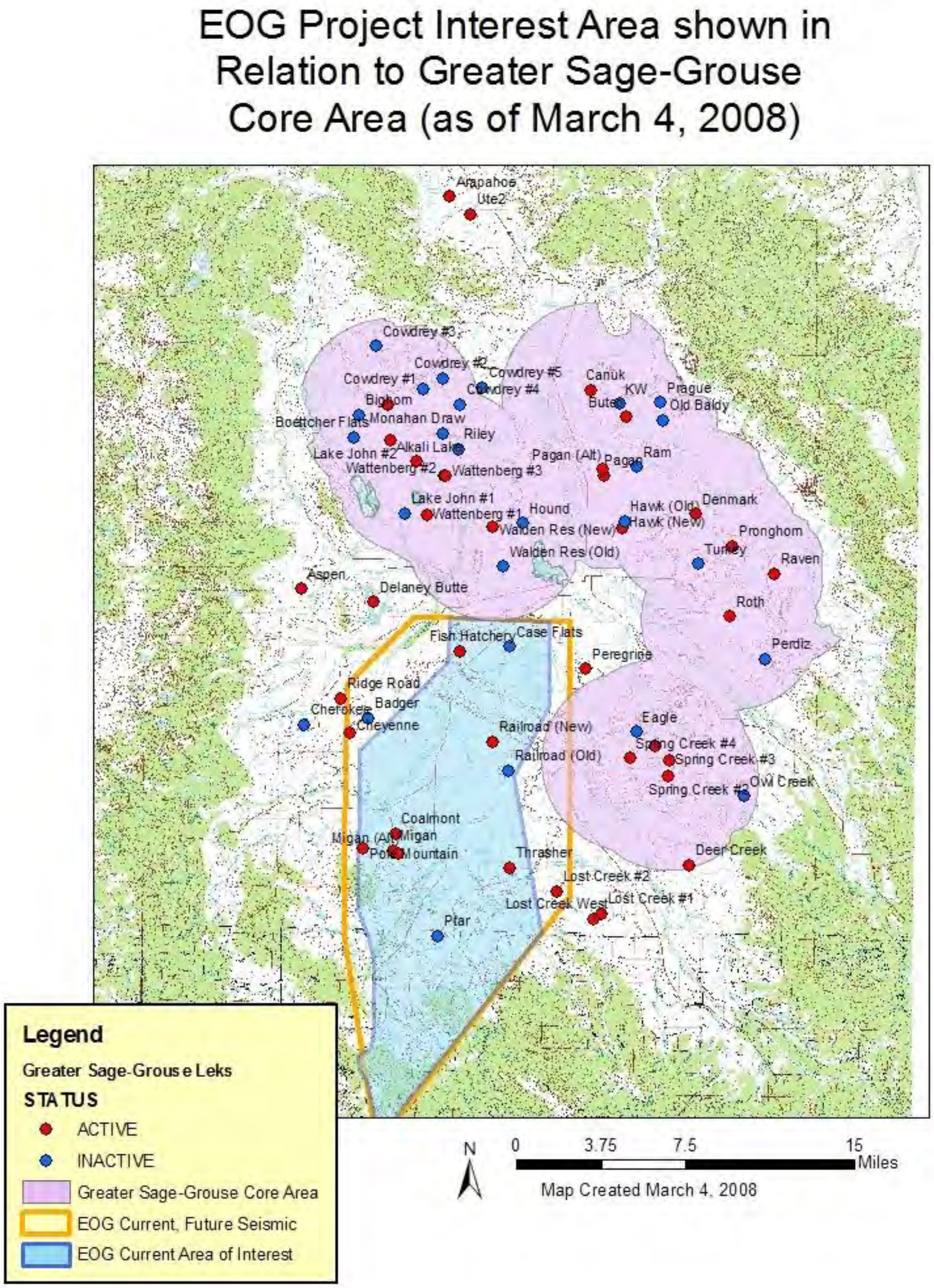


Figure 3. Locations of female greater sage-grouse radio-marked during April in North Park, through August 10, 2010.

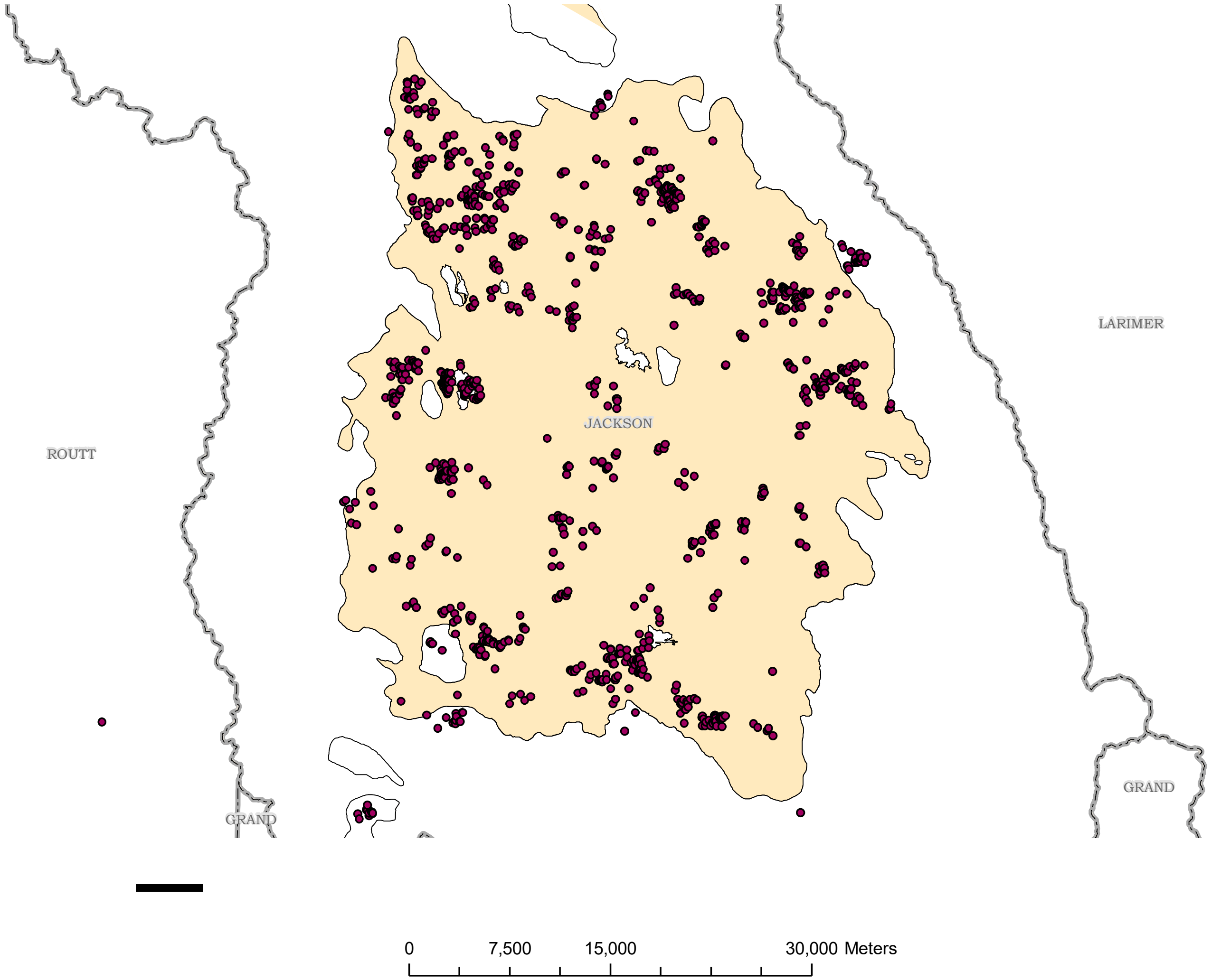


Figure 4: Capture locations for female greater sage-grouse in North Park during April 2010.

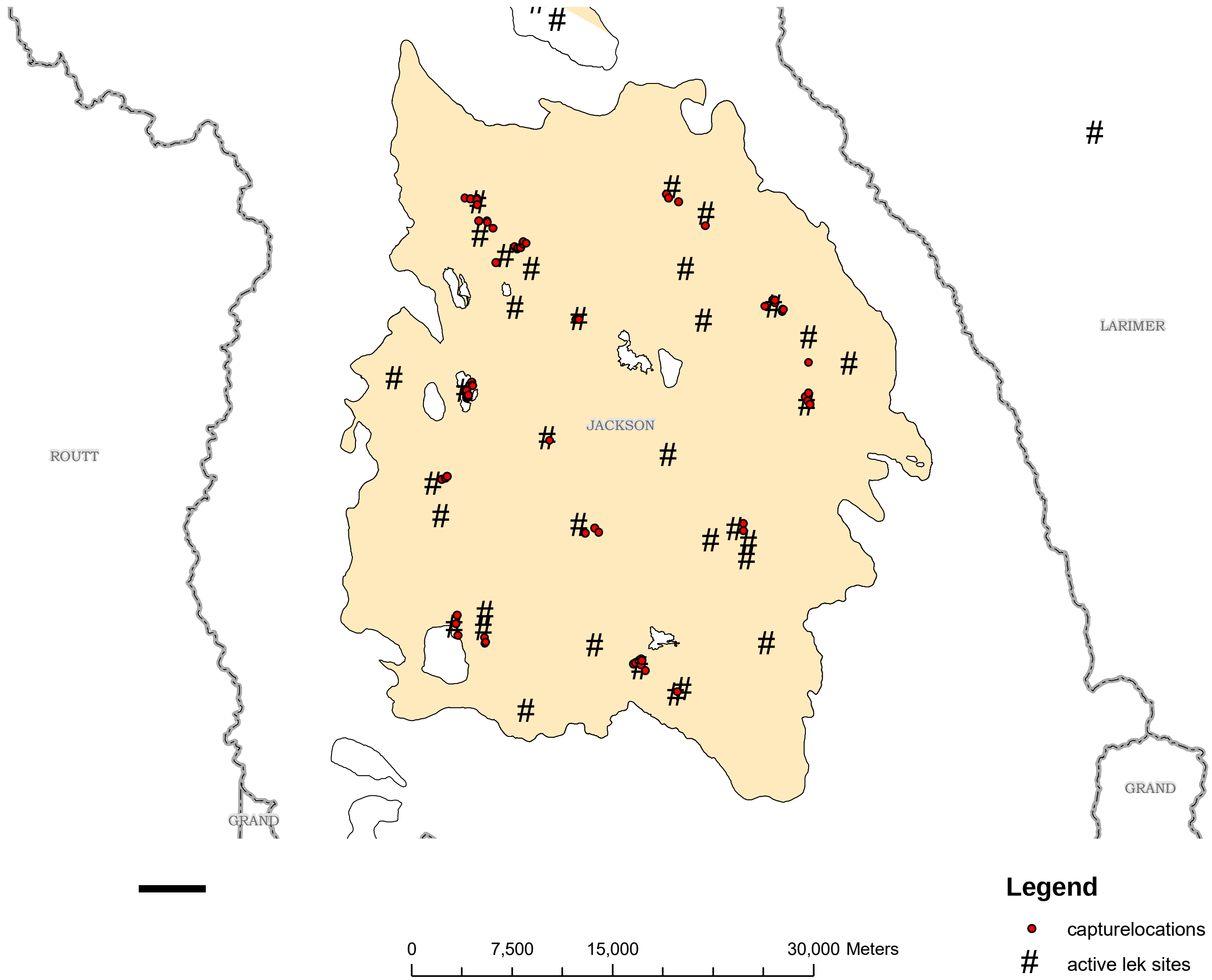
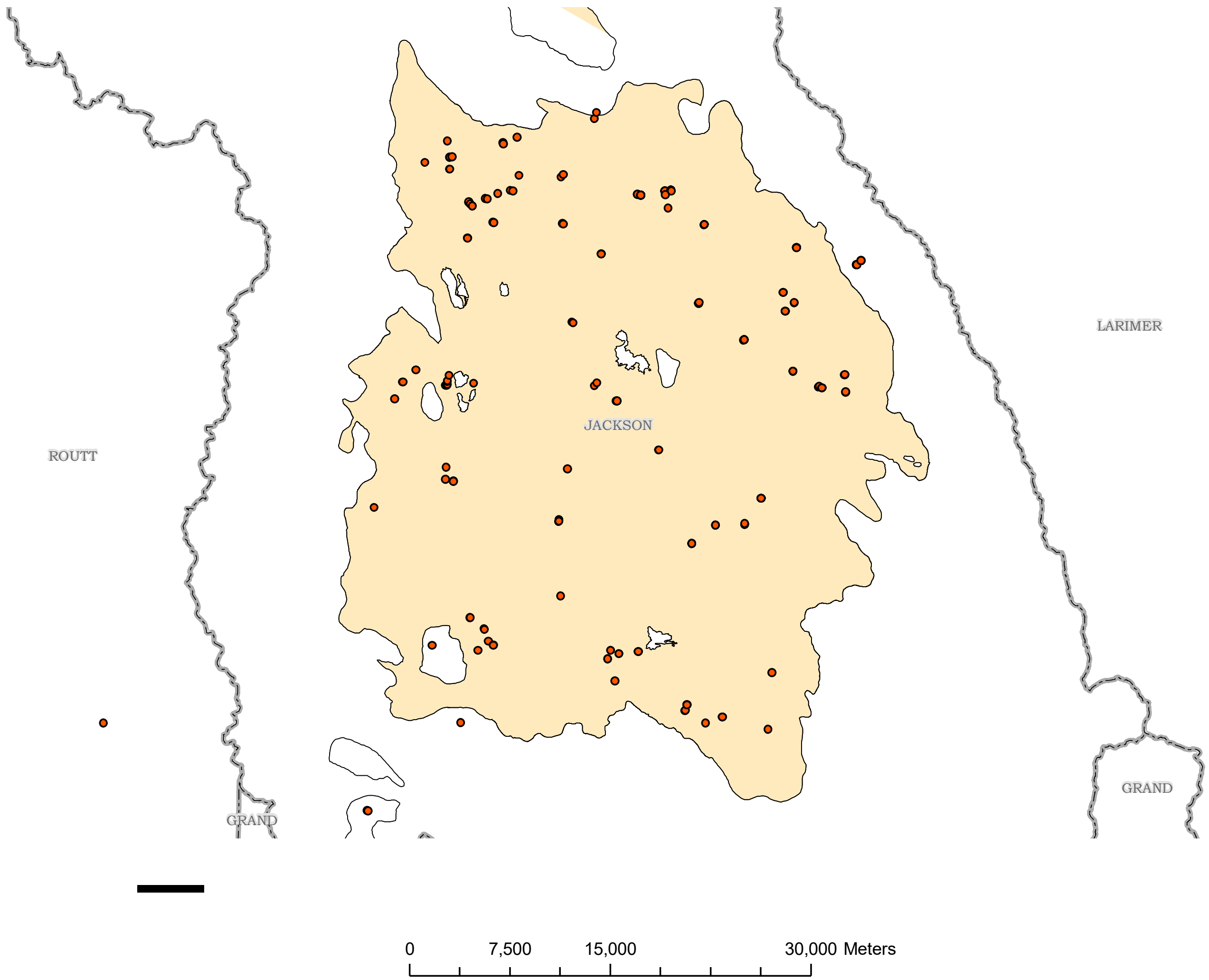


Figure 5: Nesting locations for female greater sage-grouse radio-marked during April 2010 in North Park, Colorado.



COLORADO DIVISION OF WILDLIFE - AVIAN RESEARCH PROGRAM
PROGRESS REPORT
September 2010

TITLE: Hiawatha Regional Energy Development Project and Greater Sage-grouse Conservation in Northwestern Colorado and Southwestern Wyoming. Phase I: Winter and Breeding Habitat Selection and Maps

AUTHOR: B. L. Walker

PROJECT PERSONNEL: A. D. Apa, K. Eichhoff, B. deVergie, B. Petch, M. B. Rice, and C. Woodward

Period Covered: December 1, 2007 - August 1, 2009

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

ABSTRACT

The proposed Hiawatha Regional Energy Development project overlaps greater sage-grouse (*Centrocercus urophasianus*) occupied range in northwestern Colorado and south-central Wyoming. However, industry and agencies need higher-resolution maps showing where sage-grouse are most likely to occur during each season to streamline development planning and mitigation and to guide sage-grouse conservation efforts. We conducted multi-scale habitat selection analyses using 850 winter locations from 160 radio-marked female greater sage-grouse and 622 breeding-season locations from 137 radio-marked greater sage-grouse collected from 2005-2009 within the Hiawatha project area. We used logistic regression to test landscape-level habitat features at various scales (100-m, 350-m, 740-m, and 1000-m) that birds used to select habitat in each season. Winter models validated well against an independent sample of 142 locations from 34 marked sage-grouse ($R^2 > 0.945$). In winter, sage-grouse selected landscapes with greater sagebrush habitat within 740-m, and they were more likely to use such areas when they also had more sagebrush within 100 m. Wintering birds also selected patches with flat topography (100-m scale) and higher elevation portions of the field, but they avoided landscapes with desert mat saltbush (―salt-sage") habitat within 1000 m. Breeding sage-grouse selected landscapes with greater sagebrush habitat within 1000 m, patches with flat topography within 350 m, small amounts of non-sagebrush habitat, and higher-elevation portions of the field. They avoided landscapes with greater desert mat saltbush habitat within 1000 m. Validation of breeding-season models indicated acceptable fit ($R^2 > 0.74$), but additional variables may need to be considered. High-priority winter and breeding habitat largely overlapped. High-priority habitats include previously known areas (e.g., G Flat, Whiskey Draw, Sugarloaf, Rifes Rim) and many new areas in the northern, eastern, and northeastern portions of the field (south of Bitter Creek Road, south of Chicken Creek, Alkali Bench, Crooked Wash). The majority of wintering birds used areas with 57-86% (mean 70%) sagebrush habitat within 740 m and 69-99% (mean 80%) sagebrush habitat within 100 m. The majority of breeding birds used areas with 56-82% (mean 68%) sagebrush habitat within 1000 m. The southwestern portion of the field contains high-priority habitat for sage-grouse in Colorado that conflicts with proposed development focus areas. Development in the Whiskey Draw, Owl Bench, Rifes Rim, and Bitter Creek areas would also directly affect wintering habitat for birds that breed in Colorado. Development of high-priority sage-grouse habitat near the Chicken Creek, Alkali Bench, and Crooked Wash leks may be a concern in Wyoming.

Regular movements of bird across the Colorado-Wyoming state line suggest this region should be managed as a single population. We are reclassifying the original high-resolution color infrared imagery using Definiens software to improve accuracy of the vegetation classification before running the final local vs. landscape winter analysis; we will present results from that analysis in a future progress report.

HIAWATHA REGIONAL ENERGY DEVELOPMENT PROJECT AND GREATER SAGE-GROUSE CONSERVATION IN NORTHWESTERN COLORADO AND SOUTHWESTERN WYOMING. PHASE I: WINTER AND BREEDING HABITAT SELECTION AND MAPS

Progress Report, December 1, 2007 - August 1, 2009

Brett L. Walker

PROJECT OBJECTIVES

The objectives of this project are to: (1) generate high-resolution maps of important sage-grouse wintering and breeding habitat within the proposed Hiawatha gas field; (2) identify landscape-scale wintering and breeding habitat criteria; (3) evaluate the relative importance of local vs. landscape-level habitat features on winter habitat selection; and (4) assess the influence of historical energy development on sage-grouse habitat use.

SEGMENT OBJECTIVES

INTRODUCTION

Questar Exploration and Production and Wexpro Company are currently developing the Hiawatha Regional Energy Development project along the border between northwestern Colorado and southwestern Wyoming (Questar 2006). Recent research by Colorado Division of Wildlife (CDOW) and the University of Idaho has documented that many sage-grouse nest, raise broods, and summer on Cold Springs Mountain and Beaver Basin, then move northeast to winter within the boundaries of the proposed gas field (Fig. 1). Sage-grouse that breed and nest in adjacent areas of Wyoming also winter within the proposed Hiawatha project area. Some females on the Colorado side nest and raise young in the southwestern portion of the field.

Greater sage-grouse are of concern to CDOW due to historical population declines, range contraction (Schroeder et al. 1999, 2004), and potential for listing the species under the Endangered Species Act (DOI 2005). Intensive gas development can also have negative impacts on local sage-grouse populations (Lyon and Anderson 2003, Holloran 2005, Kaiser 2006, Aldridge and Boyce 2007, Walker et al. 2007, Doherty et al. 2008, Holloran et al. 2010, Harju et al. 2010). Sage-grouse often move long distances to find suitable winter habitat (Eng and Schladweiler 1972, Connelly et al. 1988, Robertson 1991) and typically return to those areas year after year (Beck 1977, Schroeder et al. 1999). Moreover, because sage-grouse from distinct breeding areas often congregate in specific habitat types in winter, impacts in wintering habitat may have disproportionate effects on larger regional breeding populations (Beck 1977, Schoenberg 1982, Doherty et al. 2008). Documented movement of marked sage-grouse between Colorado and Wyoming on the west side of the field from 2005-2007 also suggested that portions of the proposed field in Wyoming contained important wintering habitat for breeding birds from the Hiawatha-Cold Springs core area in Colorado. CDOW is concerned that the Hiawatha project, including development in Wyoming, may lead to substantial declines in Colorado-side core areas and cause populations to fall below targets established by CDOW and the NW Colorado local working group.

Identifying and delineating important seasonal habitats prior to energy development is critical for agencies to make informed decisions about how to balance energy development with wildlife conservation. Efforts have been made by industry and federal and state agencies to avoid, minimize, and mitigate impacts of energy development on sage-grouse (e.g., Questar 2006), including conducting wildlife surveys and adhering to spatial and timing restrictions. However, in most areas slated for development, seasonal habitats have not been adequately mapped at a high enough resolution to be used in detailed planning, mitigation, and conservation efforts (Manly et al. 2002, Doherty et al. 2008). For this reason, mapping seasonal habitats is listed as a top priority in the Colorado greater sage-grouse state-wide conservation plan (CGSSC 2008).

Managers also lack appropriate landscape-scale guidelines for sage-grouse habitat. Research over the past four decades has carefully documented local-scale features of habitat required by sage-grouse in each season, including the height and canopy cover of shrubs, grass height and cover, forb abundance, etc. (for review, see Schroeder et al. 1999, CGSSC 2008, Hagen et al. 2007). However, only two studies have examined landscape-scale habitat requirements (Homer et al. 1993, Doherty et al. 2008). In other words, we lack quantitative criteria for how much sagebrush habitat is required at which scales to maintain viable breeding and wintering populations. However, recent advances in resource selection modeling and availability of high-resolution imagery now allow mapping predicted probability of habitat use at high resolution over large scales. This approach also allows competing hypotheses to be addressed about the influence of local and landscape factors on habitat selection and external validation of models against independent datasets to ensure findings are robust (Boyce et al. 2002, Johnson et al. 2006).

The objectives of this project are to: (1) generate high-resolution maps of important sage-grouse wintering and breeding habitat within the proposed Hiawatha gas field; (2) identify landscape-scale wintering and breeding habitat criteria; (3) evaluate the relative importance of local vs. landscape-level habitat features on winter habitat selection; and (4) assess the influence of historical energy development on sage-grouse habitat use. In this progress report, we present results and maps from updated breeding and winter habitat selection analyses (objective 1). This information is intended to assist Questar Exploration and Production, the Bureau of Land Management, and landowners in identifying critical wintering and breeding areas to conserve sage-grouse populations and habitats in those areas as part of the development planning process.

METHODS

Study Site

The study was conducted within the boundary of the proposed Hiawatha Regional Energy Development project in northwestern Colorado and south-central Wyoming (Fig. 1).

Field Methods

We captured and radio-marked 13 females in Dec 2007-Jan 2008, 43 females in Mar-Apr 2008, 57 females in Aug-Nov 2008, and 30 females from Mar-Apr 2009 by spotlighting and hoop-netting at night (Giesen et al. 1982, Wakkinen et al. 1992) within the proposed Hiawatha field boundary. All captured birds were sexed, aged, and fitted with aluminum, numbered leg bands and 17-22 g, necklace-style VHF radio collars (Advanced Telemetry Systems model A4060; Isanti, MN). This augmented a larger sample of 96 VHF radio-collared females monitored within the project area from 2005-2008 as part of a joint University of Idaho-CDOW dispersal study. Field crews attempted to collect exact GPS locations (±10-15 m) on radio-collared birds once every two weeks from 1 Dec through 7 Mar from 2007-2009 and once a week from 8 Mar through late June or early July in 2008-2009, depending on the timing of the breeding season.

Study Design

We conducted habitat selection analyses using resource selection function approach (RSF). We employed a used vs. pseudo-absence design rather than a used vs. available design (as in previous analyses) to reduce contamination of absence points (Keating and Cherry 2004). We pooled used locations of all marked individuals to make inferences at the population level (Design II; Erickson et al. 2001, Manly et al. 2002). We then conducted logistic regression on used (1) vs. pseudo-absence (0) points.

Used vs. Psuedo-Absence Points

We included each location of a radio-marked bird once in the analysis as a used location. Unlike previous analyses, we opted not to censor locations of marked birds that occurred within flocks with other marked birds because it is unclear statistically whether such points are actually non-independent and doing so may bias analyses by giving less weight to flocks that contained more marked birds. We defined breeding-season locations as those during the pre-nesting, nesting, and early brood-rearing periods (CGSSC 2008). We defined the start of the breeding season as 15 March in each year. We identified the end date for each breeding season in each year by adding 14 days to the date on which 95% of birds were estimated to have completed nesting. The end of the breeding season varied by up to 3 weeks among years (e.g., 14 June in 2005, 20 June in 2006, 30 June in 2007, 7 July in 2008, and 23 June in 2009). We included locations from both successful and unsuccessful hens during this period. We used locations from 80% of radio-marked individuals to build models and 20% for validation. The final data set for building models contained 708 winter locations from 126 individuals and 525 breeding locations from 112 individuals. We considered all areas and all habitats as available in both analyses for two reasons. First, sage-grouse in this area regularly fly longer distances than the extent of the imagery, so we felt that all birds were capable of accessing any part of the study area at any time. Second, avoidance of certain types of habitats (e.g., pinyon-juniper on steep hillsides) is as important for mapping probability of use as is preference for other habitat types (e.g., sagebrush-covered plateaus), so it is important to include areas of known non-habitat in the analysis. To generate pseudo-absence points, we randomly selected available points from within the project area with the restriction that they could not fall within a dissolved average daily movement distance buffer around used points. The rationale behind using daily movement distance is that marked birds could have used any location within that buffer on the date we obtained the location without our detecting it. This sampling design is intended to eliminate undetected used points from the available sample, essentially generating a set of pseudo-absence points which marked birds were highly unlikely to have used. We generated twice the number of pseudo-absence points as used points in each analysis to ensure adequate representation of all habitat types.

Variables

Wintering and breeding sage-grouse are thought to prefer areas with sagebrush habitat and gentle terrain and to largely avoid non-sagebrush habitats and areas with rugged terrain (Hupp and Braun 1989, Homer et al. 1993, Connelly et al. 2000, Doherty et al. 2008). Therefore, we considered six continuous variables in each analysis, all of which represent biologically plausible features that influence sage-grouse select winter habitat: (1) proportion sagebrush habitat, (2) proportion riparian habitat, (3) proportion desert mat saltbush (i.e., ―salt-sage") habitat, (4) proportion barren habitat, (5) proportion non-sagebrush shrub habitats, and (6) a roughness index to describe topography. Proportion sagebrush habitat included all sagebrush habitat types combined (moderate density and dense sagebrush, mixed shrub-grassland, basin big sage-greasewood, and rock-low sage). Proportion riparian habitat included all riparian habitat types combined (riparian willow, greasewood, riparian grass/forbs, riparian woodland, stock ponds, and irrigated agriculture or pasture). Proportion barren habitat included rock talus, rock talus/dense low sage, badlands, and disturbed areas other than well pads, roads, or pipeline cuts. Proportion non-sagebrush shrub habitat included manzanita, juniper/pinyon-juniper, mountain mahogany/mixed shrub, and bitterbrush/sagebrush/mountain shrub. For sagebrush, we considered models with interactions across scales to test whether use depended on sagebrush habitat at multiple scales and quadratic models to test whether birds selected for intermediate amounts of sagebrush habitat. We calculated habitat metrics using the vegetation layer provided by Questar and classified by TRC Environmental, Inc. based on high-resolution, color-infrared photography (Fig. 2). An independent, post-classification accuracy assessment of the TRC vegetation layer by CDOW indicated that pooled vegetation classes used in analyses had an overall accuracy of 76.6% and an overall kappa statistic of 0.71. We calculated an index of the roughness of the terrain by calculating the standard deviation of elevation of pixels within the buffer from a 10-m resolution digital elevation model (Doherty et al. 2008).

Scale

We measured all variables using a circular buffer at 3 scales around used and pseudo-absence points for the winter analysis: 100-m, 740-m, and 1000-m. These values indicate the radius of the buffer. We measured variables at the same three scales above, plus a 350-m scale, for the breeding analysis. We added the 350-m scale to facilitate comparison with new data on landscape-scale nest-site selection from Wyoming and Montana (Doherty et al. 2010). The 100-m scale and 350-m scales represent patch-scale habitat selection (the scale at which birds can see and assess the habitat around them). We used the 740-m and 1000-m scales to represent landscape-scale habitat selection, scales at which other ecological factors such as the availability of escape cover or the distribution and abundance of predators, might influence habitat selection. We would have preferred to analyze selection at larger scales, but proximity of birds to the edge of the imagery became problematic. The 740-m scale represents an intermediate scale between 100 m and 1000 m in terms of area.

Analyses

We first assessed support for each variable across scales to identify the scale(s) that best represented sage-grouse habitat selection based on log-likelihood values. Variables > 2 AIC_c units below the best model and for which 95% CIs of odds ratios overlapped 1.0 were excluded from further consideration. All other variables were included in forward stepwise regression, with the exception that we did not allow correlated variables ($r > 0.7$) or the same variable at different scales in the same model, with the exception of a model with an interaction of sagebrush across scales. We checked for stability of regression coefficients and associated standard errors in models with correlated variables ($r > 0.4$) and excluded models in which regression coefficients switched signs or had inflated standard errors. We used AIC_c values to assess relative support for different models (Burnham and Andersen 2002). We then converted regression coefficients from the best model into a spatially-explicit layer showing relative probability of use by applying them to GIS layers using a resource selection function across the entire landscape.

Model Validation

We tested the robustness and predictive power of our best model following validation techniques outlined in Johnson et al. (2006). This involved: (1) dividing the RSF values into 6 ordinal bins, (2) calculating the midpoint RSF value and area for each bin, (3) calculating the expected number of validation observations in each bin based on the area within that bin and probability of use from the best approximating model, and (4) regressing the observed number of validation locations in each bin against the expected number of locations in each bin. We randomly selected 20% of the individuals in the database and used locations from those individuals for validation. Validation datasets contained 142 locations from 34 individuals for the winter analysis and 97 locations from 25 individuals for the breeding-season analysis. No individuals or locations used to build the model were included in validation data. Models that fit the data should have a high R^2 value, a slope of 1.0, and an intercept not different than zero (Johnson et al. 2006).

Interstate movement

We plotted breeding and winter locations of birds captured in Colorado vs. those captured in Wyoming to assess broad patterns of movement within the field and across the state boundary.

RESULTS

Winter analyses

Eight variables were retained after univariate analysis and were considered in the final regression analysis: proportion sagebrush habitat within 740 m and 100m (plus an interaction term), roughness within 100 m, proportion riparian habitat within 740 m, proportion desert mat saltbush habitat within 1000 m, proportion non-sagebrush shrubs within 1000 m, proportion barren habitat within 100 m, and elevation. The forward stepwise regression produced a best approximating model that included proportion sagebrush habitat within 740 m and 100m plus an interaction term, roughness within 100 m, proportion desert mat saltbush habitat within 1000 m, and elevation (Table 1). Regression coefficients indicated that sage-grouse selected landscapes with more extensive sagebrush habitat within 740-m. Within those areas, birds also selected patches with greater sagebrush within 100 m (Fig. 3). They also selected areas with locally flat topography and higher elevation portions of the field, whereas they avoided landscapes with extensive desert mat saltbush (―salt-sage") habitat (Table 1). We used coefficients from the best approximating model to generate the winter habitat use map. The resulting RSF map was divided into 6 ordinal bins that represent areas with varying relative probability of use by wintering greater sage-grouse (Figs. 4, 5). Together, RSF bins 5 and 6 (orange and red areas combined) represent 81% of the predicted high-priority winter habitat (Figs. 4, 5).

Breeding analyses

Seven variables were retained after univariate analysis and were considered in the final regression analysis: proportion sagebrush habitat within 1000 m, proportion riparian habitat within 740 m, proportion desert mat saltbush habitat within 1000 m, proportion non-sagebrush shrubs within 1000 m, proportion barren habitat within 1000 m, roughness within 350 m, and elevation. In the final stepwise analysis, collinearity among variables resulted in several models with unstable estimates of regression coefficients and inflated standard errors. The two best models with stable coefficients and standard errors included: (Model 1) desert mat saltbush habitat within 1000 m, non-sage shrubs (incl. PJ) within 1000 m, roughness within 350 m, barren habitat within 1000 m, and elevation; and (Model 2) sagebrush habitat within 1000 m, non-sage shrubs (incl. PJ) within 1000 m, roughness within 350 m, and elevation (Table 2). Of these two models, model 2 had a higher validation R^2 (0.74 vs. 0.71), so we used that model to draw inferences and for mapping. Regression coefficients from both models indicated that sage-grouse preferred landscapes with extensive sagebrush habitat within 1000 m, local patches with flat topography within 350 m, higher-elevation habitats near the edge of the field, and those that contained a small proportion of non-sage shrub habitat within 1000 m (Table 3). Birds selected against landscapes with extensive barren or desert mat saltbush habitats within 1000 m. The resulting RSF map was divided into 6 ordinal bins that represent areas with varying relative probability of use by breeding greater sage-grouse (Figs. 6, 7). Together, RSF bins 5 and 6 (orange and red areas combined) represent 73% of the predicted high-priority breeding habitat (Figs. 6, 7).

Mapping

Important wintering areas for greater sage-grouse within the Hiawatha Regional Energy Development project area occur near the G Flat, G Flat South, Whiskey Draw, Sugarloaf, Sugarloaf South, Owl Bench (not shown on map, NW of Whiskey Draw), Rifes Rim East, Bitter Creek, Chicken Creek, Alkali Bench, and Crooked Wash leks (active), as well as an area northeast of the Hiawatha oil camp (Figs. 4, 5). High-priority breeding habitat largely overlapped with high-priority wintering habitat.

Validation

The winter model was a reliable predictor of an independent dataset with 142 winter locations from randomly-selected 34 marked individuals (R^2 = 0.945; slope = 1.096 [95% CI: 0.728 to 1.465]; intercept = -2.284 [95% CI: -15.345 to 10.777]; Fig. 8). The breeding model predicted an independent dataset of 97 winter locations from 25 marked individuals, but the relationship was poorer than for the winter model (R^2 = 0.74; slope = 1.25 [95% CI: 0.228 to 2.283]; intercept = -4.128 [95% CI: -26.899 to 18.642]; Fig. 9).

Landscape-scale Habitat Guidelines

The majority of wintering sage-grouse used areas with 57-86% (mean 70%) sagebrush habitat within 740 m, 69-99% (mean 80%) sagebrush habitat within 100 m, and 1-33% desert mat saltbush habitat within 1000 m (Table 3). Similarly, the majority of sage-grouse locations during the breeding season were in areas with 56-82% (mean 68%) sagebrush habitat within 1000 m, 0-0.5% non-sagebrush shrub habitat within 1000 m, 0-0.7% barren habitat within 1000 m, and 0-25% desert mat saltbush habitat within 1000 m (Table 4).

Development Conflicts

Some proposed focus areas overlap with high-priority winter and breeding habitats (Figs. 10, 11). These include areas near the G Flat, G Flat South, Sugarloaf, Sugarloaf South, Alkali Bench, Crooked Wash, and Chicken Creek leks, and NE of Hiawatha Oil Camp. Development in the Whiskey Draw, Owl Bench, Bitter Creek, and Rifes Rim areas would be a major concern for conservation of sage-grouse that breed in the Cold Springs/Hiawatha core population in Colorado. In conjunction with 0.6 mi. lek buffers designed to protect lekking males, these areas may require additional efforts to avoid, minimize, or mitigate impacts on wintering flocks and nesting and brood-rearing females (e.g., surface density caps, well-pad density thresholds).

Winter and Breeding Habitat Use and Oil and Gas Development

We present winter and breeding habitat maps overlaid with active (drilling, drilled, producing, shut-in, and injection wells) and inactive (dry hole, abandoned) wells as of 1 Sept 2008 from the Colorado Oil and Gas Conservation Commission and Wyoming Oil and Gas Conservation Commission to visually show the juxtaposition of sage-grouse locations, winter and breeding habitat use, and oil and gas development (Figs. 12, 13). No radio-marked birds were documented using the areas around Hiawatha oil camp during the winter despite the presence of suitable topography and landscape-level habitat features for wintering and breeding birds. Developed areas near Alkali Bench and south of Chicken Creek were also rarely used by wintering or breeding birds. In contrast, some use of developed areas was observed in the area north of Sugarloaf lek in the SW corner of the field.

Interstate Movement

Sage-grouse captured within the Hiawatha-Cold Springs core area in Colorado regularly moved back and forth between Colorado and Wyoming on the western side of the Hiawatha project area, as did birds captured on the west side of the field in Wyoming (Fig. 14). Marked birds captured in the northeast, east, and southeast portions of the field largely remained in Wyoming (Fig. 13), suggesting less interstate movement on the east side of the field. However, data from flights and GPS transmittered birds, suggest at least some interstate movement between the Alkali Bench/Crooked Wash area and Racetrack Flat, Dugout Draw, and Sand Wash in Colorado (data not shown).

Lek Buffers

Leks buffers are designed to protect males during the breeding season. By themselves, 0.6 mi. buffers are ineffective for conserving sage-grouse because most breeding and wintering habitats fall outside 0.6 mi. lek buffers (Figs. 15, 16). Some areas within 0.6 mi. contained unsuitable breeding habitat (Fig. 15) and some areas within 4-mi. buffers around leks contained unsuitable breeding and wintering habitat (Figs. 15, 16). The majority of high-priority breeding and wintering habitat in the project area would have been encompassed by a 4-mi. buffer around leks, with the exception of some areas in the central portion of the field. Is it unclear whether undiscovered leks are present in those areas. Several leks were discovered in 2008 and 2009 (Bitter Creek, Granary Draw, Alkali Bench, Crooked Wash, and Sugarloaf South). Had these leks not been discovered, several important breeding areas would have been overlooked and excluded during the planning process.

DISCUSSION

Current maps represent a substantial improvement over our preliminary maps from 2008 because increased trapping and tracking of marked individuals in the northern and eastern portions of the field in

2008-2009 allowed us to expand inference to the entire project area. As predicted from our preliminary analysis, we documented substantial winter and breeding use in the eastern half of the field.

Our findings are consistent with previous studies that documented a preference among wintering and nesting sage-grouse for areas with extensive sagebrush habitat and flat terrain and avoidance of deeply incised riparian areas and non-sagebrush habitats (Hupp and Braun 1989, Homer et al. 1993, Doherty et al. 2008, Doherty et al. 2010). These results are also consistent with studies of sage-grouse diets that indicate nearly complete reliance on sagebrush for winter forage (Remington and Braun 1985, Welch et al. 1991) as well as major reviews of sage-grouse habitat requirements indicating that both wintering and breeding birds strongly prefer landscapes with extensive sagebrush habitat (Connelly et al. 2000, Crawford et al. 2004). Selection for higher-elevation sagebrush habitat within the field in both the winter and breeding analyses may be explained by higher elevation areas having higher precipitation and soil moisture that allow greater grass height, forb cover, and insect abundance than in the drier central portion of the field. These features are typically selected by nesting females (Hagen et al. 2007) and increase nest success and chick survival (Holloran et al. 2005, Doherty et al. 2010). The final breeding regression model included one pattern that requires caution in interpretation. Non-sagebrush shrub-woodland (e.g., pinyon-juniper, mountain shrubs) within 1000 m was estimated to have a positive effect on probability of sage-grouse breeding use. This is a correlational rather than cause-and-effect relationship. First, no breeding or winter locations occurred in non-sagebrush shrub or PJ habitat. Second, non-sagebrush shrubs (e.g., pinyon-juniper, mountain shrubs) only occur along the periphery in the SW, NW, and NE corners of the field (Fig. 2), all of which are adjacent to important sagebrush habitats used by grouse.

Our study also emphasizes the value of using seasonal habitat use maps to identify crucial habitat when high-resolution telemetry and remote sensing data are available. Some areas within lek buffers around leks contained unsuitable habitat, and some high-priority habitats that were not included in lek buffers were identified using seasonal habitat maps. Our findings also emphasize the importance of finding and documenting all leks when using lek-based management and conservation strategies (e.g., lek buffers, core areas derived from lek location and count data).

Although sage-grouse are thought to avoid areas with energy infrastructure (roads, pipelines, wells, etc.; Lyon and Anderson 2003, Doherty et al. 2008, Holloran et al. 2010), we did not attempt to quantitatively address this question in the current analysis. Anecdotally, we observed almost no use by marked birds of developed areas with otherwise suitable landscape-level habitat and topography near Hiawatha Oil Camp and in the ―Five Spur” area south of Chicken Creek (Figs. 5, 7). Five nights of trapping in sagebrush around the Hiawatha Oil Camp and Five Spur areas in summer and fall 2008 yielded no sightings and no captures. Two days of winter snow-track surveys in preliminary ―high priority” winter habitat near Hiawatha Oil Camp in February 2009 also yielded no sage-grouse detections. We anticipated that at least some birds captured on the east side of the project area in 2008 would have nested and raised broods in the Hiawatha oil camp area in spring 2009 based on vegetation and topography, but no birds were detected using that portion of the field. In contrast, marked birds used sagebrush habitats near active development north of the Sugarloaf lek; these birds typically moved back and forth between Sugarloaf area and the G Flat area further west.

We were unable to gather enough winter locations in 2007-2008 (102) and 2008-2009 (199) to conduct a local-scale (i.e., 30-m) vs. landscape scale (i.e., 100-1000-m) analysis, so we opted to continue tracking marked birds and collecting local-scale vegetation data this winter (2009-2010). We are also reclassifying the original high-resolution color infrared imagery with Definiens software to improve accuracy of the vegetation classification before running the final local vs. landscape winter analysis this summer. Results from that analysis will be summarized in the final progress report in December 2010 (Table 5).

ACKNOWLEDGMENTS

We thank Tom Thompson and Kerry Reese at University of Idaho for contributing an extensive dataset of sage-grouse locations, field crew supervisors and technicians for collecting field data, and the Vermillion Ranch, John and Marianna Raftopolous, and Don Hartley for providing access to private land and for feedback on the project. Questar Exploration and Production, the Southwest Wyoming Sage-Grouse Local Working Group, and the Colorado Division of Wildlife provided funding for the project. Karin Eichhoff and Mindy Rice provided valuable assistance with GIS analyses. Questar provided a classified vegetation map to facilitate habitat selection analyses. Personnel from Wyoming Game and Fish Department and the Rock Springs and Little Snake field offices of the Bureau of Land Management provided valuable logistical support.

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Table 1. Regression coefficients for variables in the best approximating model describing greater sage-grouse landscape-scale winter habitat selection in the Hiawatha Regional Energy Development project area, 2005-2009.

Intercept $\beta_0 \pm$ SE	Sage 740-m[1] $\beta_1 \pm$ SE	Sage 100-m[2] $\beta_3 \pm$ SE	Roughness 100-m[3] $\beta_2 \pm$ SE	Sage 100-m x 740-m[4] $\beta_5 \pm$ SE	Elevation (m) $\beta_4 \pm$ SE	Desert mat 1000-m[5] $\beta_6 \pm$ SE
-18.9183 ± 2.7137	5.9274 ± 1.0241	3.5898 ± 0.7025	-0.2811 ± 0.0453	-3.5825 ± 1.2052	0.0070 ± 0.0013	-1.5219 ± 0.5587

[1] Sage 740-m = proportion sagebrush habitat within 740 m.
[2] Sage 100-m = proportion sagebrush habitat within 100 m.
[3] Roughness 100-m = standard deviation of elevation within 100 m.
[4] Sage 100-m x 740-m = interaction term between Sage 740-m and Sage 100-m.
[5] Desert saltbush = desert mat/cushion plant saltbush (i.e., ―salt-sage") habitat within 1000 m.

Table 2. Regression coefficients in the best approximating models describing greater sage-grouse landscape-scale breeding habitat selection in the Hiawatha Regional Energy Development project area, 2005-2009.

Model	AIC$_c$	Intercept $\beta_0 \pm$ SE	Sage 1000-m[1] $\beta_1 \pm$ SE	Roughness 350-m[2] $\beta_2 \pm$ SE	Elevation (m) $\beta_3 \pm$ SE	Non-sage/PJ 1000-m[3] $\beta_4 \pm$ SE	Barren 1000-m[4] $\beta_4 \pm$ SE	Desert mat 1000-m[5] $\beta_4 \pm$ SE
1	867.00	-24.7882 ± 4.3313	-	-0.4261 ± 0.0325	0.0135 ± 0.0020	8.4086 ± 2.1900	-4.3246 ± 1.4660	-4.9623 ± 0.5254
2	903.48	-25.6016 ± 4.2458	3.9836 ± 0.5160	-0.4212 ± 0.0317	0.0121 ± 0.0020	15.0877 ± 2.1263	-	-

[1] Sage 1000-m = proportion sagebrush habitat within 1000 m.
[2] Roughness 350-m = standard deviation of elevation within 350 m.
[3] Non-sage/PJ 1000-m = proportion non-sagebrush shrubs and pinyon-juniper habitat within 1000 m.
[4] Barren 1000-m = proportion barren habitat within 1000 m.
[5] Desert saltbush = desert mat/cushion plant saltbush (i.e., ―salt-sage") habitat within 1000 m.

Table 3. Summary of vegetation and topography variables at selected scales at winter locations of marked female greater sage-grouse in the Hiawatha Regional Energy Development project area, 2005-2009.

Descriptive statistics	Sage 740-m[1]	Sage 100-m[2]	Roughness 100-m[3]	Elevation (m)	Desert mat 1000-m[4]
Mean ± SE	0.701 ± 0.006	0.798 ± 0.009	2.116 ± 0.040	2194 ± 1.9	0.164 ± 0.559
Median	0.703	0.908	1.900	2192	0.081
Mode	0.512	1.000	2.900	2184	0.346
(25-75% quantiles)	(0.57-0.86)	(0.69-0.99)	(1.421-2.408)	(2165-2228)	(0.01-0.33)
(5-95% quantiles)	(0.39-0.95)	(0.29-1.00)	(0.773-4.098)	(2110-2285)	(0.00-0.48)

[1] Sage 740-m = proportion sagebrush habitat within 740 m.
[2] Sage 100-m = proportion sagebrush habitat within 100 m.
[3] Roughness 100-m = standard deviation of elevation within 100 m.
[4] Desert saltbush = desert mat/cushion plant saltbush (i.e., ―salt-sage") habitat within 1000 m.

Table 4. Summary of vegetation and topography variables for selected scales at breeding locations of marked female greater sage-grouse in the Hiawatha Regional Energy Development project area, 2005-2009.

Descriptive statistics	Sage 1000-m[1]	Roughness 350-m[2]	Non-sage/PJ 1000-m[3]	Elevation (m)	Barren 1000-m[4]	Desert mat 1000-m[5]
Mean ± SE	0.678 ±	6.755 ±	0.044 ±	2217 ± 2.8	0.045 ± 0.002	0.148 ±
Median	0.008	0.187	0.004	2202	0.002	0.007
Mode	0.688	6.062	0.000	2292	0.000	0.060
(25-75%)	0.726	3.562	0.000	(2165-2288)	(0.000-0.007)	0.062
	(0.56-0.82)	(4.75-7.75)	(0.000-0.005)			(0.00-0.25)
(5-95%)	(0.36-0.96)	(3.50-11.25)	(0.000-0.220)	(2127-2310)	(0.000-0.017)	(0.00-0.53)

[1] Sage 1000-m = proportion sagebrush habitat within 1000 m.
[2] Roughness 350-m = standard deviation of elevation within 350 m.
[3] Non-sage/PJ 1000-m = proportion non-sagebrush shrubs and pinyon-juniper habitat within 1000 m.
[4] Barren 1000-m = proportion barren habitat within 1000 m.
[5] Desert saltbush = desert mat/cushion plant saltbush (i.e., ―salt-sage”) habitat within 1000 m.

Table 5. Updated timeline for greater sage-grouse habitat selection and conservation planning map research in the Hiawatha Project area, Moffat Co., Colorado and Sweetwater Co., Wyoming, 2007-2010.

TASK	START DATE	END DATE
Capture grouse and attach transmitters 2007	COMPLETE	COMPLETE
Collect local-scale data at winter locations 2007-2008	COMPLETE	COMPLETE
Document grouse locations (winter, spring, summer locations)	COMPLETE	COMPLETE
Gather GIS data layers and prepare layers for analyses	COMPLETE	COMPLETE
Capture grouse and attach transmitters 2008	COMPLETE	COMPLETE
Collect training and validation data for classifying imagery	COMPLETE	COMPLETE
Winter model development and analyses	COMPLETE	COMPLETE
Complete preliminary winter model and map	COMPLETE	COMPLETE
Nesting season model development and analysis	COMPLETE	COMPLETE
Prepare 2008 annual progress report	COMPLETE	COMPLETE
Capture grouse and attach transmitters 2009	COMPLETE	COMPLETE
Document grouse locations (winter, spring, summer locations)	COMPLETE	COMPLETE
Complete preliminary breeding model and map	COMPLETE	COMPLETE
Collect local-scale data at winter locations, 2008-2009	COMPLETE	COMPLETE
Conduct final landscape-scale habitat selection analyses	COMPLETE	COMPLETE
Complete final landscape-scale maps after incorporating 2009 data	COMPLETE	COMPLETE
Prepare 2009 annual progress report	COMPLETE	COMPLETE
Reclassify TRC imagery using Definiens software	1 Jul 2009	30 Jun 2010
Collect local-scale data at winter locations 2009-2010	COMPLETE	COMPLETE
Conduct final local vs. landscape habitat selection analyses	30 Jun 2010	31 Aug 2010
Prepare final report and manuscript	31 Aug 2010	31 Dec 2010

Figure 1. Nest and winter locations of radio-marked female greater sage-grouse (*Centrocercus urophasianus*) from 2005-2007 and known greater sage-grouse leks (as of 2007) with 4-mile buffers (green overlay) in relation to the Hiawatha project area boundary, NW Colorado and SW Wyoming. All locations are from greater sage-grouse radio-marked in Colorado from 2005-2007 only. Five additional active leks discovered by WGFD and CDOW in 2008-2009 and nests and locations of birds captured in Wyoming are reflected in later figures.

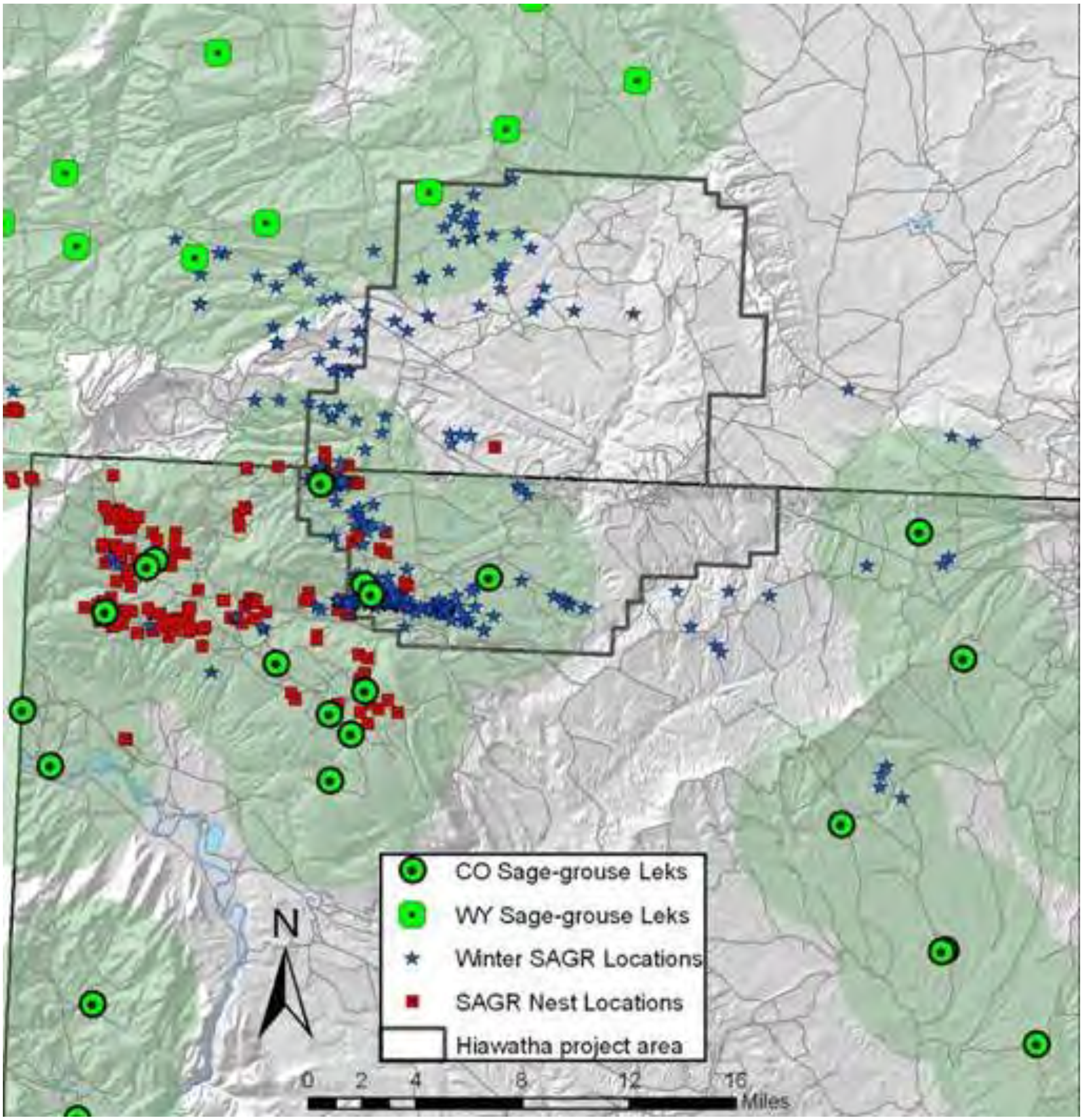


Figure 2. Vegetation map classified by TRC Environmental, Inc. and provided by Questar showing vegetation types that contributed to habitat selection analyses.

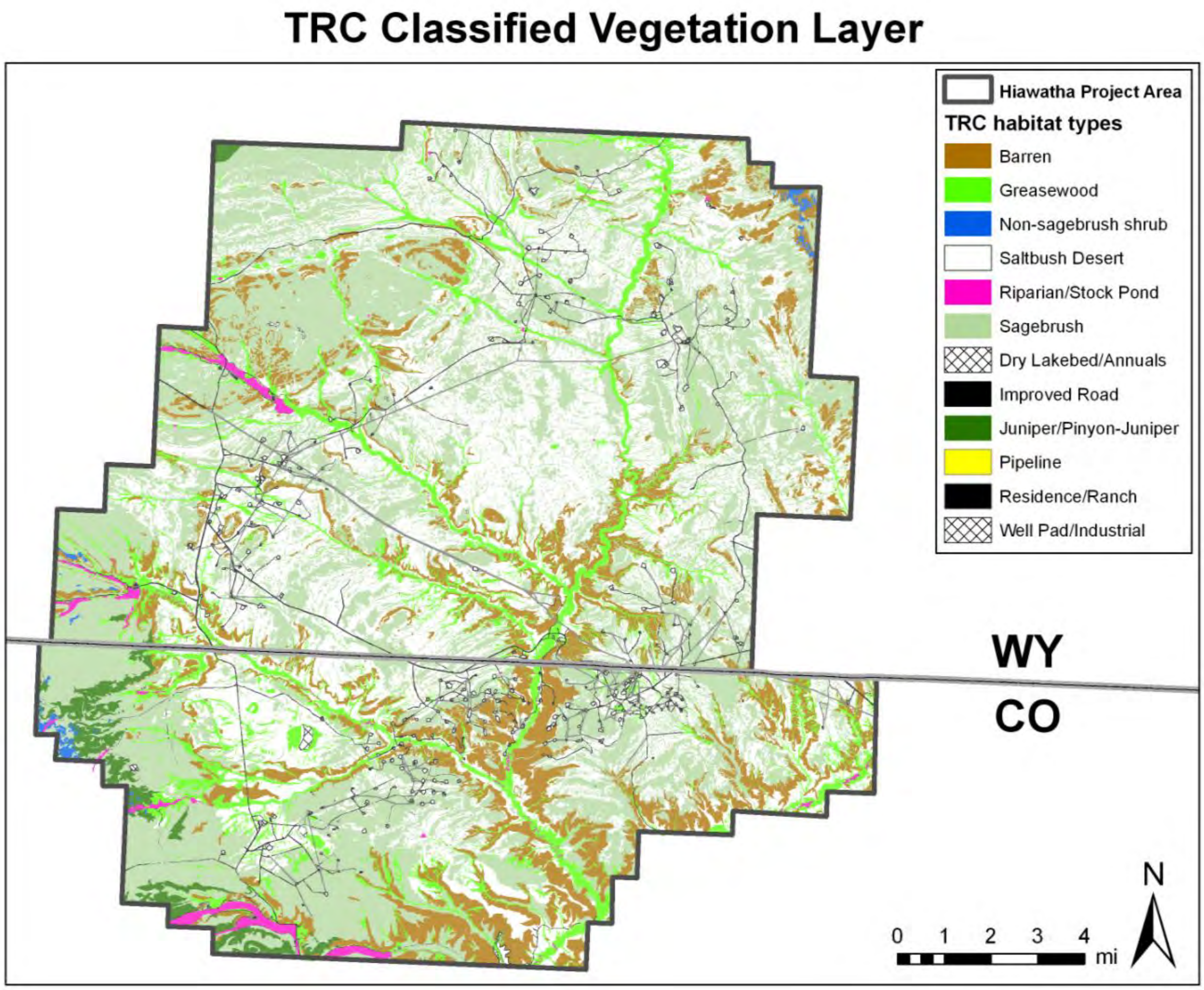


Figure 3. Relationships between relative probabilty of winter use by greater sage-grouse and proportion sagebrush within 740 m and 100 m in the Hiawatha Regional Energy Development project area, 2005-2009. 69% and 99% are the 25% and 75% quartiles of observed values for proportion sagebrush habitat within 100-m at winter sage-grouse locations (Table 2).

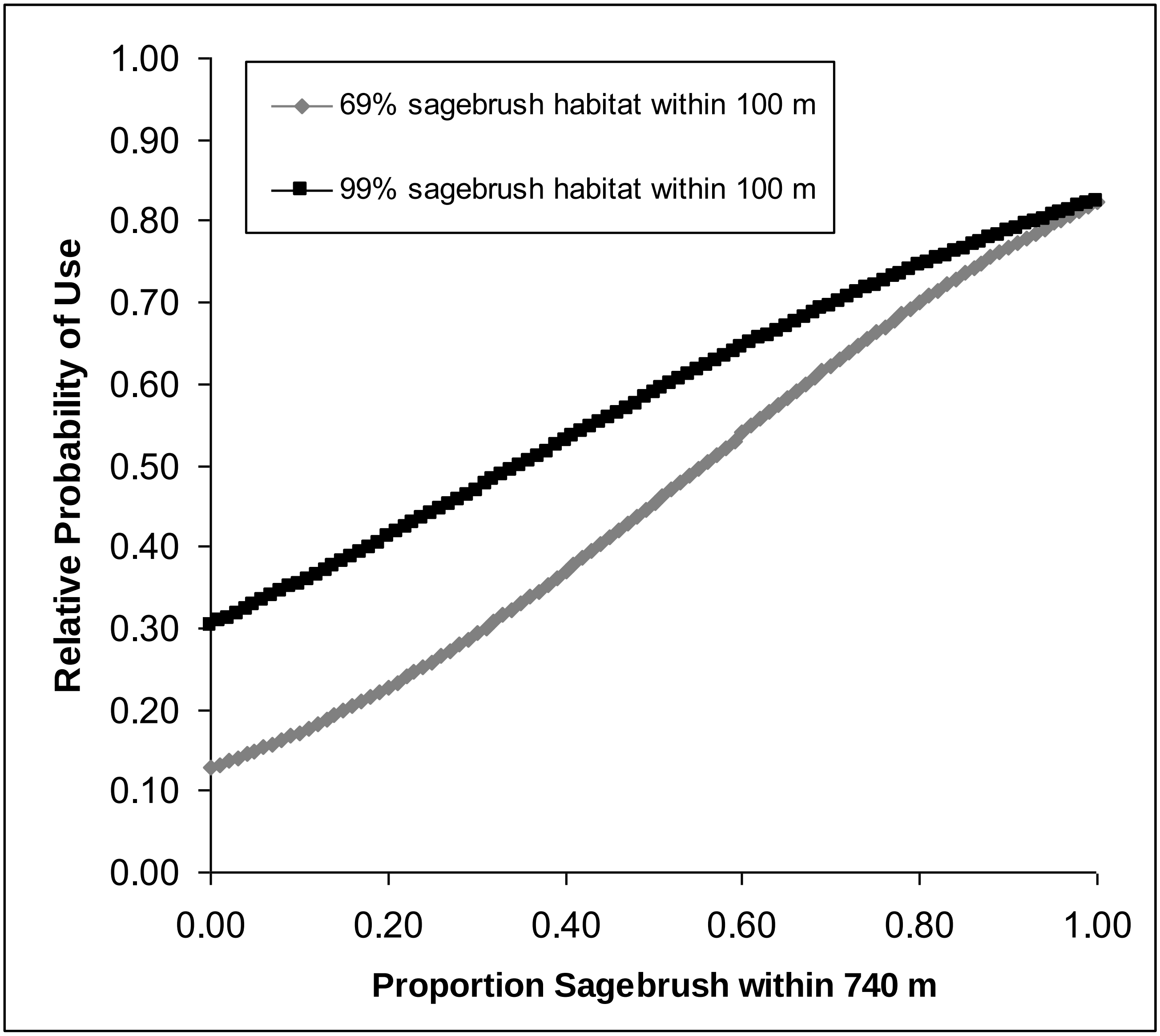


Figure 4. High-resolution winter habitat-use map for greater sage-grouse in the Hiawatha Regional Energy Development project area based on vegetation, topography, and marked bird winter locations, 2005-2009. Red and orange areas combined show high-priority habitat that encompass 81% of predicted winter sage-grouse locations. Most high priority wintering areas are on top of plateaus with extensive sagebrush and away from major drainages and areas with riparian and desert mat/cushion plant saltbush (i.e., ―salt-sage") habitat. Locations used to build (black stars) and test (white stars) the model are shown. The Owl Bench lek is just off the map NW of the Whiskey Draw lek.

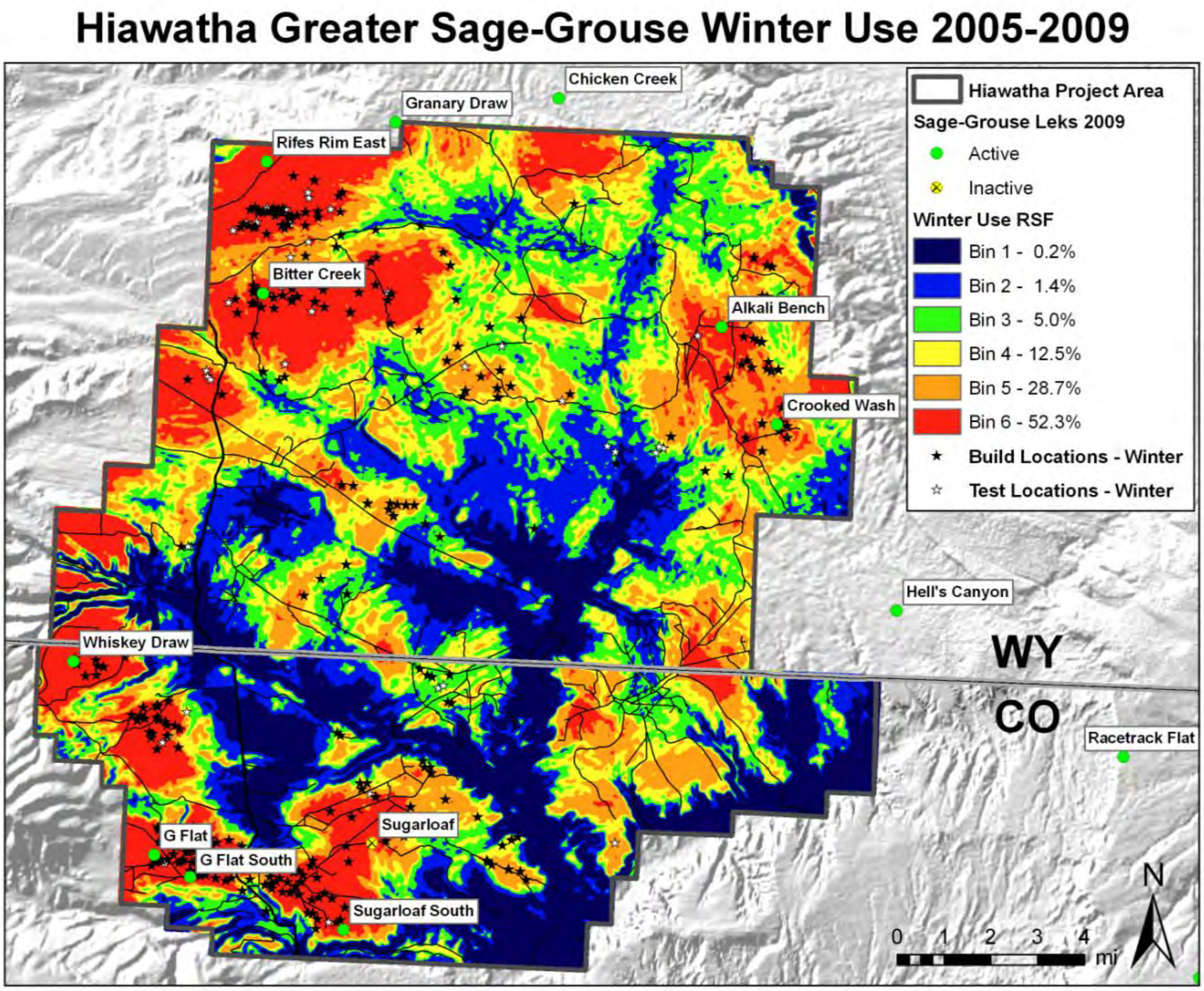


Figure 5. High-resolution winter habitat-use map for greater sage-grouse in the Hiawatha Regional Energy Development project area with all marked and unmarked bird winter locations, 2005-2010 (through 02-14-10).

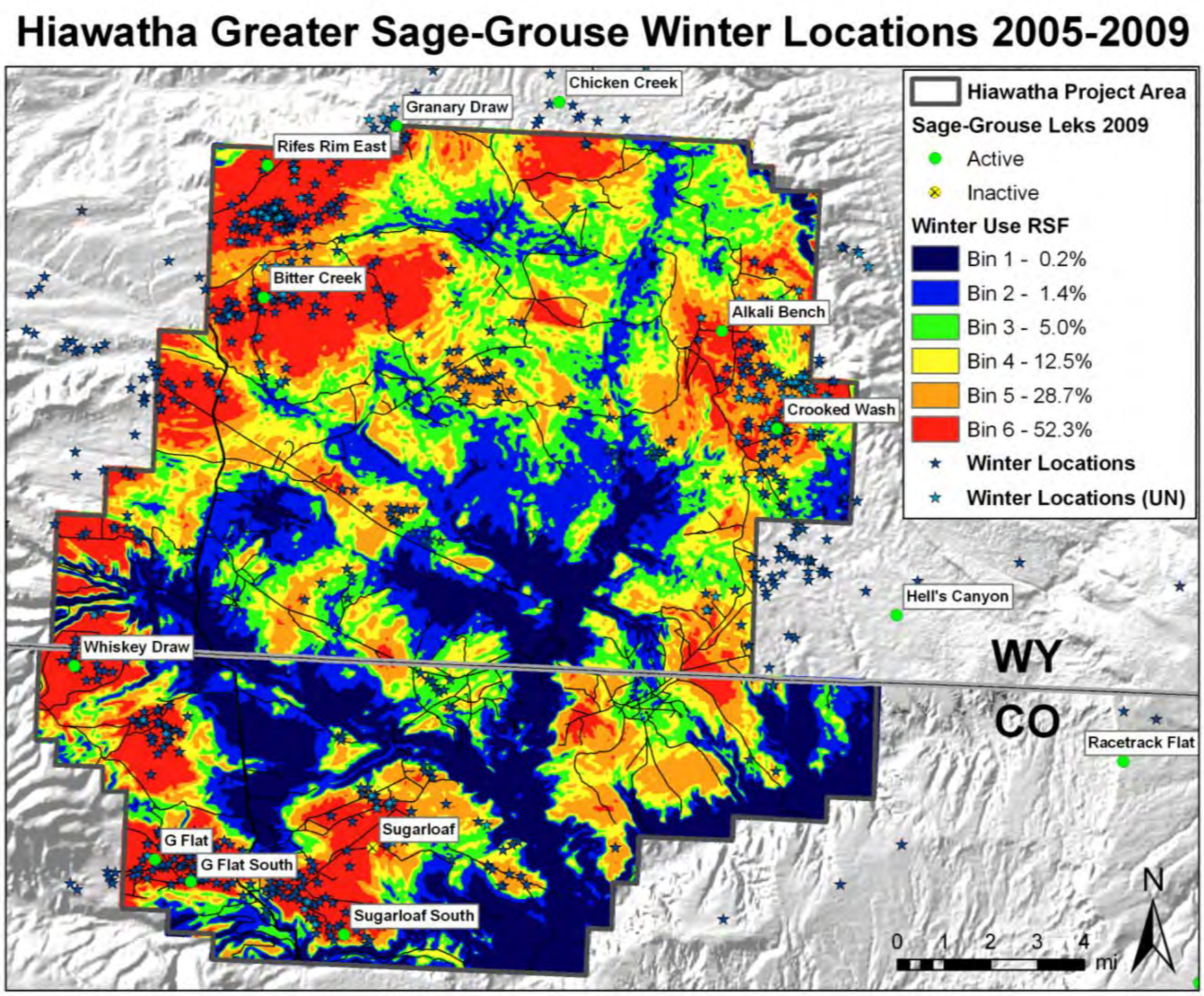


Figure 6. High-resolution breeding habitat-use map for greater sage-grouse in the Hiawatha Regional Energy Development project area based on vegetation, topography, and marked bird breeding-season locations, 2005-2009. Red and orange areas combined show high-priority habitat that encompass 73% of predicted breeding locations. Most high priority breeding areas are on top of plateaus with flat topography and extensive sagebrush and away from major drainages and areas with extensive desert mat/cushion plant saltbush (i.e., ―salt-sage") habitat. Locations used to build (black circles) and test (white circles) the model are shown.

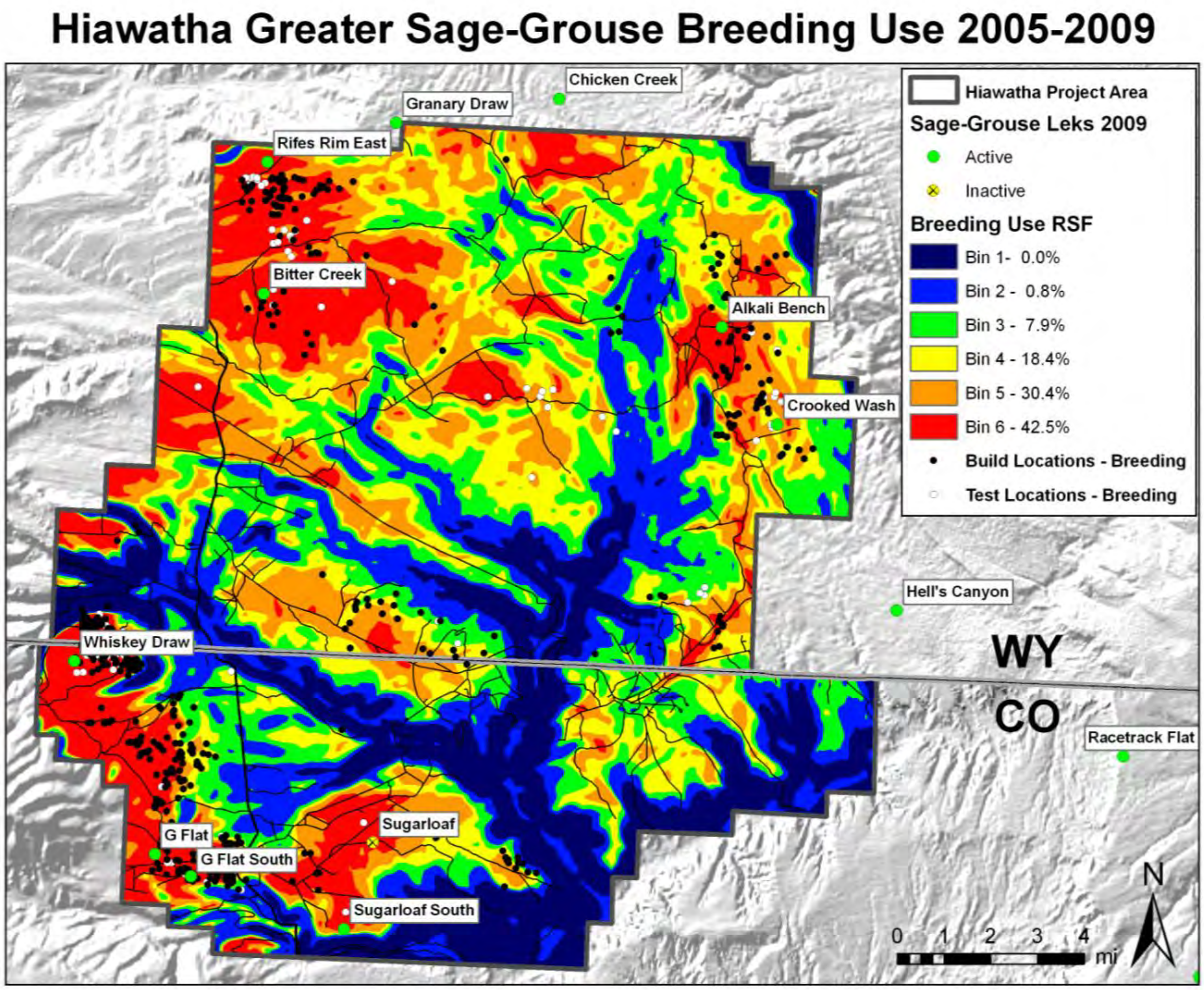


Figure 7. High-resolution breeding habitat-use map for greater sage-grouse in the Hiawatha Regional Energy Development project area with all marked and unmarked bird breeding-season locations, 2005-2009.

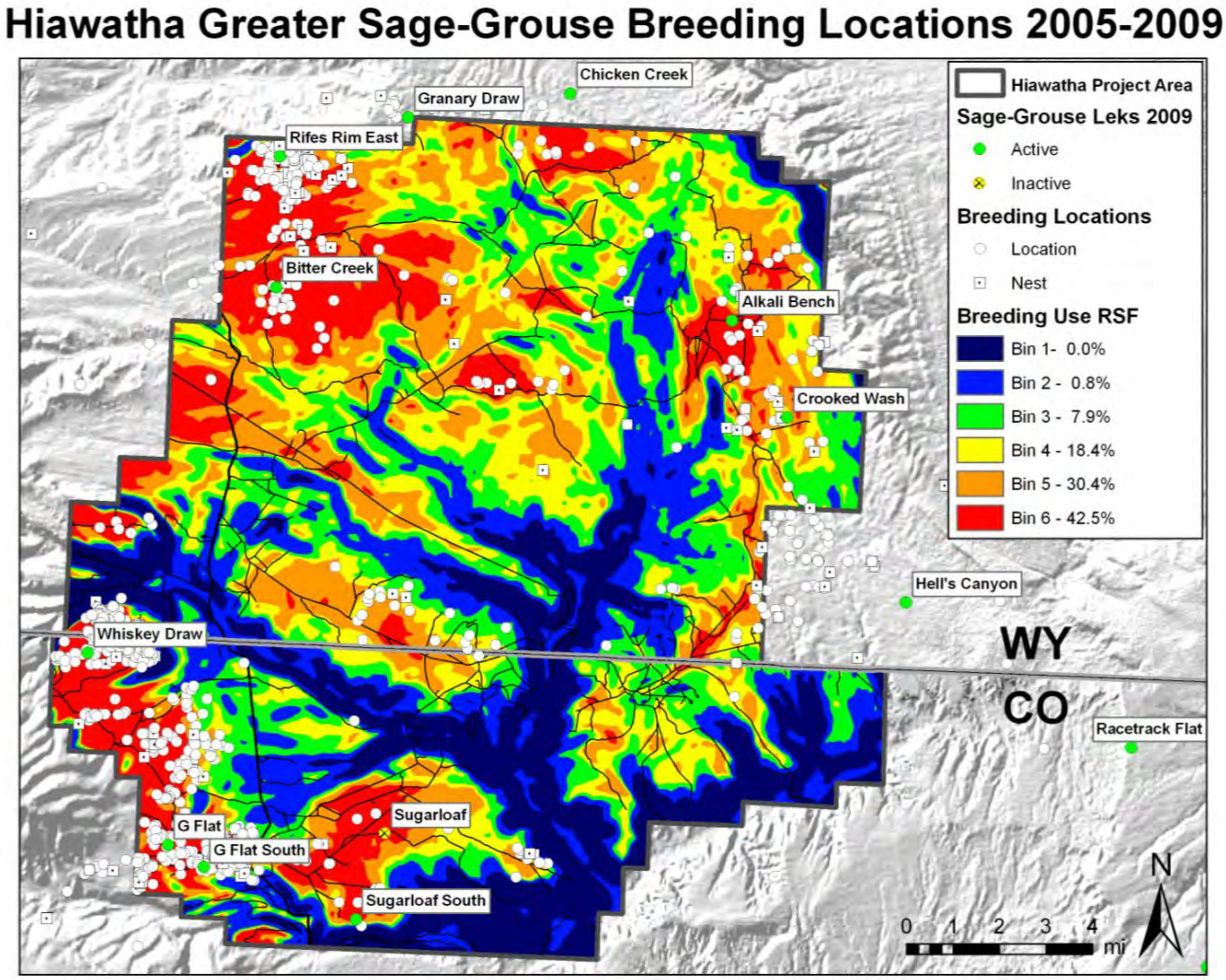


Figure 8. Regression of observed vs. expected no. of independent greater sage-grouse winter locations in each of 6 RSF bins in the Hiawatha Regional Energy Development project area, 2005-2009. Dashed line shows expected pattern under perfect model fit. Expected no. of locations are calculated from the area of each bin (1-6) multiplied by its median relative probability of use multiplied by the number of validation locations available.

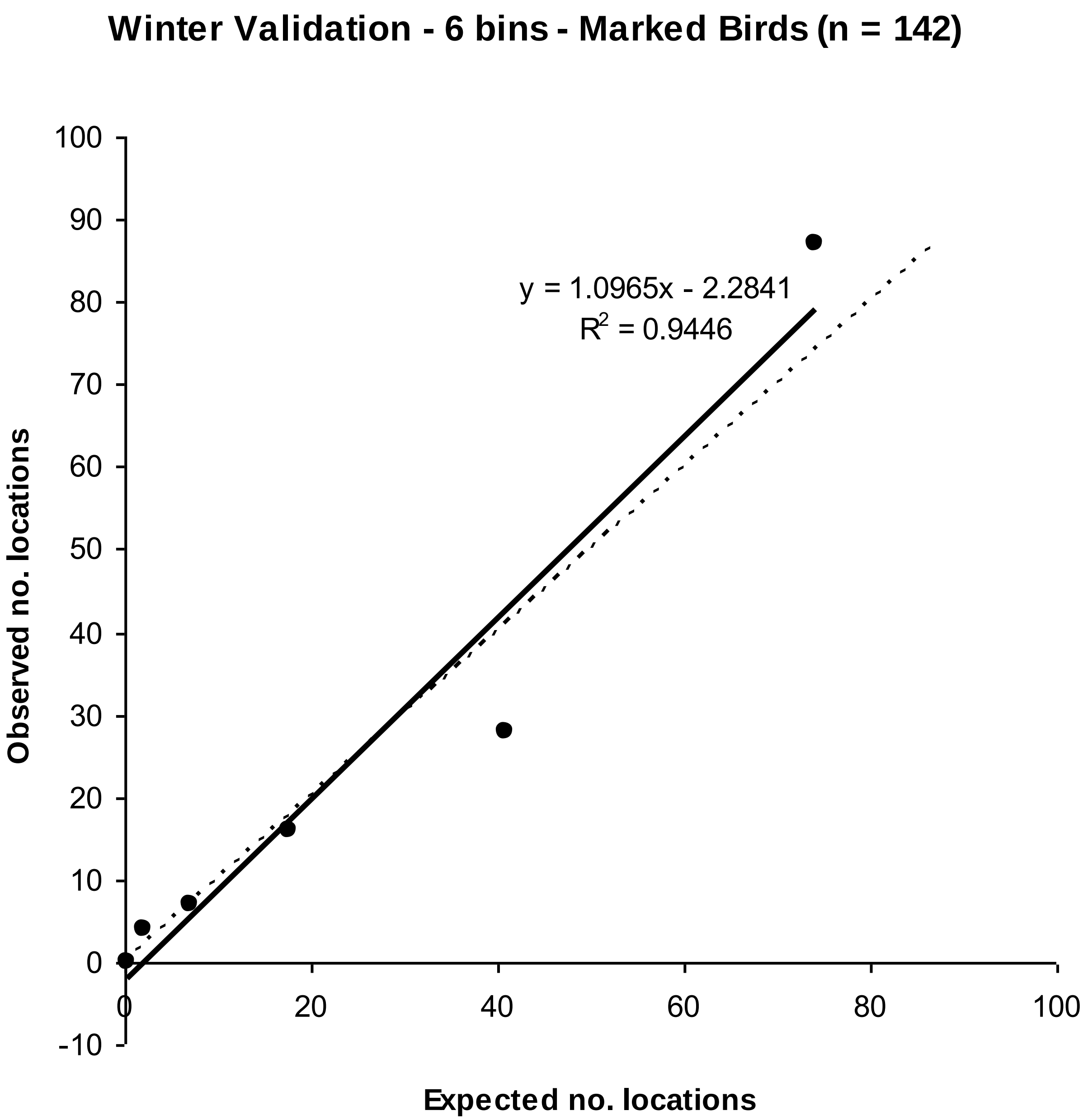


Figure 9. Regression of observed vs. expected no. of independent greater sage-grouse breeding locations in each of 6 RSF bins in the Hiawatha Regional Energy Development project area, 2006-2009. Dashed line shows expected pattern under perfect model fit. Expected no. of locations are calculated from the area of each bin (1-6) multiplied by its median relative probability of use multiplied by the number of validation locations available.

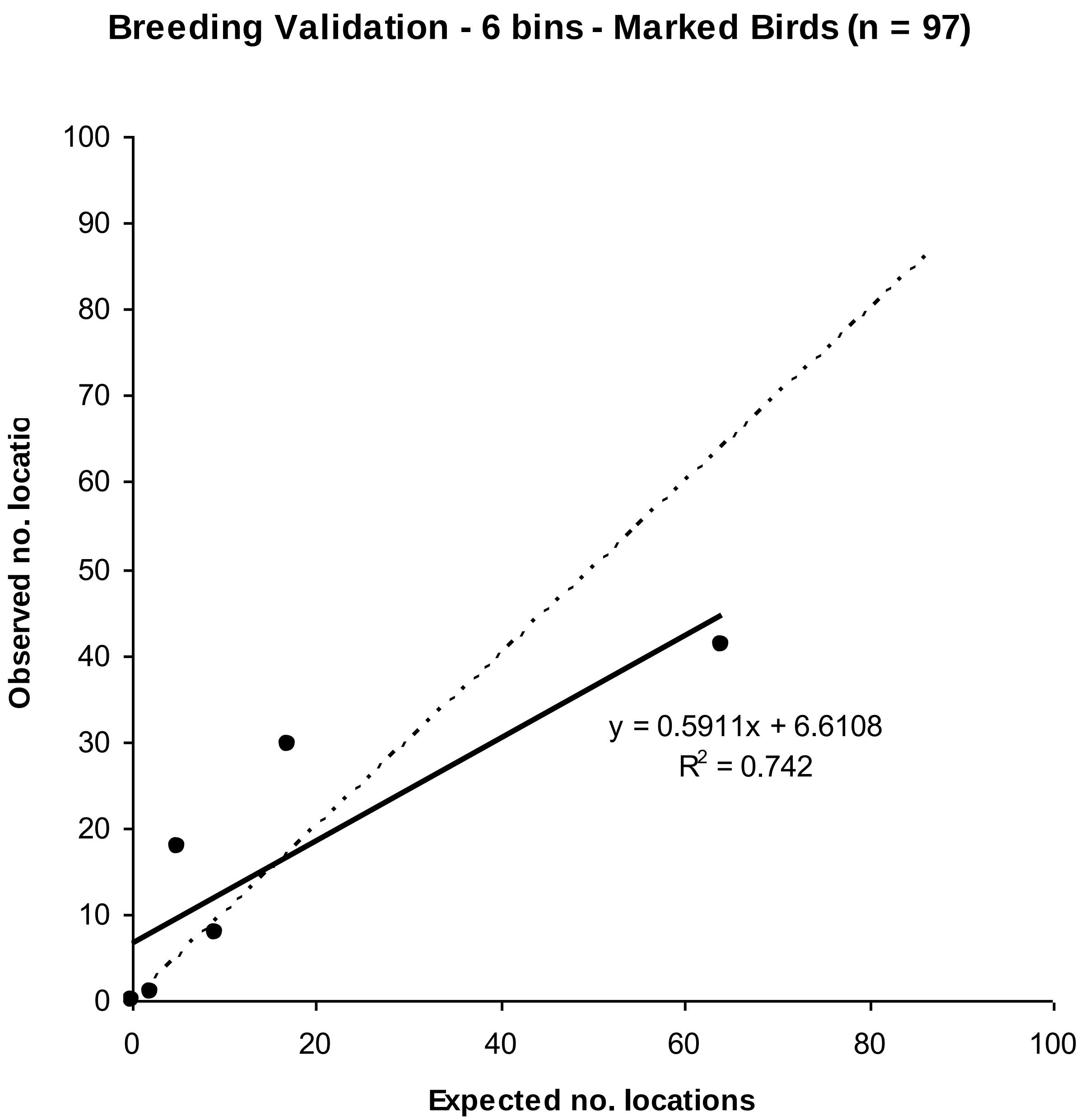


Figure 10. Winter habitat-use map for greater sage-grouse in the Hiawatha Regional Energy Development project area overlaid with all winter marked and unmarked bird locations 2005-2009 and the conceptual proposed focus area for development in the preferred alternative of the BLM's Hiawatha PDEIS from July 2008.

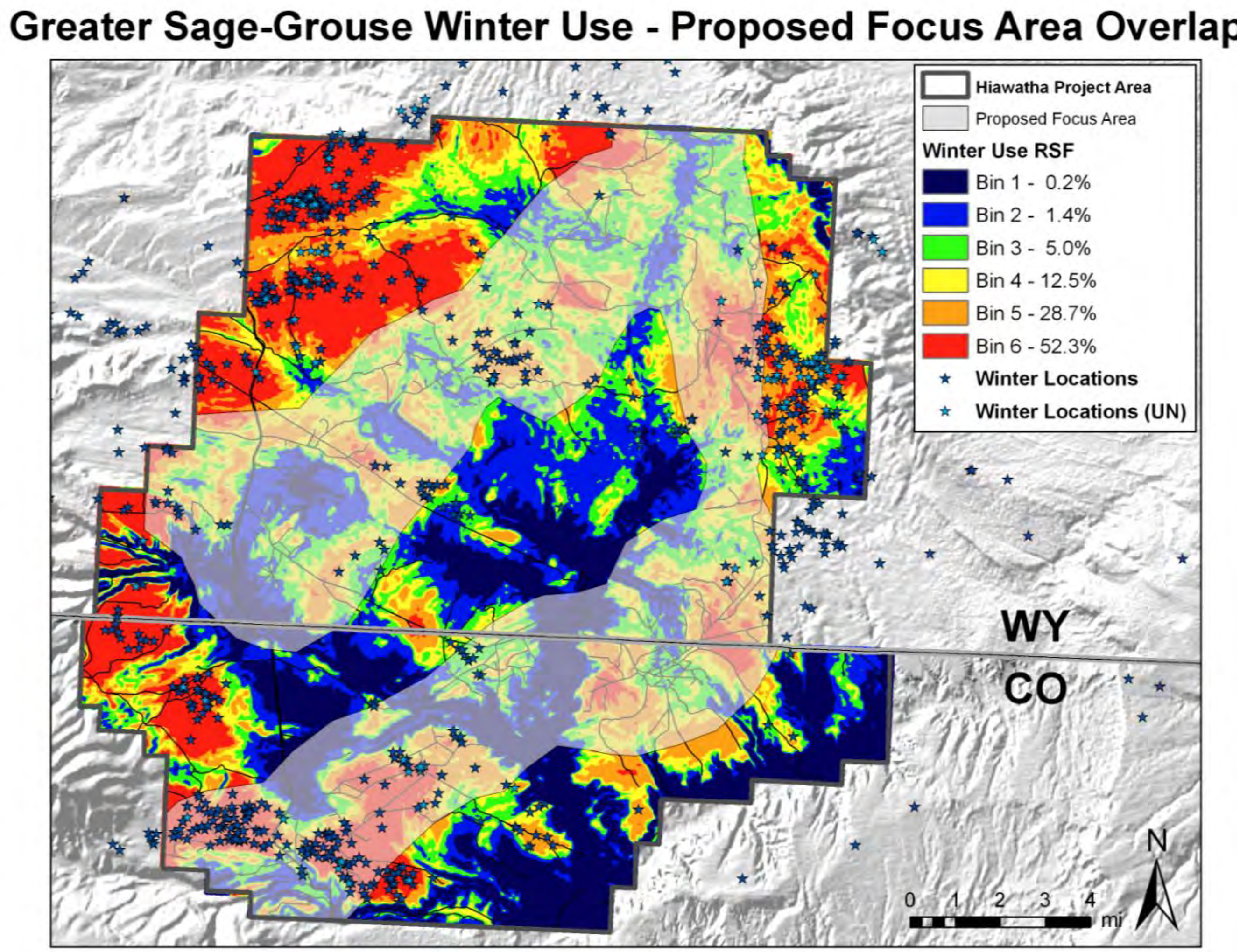


Figure 11. Breeding habitat-use map for greater sage-grouse in the Hiawatha Regional Energy Development project area overlaid with all breeding-season marked and unmarked bird locations 2005-2009 and the conceptual proposed focus area for development in the preferred alternative of the BLM's Hiawatha PDEIS from July 2008.

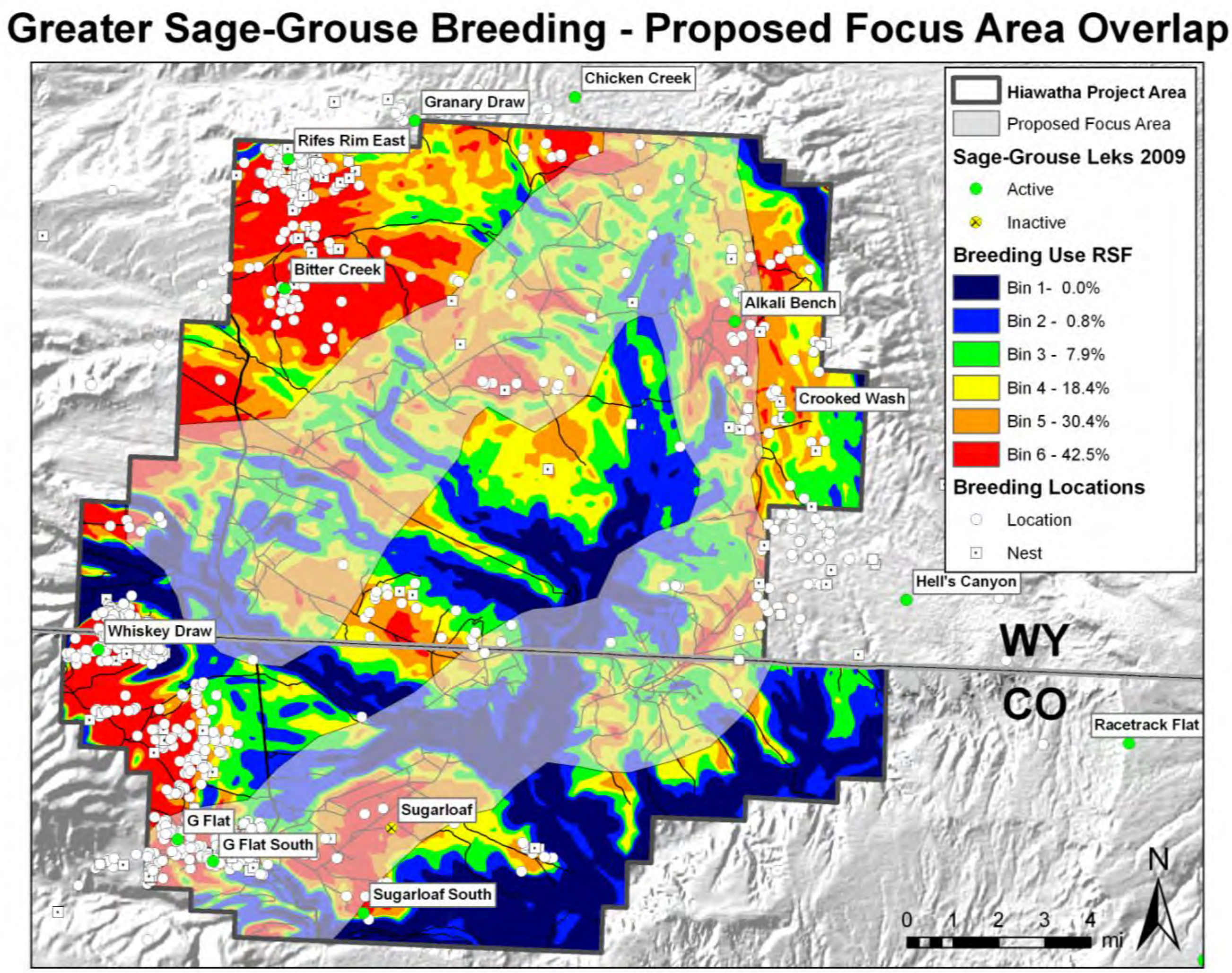


Figure 12. Winter habitat-use map for greater sage-grouse overlaid with all documented winter locations of marked and unmarked females and active (drilling, drilled, producing, shut-in, and injection wells) and inactive (dry hole, abandonded) well pads in the Hiawatha Regional Energy Development project area as of 1 Sept 2008 (from Colorado Oil and Gas Conservation Commission and Wyoming Oil and Gas Conservation Commission data).

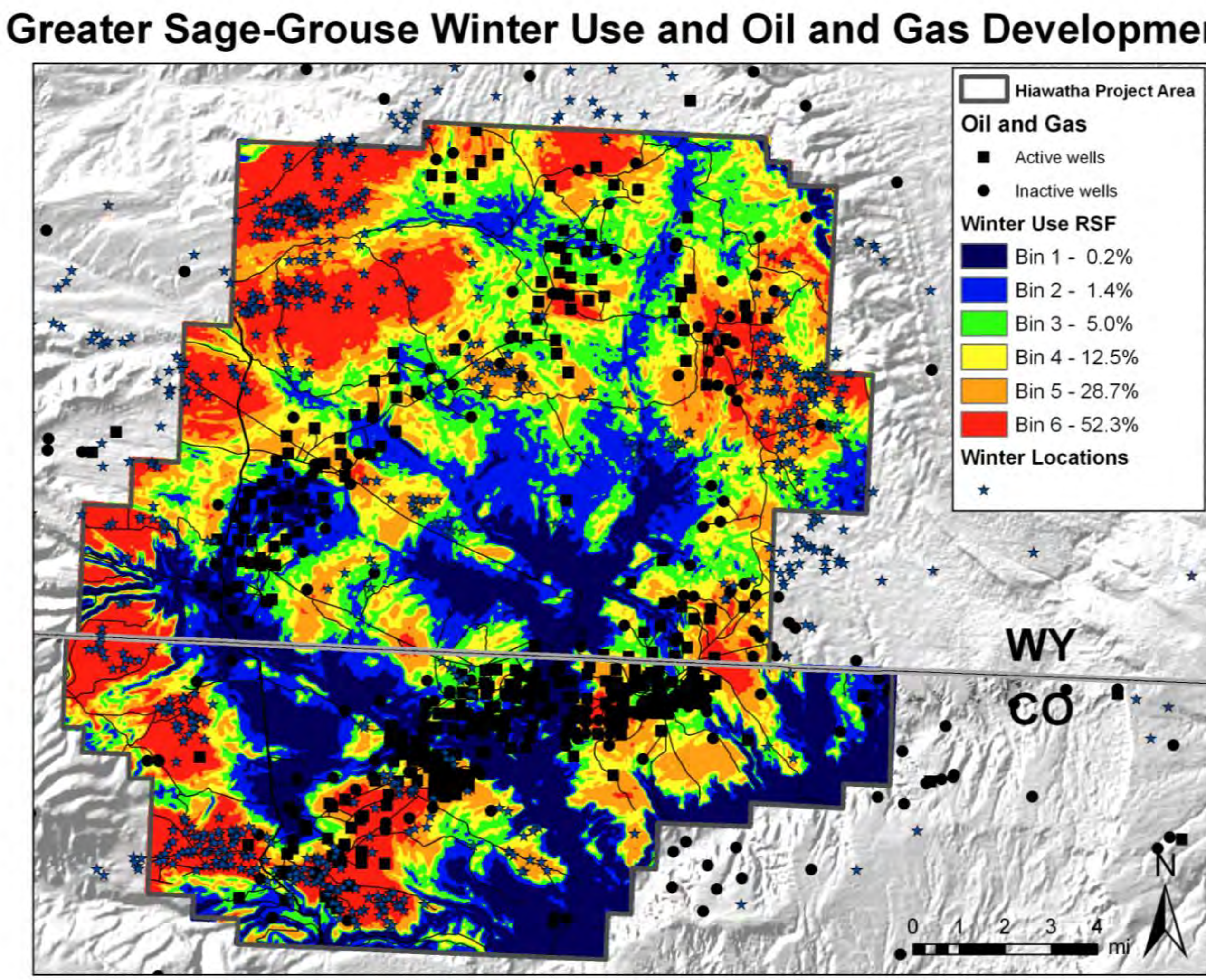


Figure 13. Breeding habitat-use map for greater sage-grouse overlaid with all documented breeding-season locations of marked and unmarked females and active (drilling, drilled, producing, shut-in, and injection wells) and inactive (dry hole, abandoned) well pads in the Hiawatha Regional Energy Development project area as of 1 Sept 2008 (from Colorado Oil and Gas Conservation Commission and Wyoming Oil and Gas Conservation Commission data).

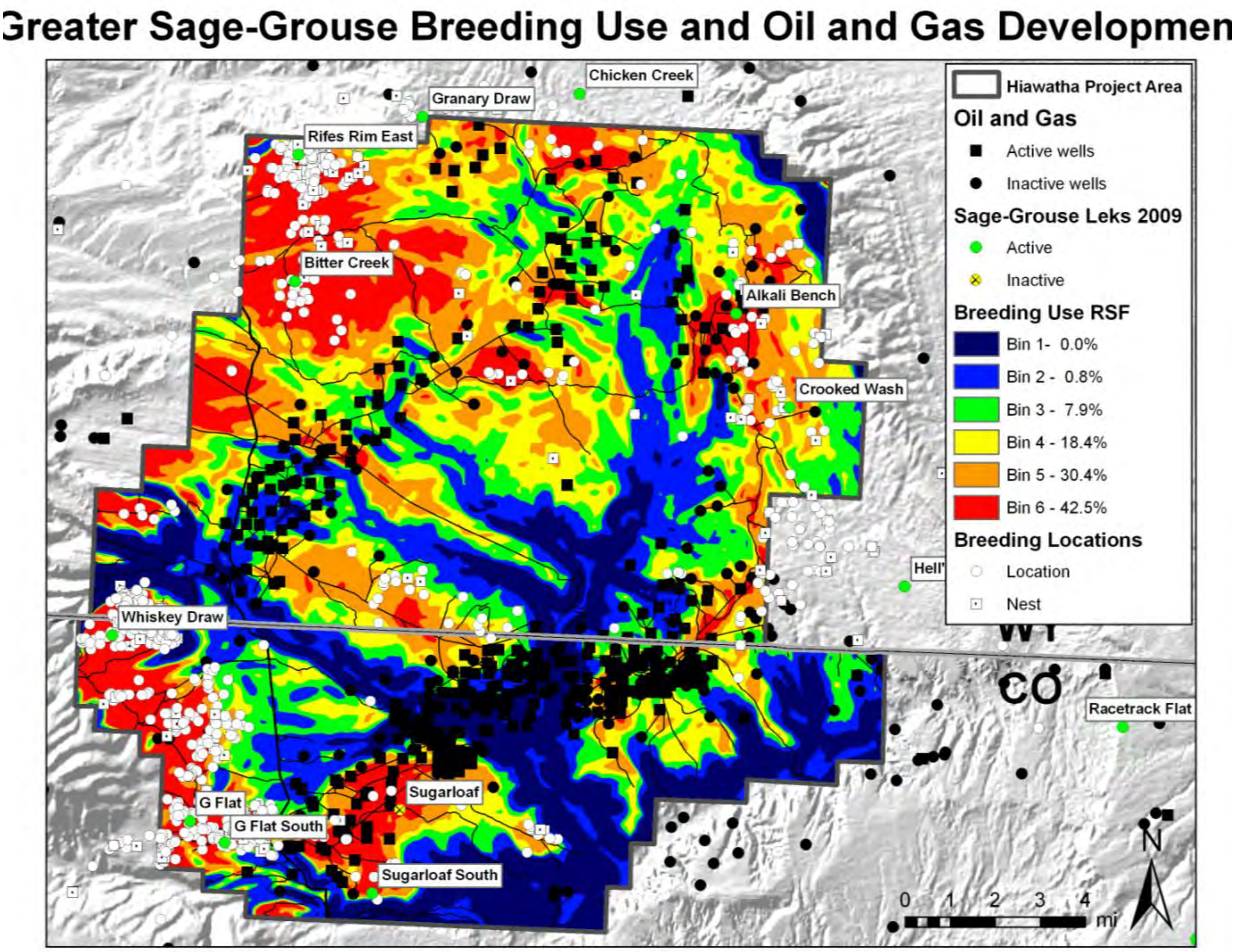


Figure 14. Documented interstate movements of marked female greater sage-grouse in the Hiawatha Regional Energy Development project area, 2005-2009.

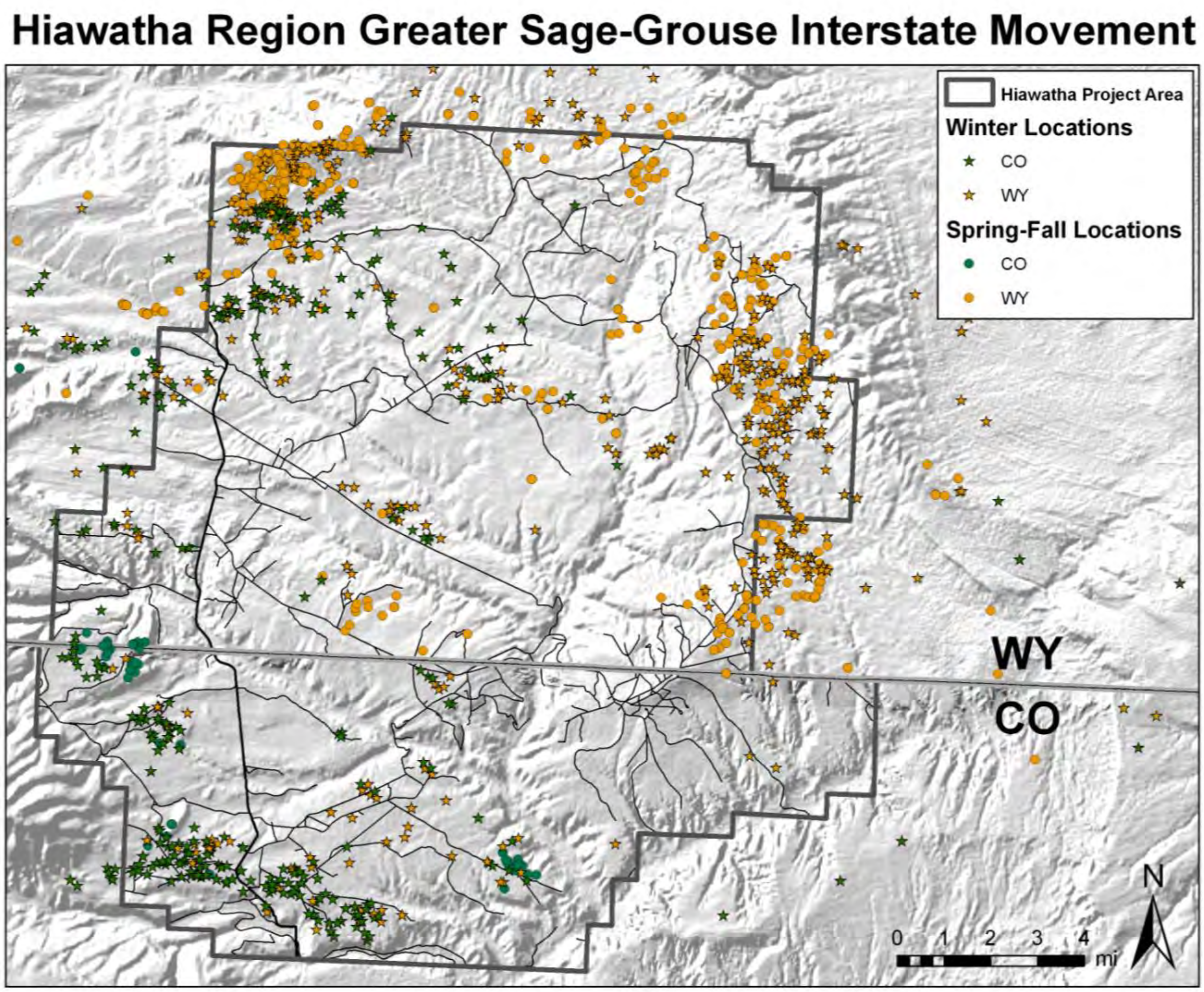


Figure 15. Breeding habitat-use map for greater sage-grouse overlaid with all breeding-season locations of marked and unmarked females and known leks (as of spring 2009) in the Hiawatha Regional Energy Development project area with 0.6 mi. (blue) and 4 mi. (purple) lek buffers.

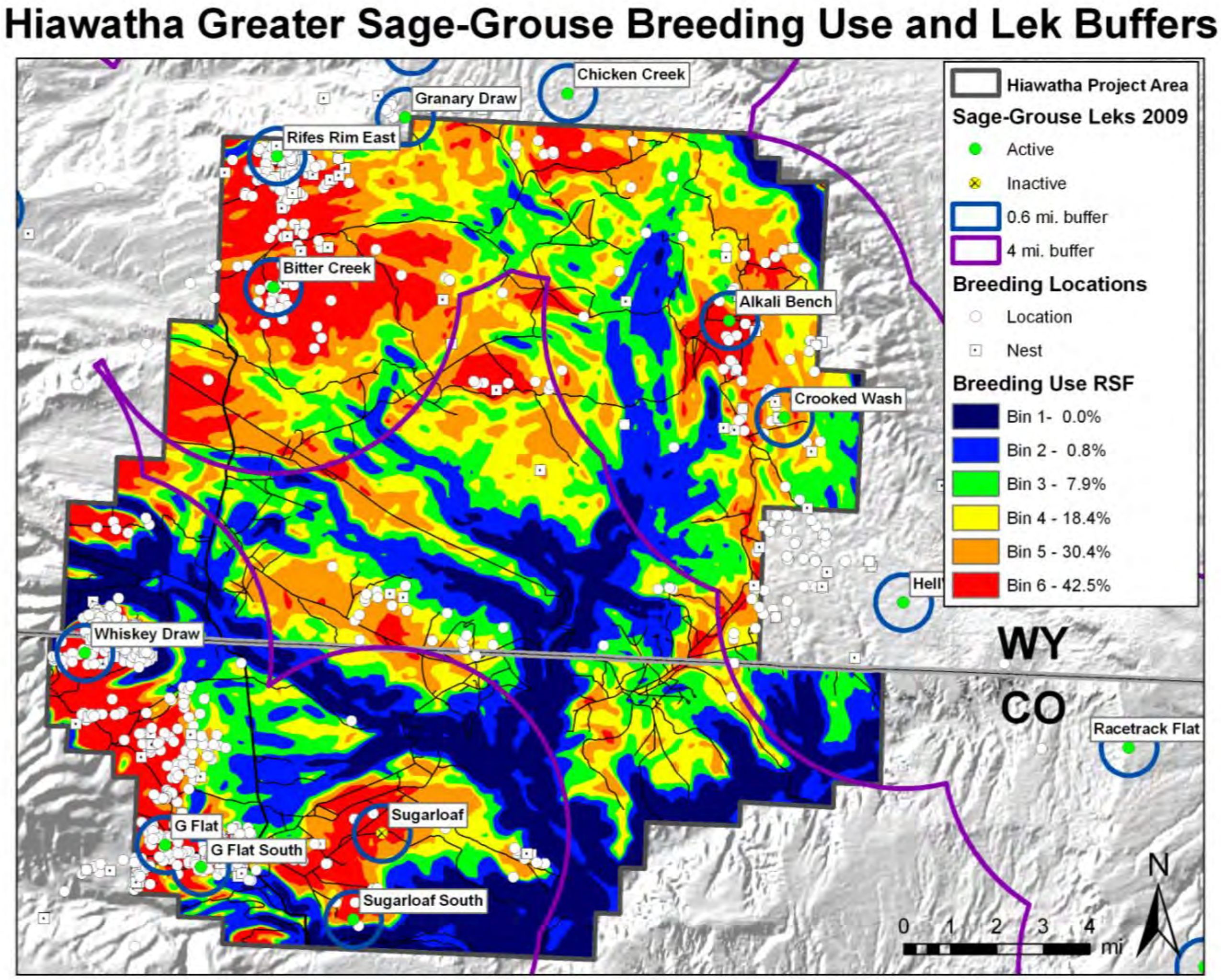
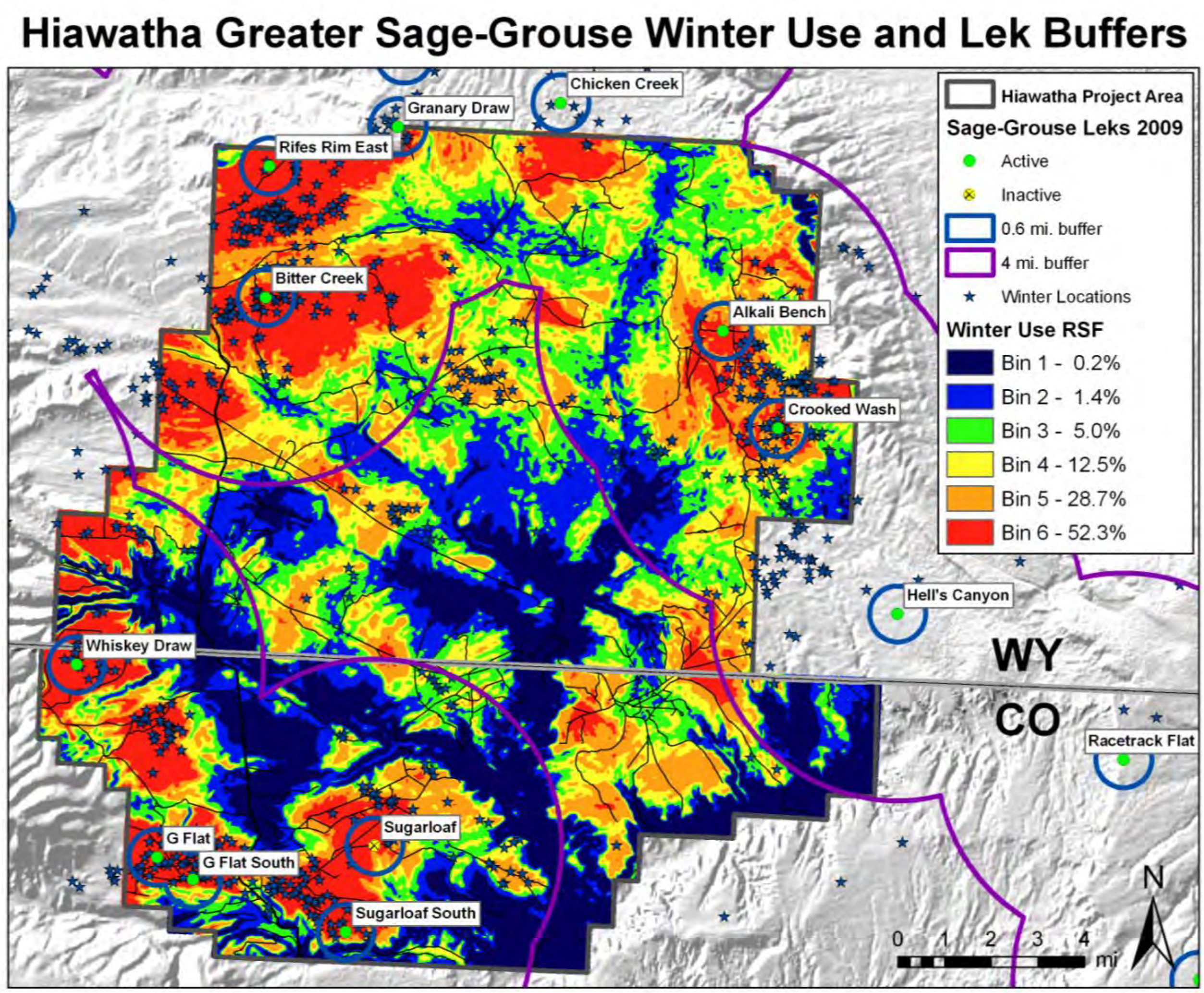


Figure 16. Winter habitat-use map for greater sage-grouse overlaid with all winter locations of marked and unmarked females and known leks (as of spring 2009) in the Hiawatha Regional Energy Development project area with 0.6 mi. (blue) and 4 mi. (purple) lek buffers.



COLORADO DIVISION OF WILDLIFE – AVIAN RESEARCH PROGRAM
Final Report
September 2010

TITLE: Seasonal Habitat Use, Movements, Genetics, and Vital Rates in the Parachute/Piceance/Roan Population of Greater Sage-Grouse

AUTHOR: A. D. Apa

PROJECT PERSONNEL: J. Broderick, B. Petch, J.T. Romatzke

Period Covered: March 1, 2006 – August 31, 2008

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ABSTRACT

Greater sage-grouse (*Centrocercus urophasianus*, GRSG) historically inhabited sagebrush steppe habitat in at least 13 states and 3 Canadian provinces, and now occur in 11 states and 2 provinces. Habitat loss, fragmentation, and degradation are commonly suggested as reasons leading to the decline of GRSG and other sagebrush obligate avian species. The Colorado Division of Wildlife (CDOW) has been concerned with persistence of the Parachute/Piceance/Roan (PPR) GRSG population since at least the early 1990s. The PPR is one of several small, spatially fragmented populations of GRSG in Colorado. The specific objectives of this research project were to: 1) Obtain baseline information on genetic characteristics, 2) Acquire current estimates of nesting effort, apparent nest success, renesting effort and success, female breeding success, and survival rates of adult and yearling females and males as well as juveniles up to 30-50 days of age, 3) Measure movements and seasonal habitat use patterns and, 4) Measure micro-habitat characteristics at nest and brood-rearing sites and compare these with measures at random sites. The area occupied by the PPR GRSG population is located in Rio Blanco and Garfield counties, Colorado. In the spring and fall of 2006 and 2007 and the spring of 2008, 79 (12 M; 67 F) GRSG were captured and radio-marked; in 2007, 39 day-old chicks were also radio-marked. The mass of grouse capture varied by age and time of year captured. Nest initiation rates were 67%, 94%, and 63% for females in 2006, 2007, and 2008, respectively. Sixty nests were documented throughout the course of the study. Apparent nest success through the study period was 40%. Adult female annual survival was 0.65 and yearling female annual survival was 0.48. Grass height and big sagebrush (*Artemisia tridentata*) height were taller and perennial grass cover, total shrub cover, and big sagebrush cover were higher at nest sites when compared to random sites. Total shrub cover was lower (34% vs. 46%) and big sagebrush height was shorter at brood-rearing sites when compared to random sites. Sixty-nine percent of nests were located within 3.2 km (2 miles) of their lek of capture while 81% were located within 6.4 km (4 miles) of their lek of capture. Female survival was slightly higher and yearling female survival was dramatically lower than other reports previously documented. Total shrub cover at nest sites exceeded recommendations in the Colorado Greater Sage-Grouse Conservation Plan (CCP). Big sagebrush height and cover both exceeded the CCP guidelines as well. Nearly 80% of females nested on westerly and easterly aspects on high or moderate slopes. Any management scenarios that decrease big sagebrush and non-big sagebrush cover should be avoided or viewed with extreme caution even in a research scenario. Female survival (especially yearlings and chicks) needs further evaluation. Based on population viability analyses of the PPR GRSG population in the CCP, the persistence of this species in the PPR could be problematic if yearling survival rates and chick survival rates documented during this study continue.

SEASONAL HABITAT USE, MOVEMENTS, GENETICS, AND VITAL RATES IN THE PARACHUTE/PICEANCE/ROAN POPULATION OF GREATER SAGE-GROUSE
Final Report, March 1, 2006 - August 311, 2008
Anthony D. Apa

INTRODUCTION

Greater sage-grouse (*Centrocercus urophasianus*, GRSG) historically inhabited sagebrush steppe habitat in at least 13 states and 3 Canadian provinces, and now occur in 11 states and 2 provinces (Schroeder et al. 2004). GRSG are of particular conservation concern because populations have experienced dramatic range-wide declines over the past 40 years (Connelly et al. 2004). In addition, some view GRSG as an umbrella species for sagebrush habitats (Rich and Altman 2002).

Habitat loss, fragmentation, and degradation are commonly suggested as reasons leading to the decline of GRSG and other sagebrush obligate avian species (Knick et al. 2003). Populations are migratory, moving >10 km to access seasonal habitats across large sagebrush landscapes, or are more sedentary, using the same habitats throughout the year to meet their life history requirements (Connelly et al. 2000). In small populations, human influences or other environmental perturbations may have more pronounced on population persistence by overwhelming the natural variation in stochastic environmental, genetic, and demographic parameters (Mills et al. 2005).

The largest, most persistent (>500 breeding birds) populations of GRSG in Colorado are found in Jackson, Moffat, Rio Blanco, and Routt counties (Braun 1995, Colorado Division of Wildlife 2008). Small (<200 males), isolated populations of GRSG are found in the Parachute/Piceance/Roan (PPR) area in Garfield and Rio Blanco counties, northern Eagle and southern Routt Counties (Schneider and Braun 1991, Colorado Division of Wildlife 2008), northwest Larimer County, and the Meeker/White River area in eastern Rio Blanco County (Colorado Division of Wildlife 2008). Oil and gas development activity is rapidly expanding the PPR area, and industry has expressed their interest in evaluating mitigation efforts and understanding the baseline habitat use, movements, and vital rates of this population.

GRSG from Eagle County, North Park, and Middle Park, Colorado function as a genetically-related group. Birds within each group are genetically similar, while genetic relatedness differs between groups (Oyler-McCance et al. 2005a). The genetic relatedness of GRSG inhabiting the PPR area is unknown compared to other populations in Colorado or elsewhere (Oyler-McCance et al. 2005a). Genetic information is needed in the event that future translocations of GRSG to and from the PPR population are needed.

The Colorado Division of Wildlife (CDOW) has been concerned with persistence of the PPR GRSG population since at least the early-1990s and discontinued hunting this population in the mid-1990s due to declining wing receipts and other indicators that the population may have been declining. Limited information is available for PPR GRSG including habitat use and seasonal movements (Krager 1977, Hagen 1999), lek complexes (Krager 1977), and harvest data used to compute sex and age ratios (Colorado Division of Wildlife 1995). The limited information that does exist does not provide a clear picture as to historical or current population levels or trends in vital rates.

Given the current status of this small population and the landscape changes that are expected to occur over the next 5-10 years, there is a pressing need to obtain current, detailed baseline information on the population ecology of PPR GRSG and provide this information to managers. The CDOW is interested in working with the oil and natural gas industry and other land owners and managers in the PPR area to sustain the PPR GRSG population and plan for future management actions. Baseline information is needed to assess the current population status and expected future trend of PPR GRSG, and for identifying alternative management strategies for this population.

The specific objectives of this research project were to:

1. Obtain baseline information on genetic characteristics of GRSG in the PPR population.
2. Acquire current estimates of reproductive parameters (nesting effort, apparent nest success, and renest success, and female success) and survival rates of PPR adult and yearling females and males as well as juvenile GRSG up to 30-50 days of age.
3. Measure movements and seasonal habitat use patterns of PPR GRSG on a landscape level.
4. Measure micro-habitat characteristics at nest and brood-rearing sites.

STUDY AREA

The area occupied by the PPR population of GRSG is located in Rio Blanco and Garfield counties (Fig. 1). Hagen (1999:9) described the area: ―The Piceance Basin-Roan Plateau is bordered on the north by the White River and on the south by the Colorado River. The Utah border is ~80 km to the west and the Grand Hogback borders the basin on the east. The study area encompasses approximately 1,400 km^2 of the ~ 3,000-km^2 region. The specific boundaries of the study area are the Dry Fork of Piceance Creek and Big Duck Creek to the north, and Skinner Ridge, Jack Rabbit Ridge, and Roan Creek to the southwest and south. Cathedral Bluffs defines the western limit and Colorado Highway 13 is the eastern boundary. Piceance Creek bisects the eastern third of the study site."

―The climate of the Piceance Basin is semiarid and exhibits extreme differential levels of monthly precipitation. Consecutive months often receive little precipitation. Mean annual precipitation was 35.3 ± 18.7 cm for eight weather stations in the region for 1951-70 (Cottrel and Bonham 1992) and snowfall comprised ~ 50% of the total precipitation. The mean annual temperature varies from7^{o} C at 1,800 m to -1^{o} C at 2,700 m." (Hagen 1999:9).

―The topography of the study areas has been described as a structural basin (Tiedeman and Terwilliger 1978) or a plateau that is dissected by narrow drainages. The sagebrush steppe consists of undulating north-south ridges parallel to each other. The ridge tops vary in width from 0.5 to 3 km, and 1 to 30 km in length. The ridges are gently rolling; however, the drainages that separate them are steep. Specifically, the ridges in the southern part of the study area are divided by canyons that drop nearly 1 km, vertically, in <500 m, horizontally; typically the elevation change is more gradual. Elevations vary from 1,800 m on Piceance Creek to 2,700 m at the upper reaches of the plateau. The higher elevation areas are known locally as the ―summer range" as they are the location for summer grazing of livestock." (Hagen 1999:9).

―Vegetation is dependent upon slope, aspect, and elevation. Three subspecies of big sagebrush (*Artemisia tridentata*) occupy the basin, and location of *Artemisia tridentata ssp.* is dependent upon soil type (Cottrell and Bonham 1992). Basin big sagebrush (*A. t. tridentata*) is the prevalent vegetation throughout the drainages at elevations of 1,800 – 2,000 m (Cottrell and Bonham 1992). Typically basin big sagebrush grows taller and denser than mountain big sagebrush (*A. t. vaseyana*) and Wyoming big sagebrush (*A. t. wyomingensis*) (Cottrell and Bonham 1992). *A. t. wyomingensis* is restricted to upland ridges at elevations of 1,900 – 2,000 m (Cottrell and Bonham 1992). *A. t. vaseyana* is confined to high mountain areas at elevations > 2,100 m (hereafter all references to big sagebrush will refer to *A. t. vaseyana*, unless otherwise noted)." (Hagen 1999:9).

―Pinyon pine (*Pinus edulis*) and juniper (*Juniperus spp.*) woodlands dominate the landscape until ~2,100 m. Big sagebrush, Utah serviceberry (*Amelanchier utahensis*), Gambel oak (*Quercus gambelii*), and antelope bitterbrush (*Purshia tridentata*) comprise most of the transition vegetation type. Low and rubber rabbitbrushes (*Chrysothamnus viscidiflorus, C. nauseosus*) are prevalent throughout the basin. Elevations of 2,400 to 2,600 are dominated by big sagebrush interspersed with bunchgrass meadows. North aspects often host substantial groves of quaking aspen (*Populus tremuloides*), serviceberry, and mountain snowberry (*Symphoricarpos oreophilus*). Big sagebrush and Douglas-fir (*Pseudotsuga menziesii*) dominate south and northwest aspects at elevations > 2,500 m, respectively. Free water can be scarce in dry years or late in the summer as most springs are in the bottom of steep canyons." (Hagen 1999:9).

METHODS

Capture and Marking of Grouse

During the spring of 2006, 2007 and 2008 and the fall of 2007, GRSG were captured using night spot-lighting techniques (Giesen *et al.* 1982, Wakkinen *et al.* 1994) and radio-marked. Captures were not randomly distributed throughout the study area, but were opportunistic on or near strutting grounds in the spring and by radiating away from the strutting grounds to appropriate capture locations. In the fall, GRSG were captured using the same techniques in concentration areas identified by tracking radio-marked females.

All GRSG captured were weighed using an electronic scale (to the nearest 1 g) and marked with aluminum, uniquely numbered leg bands. Age and gender was determined using wing (Dalke *et al.* 1963) and other plumage or morphological characteristics.

Female GRSG were preferentially captured, although a sample of males was captured in 2006. A small sample of males and all females were equipped with a 17-g necklace-mounted radio transmitter with a 4-hour mortality circuit. Each transmitter had a nominal battery life of 18 months and had a 30 cm antenna that was placed dorsally between the wings and down the back of the grouse. The radio transmitters were 0.8% and 0.56% of the body weight of an adult and yearling male, respectively, and 1.0% and 1.2% of the body weight of adult and yearling females, respectively. Any juveniles captured were radio-marked if their body mass was >900 g.

In 2007, day-old chicks were radio-marked to estimate survival rates. Once nest monitoring revealed the successful hatch, all chicks in the brood were captured 1-2 days after hatching. Radio-marked brood females were located <2 hours after sunrise in order to capture chicks while the female was brooding. Chicks were captured by hand and held in cotton bags for processing and to facilitate thermoregulation. All chicks within a brood were weighed and had a secondary feather collected. Two to four chicks/brood were randomly selected and a 1.4 gram, 60-day radio-transmitter was attached along the dorsal midline between the chick's wings (Burkepile *et al.* 2002). Chicks were released together at the capture location and monitored (<1 hr) to confirm the immediate survival of the chicks.

Genetic Data

Blood samples were obtained by slightly over-clipping a toenail of all captured mature GRSG, and 2 - 3 drops of blood and were placed into a microfuge tube previously coated with EDTA (Oyler-McCance 1999). The blood samples in addition to feather samples were frozen at –20°C and stored at the Rocky Mountain Center for Conservation Genetics and Systematics in the Department of Biological Sciences at the University of Denver (Center). All genetic analyses were conducted by Dr. Sara Oyler-McCance at the Center. DNA was extracted from blood samples using the GenomicPrep Blood DNA Isolation Kit (Amersham Biosciences) using the modifications of Oyler-McCance *et al.* (2005b). A 146 base pair portion of hypervariable control region I was amplified using the Polymerase Chain Reaction (PCR) and sequenced using a dye terminator cycle sequencing reaction (Beckman Coulter CEQ8000) as described by Benedict *et al.* (2003). This region was used because it was known to contain approximately

92% of the variable sites in a larger 380 base pair region spanning control region I (Kahn *et al.* 1999). A final report was prepared and delivered to CDOW.

Survival and Seasonal and Daily Movements

Movements and survival of radio-marked GRSG were monitored 1-2 times/week. General locations were obtained by triangulation and radio-marked birds were not flushed. Hand-held Yagi antennas, attached to a receiver/scanner, were used to located radio-marked grouse. The loudest-signal method was used to locate transmitters (Springer 1979). Monitoring periods were distributed among 3 diurnal periods; morning (< 4 hours following sunrise), midday (> 4 hours after sunrise) and evening (< 4 hours before sunset). All grouse were circled at a 50 – 100 m radius (Apa 1998) to determine habitat type use. Precise Universal Transverse Mercator (UTM) locations were not possible at the time of location (the bird was not flushed), so the observer selected a location ≤ 50 m in one of the 4 cardinal directions from the estimated location of the bird. The observer collected a Global Positioning System (GPS) location and then manually corrected the UTM location. General cover types were recorded as shrub steppe (sagebrush), wet meadow, mountain shrub, oakbrush, grassland or agricultural field.

Females with radio-marked chicks were monitored daily to determine chick survival and brood location. Brood positions were determined by locating the female and circling to within 25 m. Position and relationship (i.e., distance) of radio-marked chicks in relation to the female were also recorded. In addition, cover type was determined at all locations. Daily observation of broods continued for 30 days or until death or transmitter failure. Efforts were made to find all chicks immediately after becoming separated or missing from broods to determine fate and/or cause of mortality. Brood locations were collected among 4 time periods: brooding (< 2 hour after sunrise or before sunset), morning (0800-1100), mid-day (1100-1400), and afternoon (1400-1800) throughout the study. After day 30, radio-marked chicks and females were located every 1-3 days.

Fixed-wing aircraft assisted to locate any grouse not located by ground monitoring or lost during ground monitoring efforts. General locations were identified aerially and ground locations were identified within 48 hours.

Microhabitat Characteristics

When a female appeared to be incubating, the nest location was determined using binoculars as described by Apa (1998). Once a female was confirmed as incubating, she was not disturbed during incubation. Diagrams of the nest location were drawn to assist in nest location after the completion of nesting. The precise UTM location was collected following the cessation of nesting. A nest was considered successful if ≥ 1 egg hatched (Rearden 1951).

In 2006, vegetation measurements were collected at nest sites as described by Beck (2006a). A slightly different approach was used in 2007. In 2007, all nest sites had four 10-m transects placed in the cardinal directions intersecting at the nest bowl. The nest shrub species and height was measured. The height of the lowest live and dead shrub branch above the nest bowl was measured from the edge of the nest bowl. Canopy cover (foliar intercept) of the shrub species overstory was ascertained using line-intercept (Canfield 1941). Height of the nearest big sagebrush shrub within 1 m of the transect line was measured at 2.5 m, 5 m, and 10 m. Grass height was measured for the nearest grass part at the points where the edge of the nest bowl and the transect lines intersected, and at the 1 m point on each transect.

The percent of forbs, annual and perennial grass cover, bareground, and litter horizontal understory cover was estimated using 50 x 25 cm microplots (Daubenmire 1959). Twelve cover classes were used and delineated as: <1%, 1-10%, 11-20%, 21-30%, 31-40%, 41-50%, 51-60%, 61-70%, 71-80%, 81-90%, 91-99%, >99%. The first 2 microplots were located on opposing sides of the nest bowl. Grass and forb height were also measured in subsequent plots placed systematically along the transects at

2.5, 5, and 10 m. In addition, the distance to nearest visible roadways, telephone poles, powerlines, and fence posts were determined.

The same vegetation data sampling techniques were collected at random locations for comparison with nest locations. Random locations were obtained by using randomly selected UTM coordinates in the study area. Grouse movements delineated the study area boundary.

Females with broods, unsuccessful females, and males were located by the loudest-signal method 1-2 times per week. At each location, date, time, UTM coordinates, slope and aspect were recorded. Unsuccessful females and males were located in the same manner as females with broods. When females with broods were circled, the intersection point of flags placed in the cardinal directions were used to identify the center of the brood location.

At the center of each brood location identified for vegetation sampling, the same vegetational structural characteristics were measured. One random site was selected for each brood vegetation site and the same vegetation sampling occurred. The aspect categories included northerly (315 – 45^o), easterly (46 – 135^o), southerly (136 – 235^o) and westerly (226 – 314^o).

The angle of inclination is measured and converted to percent slope. Categories include flat (0%), low slope (0 – 9%), moderate slope (10 – 18%), and high slope (> 19%).

Statistical Analyses

All statistical analyses were performed using statistical analysis software (SAS; SAS Institute 2003). Bird locations were entered into a geographic information system for analysis. Habitat selection and movements were evaluated with these data. The vegetation analysis includes 4th order selection (Johnson 1980) (nest or brood site) and 3rd order selection (nest or brood sites versus random site in the study area) (Johnson 1980). Additional analyses may include components of home range and other seasonal use components. Univariate and multivariate statistical approaches were used to characterize habitat and examine possible differences. Analysis of variance (ANOVA) and multivariate analysis of variance (MANOVA) were used. All variables were examined for univariate and multivariate normality. Those variables with non-normal distributions ($\alpha > 0.10$) were transformed using standard data transformation techniques (Zar 1984). Following data transformations, remaining variables were evaluated for their correlative nature and significant correlations ($\alpha > 0.10$) were removed from future analyses due to problems associated with colinearity and statistical power (Johnson and Wichern 1992). Other multivariate procedures such as principal components analysis and/or stepwise logistic regression will be used in future analyses to further evaluate habitat characteristics at nest and brood locations. An analyses of physiographic (slope, aspect, and elevation) characteristics was conducted using Chi-square or univariate analysis.

Annual and project-long survival rates for grouse were estimated by gender, age (adult, yearling, and fall juveniles) with the Kaplan-Meier product limit estimator (Kaplan and Meier 1958) modified for staggered entry (Pollock *et al.* 1989) where appropriate.

RESULTS

Capture and Marking of Grouse

In the spring and fall of 2006 and 2007 and the spring of 2008, 79 (12 M; 67 F) GRSG were captured and radio-marked (Table 1). Males were captured and radio-marked in 2006 only.
The age ratio of females captured varied by year. In 2006, 56% (n = 9/16) were adults and 44% (n = 7/16) were yearlings. Three females captured in the fall of 2006 were classified as yearlings but might have been juveniles produced in 2006.

The mass of GRSG at capture varied by age and time of year. Adult male mass ($\bar{x}$ ± SE) was 2,562 ± 86 g (*n* = 8) while yearling male mass was 2,437 ± 46 g (*n* = 4). Female mass differed by age class ($F_{3,57}$ = 22.37; $P < 0.0001$). Adult females weighed more (P = 0.0008) than yearling and juvenile (P = 0.0002) greater sage-grouse. Adult female mass [1,503 ± 34 g (*n* = 31)] was over 350 g heavier than juveniles [1,143 ± 51 g (*n* = 6)] and approximately 100 g heavier than yearlings [1,408 ± 23 g (*n* = 24)]. Spring captured yearling female mass was not significantly different from fall juvenile mass (P = 0.5081). The mass of female grouse also varied ($F_{2,52}$ = 17.34 $P < 0.0001$) when the season of capture was considered. Spring female mass [1,509 ± 22 g (*n* = 38)] was nearly 300 g heavier than fall female mass [1,356 ± 45 (*n* = 17)].

Nesting

Nests were initiated by 67% (*n* = 6/9), 94% (*n* = 33/35), and 63% (*n* = 17/27) of radio-marked females in 2006, 2007, and 2008, respectively. Nests were initiated by 84% (*n* = 37/44) of adult females and 81% (*n* = 22/27) of yearling females in the three years of the study.

Sixty nests were monitored, including 6 nests in 2006, 37 in 2007 and 17 in 2008. Apparent nest success (percentage of nests in which at least 1 egg hatched) over the study period was 40% (*n* = 24/60). In 2006, apparent nest success was 0% (*n* = 0/6) and in 2007 and 2008 apparent nest success was 46% (*n* = 17/37) and 40% (*n* = 7/17), respectively. Throughout the study adult and yearling female apparent nest success was 40% (*n* = 16/40) and 40% (*n* = 8/20), respectively.

Female success (percentage of females having a successful nest) is a more useful demographic parameter than nest success. Over the course of the study, female success was 34% (*n* = 24/71). Female success in 2006, 2007, and 2008 was 0% (*n* = 0/9), 49% (*n* = 17/35), and 26% (*n* = 7/27), respectively. Four nests were located after a first nesting attempt failed (renests) and all were unsuccessful.

Survival

Adult female annual survival was 0.65 (95% CI = 0.49 – 0.77; *n* = 27), while survival during the duration of the research project (29 months) was 0.35 (95% CI = 0.17 – 0.52; *n* = 27). Yearling female annual survival was 0.48 (95% CI = 0.34 – 0.58; *n* = 32), while project duration survival was 0.17 (95% CI = 0.07 – 0.27; *n* = 32). Adult male annual survival was 0.58 (95% CI = 0.0 – 0.87; *n* = 8) and project duration survival was 0.27 (95% CI = 0.0 – 0.71; *n* = 8). Yearling male annual survival was 0.56 (95% CI = 0.0 – 0.85; *n* = 5) and project duration survival was 0.25 (95% CI = 0.0 – 0.67; *n* = 5). Juvenile survival was not calculated due to sample size issue and time of capture.

In 2007, we estimated chick survival (1–30 days) of 39 individual chicks from 14 broods. The average number of chicks marked/brood was 2.8 (range 2–4). Survival ($\bar{x}$ ± SE) through 7 days was 0.56 ± 0.08 (*n* = 39). Survival through 14 days was 0.31 ± 0.08 (*n* = 39), and survival through 30 days was 0.12 ± 0.07 (*n* = 39) at 30 days (Fig. 2). Only 2 chicks remained radio-marked after 30 days of age. Apparent brood survival was 86% (*n* = 12/14) at 7 days, 62% (*n* = 9/14) at 14 days, and 14% (*n* = 2/14) at 30 days.

Microhabitat Characteristics

Nests. – Variables without normal distributions were transformed using a $\log_{10}$ transformation. The transformed variables included forb cover, annual grass cover, perennial grass cover, and dead shrub cover. Each of these variables achieved normality following transformation. The variables of bare ground, litter cover, total shrub cover, grass height, forb height, big sagebrush height, and big sagebrush cover were normally distributed. To narrow the suite of variables describing nest and brood sites and reduce complications of colinearity, correlated variables were identified and one or both were removed from the analyses. The variables included in the analyses were forb cover, perennial grass cover, total shrub cover, grass height, big sagebrush height, and big sagebrush cover.

I performed a MANOVA with the aforementioned variables to investigate potential differences between nest and random sites (3rd order selection), and differences were detected (Wilks' $\lambda = 0.69$; $F_{6,97} = 7.38$; $P < 0.0001$). Grass height was taller ($F_{1,102} = 20.83$; $P < 0.0001$) and perennial grass cover ($F_{1,102} = 8.13$; $P = 0.0053$) was greater at nest sites compared to random sites. There was no difference in forb cover ($F_{1,102} = 0.01$; P = 0.9426). Big sagebrush height was 18 cm taller ($F_{1,102} = 15.70$; $P < 0.0001$) at nest sites compared to random sites. Total shrub cover ($F_{1,102} = 33.88$; $P < 0.0001$) and big sagebrush cover ($F_{1,102} = 19.66$; $P < 0.0001$) were greater at nest sites versus random sites (Fig. 3; Table 2).

Vegetation structure at the immediate nest site was also evaluated at 3rd order selection, and differences were detected (Wilks' $\lambda = 0.69$; $F_{3,54} = 8.19$; $P < 0.0001$). The lowest branch of the shrub above the nest bowl was higher ($F_{1,56}$; $P = 0.0015$) from the ground than on shrubs at random sites (22 vs 15 cm). In addition, the height of the shrub at the nest was 30 cm taller ($F_{1,56} = 23.00$; $P < 0.0001$) than random sites. Grass height was the same ($F_{1,56} = 3.50$; $P = 0.0666$) between nest sites and random sites.

At 4th order selection levels, female greater sage-grouse nested under nest bushes (all big sagebrush) that were 10 cm taller ($t_{2,68} = 2.15$; $P = 0.0352$) than the mean big sagebrush height within 10 m of the nest. In contrast, grass height at the nest had similar heights ($t_{2,68} = -0.3068$; $P = 0.7586$) at the nest bowl and mean grass heights within 10 m of the nest. The same set of variables was compared between successful and unsuccessful nests. All 6 variables were strongly similar between successful and unsuccessful nests (Wilks' $\lambda = 0.93$; $F_{6,30} = 0.38$; $P = 0.8832$).

The stepwise logistic regression included 7 variables. The variables include total shrub cover, grass height, big sagebrush height, big sagebrush cover, forb cover, perennial grass cover, and slope. Three of the variables were identified as significant contributors to the logistic regression model with 69% (n = 25/36) of the nests being correctly classified. Slope (Wald $\chi^2_3 = 22.12$; $P < 0.0001$) (Fig. 4), total shrub cover (Wald $\chi^2_3 = 13.76$; $P = 0.0002$) (Fig. 5), and big sagebrush cover (Wald $\chi^2_3 = 4.82$; $P = 0.0281$) (Fig. 6) were selected and retained in the model. The logistic models is:

Logit (P) = 8.0288 + (- 5.6286)(total shrub cover) + (- 5.2965)(big sagebrush cover) + (- 0.2484)(slope)

Nest sites were associated with aspect ($\chi^2_3 = 15.06$; $P = 0.0018$), with nest sites more prevalent (77.7%) on westerly and easterly aspects. Females nested on westerly facing aspects more than expected and there were fewer than expected sites available at the random sites. Females nested on northerly aspects less than expected but more random sites were present than expected. There was also significant evidence that there was an association between slope and nest site use ($\chi^2_3 = 30.43$; $P < 0.0001$). Use was dominated (91%) on high and moderate slopes (> 10% slope). Nest sites were located on nearly twice the frequency as expected on high slope sites. No nests were found on sites with flat slope (0%) and the random sites suggest that there are only a small number of those sites available in this study area. No relationship ($F_{1,102} = 3.24$; $P = 0.0746$) was found with elevation when nest use sites and random sites were compared. Nest sites were located at 2,454 ± 10 m while random sites were 2,488 ± 12 m, a separation of only 30 m.

Brood-Rearing. – A MANOVA of the aforementioned variables at brood sites was performed to investigate possible 3rd order differences between brood and random sites through the study area. Analysis was conducted on 29 brood locations. Significant (Wilks' $\lambda = 0.83$; $F_{6,89} = 3.01$; $P = 0.01$) results were detected and total shrub cover was lower ($F_{1,94} = 8.52$; $P = 0.0044$) (34 vs 46%) and big sagebrush height was shorter ($F_{1,94} = 5.81$; $P = 0.0179$) at brood-rearing sites when compared to random sites. In contrast, the remaining structural variables were not different between brood-rearing and random sites (Fig. 7; Table 3).

The stepwise logistic regression included 7 variables. The variables include total shrub cover, grass height, big sagebrush height, big sagebrush cover, forb cover, perennial grass cover, and slope. One variable was identified as a significant contributor to the logistic regression model with 14% (n = 4/29) of the nests being correctly classified. Total shrub cover (Wald $\chi^2_3 = 9.05$; $P = 0.0026$) (Fig. 8, 9) was selected and retained in the model. The logistic models if as follows:

$$\text{Logit (P)} = -\ 0.8119 + (3.9958)(\text{total shrub cover})$$

There was no significant ($\chi^2_3 = 2.71$; $P = 0.4381$) evidence of an association between brood-rearing sites and random sites with respect to aspect. Use was distributed across aspects as expected. There was no significant association with slope and brood use as well ($\chi^2_3 = 2.17$; $P = 0.5381$). Ninety percent of locations were found on 0 – 18% slope. Brood sites were located at 2,471 ± 10 m elevation while random sites were 2,488 ± 12 m, a separation of only 9 m with no differences ($F_{1,96} = 0.76$; $P = 0.3862$).

Movements

Locations of radio-marked female GUSG are presented for the breeding (Fig. 10), summer (Fig. 11), and winter (Fig. 12) seasonal periods. GUSG were distributed throughout the PPR area, with concentrations in the eastern and western portions of the range.

Female grouse captured in the spring moved a median distance 956 m (25% and 75% Quartiles) (395, 3,392 m; *n* = 48) from the lek of capture to nest. Fall captured females moved a median distance of 1,211 m (916, 2,292 m; *n* = 12) from the capture location to nest. Among renesting females, the median distance moved between consecutive nests within a breeding season was 819 m (556, 2,690 m; *n* = 4). Among radio-marked females that were monitored and nested in >1 year, the distance between nest sites across years was a median of 345 m (208, 851 m; *n* = 13). Sixty-nine percent of nests (*n* = 33/48) were located within 3.2 km (2 miles) of their lek of capture while 81% (*n* = 39/48) were located within 6.4 km (4 miles) of their lek of capture (Fig. 13).

Genetic Data

Genetic samples were collected from all birds captured (adults, yearlings, and chicks). A complete report of the genetic analyses is in Appendix A. Sixty-five individuals were genetically sequenced. They illustrated 8 different haplotypes and 5 of those haplotypes have been found in other GRSG populations in Colorado. The level of genetic diversity was also evaluated and it was found that the PPR population had levels of genetic diversity that were similar to other populations in Colorado. Although there was a unique haplotype found in the PPR population, other Colorado populations also had unique haplotyypes and as sample sizes increase it is likely that these haplotypes will no longer be unique.

DISCUSSION

This research project was developed to collect baseline information on the demography, genetics, movements, and 3rd and 4th order habitat use of GRSG in the PPR. The project was initiated by the CDOW in March 2006 (Beck 2006a, 2006b, 206c) and then continued by A. D. Apa from November 2006 through August 2008. At the on-set of the project, private land access was limited to localized portions of the PPR, but by March 2007, access issues were resolved and access was granted throughout most of the PPR.

In small populations of GRSG it is difficult to obtain adequate sample sizes for rigorous statistical analyses. Therefore, several years of data must be collected and summarized to make meaningful conclusions. Therefore, this report only provides a ―snap-shot" into population performance and seasonal movements. The PPR has exhibited all the challenges of small populations and additional years of data will be needed to have a more complete understanding of the dynamics of this population.

Small numbers of birds were captured in 2006 because of a naïve trapping crew and understanding the logistics of a new study area. Many of those challenges were resolved and captures increased in 2007. Captures declined in 2008 due to weather logistics and physical access into the PPR to trap. Additionally, bird locations were difficult to obtain because weather restricted access to the study area in 2008.

Adult and yearling female mass in the PPR (range 1,207–2,011 g) was similar to other studies (Patterson 1952, Dalke et al. 1963, Wallestad 1975, Beck and Braun 1978, Autenrieth 1981, Hausleitner 2003). These authors also found yearling females weighing less than adults and a similar result is reported for the PPR where yearling female mass 100 g less than adults.

Connelly *et al.* (2004) reported female nest initiation rates of 79.9% with a range of 63–100%. The accuracy of this estimate is highly dependent upon research objectives and methodology and the skill of the investigators. Others have reported nest initiation rates for adults are higher than for yearling females (Connelly *et al.* 2001, Hausleitner 2003, Thompson 2007). The nest initiation rate in the PPR (84% adults; 81% yearlings) are on the lower end of what is reported but are within the range of other Colorado reports (range 79–92%).

Apparent nest success is a demographic parameter reported throughout GRSG literature. Nest success varies widely and has been reported to range from 14.5 – 86.1% (Connelly *et al*. 2004). The average for 16 studies summarized by Connelly et al. (2004) was 47.7%. Although the PPR is on the lower end of apparent nest success (40%), it is within the range reported across the range and in Colorado (Hausleitner 2003, Thompson *et al.* 2005, Thompson 2006, 2007).

Female success in Colorado ranges from 36% to 57% (Hausleitner 2003, Thompson *et al.* 2005, Thompson 2006, 2007) with an average of 43%. Female success in the PPR (34%) was well below the average reported in Colorado. This rate is of paramount interest due to the low renesting rates reported for GRSG in Colorado of 8 and 15% (Hausleitner 2003) and across the range (Connelly *et al.* 2004).

Female and male survival rates across GRSG distribution range from 55–75% (Connelly et al. 2004). Adult female survival ranges from 48 – 65% and yearling female survival ranged from 71–78% (Connelly *et al.* 2004). Zablan *et al.* (2003) found in North Park, Colorado, that adult female survival was 0.59 (95% CI 0.57–0.61), yearling female survival was 0.78 (95% CI; 0.71–0.75), adult male was 0.36 (95% CI; 0.35–0.45) and yearling male survival was 0.63 (95% CI; 0.57–0.65). In the PPR female adult survival was slightly higher, yearling female survival was dramatically lower, adult male survival was slightly higher, and yearling male survival was about the same when compared to other reports. The samples sizes for males are very small and must be interpreted with caution. In contrast, yearling female survival in the PPR is 48% and the CI's do not overlap on the lower end with what is reported in the literature (0.57). This demographic parameter is concerning and must be further investigated as it may have long-term impact on population persistence. Changes in adult and juvenile female survival, as well as clutch size, are demographic parameters that have the greatest influence on population growth and persistence (Colorado Division of Wildlife 2008).

Chick survival was investigated only during the 2007 season. Therefore, the results must be interpreted with caution. Previous research in Colorado (Thompson *et al.* 2005, Thompson 2006, 2007) reported chick survival to 14 days ranged from 39-78% and survival through 28 days ranged from 14-73%. With one year of survival data, a 14-day survival rate of 31% is within, but on the lower end of other research in Colorado. At 30 days, the survival rate of 12% is lower than the lowest of 3 years in northwestern Colorado at 14%. Apparent brood survival in the PPR of 62% at 14 days and 14% at 28 days is also lower than reported in 2 years in northwest Colorado of 81% and 78% in 2005 and 85 and 74% in 2006. Further research on chick survival with larger sample sizes is needed.

Numerous studies have described fourth order selection of nest habitat characteristics (Connelly et al. 2004). Nesting female GRSG in the PPR followed similar habitat use patterns, but in most cases used structural habitat characteristics that met or exceeded reported structural use characteristics, national guidelines, (Connelly *et al.* 2000) or Colorado developed guidelines (Colorado Division of Wildlife 2008).

Total shrub cover at nest sites exceeded recommendations in the Colorado Conservation Plan (CCP). Big sagebrush height and cover both exceeded the CCP guidelines as well. Grass height and perennial grass cover measures both met the guidelines and only forb cover did not meet the guidelines by approximately 3% (12.2% vs 15%). Additionally, the mean of 12.2% is a mean of midpoints in the Daubenmire category of 10–20%. Therefore it is unlikely that there are forb cover issues in the PPR. Notably, total shrub cover and big sagebrush height exceeded the guidelines at random sites as well, but female GRSG still used sites with higher total shrub cover and taller big sagebrush height than was available at random. This suggests that females are seeking very dense vegetation structure to nest in the PPR, even when less dense vegetation is available. Measures of grass height and big sagebrush cover at random sites in the PPR met the CCP guidelines, but females used nest sites that exceeded these measures at random sites.

Total shrub cover, big sagebrush cover, and slope were good predictors of nest sites. As slope, total shrub and big sagebrush cover increased so did the likelihood that a site was a suitable nest site. Females GRSG in the PPR appear to be using steep sites with dense shrub cover that exceeds recommended guidelines.

Although total shrub cover was greater and big sagebrush height was taller at brood locations than at random locations, these measures at random sites met or exceeded the CCP guidelines (Colorado Division of Wildlife 2008). All other variables measured for this study met the CCP guidelines for brood-rearing (summer) habitat. Total shrub cover was positively related with brood-rearing use sites, i.e., as total shrub cover increases, the likelihood of a site being classified as a brood-rearing site increases.

Nearly 80% of females nested on westerly and easterly aspects on high or moderate slopes. There is very little flat or low slope available for use and the females use sites accordingly. There was no association with aspect or slope for brood-rearing sites, although 90% of locations were found on 0–18% slope.

The PPR is not a typical mildly undulating flat study area as is found in most of the GRSG range; it has deep canyons separate by narrow big sagebrush dominated ridges. This rough topography is not a barrier to movement and the PPR females which illustrated movements very similar to other females marked in Colorado (Colorado Division of Wildlife 2008). The median distance from the lek of capture to nest was approximately 1 km. Sixty-nine percent of females nested within 3.2 km of their lek of capture and 81% nested within 6.4 km of their lek of capture with individual females nesting as close as 57 m and as far as 14.7 km from their lek of capture.

MANAGEMENT RECOMMENDATIONS

Local scale micro-habitat use at nests and brood-rearing sites must be considered in overall management because PPR GRSG are nesting and raising broods in areas of shrub structure that exceed most reports across the range of GRSG. Habitat guidelines must be specific to the PPR and not extrapolated from other areas. The PPR is a high elevation mesic mountain big-sagebrush community interspersed with mountain shrub communities. Greater sage-grouse females nested and raised broods in sites that exceeded the CCP guidelines. They used nest sites that also exceeded what was available at random through the study area of the PPR. Nest sites were located on relatively steep and not always sagebrush dominated communities that provided excellent understories even though forb cover values seems somewhat marginal. Therefore any management scenarios that decrease big sagebrush or other shrub cover (Table 4) should be avoided or viewed with extreme caution even under a research scenario since this is a small isolated population.

Female survival (especially yearlings and chicks) needs further evaluation. Based on analyses of the PPR grouse population in the CCP, the persistence of this species in the PPR could be problematic if yearling survival rates and chick survival rates sampled in the short duration of this study continue. Precise and credible measures of chick survival need to be continued and validated with telemetry research to understand year to year variability.

PPR genetics do not suggest any anomalies although they do retain unique hapolotypes not observed in other GRSG populations in Colorado. Therefore, persistence of this population, as with all populations, is critical to retain genetic diversity throughout the isolated populations of Colorado.

ACKNOWLEDGEMENTS

J. Beck initiated this study and led the field work in 2006. B. Miller was crew leader for the 2007 and 2008 portions of this project. Seasonal habitat use maps were created by K. Eichhoff. Technicians that worked on the project included L. Dennis, A. Gmyrek, E. Phillips, A. Pratt, and A. Wiese. Funding for this project was provided by the Colorado Division of Wildlife, Encana Corporation, The Williams Companies Incorporated, and ConocoPhillips Company.

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Table 1. Number, age, and gender of greater sage-grouse captured and radio-marked in the Parachute/Piceance/Roan (PPR) study area in west-central Colorado, 2006-2008.

		Male			Female				
Year	Period	Adult	Yearling	Total	Adult	Yearling	Juvenile	Total	Total
2006	Spring	8	4	12	3	6	-	9	21
	Fall	-	-	0	4	3	-	7	7
	Total	8	4	12	7	9	0	16	28
2007	Spring	-	-	0	14	14	-	28	28
	Fall	-	-	0	10	-	6	16	16
	Total	0	0	0	24	14	6	44	44
2008	Spring	-	-	0	2	5	-	7	7
Grand total		8	4	12	33	28	6	67	79

Table 2. Micro-habitat variables ($\bar{x}$ ± SE) of total shrub cover, grass height, big sagebrush height, big sagebrush cover, forb cover, and perennial grass cover at nest and random sites sampled in the Parachute/Piceance/Roan (PPR) study area in west-central Colorado, 2006-2008.

	Site type				
	Nest		Random		
Variable	*n*	Mean ± SE	*n*	Mean ± SE	*P*
Total shrub cover	37	67.7 ± 2.2	67	46.0 ± 2.4	< 0.0001
Grass height	37	35.9 ± 1.3	67	28.7 ± 0.9	< 0.0001
Big sagebrush height	37	81.8 ± 2.8	67	63.7 ± 3.0	< 0.0001
Big sagebrush cover	37	37.6.± 2.1	67	24.8 ± 1.8	< 0.0001
Forb cover[1,2]	37	12.2 ± 1.1	67	12.5 ± 0.8	0.9426
Perennial grass cover[1,2]	37	26.8 ± 2.5	67	19.4 ± 1.6	0.0053

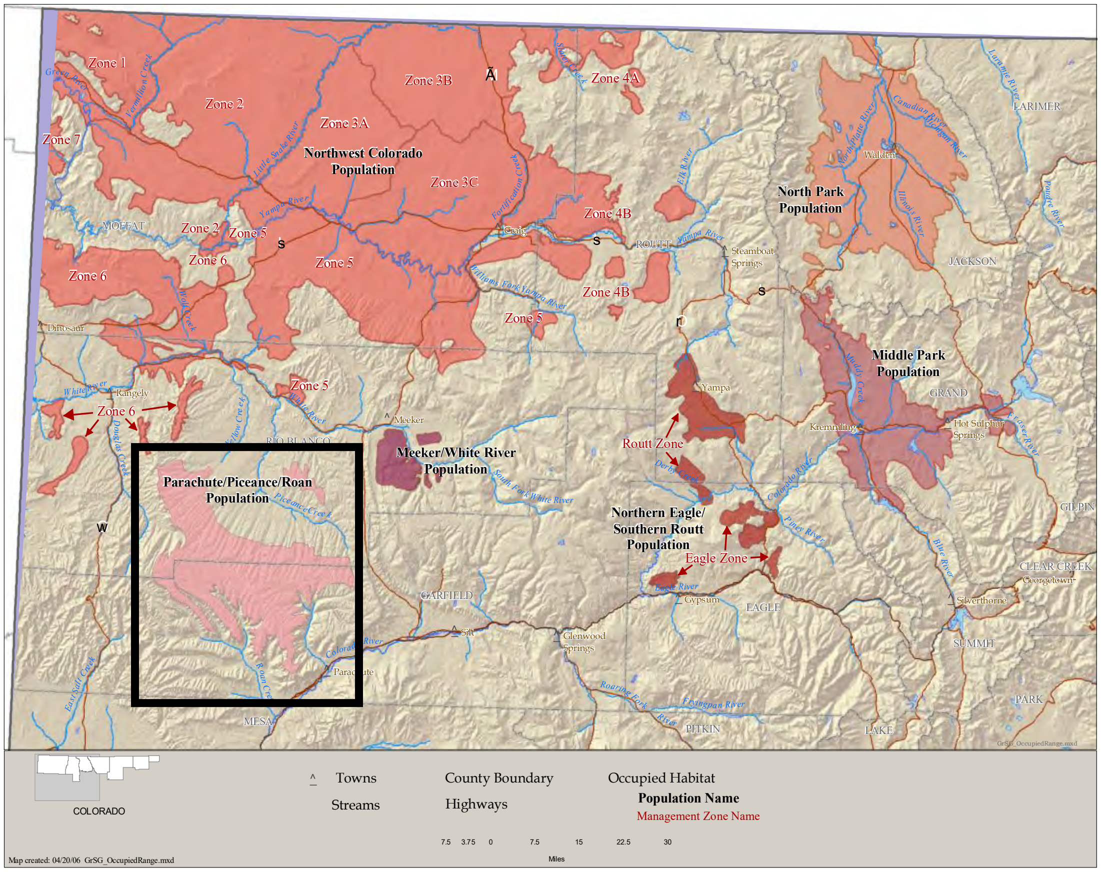
[1]Analysis conducted on transformed values, untransformed means reported.
[2]This value is a mean of midpoints for Daubenmire categories. Forb cover mean is in Daubenmire category of 10-20% at nest sites and random sites. Perennial grass cover is in Daubenmire category 20-30% for nest sites and 10-20% for random sites.

Table 3. Micro-habitat variables ($\bar{x}$ ± SE) of total shrub cover, grass height, big sagebrush height, big sagebrush cover, forb cover, and perennial grass cover at brood-rearing and random sites sampled in the Parachute/Piceance/Roan (PPR) study area in west-central Colorado, 2006-2008.

	Site type				
	Nest		Random		
Variable	*n*	Mean ± SE	*n*	Mean ± SE	*P*
Total shrub cover	29	33.6 ± 2.9	67	46.0 ± 2.4	0.0044
Grass height	29	25.7 ± 1.3	67	28.7 ± 0.9	0.0565
Big sagebrush height	29	51.3 ± 2.8	67	63.7 ± 3.0	0.0179
Big sagebrush cover	29	20.9.± 2.5	67	24.8 ± 1.8	0.2319
Forb cover[1,2]	29	12.4 ± 1.1	67	12.5 ± 0.8	0.8322
Perennial grass cover[1,2]	29	22.7 ± 2.5	67	19.4 ± 1.6	0.1470

[1]Analysis conducted on transformed values, untransformed means reported.
[2]This value is a mean of midpoints for a Daubenmire category. FORBCOV is in the Daubenmire category of 10 – 20% for brood sites and random sites. PERGRASSCOV is in the Daubenmire category of 20 -30% for brood sites and 10 – 20% for random sites.

Figure 1. Location of the Parachute/Piceance/Roan (PPR) study area in relation to the overall statewide range of greater sage-grouse in northwestern Colorado, USA.



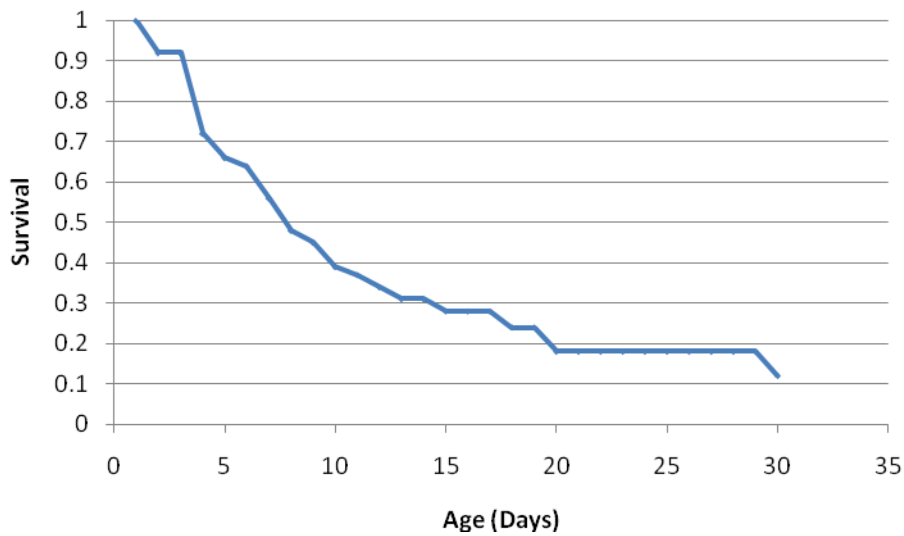


Figure 2. Greater sage-grouse chick survival from 1 – 30 days of age in the Parachute/Piceance/Roan (PPR) study area of west-central, Colorado, 2007.

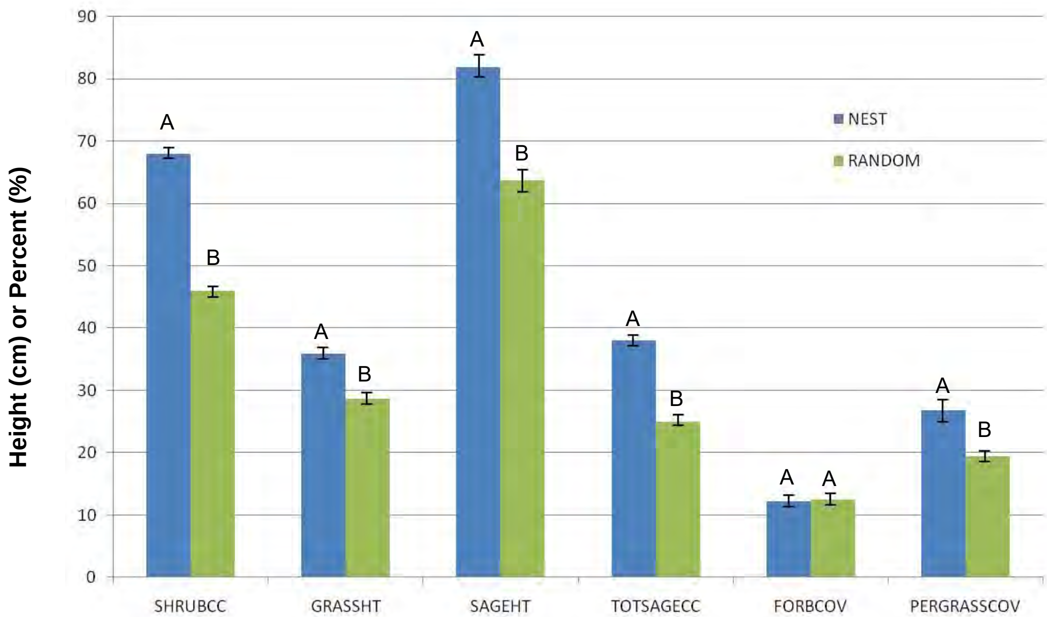


Figure 3. The percent ($\bar{x} \pm$ SE) of total shrub cover (SHRUBCC), big sagebrush cover (TOTSAGECC), forb cover (FORBCOV), and perennial grass cover (PERGRASSCOV) and height (cm) ($\bar{x} \pm$ SE) of understory perennial grass height (GRASSHT) and big sagebursh height (SAGEHT) at nest and random sites in the Parachute/Piceance/Roan (PPR) population of greater sage-grouse in west-central Colorado, 2007. Columns with the same letters are not statistically different.

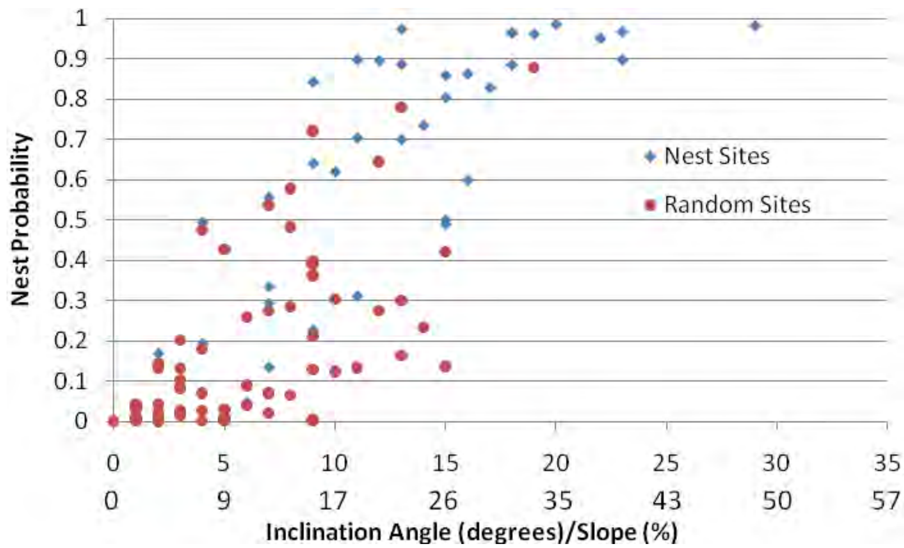


Figure 4. The estimated probability of a greater sage-grouse nest versus a random site when slope is entered into a logistic regression in the Parachute/Pieceance/Roan (PPR) population in west-central Colorado, 2007.

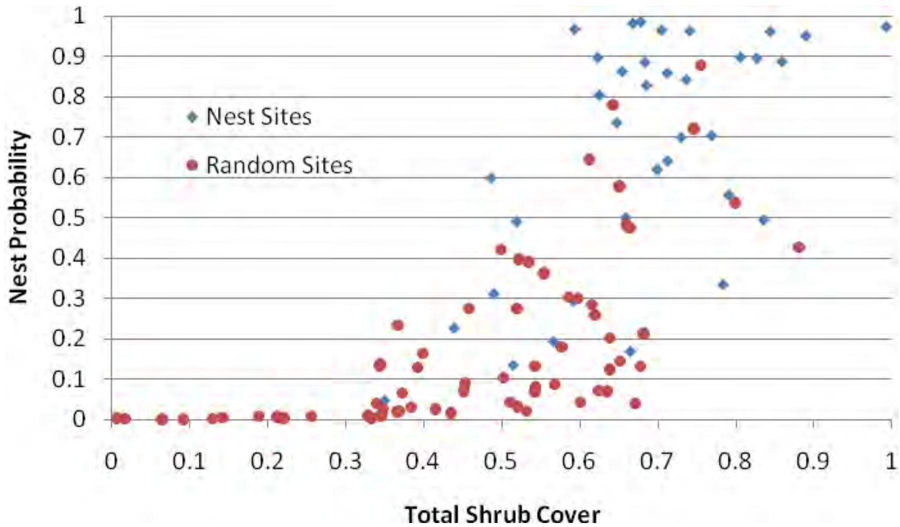


Figure 5. The estimated probability of a greater sage-grouse nest versus a random site when total shrub cover is entered into a logistic regression in the Parachute/Pieceance/Roan (PPR) population in west-central Colorado, 2007.

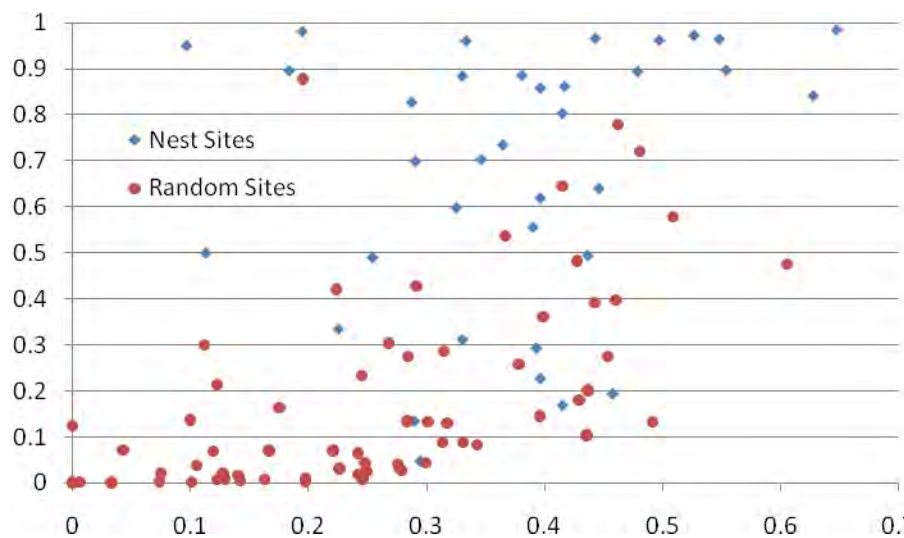
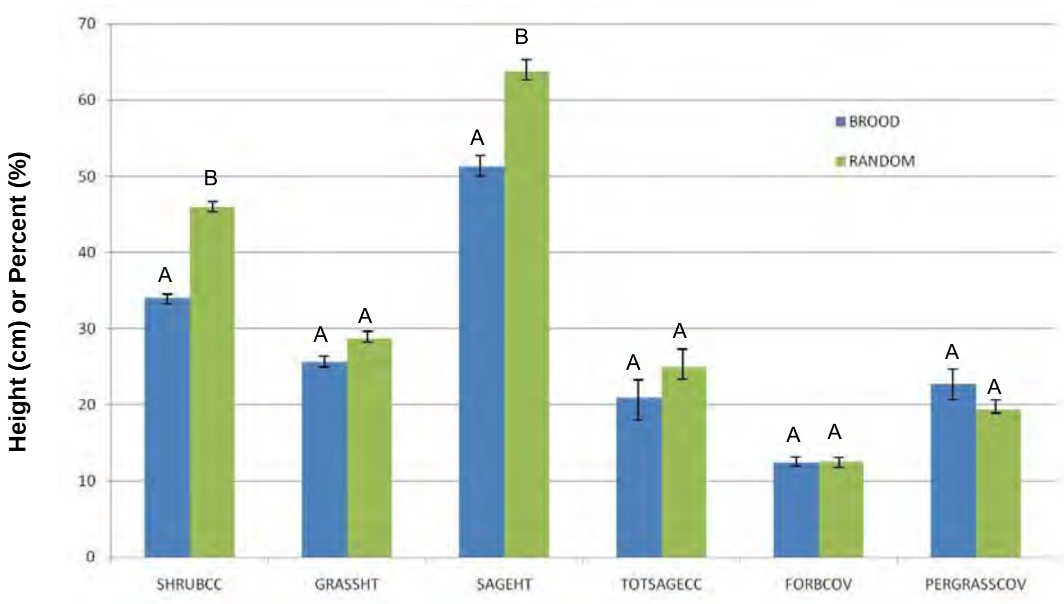


Figure 6. The estimated probability of a greater sage-grouse nest versus a random site when big sagebrush cover is entered into a logistic regression in the Parachute/Pieceance/Roan (PPR) population in west-central Colorado, 2007.

Figure 7. The percent ($\bar{x} \pm$ SE) of total shrub cover (SHRUBCC), big sagebrush cover (TOTSAGECC), forb cover (FORBCOV), and perennial grass cover (PERGRASSCOV) and height (cm) ($\bar{x} \pm$ SE) of understory perennial grass height (GRASSHT) and big sagebursh height (SAGEHT) at brood-rearing and and random sites in the Parachute/Piceance/Roan (PPR) population of greater sage-grouse in west-central Colorado, USA, 2007. Like numbers are not different.



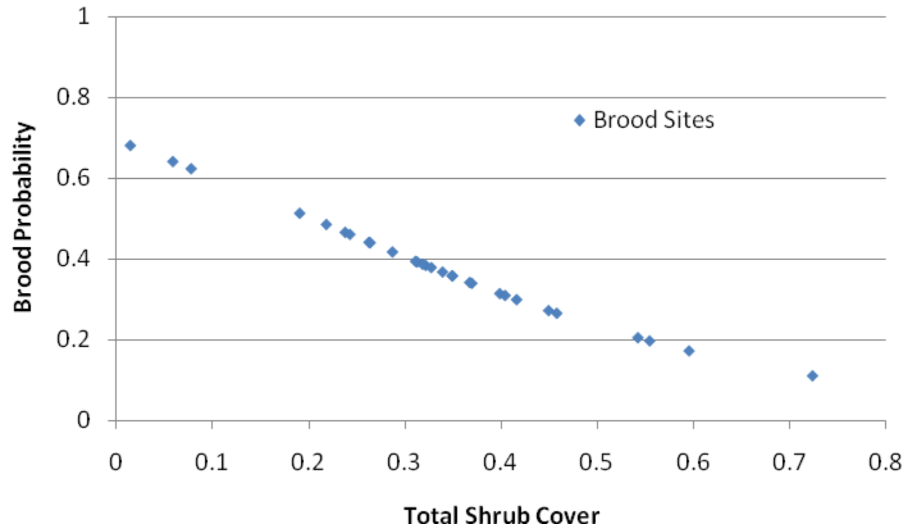


Figure 8. The estimated probability of a greater sage-grouse brood sites when total shrub cover is entered into a logistic regression in the Parachute/Pieceance/Roan (PPR) population in west-central Colorado, 2007.

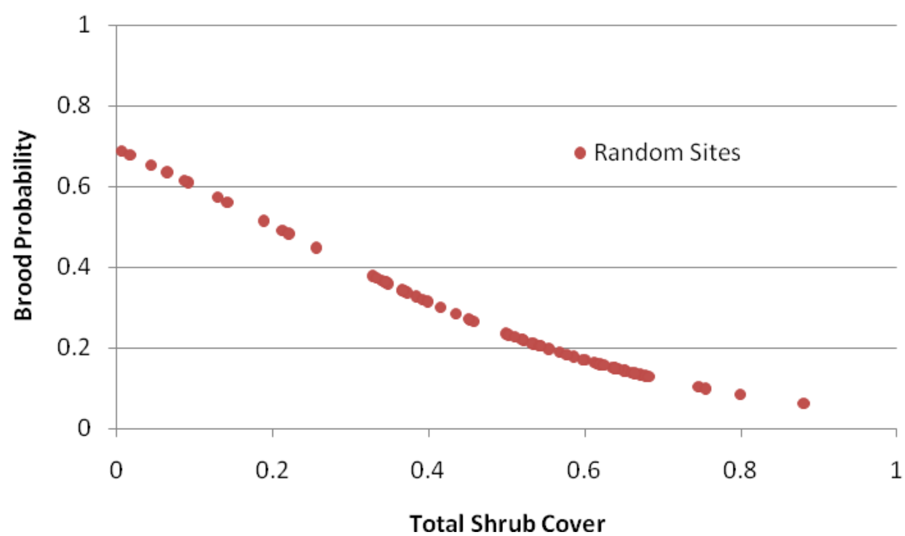


Figure 9. The estimated probability of a random sites when total shrub cover is entered into a logistic regression in the Parachute/Pieceance/Roan (PPR) population in west-central Colorado, 2007.

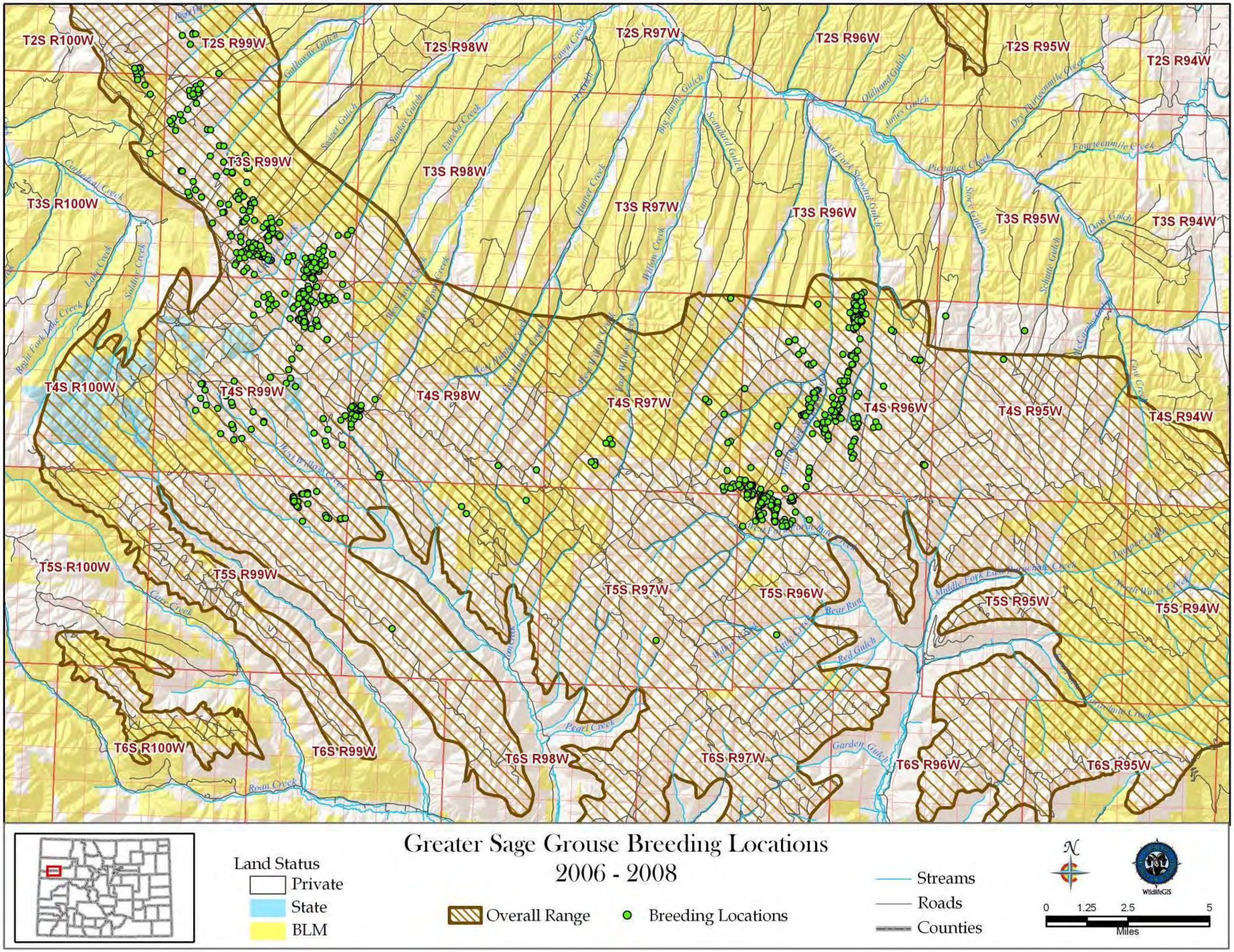


Figure 10. Breeding habitat (April – June) locations of male and female greater sage-grouse in the Parachute/Piceance/Roan (PPR) population in west-central Colorado, 2006-2008.

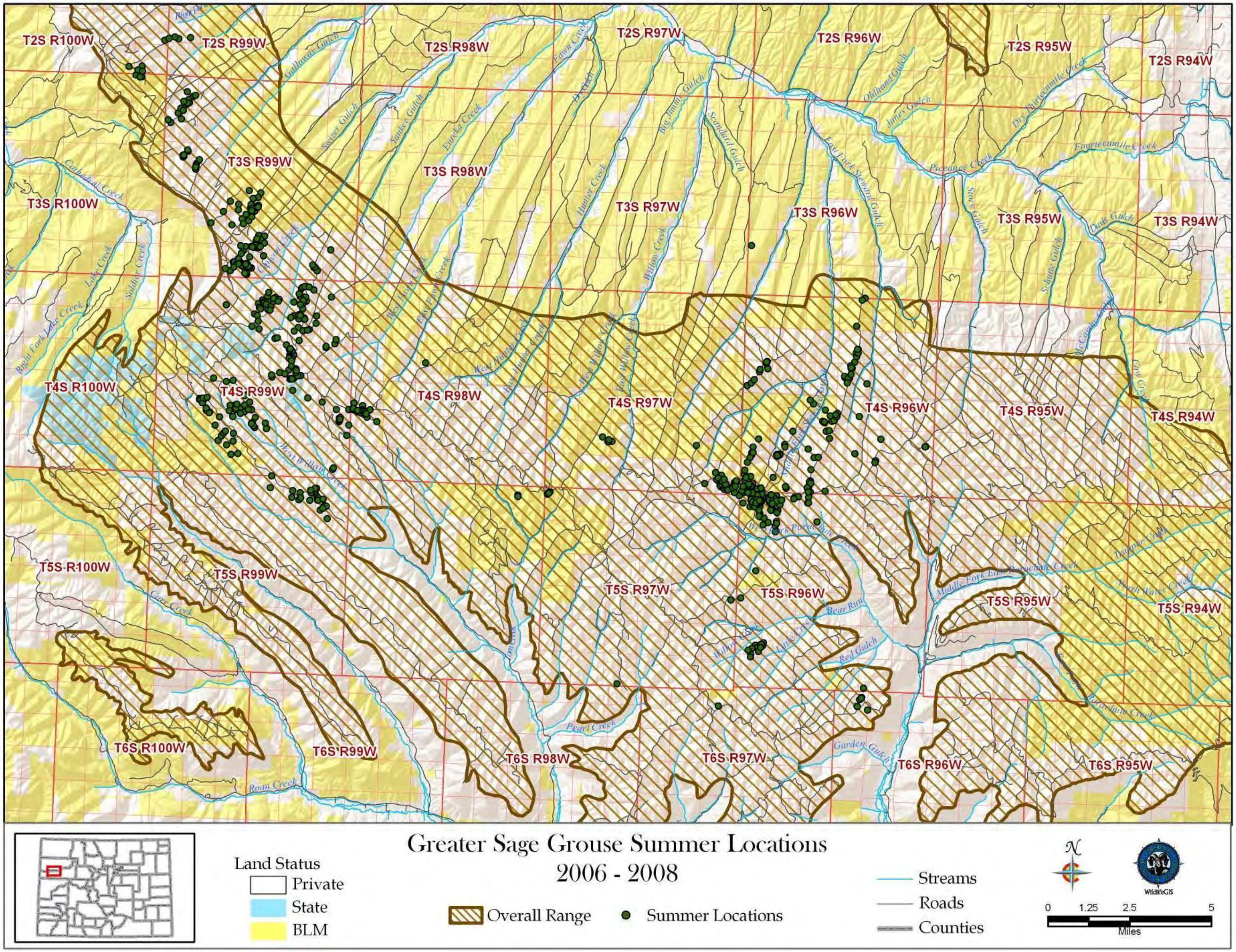


Figure 11. Summer habitat (July – September) locations of male and female greater sage-grouse in the Parachute/Piceance/Roan (PPR) population in west-central Colorado, 2006-2008.

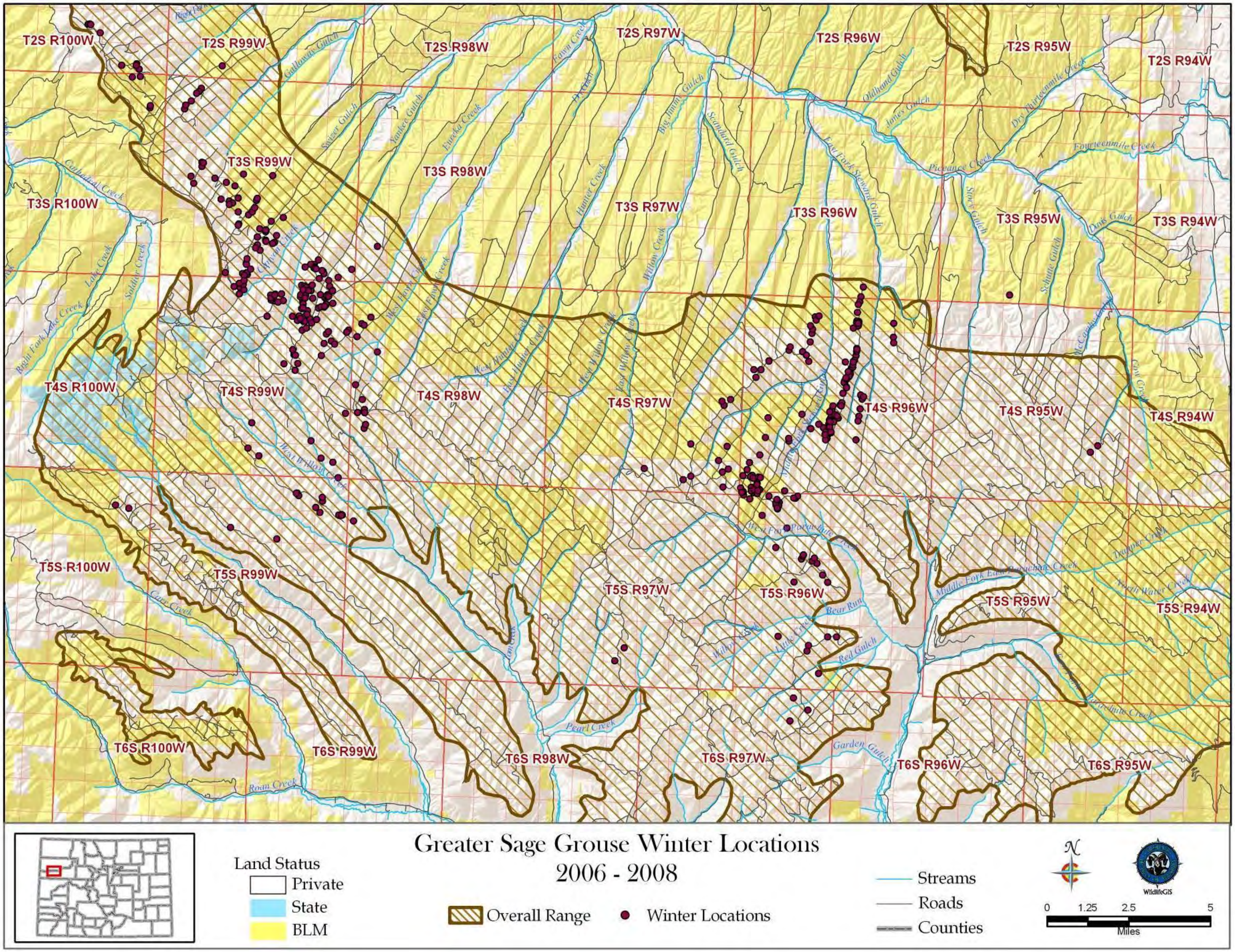


Figure 12. Winter habitat (October – March) locations of male and female greater sage-grouse in the Parachute/Piceance/Roan (PPR) population in west-central Colorado, 2006-2008.

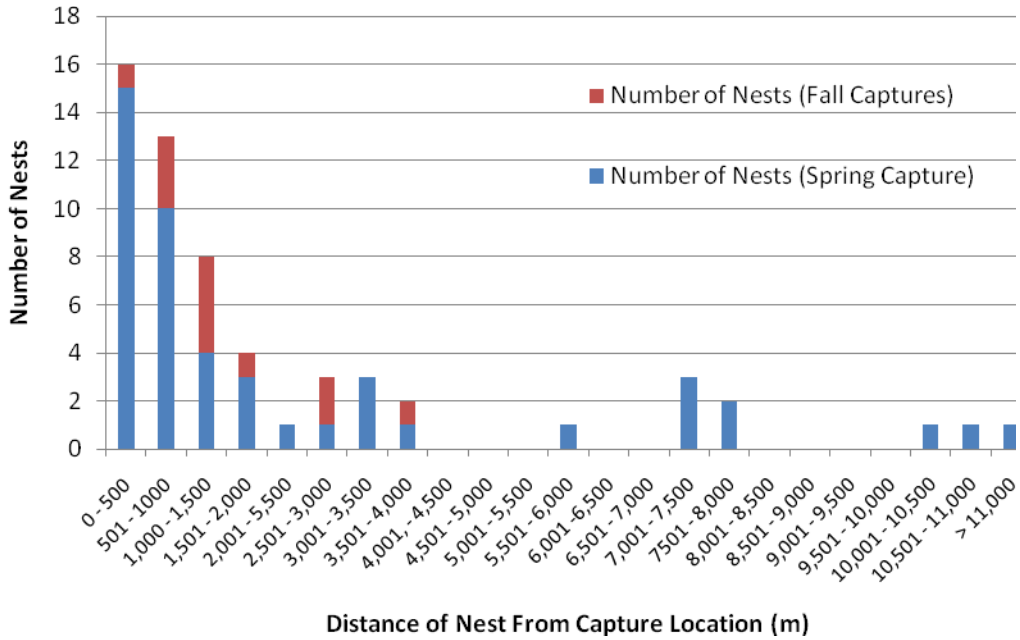


Figure 13. The number of nests and frequency of distribution for spring and fall captured locations to nest sites by female greater sage-grouse in the Parachute/Piceance/Roan (PPR) population in west-central Colorado, 2006 – 2008.

APPENDIX A

Genetic Make-up of the Parachute/Piceance/Roan Population of Greater Sage-grouse

FINAL REPORT

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Introduction

The Parachute/Piceance/Roan (PPR) population of Greater Sage-grouse (*Centrocercus urophasianus*) is one of several small, isolated populations of Sage-grouse (*Centrocercus spp.*) in the state of Colorado. Habitat for Greater Sage-grouse in this area is naturally fragmented and is undergoing rapid oil and gas development. For this reason, it is important to identify baseline information on the genetic characteristics of this population, as it will be used to assess current population status and to help identify future management strategies for this population.

Previous genetic studies (Kahn et al. 1999, Oyler-McCance et al. 2005a) have characterized the genetic make-up of five Greater Sage-grouse populations in Colorado using mitochondrial DNA (mtDNA) sequence data and data from nuclear microsatellites. The populations used in these studies included North Park, Middle Park, Eagle, Cold Springs, and Blue Mountain. The objective of this study was to characterize the PPR population using the same mtDNA and nuclear markers as have been used previously (Kahn et al. 1999, Oyler-McCance et al. 2005a) so that a direct comparison could be made between PPR and the five other characterized Greater Sage-grouse populations in Colorado.

Materials and Methods

Tissue collection and DNA extraction

Seventy blood and feather samples were collected from the PPR population during various research projects. DNA was extracted from blood samples using the GenomicPrep Blood DNA Isolation Kit (Amersham Biosciences) using the modifications of Oyler-McCance et al. (2005b).

Mitochondrial sequencing

A 146 base pair portion of hypervariable control region I was amplified using the Polymerase Chain Reaction (PCR) and sequenced using a dye terminator cycle sequencing reaction (Beckman Coulter CEQ8000) as described by Benedict et al. (2003). This region was used because it was known to contain approximately 92% of the variable sites in a larger 380 base pair region spanning control region I (Kahn et al. 1999).

Microsatellite fragment analysis

Seven nuclear microsatellite loci (LLST1, SGCA5, SGCA9, SGCA11, LLSD3, LLSD8, and ADL0230) were screened using the methods described in Oyler-McCance et al. (2005b). Briefly, PCR reactions were performed using a dye-labeled forward primer and amplified products were then run on the CEQ 8000 Genetic Analysis System (Beckman Coulter). One locus, SGCA11, was dropped due to difficulty comparing it to previous data.

Data analysis

All mtDNA sequences were edited and aligned using Sequencher Version 4.1.4 and haplotypes were identified. Measures of genetic diversity were calculated in Arlequin 2.000 (Schneider et al. 2000) as were pairwise population F_{ST} tests. Populations were deemed to be significantly different using a Bonferroni corrected P value of 0.003. Pairwise F_{ST} values were then used to construct a neighbor-joining network in PHYLIP 3.57 (Felsenstein 1989) that was viewed using the program TREEVIEW (Page 1996).

The mean number of alleles for each population were calculated and the observed and expected levels of heterozygosity were estimated using Genalex (Peakall and Smouse 2006). Microsatellite loci were tested (by population) for departures from Hardy-Weinberg equilibrium (Guo and Thompson 1992) using the computer program Arlequin 2.000 (Schneider et al. 2000). Pairwise population genetic distances (R_{ST}) were calculated in Arlequin 2.000 (Schneider et al. 2000). Populations were deemed to be significantly different using a Bonferroni corrected P value of 0.003. Pairwise R_{ST} values were then used to construct a neighbor-joining network in PHYLIP 3.57 (Felsenstein 1989) that was viewed using the program TREEVIEW (Page 1996).

Population structure was also examined using STRUCTURE 2.00 software (Pritchard et al. 2000). In this program, individuals are grouped into clusters without regard to the assigned population using a model-based clustering analysis. The number of —populations" (K) was initially estimated by conducting five independent runs each of K = 1- 10 with 100,000 Markov Chain Monte Carlo (MCMC) repetitions and a 100,000 burnin period using the model with admixture, correlated allele frequencies, and no prior information. An additional set of five independent runs was then conducted with K= 1 - 5 with 500,000 MCMC repetitions and a 500,000 burnin period using the above model.

Results

Mitochondrial Sequence Analysis

Of the 65 individuals sequenced, 8 different haplotypes were found (Table 1, Fig. 1). Of those 8 haplotypes, 5 were found elsewhere in Colorado. Three of those haplotypes (A, B, and C) were common in Colorado, found in at least 4 of the 5 other populations. Haplotypes E and H are also shared with Colorado populations (Table 1) yet with three or less populations. Haplotype W, which occurs in PPR and not elsewhere in Colorado, is found in Wayne and Rich counties in Utah and also in the Strawberry Valley population in Utah (Oyler-McCance et al. 2005a). Haplotype EU is also found in the Rawlins, Wyoming population (Oyler-McCance et al. 2005a). A new haplotype (labeled New3) was found in PPR and is not found elsewhere among Greater Sage-grouse (Oyler-McCance et al. 2005a). This haplotype is very closely related to haplotype B with only one substitution differing between them.

Levels of genetic diversity in PPR were similar to other populations in Colorado (Table 2). PPR had 8 haplotypes, which is well within the range of the other Colorado populations with the number of haplotypes ranging from 5 in Eagle to 11 in Blue Mountain. In terms of haplotype diversity, PPR also falls well within the range of the other populations (Table 2).

Pairwise population F_{ST} tests revealed that PPR was significantly different from three other Colorado populations (Blue Mountain, Cold Springs, and Eagle). The only other significant difference in Colorado was between Blue Mountain and Eagle. This metric, however, is influenced by comparisons using widely different sample sizes. It is possible that there are more significant comparisons with PPR due to the unusually high sample size in that population. The neighbor-joining network (Fig. 2) showed that PPR was associated most closely to North Park and did not appear to be more different than other populations in Colorado.

Microsatellite Analysis

Tests for departures from Hardy-Weinberg Equilibrium (HWE) within PPR showed that no locus was out of HWE. Levels of genetic diversity in PPR, measured using microsatellite data, were comparable to other populations in Colorado. The mean number of alleles per locus in PPR was 5.67 (Table 4), which again is well within the range of other populations in Colorado with a low of 5.33 in Eagle and a high of 5.83 in Cold Springs and North Park (Oyler-McCance et al. 2005a). The mean observed heterozygosity in PPR was slightly lower (0.55) than other values in Colorado, which ranged from 0.61 in Cold Springs to 0.69 in Middle Park.

Pairwise population R_{ST} significance tests revealed that most populations in Colorado are not significantly different. PPR was found to be significantly different from Blue Mountain and Cold Springs, however. Cold Springs was shown to be the most different as it was significantly different from PPR, Blue Mountain, Eagle, and Middle Park. The neighbor-joining network (Fig. 3) showed that PPR was most closely related to Middle Park, followed by Eagle and North Park.

The STRUCTURE analysis revealed that the most appropriate number of populations (K) given the data was 1. This suggests that there is little genetic structure among populations.

Discussion

This analysis of the PPR population compared with 5 other Greater Sage-grouse populations in Colorado revealed that the genetic make-up of PPR is generally consistent with the other 5 populations. Using mtDNA sequence data, 5 of the 8 haplotypes found in PPR (66% of the PPR birds) were also found in the other populations in Colorado (Table 1, Fig 1.). Of the three PPR haplotypes not found in Colorado, 2 (EU and W) were found in the neighboring states of Utah and Wyoming. One haplotype was unique to PPR (New3) and at relatively high frequency (20%). Two other Colorado populations (Blue Mountain and Cold Springs) each also had a unique haplotype representing 10 and 8% of the populations respectively (Oyler-McCance et al. 2005a). The PPR population, had a much higher sample size (65 compared to ~ 20 in the other populations) and the sampling method was different (trapped birds in PPR vs. hunter killed birds in the rest of the Colorado birds), which may influence the potential for relatedness among samples. Additionally, the PPR population did have similar levels of genetic diversity (both in the number of haplotypes and in haplotypes diversity) as the other Colorado populations (Table 2) yet again, a higher sample size likely resulted in more haplotypes being identified. Nonetheless, it appears that the PPR population does not suffer from low diversity and appears to have diversity levels that are comparable to the other Colorado populations. The mtDNA neighbor-joining network (Fig. 2), which was constructed using F_{ST} genetic distances among populations, suggests that PPR is more closely related to North Park, Cold Springs, and Blue Mountain, than to Middle Park and Eagle. The fact that PPR is not shown to have branch lengths longer than the other Colorado populations suggests that it is not genetically distinct from all other Colorado Greater Sage-grouse populations.

The microsatellite data are relatively concordant with that of the mtDNA data. The STRUCTURE analysis found that the most appropriate number of discrete genetic clusters (K) was 1 given the data from these 6 populations, suggesting that there was little genetic structure within the data. Pairwise population R_{ST} tests (Table 5), based on allele frequencies of populations, revealed a few significant differences among populations yet these differences were primarily between Cold Springs and the other populations. This finding is highlighted with the microsatellite neighbor-joining network (Fig. 3) that shows Cold Springs as the most genetically distinct population. This network suggests that PPR is more closely related to Middle Park and Eagle, contrary to the network built with mtDNA data. This discrepancy is likely due to the different patterns of inheritance of these two types of genetic markers (maternal vs. biparental). An additional factor that could lead to minor differences between the two data sets has to do with the number of loci sampled (sampling error). While the mitochondrial genome represents one locus, multiple sites were sampled in the nuclear genome. Levels of genetic diversity in PPR (Table 4) were again similar to what had been previously been reported for populations in Colorado (Oyler-McCance et al. 2005a). The levels of mean observed heterozygosity in PPR were the lowest reported in Colorado (Table 4) yet the values are only slightly lower than those reported elsewhere (0.55 as opposed to 0.61-0.69). This could be due to a number of factors including smaller population sizes, increased fragmentation among sagebrush habitat resulting in sampled birds being more related, or merely due to the different sampling method used in this study (trapped birds vs. hunter killed birds).

In summary, the Greater Sage-grouse in PPR do not appear to be substantially different from other Greater Sage-grouse sampled in Colorado. There is some level of uniqueness (as represented by the new haplotype found in 20% of the PPR birds) yet this is not unusual as both Cold Springs and Blue Mountain also contained haplotypes that were unique to that particular population. Additionally, the levels of genetic diversity in PPR do appear to be comparable to other populations although they were reported to have the lowest levels of observed heterozygosity levels.

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Table 1. Sampling locations and mtDNA haplotype frequencies of Sage-grouse in Colorado (from Kahn et al. 1999)

	Haplotypes																				
Location	*N*	A	B	C	D	E	H	L	S	W	X	Z	AA	AC	AD	AE	AF	AL	AM	EU	New3
PPR	65	1	10	13		6	13			1										8	13
Blue Mountain	21	1	8	1	1				1			3	1	1	1	2	1				
Cold Springs	25	3	7	10	1			2				1		1							
Eagle	26	2	2	15	4		3														
Middle Park	21		7	9	2	1	1											1			
North Park	23	4	5	6	3	2	1				1								1		

Table 2. Mitochondrial DNA genetic diversity measures of Greater Sage-grouse populations in Colorado. Standard errors are in parentheses.

Population	Sample size	Number of Haplotypes	Haplotype Diversity (SE)
PPR	65	8	0.85 (0.01)
Blue Mountain	21	11	0.85 (0.07)
Cold Springs	25	7	0.77 (0.06)
Eagle	26	5	0.64 (0.09)
Middle Park	21	6	0.72 (0.07)
North Park	23	8	0.86 (0.04)

Table 3. Pairwise population F_{ST} significance tests. F_{ST} values in bold represent significant differences using a Bonferroni correct P value of 0.003.

	Population				
	PPR	Blue Mountain	Cold Springs	Eagle	Middle Park
Blue Mountain	**0.09110**				
Cold Springs	**0.07643**	0.06103			
Eagle	**0.11458**	**0.20377**	0.03766		
Middle Park	0.07123	0.07353	-0.01906	0.03400	
North Park	0.04689	0.03997	-0.00657	0.05395	0.00509

Table 4. Microsatellite genetic diversity measures of Greater Sage-grouse populations in Colorado. Standard deviations are in parentheses.

Population	Sample size	Mean # of alleles per locus	Mean observed heterozygosity	Mean expected heterozygosity
PPR	70	5.67	0.55 (0.17)	0.61 (0.20)
Blue Mountain	25	5.50	0.68 (0.22)	0.65 (0.23)
Cold Springs	30	5.83	0.61 (0.13)	0.64 (0.17)
Eagle	26	5.33	0.66 (0.24)	0.67 (0.17)
Middle Park	21	5.50	0.69 (0.10)	0.66(0.15)
North Park	22	5.83	0.66 (0.15)	0.61(0.15)

Table 5. Pairwise population R_{ST} significance tests. R_{ST} values in bold represent significant differences using a Bonferroni correct P value of 0.003.

	Population				
	PPR	Blue Mountain	Cold Springs	Eagle	Middle Park
Blue Mountain	**0.09560**				
Cold Springs	**0.21178**	**0.08328**			
Eagle	0.01375	0.03431	**0.13454**		
Middle Park	-0.03364	0.01800	**0.11034**	-0.01182	
North Park	-0.01793	-0.00044	0.06848	0.00119	-0.01986

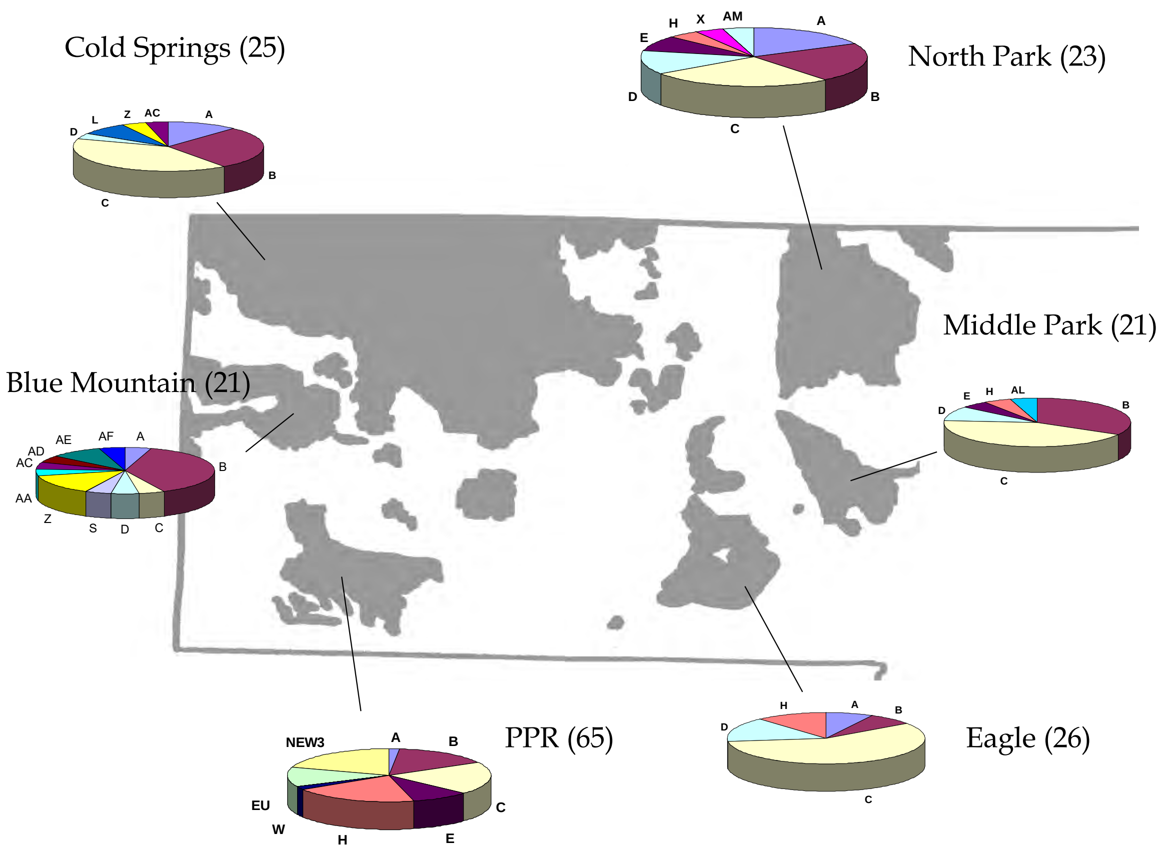

Figure 1. Distribution of mtDNA haplotypes found in PPR and 5 other previously studied populations of Greater Sage-grouse in northern Colorado (Kahn et al. 1999).

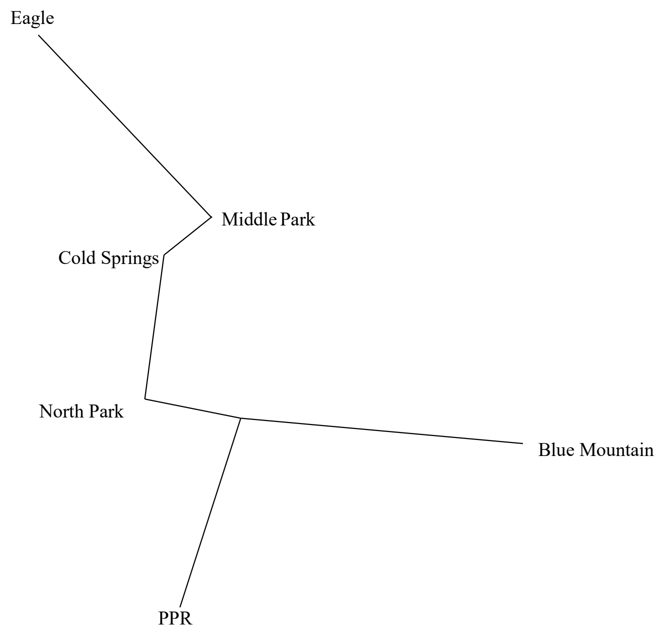

Figure 2. Mitochondrial DNA neighbor-joining network constructed using pairwise F_{ST} values as a genetic distance.

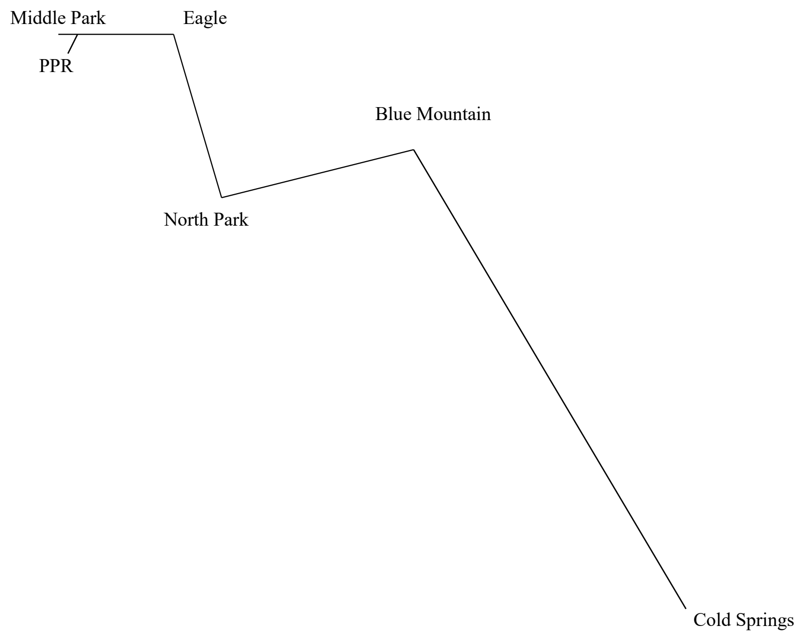

Figure 3. Microsatellite neighbor-joining network constructed using pairwise R_{ST} values as a genetic distance.

Appendix 1. Microsatellite alleles across 6 loci for PPR and the 5 other Greater Sage-grouse populations in Colorado included in this study.

		Loci											
Individual	Population	L1		S5		S9		L3		L8		ADL230	
PI 1	PI	143	146	265	275	322	332	137	145	139	139	109	111
PI 2	PI	143	143	259	265	318	332	137	137	139	139	107	113
PI 3	PI	143	143	259	265	318	318	137	137	139	139	109	113
PI 4	PI	143	143	273	275	340	340	137	137	139	139	105	111
PI 5	PI	143	146	263	265	318	340	137	137	139	139	105	111
PI 6	PI	0	0	0	0	0	0	0	0	139	139	109	109
PI 7	PI	143	143	265	275	328	332	0	0	145	145	105	107
PI 8	PI	0	0	265	273	0	0	137	137	139	139	107	111
PI 9	PI	143	143	261	265	326	342	137	145	139	139	111	113
PI 10	PI	143	143	259	275	326	342	137	145	139	145	111	113
PI 11	PI	0	0	0	0	0	0	0	0	139	139	0	0
PI 12	PI	146	146	265	265	0	0	0	0	139	139	105	111
PI 13	PI	143	146	259	259	318	332	137	145	139	145	105	107
PI 14	PI	143	143	261	265	340	342	137	141	139	139	105	111
PI 15	PI	143	146	265	265	318	364	0	0	139	139	105	113
PI 16	PI	0	0	265	265	338	364	0	0	139	139	109	109
PI 17	PI	143	143	265	275	326	340	0	0	139	145	105	113
PI 18	PI	143	146	265	265	318	342	137	147	139	145	109	109
PI 19	PI	143	143	265	275	0	0	137	145	139	139	109	109
PI 20	PI	143	143	255	275	340	364	137	141	139	145	105	105
PI 21	PI	143	143	259	265	318	318	0	0	139	139	111	113
PI 22	PI	143	143	265	271	332	366	137	141	139	139	0	0
PI 23	PI	143	143	259	265	332	366	137	137	139	139	105	109
PI 24	PI	143	143	261	275	318	338	137	141	139	139	105	107
PI 25	PI	143	146	261	275	0	0	0	0	139	159	111	113
PI 26	PI	143	146	265	275	0	0	137	137	139	159	107	107
PI 27	PI	143	146	265	271	318	358	145	145	139	159	109	109
PI 28	PI	143	146	265	271	318	318	0	0	139	159	109	109
PI 29	PI	143	143	271	275	318	360	137	145	139	159	109	109
PI 30	PI	143	146	265	271	318	322	0	0	139	139	109	113
PI 31	PI	143	143	265	265	0	0	137	137	139	139	105	105
PI 32	PI	0	0	261	273	318	332	0	0	0	0	109	109

PI 33	PI	143	143	259	261	318	340	137	137	145	145	109	109
PI 34	PI	143	143	259	273	318	340	0	0	139	145	109	109
PI 35	PI	143	146	263	265	0	0	137	137	139	139	105	109
PI 36	PI	143	146	265	265	318	318	137	137	139	139	0	0
PI 37	PI	143	143	265	265	318	360	0	0	139	139	109	111
PI 38	PI	143	143	263	265	318	340	137	137	139	139	105	111
PI 39	PI	143	143	0	0	0	0	0	0	139	145	111	113
PI 40	PI	0	0	271	271	318	332	0	0	139	145	105	113
PI 41	PI	143	143	263	275	0	0	145	145	159	159	105	109
PI 42	PI	143	146	261	273	0	0	141	145	139	145	111	113
PI 43	PI	143	143	0	0	318	358	137	145	139	139	109	109
PI 44	PI	143	143	265	265	0	0	137	145	139	139	109	113
PI 45	PI	143	143	271	273	0	0	137	145	139	139	109	113
PI 46	PI	143	143	261	273	322	332	137	147	139	145	107	109
PI 47	PI	143	146	273	275	0	0	145	145	139	139	0	0
PI 48	PI	0	0	261	265	0	0	0	0	145	159	0	0
PI 49	PI	143	143	0	0	326	364	137	137	139	145	109	109
PI 50	PI	143	146	265	273	0	0	137	147	139	139	109	109
PI 51	PI	143	143	271	275	318	318	137	145	139	139	109	109
PI 52	PI	146	146	0	0	0	0	137	141	139	139	0	0
PI 53	PI	143	146	261	265	318	326	137	137	139	139	109	109
PI 54	PI	143	143	265	265	322	332	137	137	139	139	109	109
PI 55	PI	143	143	261	271	322	322	0	0	139	139	107	109
PI 56	PI	143	143	259	261	326	326	137	137	139	139	0	0
PI 57	PI	143	143	261	265	326	326	141	141	139	145	109	113
PI 58	PI	143	146	263	263	326	326	137	145	139	139	109	113
PI 59	PI	143	143	0	0	0	0	137	137	0	0	109	109
PI 60	PI	143	146	0	0	326	326	137	137	139	159	107	109
PI 61	PI	143	143	261	265	326	326	0	0	139	145	105	105
PI 62	PI	143	146	261	271	0	0	137	141	139	159	109	111
PI 63	PI	143	146	0	0	322	322	0	0	139	145	107	109
PI 64	PI	143	143	271	273	332	332	0	0	139	139	109	111
PI 65	PI	143	146	261	265	326	342	0	0	139	139	109	113
PI 66	PI	143	143	265	265	340	340	0	0	139	145	109	109
PI 67	PI	146	146	0	0	326	332	145	145	145	159	109	111
PI 68	PI	143	146	265	275	326	332	137	137	139	145	105	109

PI 69	PI	143	146	259	261	322	332	137	141	139	159	109	109
PI 70	PI	143	143	265	271	326	326	137	147	145	145	109	109
BM1	BM	143	143	0	0	340	340	137	141	139	145	105	107
BM10	BM	143	143	259	265	322	342	137	145	145	145	105	109
BM11	BM	143	146	255	265	342	342	137	141	139	139	105	111
BM12	BM	143	143	259	273	340	342	137	145	139	159	107	107
BM13	BM	143	146	0	0	0	0	137	145	0	0	0	0
BM14	BM	143	146	259	265	318	340	137	145	139	139	105	113
BM15	BM	143	146	265	265	318	342	137	137	139	159	105	109
BM16	BM	143	146	259	263	340	340	137	137	139	159	109	109
BM17	BM	143	143	259	265	322	326	137	145	145	159	109	111
BM18	BM	143	143	265	273	318	342	137	157	139	159	105	107
BM19	BM	143	143	255	273	318	336	137	145	139	147	101	109
BM2	BM	143	143	263	273	318	328	137	145	139	145	101	109
BM20	BM	143	143	255	273	322	326	137	145	139	145	105	109
BM21	BM	143	143	255	259	318	340	137	141	139	159	101	113
BM22	BM	143	143	255	259	318	326	137	137	159	159	109	109
BM23	BM	143	143	261	265	318	340	137	137	139	159	107	111
BM24	BM	143	143	259	265	326	342	141	145	139	145	107	111
BM25	BM	143	143	255	265	322	326	137	141	139	159	105	107
BM3	BM	0	0	0	0	0	0	0	0	0	0	101	109
BM4	BM	143	143	259	259	326	326	145	145	159	159	101	111
BM5	BM	143	143	265	265	318	326	137	137	139	159	109	109
BM6	BM	143	146	261	271	322	340	139	141	139	139	109	111
BM7	BM	143	143	255	255	318	322	145	145	139	139	107	109
BM8	BM	143	143	273	275	318	326	145	145	139	165	105	111
BM9	BM	143	143	255	271	340	342	137	137	139	159	109	111
CS10	CS	143	143	0	0	318	342	137	141	139	145	105	105
CS11	CS	143	143	0	0	0	0	0	0	139	139	105	109
CS12	CS	143	146	259	273	338	340	137	137	139	159	105	109
CS13	CS	143	143	265	265	322	322	137	137	139	145	105	109
CS14	CS	143	146	273	273	318	318	137	137	139	159	105	113
CS15	CS	143	146	273	273	318	318	137	137	139	159	105	113
CS16	CS	143	143	259	265	318	318	139	145	159	159	105	111
CS18	CS	143	146	265	273	322	322	141	145	139	145	109	111
CS19	CS	143	143	259	265	322	322	137	145	139	145	105	105

CS2	CS	143	143	255	265	318	322	137	145	145	145	109	109
CS20	CS	143	146	259	277	318	324	137	137	159	159	105	109
CS22	CS	143	143	271	275	326	326	141	145	0	0	101	107
CS23	CS	143	143	255	265	318	318	141	157	145	145	101	107
CS24	CS	143	146	255	273	318	326	137	137	139	145	99	107
CS25	CS	0	0	259	265	318	324	145	157	159	159	0	0
CS26	CS	143	146	259	265	318	322	145	145	139	157	101	109
CS27	CS	143	143	259	259	318	322	137	137	145	159	101	101
CS28	CS	143	146	265	273	326	340	137	145	139	159	101	101
CS29	CS	143	143	0	0	318	340	137	145	145	159	107	109
CS3	CS	143	146	259	273	318	318	137	137	145	145	105	109
CS30	CS	143	143	255	275	322	322	145	145	145	159	103	105
CS32	CS	143	143	263	277	318	340	137	145	145	159	101	101
CS33	CS	143	146	255	263	326	340	137	137	139	159	105	109
CS34	CS	143	146	265	265	0	0	137	141	139	139	99	105
CS4	CS	143	143	265	275	318	322	137	137	145	145	105	105
CS5	CS	143	143	255	265	318	322	137	137	145	145	105	109
CS6	CS	143	143	0	0	318	342	137	137	145	145	105	105
CS7	CS	143	143	259	259	322	324	137	141	139	159	105	109
CS8	CS	143	146	259	261	318	322	137	145	139	145	105	109
CS9	CS	143	143	265	277	318	326	137	139	159	159	105	109
EG10	EG	143	143	265	265	326	342	137	145	145	159	105	111
EG11	EG	143	143	265	273	342	356	137	141	0	0	105	109
EG12	EG	143	146	265	275	318	326	145	157	139	139	109	111
EG13	EG	143	143	255	261	342	350	137	137	139	159	105	109
EG14	EG	143	146	259	273	350	350	137	141	139	159	109	109
EG16	EG	143	143	265	275	342	342	141	141	139	159	111	111
EG17	EG	143	143	261	265	326	326	137	145	139	145	111	111
EG18	EG	143	143	0	0	0	0	137	157	139	145	109	111
EG20	EG	146	146	265	273	326	326	141	141	139	159	105	109
EG21	EG	143	146	265	265	318	342	137	145	139	139	105	109
EG22	EG	143	143	265	275	318	318	137	141	145	159	109	111
EG24	EG	143	143	265	265	342	350	137	145	139	145	109	111
EG4	EG	143	146	259	273	350	350	137	141	139	159	109	109
EG5	EG	146	146	265	275	342	342	145	157	139	159	109	109
EG50	EG	143	143	265	265	344	352	141	157	139	159	103	107

EG51	EG	143	146	267	267	326	342	141	145	139	159	105	107
EG52	EG	143	143	275	275	318	318	137	141	145	159	105	107
EG53	EG	143	146	273	275	318	318	137	141	139	159	103	105
EG6	EG	143	143	265	275	318	326	137	141	139	159	0	0
EG7	EG	143	143	269	271	322	322	137	145	139	139	105	109
EG8	EG	143	143	269	271	322	322	137	145	139	139	105	109
EG9	EG	143	146	265	273	318	326	137	141	139	159	105	111
MEG1	EG	143	143	265	273	322	322	137	145	139	145	111	113
MEG2	EG	143	143	265	273	322	322	137	145	139	145	111	113
MEG3	EG	143	146	261	273	0	0	137	141	139	145	111	111
SEG1	EG	143	143	0	0	322	322	137	145	139	145	111	113
MP1	MP	143	143	259	265	328	328	137	157	139	139	105	111
MP10	MP	143	146	255	263	340	340	137	145	139	145	105	105
MP11	MP	143	143	261	277	326	328	137	137	139	145	105	113
MP12	MP	140	146	255	263	318	352	137	145	139	159	109	109
MP13	MP	143	146	271	277	318	326	137	141	139	159	105	111
MP14	MP	143	143	273	275	348	350	137	157	139	139	105	109
MP15	MP	143	143	265	265	326	350	137	137	139	139	105	105
MP16	MP	140	146	259	273	318	326	137	145	139	145	111	113
MP17	MP	143	146	273	275	342	348	137	157	139	159	109	109
MP18	MP	143	143	259	265	318	318	137	139	139	139	105	111
MP19	MP	140	143	259	273	318	326	137	141	139	145	105	111
MP2	MP	143	146	255	261	318	326	145	157	139	159	105	109
MP20	MP	143	143	255	261	0	0	137	137	139	145	109	113
MP21	MP	143	146	265	265	0	0	137	137	139	139	105	111
MP3	MP	143	143	265	265	328	342	137	145	139	139	105	111
MP4	MP	143	146	259	273	328	342	137	157	139	159	105	105
MP5	MP	143	143	265	265	0	0	137	137	145	159	109	113
MP6	MP	143	146	271	277	318	326	137	141	139	159	105	111
MP7	MP	143	143	261	265	326	328	145	157	139	145	105	105
MP8	MP	143	143	265	273	328	342	137	145	139	159	111	111
MP9	MP	143	152	275	275	318	318	141	145	139	139	105	109
NP1	NP	143	143	259	273	318	342	137	137	139	145	105	105
NP10	NP	143	143	259	271	318	318	137	145	139	139	107	111
NP11	NP	143	146	259	265	318	342	137	137	139	159	105	111
NP12	NP	143	143	259	261	318	322	145	157	139	159	105	111

NP13	NP	143	146	271	273	0	0	145	157	0	0	105	105
NP15	NP	143	143	259	265	0	0	137	145	139	145	105	105
NP16	NP	143	143	263	265	318	318	137	157	139	139	105	109
NP17	NP	143	146	265	273	322	328	153	157	145	145	105	109
NP18	NP	143	143	259	273	318	318	137	145	145	159	105	105
NP19	NP	143	143	259	259	328	328	137	137	139	159	105	109
NP2	NP	143	152	265	273	342	342	137	145	139	159	105	109
NP20	NP	143	143	265	273	318	360	137	145	139	145	105	111
NP22	NP	143	146	273	275	326	342	137	137	139	159	105	105
NP23	NP	143	146	265	271	318	350	137	137	139	145	105	105
NP24	NP	143	146	257	265	330	362	141	145	139	145	105	109
NP3	NP	143	152	259	265	318	326	137	147	139	139	105	111
NP4	NP	143	152	265	265	318	364	137	137	139	159	105	107
NP5	NP	143	143	259	273	342	342	137	137	145	159	107	111
NP6	NP	143	143	257	273	318	318	137	137	139	159	105	109
NP7	NP	143	152	265	273	318	342	137	145	139	145	105	107
NP8	NP	143	143	263	265	324	342	137	137	139	139	105	105
NP9	NP	143	143	265	265	318	328	137	137	145	159	105	109

COLORADO DIVISION OF WILDLIFE - AVIAN RESEARCH PROGRAM
PROGRESS REPORT
September 2010

TITLE: Greater sage-grouse research in the Parachute-Piceance-Roan region of western Colorado Part I: Assessment of greater sage-grouse response to pinyon-juniper removal

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Period Covered: September 1, 2008 - December 1, 2009

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

ABSTRACT

Large-scale changes to sagebrush habitats throughout western North America have led to growing concern for conservation of greater sage-grouse (*Centrocercus urophasianus*) and repeated petitions to list the species under the Endangered Species Act. Greater sage-grouse in the Parachute-Piceance-Roan (PPR) region of western Colorado face two major conservation issues: potential impacts from rapidly increasing energy development and a long-term decline in habitat suitability and range contraction associated with pinyon-juniper (PJ) encroachment. In 2006, the Colorado Division of Wildlife (CDOW) and industry partners initiated a 3-year study to obtain baseline data on seasonal habitat use, movements, vital rates, and genetics of greater sage-grouse in the PPR. CDOW has since expanded the original project to include generating high-resolution maps showing concentrated seasonal use areas and assessing the value of PJ removal to restore habitat as mitigation for energy development. Current and proposed energy development overlaps greater sage-grouse occupied range in the PPR. However, industry and agencies need higher-resolution maps showing where sage-grouse occur during each season to streamline development planning and mitigation and guide sage-grouse conservation efforts. We are currently conducting multi-scale habitat selection analyses for each season (breeding, summer-fall, winter) using ~2900 locations from 106 radio-marked greater sage-grouse collected from 2006-2009. This analysis is currently underway, and results and maps will be included in a subsequent progress report. We are also assessing the response of greater sage-grouse to experimental removal of encroaching PJ in otherwise sagebrush-dominated habitats using a before-after control-impact design. Pre-treatment surveys from winter 2008-2009 indicated that winter track occupancy, as expected, was higher on sagebrush control plots (0.012-0.069) than on plots with encroaching PJ (0.00). Data collection for winter 2009-2010 is still in progress. Summer pellet surveys indicated higher summer and winter use on sagebrush control plots than on plots with encroaching PJ, but detectability of pellets on test plots was low (mean = 0.118) and variable among observers (0.00-0.22), which may be problematic for interpretation of pellet survey data. Removal of encroaching PJ will continue in summer-fall 2010, and post-treatment monitoring will continue through 2012. Additional plots may be added in 2010 pending additional funding for removals and surveys.

GREATER SAGE-GROUSE RESEARCH IN THE PARACHUTE-PICEANCE-ROAN REGION OF WESTERN COLORADO. PART I: ASSESSMENT OF GREATER SAGE-GROUSE RESPONSE TO PINYON-JUNIPER REMOVAL

Progress Report, December 1, 2008 - August 1, 2010

Brett L. Walker, Chris Binschus, Orrin Duvuvuei, Nathan Schmitz

INTRODUCTION

Large-scale changes to sagebrush ecosystems and historical population declines (Schroeder et al. 2004) have raised concern about the status and conservation of greater sage-grouse (*Centrocercus urophasianus*) and repeated petitions for listing under the Endangered Species Act (DOI 2005). Greater sage-grouse in the Parachute-Piceance-Roan (PPR) region of western Colorado are of conservation concern due to long-term declines in habitat suitability caused by pinyon-juniper (PJ) encroachment and potential impacts from rapidly increasing energy development. PJ removal has been proposed as a way to restore sage-grouse habitat and offset or mitigate impacts of energy development in the PPR and elsewhere. However, we lack quantitative data on the magnitude and timing of such responses. The objective of this study is to measure greater sage-grouse response to experimental removal of encroaching PJ using changes in winter track and pellet occupancy in a before-after control-treatment design.

Removal of pinyon and juniper trees from areas with an existing sagebrush understory may help restore sage-grouse habitat in the PPR. Pinyon-juniper encroachment into sagebrush has been identified as a threat to the species habitat in Colorado (CGSSC 2008; Chapter IV) and range-wide (CGSSC 2008). Encroachment in the PPR has occurred over the last 150 years and is thought to be caused by fire suppression, reduced fire frequency due to removal of residual grass via livestock grazing, and a window of climatic conditions suitable for PJ establishment during the late 1800s and early 1990s (Miller and Rose 1999).

The management goal of PJ removal in the PPR is to increase suitable habitat for sage-grouse as mitigation. This management technique has been widely implemented in Colorado and range-wide in the name of habitat improvement (CGSSC 2008). However, sage-grouse response to these management actions has been poorly studied. In fact, only one published study exists that addresses sage-grouse responses to PJ removal (Commons et al. 1999). Although we suspect that sage-grouse will eventually occupy areas where PJ removal has restored suitable local habitat conditions, three key questions remain unanswered. First, what level of PJ encroachment leads to avoidance of otherwise suitable sagebrush habitat? Second, how long does it take for sage-grouse to colonize an area following PJ removal? Third, how important are landscape-scale habitat features in determining sage-grouse response to PJ removal even if local habitat conditions are suitable?

METHODS

Study Area

The study area encompasses the majority of the current occupied range of the PPR sage-grouse population (Fig. 1). Within that area, we selected a subset of suitable ridges for the PJ removal study. We concentrated our efforts in the central portion of this region and did not work on Magnolia Ridge, Brush Mountain, Skinner Ridge, or Kimball Mountain. In this area, greater sage-grouse inhabit the tops of ridges and plateaus that are dissected by steep drainages. Vegetation is dominated by mountain big sagebrush (*Artemisia tridentata vaseyana*) and mountain shrubs (e.g., serviceberry, *Amelanchier* spp.; Gambel oak, *Quercus gambelii*, snowberry, *Symphoricarpus* spp.; wild rose, *Rosa* spp., etc.) interspersed with patches of aspen (*Populus tremuloides*) and Douglas-fir (*Pseudotsuga menziesii*). Sagebrush and mountain shrub habitats on ridges give way to pinyon pine (*Pinus monophylla*) and juniper (*Juniperus* spp.) forest at lower elevations that preclude use by sage-grouse. The southeast portion of the study area is experiencing intensive energy development, whereas only limited development is present in the western portion. Some parts of the study area were either temporarily or permanently inaccessible to field crews due to physical barriers (e.g. steep drainages, snow drifts), lack of roads, or lack of access to or across private land.

Field Methods

Data from newly-collared birds augmented an existing dataset from 85 radio-collared females and males monitored during 2006-2008 as part of the original project. Capturing females in the PPR population is difficult due to poor access during the lekking season when hens attend leks and because detectability is low in the tall, dense vegetation used by birds in spring, summer, and fall. Field crews captured or recaptured and radio-marked 12 females from 3 Oct - 8 Dec 2008, 13 females from 1 Apr - 28 Apr 2009, and 22 females from 31 Aug - 10 Nov 2009 within the study area using spotlights and hoop nets at night (Wakkinen et al. 1992), shoulder-mounted net-guns, and bumper-mounted net launchers (Fig. 2). All captured birds were sexed, aged, and fitted with aluminum, numbered leg bands and 17-g necklace-style radio collars (Advanced Telemetry Systems model A4060; Isanti, MN). Field crews collected exact GPS locations (±10-15 m) on radio-collared birds approximately 1-2 times a week from September – November 2008, once approximately every 1-2 weeks from December 2008-March 2009, and approximately 1-2 times a week from April-November 2009. We regularly relocated missing birds on telemetry flights from fixed-wing aircraft as needed.

Assessment of Pinyon-juniper Removal

This phase of research focuses on assessing short-term (2-5 years) responses of sage-grouse to PJ removal. We are using a before-after, control-treatment design to compare changes in sage-grouse winter track occupancy and summer pellet occupancy among control and treatment plots before and after encroaching PJ is removed. Caution must be exercised in interpreting results because estimates of occupancy only give an index of frequency of use, rather than of habitat quality or habitat selection.

We have three levels of treatment: (1) removal plots where encroaching PJ is removed, (2) control plots where encroaching PJ is present, but not removed, and (3) sagebrush control plots. Removal plots are used to document responses of sage-grouse to PJ removal. Surveying control plots where encroaching PJ remains untreated allows us to measure background changes in sage-grouse use of areas with encroaching PJ in the absence of treatment. Surveying sagebrush control plots without any PJ allows us to estimate background changes in sage-grouse use of nearby areas where sagebrush habitat is already suitable. All plots will be surveyed for 1-2 years prior to implementing removals and for 3-4 years following removal. We survey 3 plots per treatment. The number of plots per treatment is limited by the availability of suitable adjacent ridges with encroaching PJ. All plots selected for treatments had a sagebrush understory to ensure that habitat suitability for sage-grouse is maximized once PJ is removed.

Plot selection. – We used vegetation, topography, and marked bird locations in GIS to identify potential removal and control plots in 2008, then followed up with on-site visits in summer 2009 to select final site boundaries (Fig. 3). All removal plots have sparse PJ in the overstory, a sagebrush-dominated shrub layer, suitable topography, and are adjacent to where we already have radio-marked birds. Rapidly spreading energy development in the PPR may be a problem because it has the potential to confound response metrics, so we identified areas at which development is unlikely for several years. Although energy development may eventually negate the value of PJ removal, our findings can still be used to inform managers about the effectiveness of PJ removal as mitigation. Those findings can then be used to quantify the value of off-site mitigation in other areas with encroachment in northwestern Colorado.

Winter track surveys. We will estimate changes in frequency of use by sage-grouse using occupancy measured from ground-based track surveys (MacKenzie et al. 2006). We hypothesize that, after controlling for local- and landscape-scale habitat conditions, that winter use will increase following removal of encroaching PJ, but with a time lag due to fidelity to wintering areas. This estimator gives an estimate of the proportion of the plot that sage-grouse use during the 24-36 hr survey period following a winter storm. Winter track surveys have the following assumptions: (1) all animals move and leave tracks during the survey period (between when snowfall stops and when the survey is conducted); (2) all tracks deposited in sample units during the survey period can be seen and correctly identified; (3) surveys do not influence whether or not tracks are present in sampled units; (4) pre-storm tracks can be distinguished from post-storm tracks; and (5) all sample units within a plot are surveyed on the same day. Assumption 1 is likely to be met because wintering sage-grouse typically forage during the day. It is possible that sage-grouse may snow burrow for part or all of the survey period, but entrances to snow burrows are easily visible and can be counted as tracks. Tracks may also be buried if blowing snow fills in fresh tracks. In western Colorado, winter storms are typically followed by 1-2 days of relatively calm, sunny, cold weather. To ensure that we meet Assumption 1, surveys will be aborted if windy conditions occur during the survey period. Assumption 2 is likely to be met because sage-grouse tracks can be distinguished from other birds with similar sized tracks by behavior, pellet smell, and pellet composition. Sage-grouse typically travel from one sagebrush to another, sometimes dropping leaves on the snow, as they forage, whereas dusky grouse (*Dendragapus obscurus*) typically forage on and travel between conifers and common ravens (*Corvus corax*) often double-hop on the ground rather than walking and do not eat sagebrush. Sage-grouse also leave distinctive sagebrush-filled pellets that smell strongly of sagebrush in winter. Assumption 3 may be violated if surveyors flush birds that then land within another sample unit later surveyed. Although this assumption cannot be tested or controlled for, we can record whether birds flushed from the sample unit, how many, and whether they flew toward or away from the unsurveyed portion of the plot. Birds thought to be part of a previously-detected flock can be noted as such and removed from analyses. Assumption 4 is met because surveys are conducted immediately following snowstorms. Snowfall during the storm buries old tracks, and fresh, post-storm tracks are easily distinguished from older, pre-storm tracks even when old tracks are still visible (often they are not). To meet assumption 5, we conduct surveys on one day across an equal number of plots in each treatment level following each storm. Different groups of plots may need to be sampled after different snowstorms depending on the manpower available. Vegetation data can be collected the day after if necessary, surveying to ensure that all selected sample units within plots are surveyed on the same day.

For surveys, we gridded each plot into 30 m x 30 m sample units and selected sample units to survey using a systematic-random sampling design. We selected a 30 x 30 m sample unit size so that sample units were large enough to contain sage-grouse tracks but small enough to ensure that all tracks within the sample unit were detected. Within each sample unit, we record presence or absence of sage-grouse tracks and estimate the number of individuals that left tracks. We also collect the following local habitat covariates likely to influence use at each sample unit surveyed: (1) pinyon-juniper height and density; (2) snow depth; (3) average exposed height for important dominant or co-dominant shrub species (e.g. sagebrush, mountain shrubs); (4) shrub cover of dominant or co-dominant species, and (5) approximate no. of hours since last snowfall. We will also measure important landscape-scale covariates identified as important predictors of use in winter habitat selection analyses on each sample unit in a GIS (e.g., terrain ruggedness, distance to nearest forested habitat, or amount of sagebrush habitat at specific scales) and include them as covariates in analyses to test for the influence of landscape-scale habitat variables on sage-grouse responses. Because it may take longer for sage-grouse to colonize areas farther away from currently used areas, regardless of habitat suitability following treatments, we will also include a covariate with approximate distance from nearest known-use area (estimated from habitat use by marked birds). To test for different possible patterns of the timing of colonization of treated areas by sage-grouse, we will incorporate a time-trend variable, with the prediction that use will increase either linearly or quadratically over time. We use a logit-link in the analysis to constrain occupancy estimates to a (0, 1) interval.

Winter vegetation surveys. – We measure snow depth at the sample unit center, average exposed shrub height of sagebrush and non-sagebrush shrubs, and no. of pinyon and juniper trees in three height categories (0-2 m, 2-4 m, > 4 m) within each sample unit on each visit (Connelly et al. 2003). The purpose of measuring vegetation cover is to determine whether local-scale habitat is already suitable for sage-grouse and to control for effects of among-sample unit and among-plot variation in sagebrush and non-sagebrush vegetation cover and height. We quantify sagebrush and non-sagebrush shrub cover using line-intercept methods (Canfield 1941) during the summer because using line-intercept technique is impractical in deep snow.

Winter pellet collection for genetic analysis. – No previous studies have estimated winter track occupancy for sage-grouse, and the relationship between track occupancy and the no. of individuals present remains unknown, so the method requires validation. We plan to test whether occupancy reflects true abundance by comparing occupancy estimates to abundance estimated from genetic mark-recapture results. We plan to use mark-recapture methods using non-invasive genetic samples based on winter pellet sampling to estimate the no. of individuals using each plot over the course of the winter. We collect ≥1 fecal pellet per individual track encountered during track occupancy surveys. Pellets deposited along tracks of foraging birds in winter are either fresh or recently frozen and thus highly suitable for DNA extraction. Oyler-McCance and St. John (2008) developed methods to identify individual sage-grouse from fecal pellets, and such methods appear to be reliable, with >10 polymorphic microsatellite loci available for analysis and relatively low rates of misclassification. Statistical methods are also now available that allow estimation of genotyping error if sample sizes permit (Lukacs and Burnham 2005). Tracks typically have pellets on them every 10-20 ft. (B. Walker, pers. obs.), so it is likely that pellets can be obtained for most if not all birds whose tracks cross a surveyed sample unit. Because surveys of each plot are repeated, we can use pellets collected during the second and third survey periods to estimate detectability of individuals for mark-recapture analyses. Details of genetic methods are described in Oyler-McCance and St. John (2008). Genotypes encountered across survey periods allow us to generate an encounter history data for analysis in a mark-recapture framework and estimate the number of grouse using the survey plot, the probability of a grouse remaining in the survey plot among occasions, and detection probabilities.

Summer pellet surveys. – We obtained an index of use during the summer-fall periods by estimating pellet occupancy in Jul-Oct (MacKenzie et al. 2006). Additionally, spring-fall (May-Oct) pellets can be distinguished by the presence of intact insect parts and flower heads in droppings, whereas winter (Dec-Feb) pellets consist entirely of digested sagebrush leaves (Wallestad et al. 1975). This allows us to generate separate estimates for spring-fall, winter, and year-round occupancy from pellet data. An occupancy estimator gives an estimate of the proportion of the plot on which sage-grouse have deposited pellets during the survey period. Because we cannot assume that all sage-grouse using a plot or sample unit deposit pellets (defecation rates for sage-grouse are unknown and sage-grouse may use a plot or sample unit without defecating), we cannot measure actual sage-grouse occupancy in any season, only pellet occupancy during the survey period (*contra* Dahlgren et al. 2006). Pellet surveys have the following assumptions: (1) all pellets can be correctly identified as adult or chick by size; (2) adult-sized pellets can be correctly identified as either sage-grouse or non-sage-grouse; and (3) surveys do not influence whether or not pellets are present in sampled units. Quantitative analyses only focus on adult-size pellets because pellets from dusky grouse chicks and sage-grouse chicks probably cannot be differentiated, and both species occur in the study area. Adult pellets of the two species can probably be distinguished by smell. Adult-sized sage-grouse typically consume 13-39% sagebrush throughout the spring and summer (Wallestad et al. 1975, Schroeder et al. 1999) such that adult-sized pellets typically smell strongly of sagebrush, even in summer, whereas sagebrush has never been documented in the diet of dusky grouse in any season (Zwickel 1992). Dusky grouse pellets smell of plant material, but lack the pungent smell of sagebrush, a pattern that has been double-checked by smelling pellets deposited by sage-grouse and dusky grouse encountered in the field. We train all observers to identify sage-grouse pellets by appearance, composition, and smell prior to surveys. Assumption 3 may be violated if surveyors flush birds that then land within another sample unit later surveyed. However, violation of this assumption is unlikely to meaningfully influence analyses because the number of pellets deposited in an unsurveyed sample unit during the brief window before the unit is surveyed is small compared to the entire survey window (Aug-Sept).

We used a subset of the same systematic-random sample of 30 m x 30 m sample units selected for winter track surveys for conducting pellet surveys. This allows us to use vegetation sampling data for both analyses. Crews search for foraging pellets, roost piles (day or night), and cecal piles within each 30 x 30-m sample unit. Hereafter, we refer to single pellets, roost piles, and cecal droppings simply as ―pellets". Sample units are visited in July to document, count, and remove pellets, then surveyed again for newly deposited pellets in October. Pellets within 0.1 m of each other are recorded as one pellet cluster. Sample unit centers are marked using high-visibility flagging and numbered aluminum tags. Each observer carefully and thoroughly surveys the sample unit, counts the number of pellet clusters present, counts the number of pellets within each cluster, and removes all pellets encountered from the sample unit. Pellet detectability is typically low and may vary among observers (Dahlgren et al. 2006), so we estimate detectability of pellets and observer bias by having each observer survey eight sample units in which we place clusters of fresh pellets of various sizes (1, 4, 8, and 12 pellets) at random directions and distances up to 14 m from the sample unit center. Sample units used for testing detectability are exhaustively grid-searched prior to surveys to ensure that no fresh pellets are present before the test.

Summer vegetation surveys. – We will sample and compare vegetation at locations used by marked sage-grouse in winter and within each sample unit on treatment and control plots to determine whether local-scale habitat is already suitable for sage-grouse and to control for vegetation features known to influence breeding-season habitat selection (Hagen et al. 2007). We will establish two 30-m perpendicular intersecting transects running true N-S, E-W to measure local-scale vegetation features within sample units in Aug-Sep. Along each transect, we will measure: (1) shrub canopy cover by species using the line-intercept method (Canfield et al. 1941); (2) height of the nearest shrub (excluding inflorescences) within 2.5 m; (3) height of nearest live grass (maximum droop height of leaves, excluding inflorescences); (4) height of residual dead grass (maximum droop height of leaves, excluding inflorescences); and (5) cover of ―forage" forbs within Daubenmire quadrats at 5-m intervals along transect lines. Data collected at the sample unit center point only counts as one data point. We define ―forage" forbs as those previously identified as major components of adult or juvenile spring and summer diets (Klebenow 1969, Drut et al. 1994, Barnett and Crawford 1994, Gregg et al. 2008).

Pellet survey analysis. – In the final analysis, we will consider the following local habitat covariates likely to influence grouse winter or spring-summer use at each sample unit surveyed: (1) pinyon-juniper density; (2) sagebrush and non-sagebrush canopy cover by species; (3) average sagebrush height; (4) average shrub height; (5) average live and residual grass height, and (6) ―forage" forb cover. Important landscape-scale covariates identified as important predictors of use from summer habitat selection analyses will also be measured on each sample unit in GIS and included as covariates to test for the influence of landscape-scale habitat variables on sage-grouse responses. Because it make take longer for sage-grouse to colonize areas farther away, regardless of habitat suitability following treatments, we will also include a covariate with distance from nearest known active lek. To test for different possible patterns of the timing of colonization of treated areas by sage-grouse, we will incorporate a time-trend variable. Data from each survey of each sample unit will be maintained as a separate record in the analysis. We will use a logit-link to constrain occupancy estimates to a (0, 1) interval.

Pinyon-juniper removal. In areas with sparse PJ, we may use a chainsaw crew to minimize soil disturbance ($100/acre) or a Bobcat with Fecon head ($75/acre). In areas with denser PJ, we will use a Hydroaxe ($175-$300/acre, depending on PJ density). All areas selected for treatment were in the beginning stages of encroachment (i.e., numerous small trees) to ensure that PJ removal would produce the greatest suitable sagebrush habitat for the least amount of money.

RESULTS

Seasonal Locations

Field crews and flights collected ~2900 locations from 106 marked birds (mostly females) from Apr 2006 - Aug 2009 (Fig. 4). These data are currently being used in multi-scale habitat selection models to create high-resolution maps of greater sage-grouse seasonal habitats throughout the PPR.

Winter Track Surveys

We conducted one complete set of winter track surveys on each of the 9 plots in Jan-Feb 2009. As expected, winter track occupancy was higher on sagebrush control plots than on plots with encroaching PJ (Table 1). Sagebrush control plots had winter track occupancy estimates of 0.012-0.069, whereas plots with encroaching PJ showed zero occupancy. We counted 17-45 individual tracks on control plots during the survey period, whereas we found zero tracks on plots with PJ (Table 1). Estimating the number of individuals using a sample unit based on tracks was difficult for large flock sizes greater than approximately 10, so counts of tracks must be considered an index of abundance rather than an exact count. Winter surveys from 2009-2010 are nearly complete, and those data will be analyzed in spring 2010.

Genetics

Although completing only one survey in winter 2008-2009 precluded genetic mark-recapture analyses, we collected 90 pellet samples from 10 sample units with tracks. Pellet collection is still underway this winter. These samples will provide a minimum estimate of the number of individuals using each plot from genetic markers. Contracting for the genetic analysis is underway and frozen pellet samples are in storage in Grand Junction.

Summer Pellet Surveys

We conducted one complete set of pellet surveys on each of the 9 plots in August 2009 to assess the feasibility of the survey methodology. Surveys took much longer than anticipated to complete, and we were unable to complete a follow-up survey in fall 2009. For that reason, occupancy estimates do not represent summer use of the plot in 2009, but rather accumulated use of the plot over a time period comparable with how long it takes pellets to deteriorate in the field (~2-3 years).

Pellet surveys indicated higher winter and summer occupancy rates on sagebrush control plots than on plots with encroaching PJ (Table 2). Fresh pellets (those from summer 2009) were found on 0.00-0.055 (mean = 0.018, n = 3) of control plots, whereas plots with encroaching PJ had none (mean 0.000, n = 6). Data from summer pellets of all ages indicated summer occupancy of 0.049-0.127 (mean = 0.098, n = 3) on control plots versus 0.000-0.061 (mean = 0.028, n = 6) on plots with encroaching PJ. Data from winter pellets of all ages indicated higher winter occupancy (range 0.268-0.382, mean = 0.344, n = 3) on control plots than on plots with encroaching PJ (range 0.000-0.104, mean = 0.041, n = 6).

Pellet detectability

Observers conducted pellet surveys on eight 30 x 30 m test plots. Each plot contained four piles of fresh sage-grouse pellets of different sizes (1, 4, 8, and 12 pellets). Detectability of fresh pellets was low overall (0.118) and variable among the four observers (0.00, 0.06, 0.13, and 0.22). Variable detectability may be an issue for interpretation of data from pellet surveys, particularly if effect sizes are small between treatment and control plots.

DISCUSSION

Overall, occupancy data from winter track surveys and summer pellet surveys were largely as expected, with higher occupancy on sagebrush control plots than on plots with encroaching PJ. Genetic work to estimate the no. of individuals from pellet samples in spring 2010 will help resolve whether track counts within sample units are a reliable index of the number of birds using a sample unit and whether occupancy is a reliable index of the number individuals using a plot.

We are collecting data on locations of marked females in fall 2009 through spring 2010 as a validation dataset for seasonal habitat use maps generated from 2006-2009 data (Table 3). Three sets of winter track surveys will be conducted from December 2009 - February 2010. Two sets of summer pellet surveys will be conducted 2010, one in July and a follow-up in October.

ACKNOWLEDGEMENTS

We thank field crew leaders Brandon Miller, Evan Phillips, and Kaylan Kemink, as well as numerous field technicians and volunteers for collecting field data. We thank Brad Petch, Brian Holmes, Dan Neubaum, and Kellen Keisling for assistance with logistics and field work. Larry Gepfert piloted telemetry flights. Encana, Shell, Williams, Conoco-Philips, and the Colorado Division of Wildlife provided funding and support for the project. We thank Encana, Exxon-Mobil, Williams, Conoco-Phillips, Chevron, and numerous private landowners and lessees for generously allowing access to private lands within the study area for research. We thank Heather Sauls, Ed Hollowed, and Kent Walters at the Bureau of Land Management White River Field Office for support of the project and for logistical assistance and funding for pinyon-juniper removal.

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Table 1. Raw winter track occupancy estimates (Ψ) ± SE, minimum total no. of tracks detected per plot (N), and no. sample units surveyed (n) for greater sage-grouse in January and February 2009 in the Parachute-Piceance-Roan region of western Colorado, USA.

	PJ – Pre-treatment			PJ – Control (No Treatment)			Sagebrush - Control		
	Upper Galloway	Black Sulphur	Ryan Gulch	Dry Ryan	Eureka	Stake Springs	Dry Gulch	Canyon Creek	Black Cabin
Ψ	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.069 ± 0.027	0.012 ± 0.012	0.048 ± 0.023
N	0	0	0	0	0	0	45	17	18
n	(109)	(74)	(98)	(65)	(96)	(77)	(87)	(82)	(84)

Table 2. Raw occupancy estimates ± SE for greater sage-grouse pellets surveyed in August 2009 in the Parachute-Piceance-Roan region of western Colorado, USA. n = no. sample units surveyed per plot.

PJ – Pre-treatment				PJ – Control (No Treatment)				Sagebrush - Control			
Upper Galloway	Black Sulphur	Ryan Gulch	Mean	Dry Ryan	Eureka	Stake Springs	Mean	Dry Gulch	Canyon	Black Cabin	Mean
n = 49	n = 38	n = 48	± SE	n = 55	n = 50	n = 38	± SE	n = 55	n = 41	n = 42	± SE
2009 Summer Pellet Occupancy (fresh pellets)											
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.055	0.000	0.000	0.018
± 0.000	± 0.000	± 0.000	± 0.000	± 0.000	± 0.000	± 0.000	± 0.000	± 0.031	± 0.000	± 0.000	± 0.018
Summer Pellet Occupancy (all pellets)											
0.061	0.000	0.042	0.034	0.000	0.040	0.026	0.022	0.127	0.049	0.119	0.098
± 0.034	± 0.000	± 0.029	± 0.018	± 0.000	± 0.028	± 0.026	± 0.012	± 0.045	± 0.034	± 0.050	± 0.025
Winter Pellet Occupancy (all pellets)											
0.061	0.000	0.104	0.055	0.000	0.000	0.079	0.026	0.382	0.268	0.381	0.344
± 0.034	± 0.000	± 0.044	± 0.030	± 0.000	± 0.000	± 0.044	± 0.026	± 0.066	± 0.069	± 0.075	± 0.038
Year-round Pellet Occupancy (all pellets)											
0.082	0.000	0.146	0.076	0.000	0.040	0.105	0.048	0.436	0.293	0.452	0.394
± 0.039	± 0.000	± 0.051	± 0.042	± 0.000	± 0.028	± 0.050	± 0.031	± 0.067	± 0.071	± 0.077	± 0.051

TABLE 3. Revised timeline for greater sage-grouse research (seasonal habitat maps and assessment of pinyon-juniper removal) in the Parachute-Piceance-Roan population, western Colorado, 2006-2010.

Task	Initiation	Completion
Seasonal habitat use maps		
GIS analyses and seasonal model development	31 Aug 2009	IN PROGRESS
Collect validation location dataset	1 Sep 2009	30 June 2010
Complete final model assessment and GIS map processing.	1 Mar 2010	31 Mar 2010
Prepare final report on winter habitat-use maps	31 Mar 2010	30 April 2010
Prepare final report on breeding habitat-use maps	15 Jul 2010	15 Aug 2010
Assessing response to PJ removal		
Identification of plots for PJ removal	COMPLETE	COMPLETE
Winter track surveys, pellet collection (annually)	1 Jan	1 Mar
Remove encroaching PJ (2010)	1 Aug	15 Nov
Analysis of winter track data (annually)	1 Mar	1 Jun
Analysis of genetic samples (annually, depends on no. samples)	1 Apr	1 Jun
Analysis of genetic data (annually)	1 Jun	1 Aug
Prepare cumulative report (annually)	1 Aug	1 Oct
Prepare cumulative final report	1 Aug 2012	1 Oct 2012

Figure 1. Distribution map of the Parachute-Piceance-Roan greater sage-grouse population showing occupied, potential, and vacant/unknown habitat (CGSSC 2008).

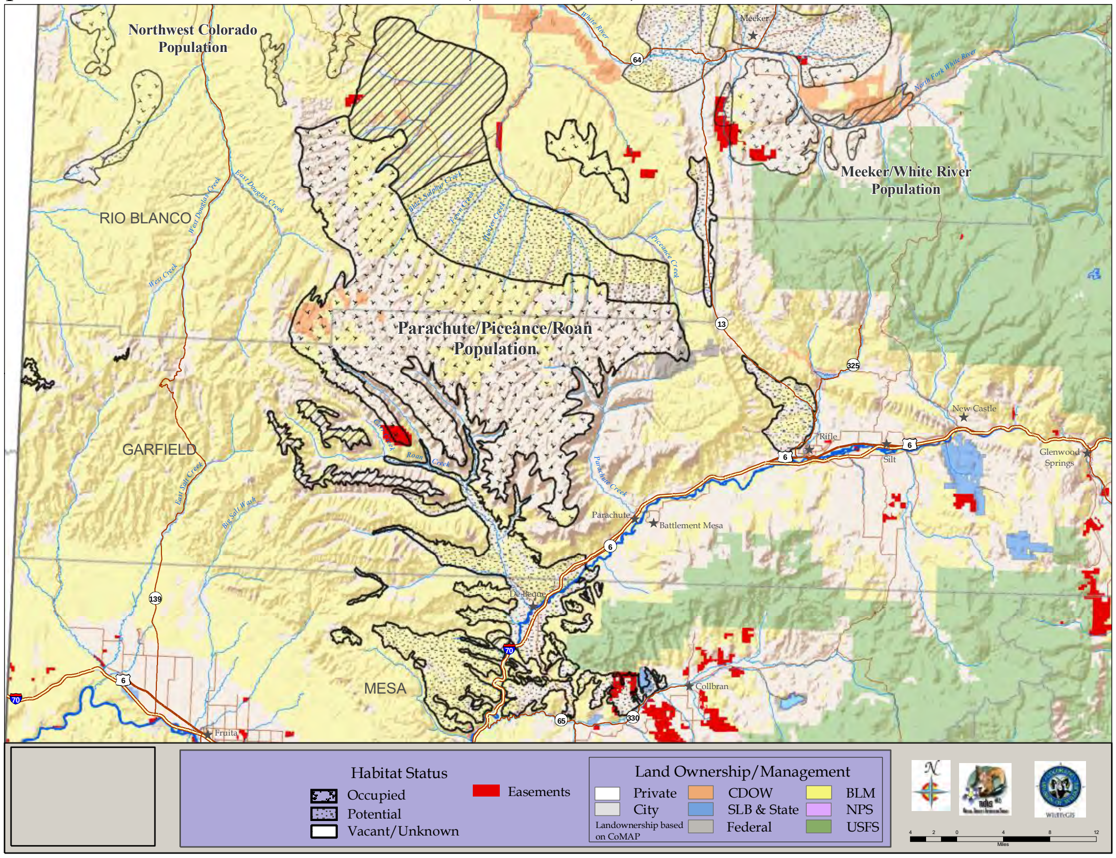

Figure 2. Bumper-mounted CODA net launcher used to capture greater sage-grouse.

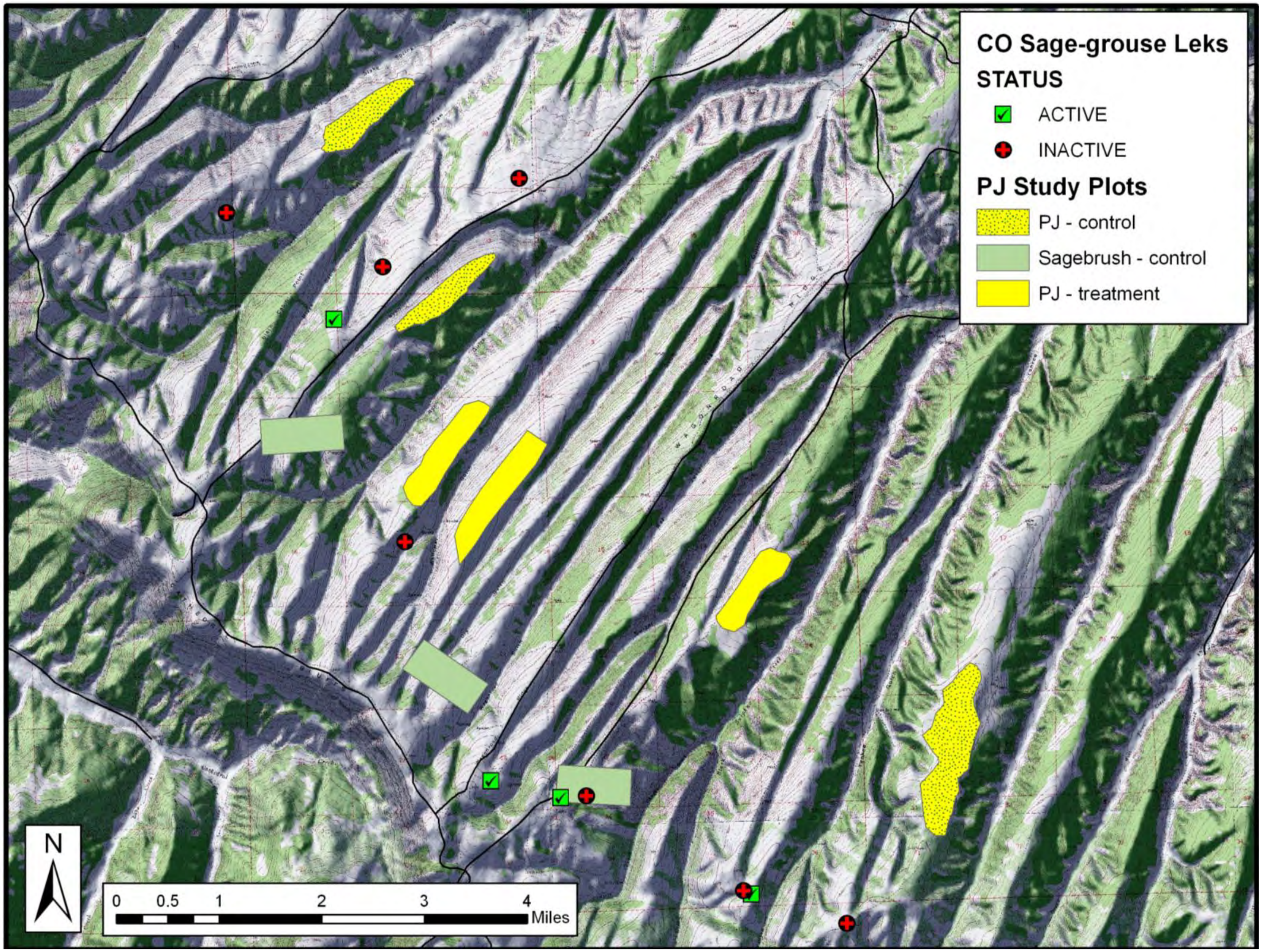

Figure 3. Study plots for the pinyon-juniper removal experiment on the west side of the PPR population.

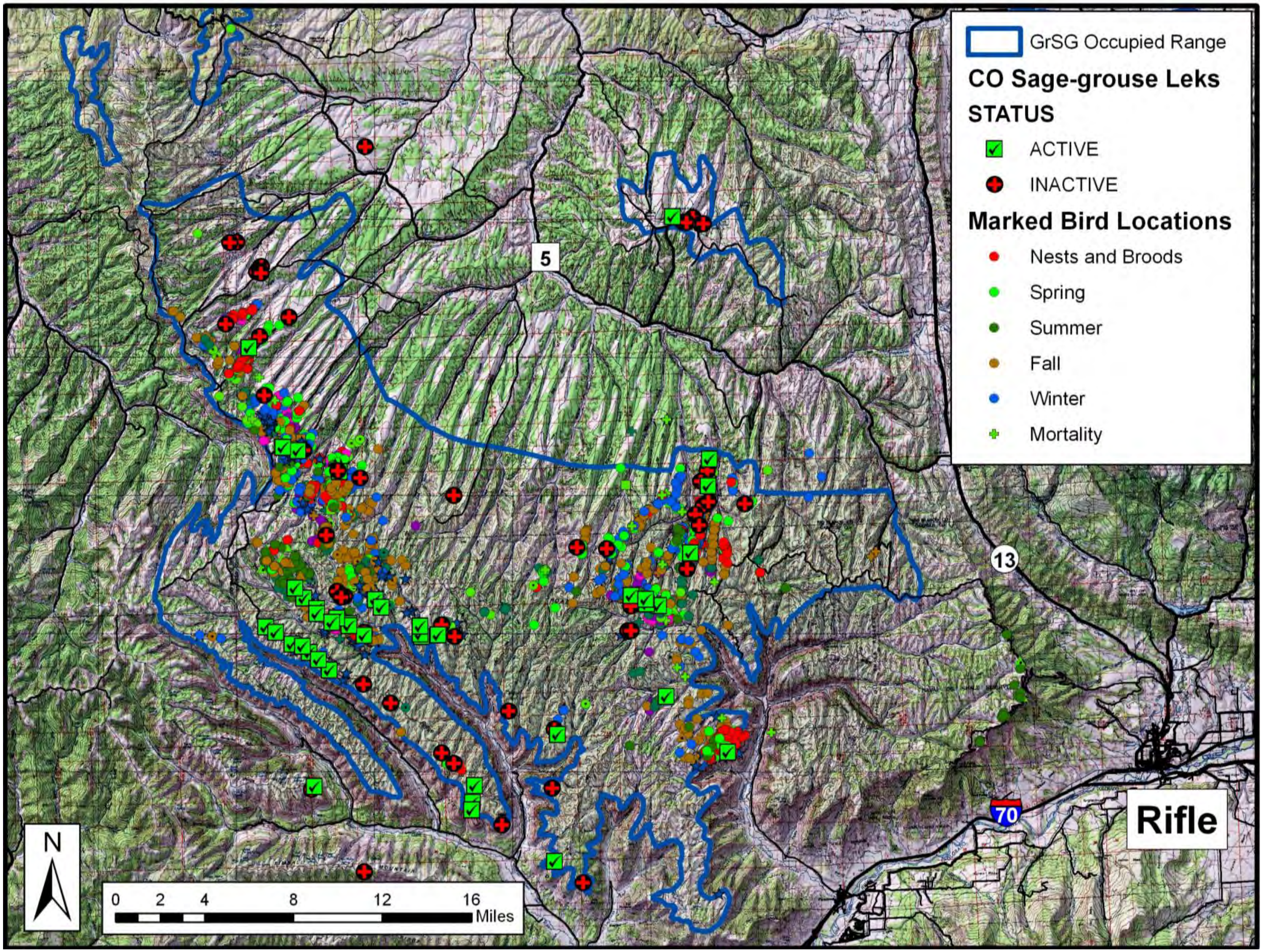

Figure 4. Occupied range, active and inactive leks, and seasonal locations of marked greater sage-grouse in the Parachute-Piceance-Roan

population, northwestern Colorado, 2006-2009. Some flight locations were collected in areas inaccessible to field crews.

COLORADO DIVISION OF WILDLIFE - AVIAN RESEARCH PROGRAM
PROGRESS REPORT
September 2010

TITLE: Greater sage-grouse research in the Parachute-Piceance-Roan region of western Colorado. Part II: Multi-scale habitat selection and seasonal habitat mapping

AUTHOR: B. L. Walker

PROJECT PERSONNEL: B. deVergie, B. Holmes, T. Knowles, B. Petch, J.T. Romatzke, A. Romero, Colorado Division of Wildlife

Period Covered: March 1, 2006 - August 1, 2010

ABSTRACT

Loss and degradation of sagebrush habitat throughout western North America has led to growing concern for conservation of greater sage-grouse (*Centrocercus urophasianus*) and repeated petitions to list the species under the Endangered Species Act. Greater sage-grouse in the Parachute-Piceance-Roan (PPR) region of western Colorado face at least two known potential stressors: increasing energy development and a long-term decline in habitat suitability associated with pinyon-juniper encroachment. In 2006, the Colorado Division of Wildlife (CDOW) and industry partners initiated a 3-year study to obtain baseline data on seasonal habitat use, movements, vital rates, and genetics of greater sage-grouse in the PPR. CDOW has since expanded that original project to include two new objectives: (1) generate high-resolution maps showing high-priority seasonal use areas for the entire population, and (2) assess the value of pinyon-juniper removal for increasing sage-grouse habitat. Industry, landowners, and state and federal agencies need high-resolution maps showing where sage-grouse occur during each season to streamline development planning, quantify mitigation needs, and guide on-the-ground sage-grouse conservation efforts. I conducted multi-scale habitat selection analyses and validation for the breeding and summer-fall seasons using a total of 1130 breeding-season locations from 102 radio-marked individuals collected from 2006-2010 and 1367 summer-fall locations from 84 radio-marked individuals collected from 2006-2009. I used logistic regression to test landscape-level habitat features at six scales (100, 350, 740, 1000, 1600, and 3200 m). Models validated well against independent locations (R^2 = 0.912-0.984). Sage-grouse selected similar habitat features at similar scales in all both seasons. They selected for greater proportion sagebrush at multiple scales (100-m and 350-m), higher elevations, and flatter terrain. They selected against proportion forest (350-m or 740-m) and proportion mountain shrub-only (740-m or 1600-m). Landscape-level guidelines for sage-grouse are based on 25%-75% quartiles of values for key predictor variables measured at used locations. Breeding areas should have: (a) less rugged topography within 100 m (roughness index = 4.82-9.55), (b) 57.6-96.2% sagebrush-dominated habitat within 100m, (c) 90.4-98.4% sagebrush + grassland + mixed sagebrush-mountain shrub habitat within 350 m, (d) 0.5-6.5% forested habitat within 350 m, (e) 0.0-1.2% mountain shrub-only habitat within 740 m, and (f) areas 140-314 m from forest. Summer-fall habitat should have: (a) less rugged topography within 100 m (roughness index 5.20-10.31), (b) 50-92% sagebrush-dominated habitat within 100 m, (c) 88.1-98.6% sagebrush + grassland + sagebrush-mountain shrub habitat within 350 m, (d) 4.5-11.5% forested habitat within 740 m, (e) 0.0-1.3% mountain shrub-only habitat within 740 m, (f) 0.0% riparian habitat within 1000 m, (g) northeast and northwest-facing terrain, and (h) areas 98-268 m from forest. Breeding and summer-fall habitat largely overlapped in this population. Sage-grouse in both seasons

selected landscapes with a mixture of sagebrush, grassland (or sparse sagebrush), and mixed sagebrush-mountain shrub habitat types over habitats with sagebrush alone. These results support three main concepts in sage-grouse habitat selection. First, sage-grouse require sagebrush year-round. Although sage-grouse used landscapes with a mosaic of habitats during breeding and in summer-fall, > 95% of used locations had a sagebrush component, and sage-grouse consistently preferred local patches dominated by sagebrush. Second, sage-grouse selected areas based on habitat features at multiple scales. Models with sagebrush at multiple scales always outcompeted those with sagebrush at only one scale, even after controlling for topography and other habitat types. Third, sage-grouse are a ―landscape" species. Birds consistently selected areas with more sagebrush habitat and less non-sagebrush habitat at large scales, even after controlling for local topography and the amount of sagebrush within 100 m. Future assessments of habitat suitability for greater sage-grouse should consider not only local-level metrics like shrub composition, height, and cover, but also topography and the amount of sagebrush and non-sagebrush habitat at multiple scales (100 - 3200 m or more). Model results also support ongoing efforts to reduce pinyon-juniper encroachment into sagebrush habitats in the PPR. Other types of treatments may be appropriate if the habitat resulting from the treatment meets both local-level and landscape-level sage-grouse habitat guidelines. CDOW can consult with landowners regarding treatments on a case-by-case basis as needed. These maps provide a starting point for answering additional ecological and management questions and for informing development planning, mitigation, and conservation strategies for greater sage-grouse in the PPR. However, model results applied outside the analysis area may not hold and should be interpreted with caution.

GREATER SAGE-GROUSE RESEARCH IN THE PARACHUTE-PICEANCE-ROAN REGION OF WESTERN COLORADO. PART II: MULTI-SCALE HABITAT SELECTION AND SEASONAL HABITAT MAPPING

Progress Report, March 1, 2006 - August 1, 2010

Brett L. Walker

PROJECT OBJECTIVES

The objective of this study is to use locations of radio-marked greater sage grouse to generate high-resolution habitat-use maps for each season for the entire PPR population.

SEGMENT OBJECTIVES

INTRODUCTION

Large-scale changes to sagebrush ecosystems and historical population declines (Schroeder et al. 2004) have raised concern about the status and conservation of greater sage-grouse (*Centrocercus urophasianus*) and repeated petitions to list both the species and distinct population segments under the Endangered Species Act (DOI 2005). Greater sage-grouse in the Parachute-Piceance-Roan (PPR) region of western Colorado are of conservation concern due long-term declines in habitat suitability caused by pinyon-juniper encroachment and potential impacts from increasing energy development. Both issues are listed as threat factors in the USFWS listing decision in spring 2010 (DOI 2010). In 2006, the Colorado Division on Wildlife (CDOW) and industry and agency partners initiated a study to obtain baseline data on sage-grouse seasonal habitat use, movements, vital rates, and genetics for the PPR population. In 2008, the Colorado Greater Sage-grouse Conservation Plan identified seasonal habitat mapping as a state-wide research priority. High-resolution maps showing concentrated seasonal use areas would be valuable for improving sage-grouse conservation and development planning. Pinyon-juniper removal has been proposed as a way to restore sage-grouse habitat and offset or mitigate impacts of energy development in the PPR and elsewhere. However, we lack quantitative data on the magnitude and timing of how sage-grouse respond to pinyon-juniper removal. The objectives of this study are to: (1) use locations of marked sage grouse to generate high-resolution habitat-use maps for each season for the entire PPR population and, (2) experimentally quantify greater sage-grouse response to removal of encroaching pinyon-juniper using changes in winter track and pellet occupancy in a before-after control-treatment design.

This is the second of three reports. Here we summarize results of multi-scale seasonal habitat selection analysis and seasonal habitat mapping efforts for breeding and summer-fall. Results of multi-scale seasonal habitat selection analysis and seasonal habitat mapping efforts for winter will follow in a separate report.

Identifying and delineating important seasonal habitats is critical for agencies, industry, and landowners to make informed decisions about how to conserve key wildlife species in the face of landscape-level energy development. However, in most areas, seasonal habitats for greater sage-grouse have not been adequately mapped at a high enough resolution to be used in detailed planning, mitigation, and conservation efforts (Manly et al. 2002, Doherty et al. 2008). For this reason, mapping seasonal habitats is listed as a top priority in the Colorado greater sage-grouse state-wide conservation plan (CGSSC 2008).

Managers also lack landscape-level guidelines for sage-grouse habitat. Sage-grouse are widely considered a ―landscape" species in that they require large areas of sagebrush habitat to persist (Schroeder et al. 1999; Connelly et al. 2000), but little quantitative data exists to evaluate that conclusion because most habitat information for this species comes from studies that measure vegetation at small scales (e.g., 15 m radius plots; Connelly et al. 2000, Hagen et al. 2007, CGSSC 2008). Research over the past four decades, including in the PPR, has carefully documented local-level features of habitat used by sage-grouse in each season, including the height, cover, and composition of shrubs, grasses, and forbs (for review, see Schroeder et al. 1999, Hagen et al.

2007, CGSSC 2008). However, only recently have studies begun to examine landscape-level habitat requirements (Homer et al. 1993, Walker et al. 2007, Aldridge et al. 2008, Doherty et al. 2008, Doherty et al. 2010), and almost no published data are available to determine how much sagebrush habitat is required, and at which scales, to maintain viable sage-grouse populations. It is also unclear how much non-sagebrush habitat at which scales prevents use by sage-grouse. For that reason, it is imperative to test the influence of vegetation and topography at multiple scales to determine which scale(s) sage-grouse use in selecting habitat and to generate quantitative criteria for landscape-level conservation.

Recent advances in resource selection modeling and availability of high-resolution imagery allow mapping the relative probability of habitat use at high resolution over large areas (Johnson et al. 2006, Doherty et al. 2008). This approach also allows competing hypotheses to be addressed about the influence of local and landscape factors at multiple scales on habitat selection and external validation of models against independent datasets to ensure findings are robust (Boyce et al. 2002, Johnson et al. 2006).

The specific objectives of the multi-scale habitat selection analysis and seasonal habitat mapping component of the PPR project are to: (1) generate high-resolution maps of important sage-grouse breeding, summer-fall, and wintering habitat for the PPR population, (2) identify the appropriate scale at which habitat features influence habitat use, and (3) quantify landscape-level habitat criteria. In this progress report, we present results and maps from breeding and summer-fall habitat selection analyses.

METHODS

Study Area

The study area encompassed the majority of occupied range of the PPR sage-grouse population as of 2006 as defined in the Colorado Greater Sage-grouse Conservation Plan (CGSSC 2008; Fig. 1) plus a 3 km buffer to include some marked birds that moved outside this boundary as well as adjacent areas of unoccupied habitat (Fig. 2). This area is a mix of public and private land with >20 major landowners (Fig. 3). Only part of the study area could be used in analyses due to restrictions on access and logistical issues. For that reason, I restricted use of data points to an ―analysis area” within which radio-marked birds would have been regularly available for tracking by field crews (Fig. 4). CDOW updated the occupied range boundary in July 2010 (Fig. 4). I applied results of the modeling to the entire 2010 occupied range boundary plus a 3 km buffer (including the Magnolia section) because these areas were adjacent to and similar enough in vegetation and topography to the analysis area that extrapolation seemed reasonable. However, model results applied outside the analysis area may not hold and should be interpreted with caution.

Field Methods

Capturing females in the PPR population is difficult due to poor access during the lekking season when hens attend leks and because they are difficult to see in the tall, dense vegetation used by birds in spring, summer, and fall. Field crews captured or recaptured and radio-marked 12 females from 3 Oct - 8 Dec 2008, 13 females from 1 Apr - 28 Apr 2009, and 22 females from 31 Aug - 10 Nov 2009 within the study area using spotlights and hoop nets at night (Wakkinen et al. 1992), shoulder-mounted net-guns, and bumper-mounted net launchers. All captured birds were sexed, aged, and fitted with aluminum, numbered leg bands and 17-g or 22-g necklace-style radio collars (Advanced Telemetry Systems model A4060; Isanti, MN). Data from these birds augmented an existing dataset of 85 radio-collared females and males monitored during 2006-2008 as part of the original project. Field crews collected exact GPS locations (±10-15 m) on radio-collared birds approximately 1-2 times a week from September - November 2008, once approximately every 1-2 weeks from December 2008-March 2009, and approximately 1-2 times a week from April-November 2009. Field crews relocated missing birds on telemetry flights from fixed-wing aircraft as needed; temporarily missing birds were monitored on average less often than other birds. From September 2008 through July 2010, field crews recorded the major habitat type and dominant and sub-dominant shrub species within 15 m of the exact location where marked birds were found. Habitat types were classified as either aspen, barren, coniferous forest, grassland, mixed sagebrush-mountain shrub, mountain shrub, sagebrush, road (dirt or gravel road or two-track), pipeline, or well pad.

Multi-scale Habitat Selection Analyses

Study design. I conducted habitat selection analyses using resource selection function approach (RSF). I employed a used vs. pseudo-absence design rather than a used vs. available design to reduce contamination of absence points (Keating and Cherry 2004). I pooled used locations of all marked individuals to make inferences at the population level (Design II; Erickson et al. 2001, Manly et al. 2002). I then conducted logistic regression on used (1) vs. pseudo-absence (0) points in R, version 2.11.0 (R Core Development Team, 2010).

Used vs. Pseudo-Absence Points. I included each location of a radio-marked bird once in the analysis as a used location, with the exception that we considered each nest as only one location. I opted to retain locations in which marked birds were found in a flock with another marked bird(s) because it is unclear statistically whether such points are actually non-independent and doing so may bias analyses by giving less weight to flocks that had more marked birds. I defined breeding-season locations as those during the pre-nesting, nesting, and early brood-rearing periods (CGSSC 2008). I defined the start of the breeding season as 16 March in each year, as that is when females begin moving from individual wintering areas to nesting areas. I identified the end date of the breeding season in each year by adding 14 days to the date on which 95% of birds were estimated to have completed nesting. I included locations from both successful and unsuccessful hens during this period. I defined the end of the summer-fall season as November 30 in each year, as that when significant snowfall occurs and birds shift from individual summer-fall ranges to wintering areas. I used locations collected from 2006-2009 to build models. Final data sets for building models contained 1072 breeding-season locations from 93 individuals and 1112 summer-fall locations from 67 individuals.

I generated pseudo-absence points within a portion of the study area referred to as the ―analysis area" where field crews would have had regular, authorized access for monitoring radio-marked birds (Fig. 4). I considered all habitats within the analysis area as available for two reasons. First, marked sage-grouse have shown long-distance movements within the study area, so we felt that all birds were capable of accessing any part of the analysis area at any time within a given season. Second, avoidance of certain types of habitats is as important for mapping probability of use as is preference for other habitat types, so it is important to include areas of known non-habitat in analyses. To generate pseudo-absence points for each season, we randomly selected available points from within the analysis area with the restriction that they could not fall within a dissolved average daily movement distance buffer around used points for that season. Average daily movements were 165 m during the breeding season and 240 m during summer and fall. The rationale behind using average daily movement distance is that a marked bird could have used any point within that distance on the same day without the field crew detecting the bird at that point. This sampling design is essentially a sample of available points with undetected used points removed. In other words, it represents a set of pseudo-absence points that marked birds were highly unlikely to have used. I used equal numbers of used and pseudo-absence points in the breeding and summer-fall analyses because we had sufficient sample sizes for pseudo-absence points to fully represent habitat types within the analysis area. I selected pseudo-absence points only from within the analysis area; otherwise locations that marked birds used but where field crews lacked access would have been overrepresented in the pseudo-absence sample.

Hypotheses and variables tested. Sage-grouse typically occur in sagebrush habitat and largely avoid non-sagebrush habitats and areas with rugged terrain (Hupp and Braun 1989, Homer et al. 1993, Connelly et al. 2000, Doherty et al. 2008). For that reason, all models included effects of sagebrush and non-sagebrush habitat at various scales and topography. To test the hypothesis that sage-grouse are a ―landscape" species, I allowed models with sagebrush measured only at the smallest scale (a ―local-level model") to compete against models with sagebrush measured at larger scales (―landscape" models), and against models with additive effects of sagebrush at both scales or an interaction of sagebrush variables across scales. Because it is well-established that sage-grouse prefer sagebrush habitat at small scales (Connelly et al. 2000, Hagen et al. 2007), the landscape hypothesis predicts that there should be a positive effect of sagebrush at a larger scale over and above a positive effect of sagebrush at the smallest scale (100-m), after controlling for avoidance of non-sagebrush habitats and topography. There are also two competing hypotheses about the diversity of habitat types that sage-grouse prefer. One hypothesis suggests that sagebrush habitat has enough within-habitat variation in diversity and structure of shrubs, grasses, and forbs to accommodate all their seasonal habitat needs – this hypothesis predicts that sagebrush-only or sagebrush-dominated habitats will be the best predictor of habitat use. An alternative is that sagebrush habitat by itself does not vary enough meet all their seasonal habitat needs so sage-grouse prefer a mosaic of sagebrush, grassland, and sagebrush mixed with other shrubs (Crawford et al. 2004). This hypothesis predicts that sage-grouse will most strongly select some combination of sagebrush, grassland, and sagebrush-mountain shrub habitats. Sage-grouse diets in spring, summer, and fall consist of a mix of sagebrush, forbs, and insects (Wallestad et al. 1975, Drut et al. 1994, Gregg et al. 2008), so I predicted that a combination of sagebrush, grassland, and mixed sagebrush-mountain shrub habitat would be selected more strongly than sagebrush-only or sagebrush-dominated habitats. Finally, I hypothesized that sage-grouse would avoid forested habitats because they are commonly used by raptors that prey on sage-grouse, such as northern goshawk (*Accipter gentilis*) and great horned owl (*Bubo virginianus*). This hypothesis predicts that sage-grouse will strongly avoid areas with greater forested habitat, specifically aspen, conifer, and pinyon-juniper, and they will prefer areas further from forest. Based on general habitat preferences, I also predicted that sage-grouse would strongly avoid areas with other non-sagebrush habitat at large scales as well, such as mountain shrub-only and barren habitats. Mountain shrub-only habitat typically lacks any sagebrush component and consists of serviceberry [*Amelanchier utahensis*], Gambel oak [*Quercus gambelii*], antelope bitterbrush [*Purshia tridentata*], mountain mahogany [*Cercocarpus* spp.], snowberry [*Symphoricarpus* spp.], wild currant [*Ribes* spp.], and wild rose [*Rosa* spp.]).

I considered 15 continuous cover-type variables in each analysis. The first nine variables are ―sagebrush” variables: (1) proportion sagebrush-only habitat, (2) proportion sagebrush-dominated habitat, (3) proportion mixed sagebrush-mountain shrub habitat, (4) proportion sagebrush-only + grassland habitat, (5) proportion sagebrush-dominated + grassland habitat, (6) proportion sagebrush-only + mixed sagebrush-mountain shrub habitat, (7) proportion sagebrush-dominated + mixed sagebrush-mountain shrub habitat combined, (8) proportion sagebrush-only, mixed sagebrush-mountain shrub, and grassland habitat combined, and (9) proportion sagebrush-dominated, mixed sagebrush-mountain shrub, and grassland habitat combined. I also tested (10) proportion forested habitat, (11) proportion grassland habitat (if not included in sagebrush metrics), (12) proportion mountain shrub-only habitat, (13) proportion barren habitat, (14) proportion riparian habitat, and (15) distance to forest (linear and quadratic). I calculated all habitat metrics from cover types in a classified state-wide vegetation layer developed by the Colorado Vegetation Classification Project (CVCP; Fig. 5). I combined cover types in the CVCP layer to generate a smaller number of more general habitat classes relevant to the hypotheses being tested (Table 1).

I also considered topographic variables derived from a 10-m digital elevation model, including elevation, slope, an index of terrain roughness, and aspect to address the influence of topography. The index of terrain roughness was calculated as the standard deviation of the elevation of pixels within the buffer (Doherty et al. 2008). Aspect was converted from degrees to a scale representing extent of southern exposure from 0-1 (0 = north; 1 = south) using the transformation: $[1-\cos([2\pi * \text{aspect}]/360)]/2$. I predicted that sage-grouse would use higher elevation areas with gentle slopes and low values of terrain roughness. I also predicted that sage-grouse would use areas with greater southern exposure during breeding because snow melts off earlier in spring, exposing forbs and nesting shrubs sooner, and sagebrush on north-facing slopes is more likely to remain buried under snow for longer. I predicted greater use of north-facing slopes in summer and fall because they remain mesic for longer and should have a higher abundance of forbs and insects for longer. I had no *a priori* reason to anticipate an effect of terrain ruggedness at large scales, so it was only measured at the three smallest scales (100, 350, and 740 m). I did not include oil and gas or other types of infrastructure (roads, power lines, vehicle traffic, etc.) as predictors because data on the distribution of these features were not available for each year across the entire study area.

Scale. I measured habitat variables using a circular buffer at six scales around used and pseudo-absence points for all analyses: 100, 350, 740, 1000, 1600, and 3200 m (values indicate radius of the buffer). I selected these scales, in part, to match those of studies in other parts of the species' range (Doherty et al. 2010, Walker 2010). The 100-m scale represents patch-level habitat selection, the scale at which birds can see and assess the habitat around them. We used 100 m to minimize the influence of GPS unit error (± 26 m). I used the 350-m and larger scales to represent landscape-level habitat selection, scales at which other ecological factors such as the availability of escape cover or the distribution and abundance of predators, might influence habitat selection. Because there is no *a priori* reason to think that any specific scale would be most influential, I selected values of 1000, 1600, and 3200 m (0.6 mi. 1 mi., and 2 mi.) to make them relevant to management.

Analyses. I first assessed support for each variable across scales to identify the scale(s) that best represented sage-grouse habitat selection based on log-likelihood values. Variables > 2 AIC_c units below the best model and for which 95% CIs of odds ratios overlapped 1.0 in univariate analyses were excluded from further consideration. All other variables were used in various combinations to build the final *a priori* model set. All models in the final model set represented biologically plausible alternative hypotheses for sage-grouse habitat selection. I did not allow correlated variables ($r > 0.7$) or the same variable at different scales in the same model, with the exception of sagebrush variables across scales. I checked for stability of regression coefficients and associated standard errors in models with correlated variables ($r > 0.4$) and excluded models in which regression coefficients switched signs or had grossly inflated standard errors. I used AIC_c values to assess relative support for different models (Burnham and Andersen 2002). I then converted regression coefficients from the best model into a spatially-explicit layer showing relative probability of use by applying them to GIS layers using a resource selection function across the entire landscape. I conducted parametric bootstrapping in R (version 2.11.0) to generate 95% confidence intervals for the effects of habitat variables on relative probability of use. This involved generating a bootstrap dataset of 1000 sets of regression coefficients with the same covariance structure as the best approximating model, then finding 2.5% and 97.5% cut-offs for those values.

Model Validation. I tested the robustness and predictive power of the best model for each season following validation techniques outlined in Johnson et al. (2006). This involved: (1) dividing the RSF values into 5-6 ordinal bins, (2) calculating the midpoint RSF value and area for each bin, (3) calculating the expected number of validation observations in each bin based on the area within that bin and probability of use from the best approximating model, and (4) regressing the observed number of validation locations in each bin against the expected number of locations in each bin. Models that fit the data should have a high R^2 value, a slope of 1.0, and an intercept not different than zero (Johnson et al. 2006). I used 58 locations collected in spring 2010 from 9 birds captured in fall 2009 (and not monitored in previous breeding seasons) to validate the breeding model. For the summer-fall model, we randomly selected 20% of the individuals in the database and used 255 locations from those 17 individuals for validation. No individuals or locations used to build models were used to test models. I also overlaid seasonal habitat maps with locations of marked greater sage-grouse collected in the PPR in 1997-1998 to see how well our maps predicted locations collected a decade earlier.

RESULTS

Seasonal Locations

Field crews visited 4370 locations of 114 marked females and 14 marked males (including captures, nest visits, flight data, and mortalities) from Apr 2006 - July 2010 (Fig. 6). After removing duplicates (e.g., multiple visits to the same nest), mortalities, imprecise flight locations, and locations outside the analysis area, 3104 seasonal locations were available for analyses and model validation. Of those, 2434 locations were collected during the breeding and summer-fall seasons.

Cover Types and Shrub Species at Used Locations

At 1133 locations of marked birds visited during the breeding and summer-fall seasons from 2008-2010, 45.3% had sagebrush as the primary habitat type within 15 m, 39.2% had sagebrush-mountain shrub mix, 6.3% had grassland, 1.8% had pipeline cut, 3.1% had dirt or gravel roads or two-tracks, 2.8% had mountain shrub, 0.6% had aspen, 0.5% had well pad (either old or new), and 0.3% had barren. Of 1120 locations with shrub species recorded, 84.9% had mountain big sagebrush (*Artemisia tridentata vaseyana*) listed as the dominant shrub species, 8.1% had serviceberry, 1.6% had Gambel oak, 1.2% had yellow (*Chrysothamnus viscidiflorus*) or rubber rabbitbrush (*Ericameria nauseosa*), 0.7% had aspen (*Populus tremuloides*), 0.6% had snowberry, and the remaining 2.9% had no shrubs or other shrub species. Of the 50 locations in grassland habitat, 86% had mountain big sagebrush listed as a dominant or subdominant shrub, indicating that most grassland habitat types included some sparse sagebrush within 15 m. Mountain big sagebrush was present as a dominant or sub-dominant shrub within 15 m at 95.9% of 1120 breeding and summer-fall locations with shrub species recorded; serviceberry was present at 54.9%; green rabbitbrush, rubber rabbitbrush or broom snakeweed (*Gutierrezia sarothrae*) was present at 51.9%; Gambel's oak was present at 20.2%; and aspen was present at 3.0%.

Breeding Analyses

Ten variables were retained after univariate analysis and were incorporated into models in the final model set: (1) proportion sagebrush-dominated habitat within 100 m, (2) proportion sagebrush + grassland + mixed sagebrush-mountain shrub within 350 m, (3) proportion forest within 350 m, (4) proportion mountain shrub habitat within 740-m, (5) proportion barren habitat within 100 m, (6) roughness within 100 m, (7) distance to forest, (8) elevation, (9) slope, and (10) aspect (transformed). Two pairs of variables (roughness within 100 m and slope; proportion sagebrush + grassland + mixed sagebrush-mountain shrub within 350 m and forest within 350 m) were highly correlated; only one variable from each pair was allowed in each model and those variables were allowed to compete. An additive model with sagebrush variables at the 100-m and 350-m scales outcompeted models with effects of sagebrush at only one scale, quadratic sagebrush models, and models with interactions of sagebrush variables across scales. However, in the final model set, a negative effect of proportion forest within 350 m was a better predictor of use than was a positive effect of proportion sagebrush + grassland + mixed sagebrush-mountain shrub combined within 350 m.

The best-supported model with stable coefficients and standard errors included additive effects of proportion sagebrush-dominated habitat within 100 m, proportion forest within 350 m, roughness within 100 m, distance to forest, and elevation (Table 2). Regression coefficients indicated that breeding sage-grouse preferred patches of sagebrush-dominated habitat with locally flat topography (both at 100-m scale) within landscapes further from forest, with less forest habitat (350-m scale), at higher elevation, and with less mountain shrub-only habitat (740-m scale) (Table 2, Fig. 7). The resulting RSF map was divided into 6 ordinal bins that represent areas with varying relative probability of use by breeding greater sage-grouse (Fig. 8). Together, RSF bins 5 and 6 (orange and red areas combined) represent 94.4% of predicted breeding habitat (Fig. 8). The remaining bins each had < 5% relative probability of use.

Summer-Fall Analyses

Ten variables were retained after univariate analysis and were incorporated into models in the final model set: (1) proportion sagebrush-dominated habitat within 100 m, (2) proportion sagebrush + grassland + mixed sagebrush-mountain shrub within 350 m, (3) proportion forest within 740 m, (4) riparian habitat within 1000 m, (5) proportion barren habitat within 100 m, (6) roughness within 100 m, (7) distance to forest, (8) elevation, (9) slope, and (10) aspect (transformed). Two pairs of variables (roughness within 100 m and slope; proportion sagebrush + grassland + mixed sagebrush-mountain shrub within 350 m and forest within 740 m) were highly correlated; only one variable from each pair was allowed in each model and those variables were allowed to compete. An additive model with sagebrush variables at the 100-m and 350-m scales outcompeted models with effects of sagebrush at only one scale, quadratic sagebrush models, and models with an interaction of sagebrush variables across scales. However, a negative effect of proportion forest within 740 m was a better predictor of sage-grouse use than a positive effect of proportion sagebrush + grassland + mixed sagebrush-mountain shrub within 350 m.

The best-supported model with stable coefficients and standard errors included additive effects of proportion sagebrush-dominated habitat within 100 m, proportion forest within 740 m, proportion riparian habitat within 1000 m, roughness within 100 m, elevation, and aspect (Table 3). Regression coefficients indicated that sage-grouse in summer and fall preferred patches of sagebrush-dominated habitat (100-m scale) within larger areas with less forest (740-m scale), locally flat topography (100-m scale), higher elevations, less mountain shrub-only habitat (740-m scale), and less riparian habitat (1000-m) (Table 3, Fig. 9).

The resulting RSF map was divided into 5 ordinal bins that represent areas with varying relative probability of use by greater sage-grouse in summer and fall (Fig. 10). Together, RSF bins 4 and 5 (dark green and light green areas combined) represent 98.4% of predicted summer-fall habitat (Fig. 10). The remaining bins each had < 5% relative probability of use.

Validation

We were unable to divide RSF values into more than 5 bins for the summer-fall analysis. The majority of validation locations in all three models fell in the top RSF bin (bin 5 or 6, depending on season). All three models had reasonably high R^2 values (0.912-0.984), slopes close to 1.0, and intercepts not statistically different than 0.0. The breeding model slightly underestimated locations in RSF bin 4. The breeding validation resulted in R^2 = 0.9124, slope = 1.272 [95% CI: 0.725 to 1.819], and intercept = -2.627 [95% CI: -12.345 to 7.091] (Fig. 13a). The summer-fall validation resulted in R^2 = 0.9838, slope = 1.116 [95% CI: 0.853 to 1.379], and intercept = -5.931 [95% CI: -30.911 to 19.049] (Fig. 13b). Validation results predicted that the top two RSF bins for would contain 94.5% of breeding locations and 98.4% of summer-fall locations.

Models performed well in predicting an independent dataset of marked greater sage-grouse locations collected a decade earlier by CDOW in 1997-1998. The top two bins were predicted to contain 94.5% of breeding locations and 93.5% of summer-fall locations from 1997-1998 (Figs. 13-14).

Landscape-level Habitat Guidelines

The majority of breeding sage-grouse used areas at high mean elevation (2470 m, or ~8100 ft.) with relatively flat topography within 100 m (roughness index 4.8-9.5), 58-96% (mean 74%) sagebrush-dominated habitat within 100 m, 90-98% (mean 93%) sagebrush + grassland + mixed sagebrush-mountain shrub habitat within 350 m, 0.5-6.5% (mean 4.6%) forested habitat within 350 m, 0.0-1.2% (mean 0.8%) mountain shrub-only habitat within 350 m, and areas 140-314 m from forest (Table 4).

In summer and fall, the majority of sage-grouse used areas at a slightly higher mean elevation (2506 m, or ~8200 ft.) with relatively flat topography within 100 m (roughness index 5.2-10.3), with 50-92% (mean 69%) sagebrush-dominated habitat within 100 m, 88-98% (mean 92%) sagebrush + grassland + mixed sagebrush-mountain shrub habitat within 350 m, 4.4-11.5% (mean 8.7%) forested habitat within 740 m, 0.0-1.3% (mean 0.8%) mountain shrub-only habitat within 740 m, 0.0% (mean 0.0%) riparian habitat within 1000 m, and areas with more northeastern (262°-315°) or northwestern (45°-98°) exposure (mean was equivalent to 74° or 286° from true north) (Table 5).

DISCUSSION

Greater sage-grouse in the PPR were more likely to spend their time in areas that had both more sagebrush in the immediate vicinity (e.g., within 100 m), more sagebrush habitat at larger scales (350-m), and less forested and mountain shrub-only habitat at larger scales (e.g., 350-740 m) in both seasons. In combination with vegetation, terrain roughness within 100 m was a key predictor of sage-grouse use and consistently a better predictor than slope or aspect. Models that measured selection for sagebrush habitats at two scales were much more strongly supported in both analyses than single-scale models. Numerous previous studies have documented the importance of sagebrush habitat at even smaller scales than we measured here (e.g., 15-25 m scale; Connelly et al. 2000, Hagen et al. 2007). In combination, our finding of selection for sagebrush variables at two scales (100-m and 350-m) and published evidence for selection at local scales (e.g., within 15 m) suggests that sage-grouse are influenced by, and select habitat features at multiple scales. The scale at which sage-grouse selected sagebrush habitat was smaller in the PPR (350 m) than in NW Colorado (740-1000 m; Walker 2010). This may be because fewer sagebrush-dominated landscapes are available for use in the PPR and birds are using the largest patches of sagebrush-dominated habitat that remain.

Field observations indicate that over 95% of all habitat types used by sage-grouse in all seasons had at least some sagebrush component (i.e., some mountain big sage within 15 m). However, at 43 of those locations where sagebrush was present, it was sparse enough that they were classified as grassland instead of sagebrush in the CVCP layer. Interestingly, in both the breeding and summer-fall models, avoidance of forest was a better overall predictor of where grouse occurred than was selection for habitats with a sagebrush component (after controlling for mountain shrub-only habitat). This is likely because most of the habitat surrounding good sage-grouse habitat in the PPR (other than mountain shrub-only) is either aspen, conifer, or pinyon-juniper forest. Aspect did not play a role in the breeding model, but selection for more north-facing aspects in the summer-fall model is consistent with the hypothesis that grouse use more mesic areas as grasses and forbs on ridge tops desiccate in summer and fall.

Seasonal habitat maps support the classification of greater sage-grouse in the PPR as non-migratory, despite the fact that some individuals made long-distance movements within the study area, both within and across seasons. High-priority breeding and summer-fall habitats largely overlapped, with slightly more predicted summer-fall habitat than breeding habitat.

From a practical standpoint, high-priority areas shown on seasonal habitat maps should be considered an indicator that the appropriate cover types and topography are present at the appropriate scales and sage-grouse are likely to occur there. On our maps, an absence of locations of radio-marked sage-grouse does not necessarily indicate absence of sage-grouse, particularly in parts of the study area inaccessible to field crews or where it was logistically difficult to capture birds. Seasonal habitat maps based on landscape-level features measured in GIS provide a foundation for identifying high-priority habitat over large areas at fairly high resolution, but where sage-grouse actually occur on the ground within those high-priority areas will also depend on local-level habitat features, including percent sagebrush (and other shrub) cover, shrub height, live and residual grass height, forb abundance, etc. (Connelly et al. 2000, Hagen et al. 2007, CGSSC 2008). Additionally, error inherent in the CVCP cover type layer may contribute to inaccuracy in model predictions. No post-classification accuracy assessment has been completed for the CVCP layer, so overall accuracy of the habitat layer is unknown. Regardless, results indicate that managers should also consider both local-level and landscape-level vegetation and topography when assessing habitat suitability for greater sage-grouse in the PPR. Future on-the-ground assessments of habitat suitability should also include a GIS assessment of habitat types within 350-3200 m derived from the CVCP layer and terrain roughness from a digital elevation model.

Landscape-level habitat and topography guidelines can also help identify appropriate areas for habitat treatment. For example, treatments will only be effective if they are implemented in areas with appropriate topography for sage-grouse (e.g., gently sloped, high elevation ridges). Treatments should also focus on areas where habitat does not currently meet landscape-level guidelines, rather than areas that already do. Treatments to increase breeding and summer-fall habitat in the PPR should set a goal of achieving areas with 50-96% sagebrush-dominated habitat within 100 m, 88-96% sagebrush + grassland + mixed sagebrush-mountain shrub within 350 m, 0.5-11.5% forest with 350 m, and < 1.2% of mountain shrub-only habitat, as measured in the CVCP layer. If treatments are implemented with the goal of reducing the proportion of non-sagebrush habitat types on the landscape, they will only be effective if what remains after treatment is habitat that sage-grouse will use (e.g., removing aspen or conifer forest from an area without a sagebrush understory would not be effective). Results from both models support ongoing efforts to reduce pinyon-juniper encroachment into sagebrush habitats by BLM and CDOW in partnership with private landowners and energy companies. Other types of treatments may be appropriate if the habitat resulting from the treatment results in habitat for sage-grouse that meets both local-level and landscape-level guidelines. For example, where landscape-level guidelines have already been met (e.g., areas within RSF bins 5-6 for breeding or bins 4-5 for summer-fall), treatments may still be required to meet guidelines for sagebrush canopy cover and height, grass cover and height, etc. (CGSSC 2008). CDOW encourages a cooperative approach to treatments and can consult with landowners on a case-by-case basis.

Field crews have completed data collection on radio-marked birds. Vegetation sampling will continue through September 2010. Winter track surveys and summer pellet surveys will continue through 2012 to assess sage-grouse response to pinyon-juniper removal (Table 6).

ACKNOWLEDGMENTS

Jeff Beck supervised field data collection in 2006. Tony Apa supervised field data collection in 2007-2008 and was instrumental in the success of the field project. Karin Eichhoff conducted all GIS analyses. I thank our hard-working field crew leaders Brandon Miller, Evan Phillips, Kaylan Kemink, Chris Binschus, and Carl Bullock, as well as numerous field technicians and volunteers for collecting field data. Brad Petch, Brian Holmes, Dan Neubaum, Kellen Keisling, and Tom Knowles assisted with project logistics and field work. I thank Heather Sauls, Ed Hollowed, and Kent Walters at the Bureau of Land Management's White River Field Office for their ongoing support of the project and for logistical assistance and funding for pinyon-juniper removal. Larry Gepfert piloted telemetry flights. Encana, Shell, Williams, and Conoco-Philips provided funding and support for this project. The Colorado Division of Wildlife provided additional funding, housing, and vehicles for field work. I thank staff at Encana, Conoco-Philips, Exxon-Mobil, Shell, Williams, Conoco-Phillips, Chevron, and numerous private landowners and lessees for generously allowing crews access to private lands within the study area for research. I thank J. C. Rivale, Bill deVergie, and Ron Velarde for allowing us to use Little Hills State Wildlife Area facilities and J. C. Rivale for helping with snowmobile recovery.

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Table 1. Descriptions and habitat groupings for cover types in the Parachute-Piceance-Roan population, Colorado from the Colorado Vegetation Classification Project (CVCP).

Class no.	Cover type description	Habitat type
6	Irrigated Ag	Riparian
24	Greasewood	Riparian
31	Sagebrush/Greasewood	Riparian
34	Rabbitbrush/Grass Mix	Riparian
104	Riparian	Riparian
109	Shrub Riparian	Riparian
110	Willow	Riparian
111	Exotic Riparian Shrubs	Riparian
112	Herbaceous Riparian	Riparian
114	Water	Riparian
11	Grass Dominated	Grassland
13	Grass/Forb Mix	Grassland
18	Foothill and Mountain Grasses	Grassland
19	Disturbed Rangeland	Grassland
32	Shrub/Grass/Forb Mix	Grassland
103	Subalpine Grass/Forb Mix	Grassland
22	Sagebrush Community	Sagebrush-only, sagebrush-dominated
33	Sagebrush/Grass Mix	Sagebrush-only, sagebrush-dominated
23	Saltbush Community	Sagebrush-dominated
35	Sagebrush/Mesic Mountain Shrub Mix	Sagebrush-dominated, mixed sagebrush-mountain shrub
40	Sagebrush/Rabbitbrush Mix	Sagebrush-dominated
28	Snowberry/Shrub Mix	Mixed sagebrush-mountain shrub
48	Mesic Mountain Shrub Mix	Mixed sagebrush-mountain shrub
49	Serviceberry/Shrub Mix	Mixed sagebrush-mountain shrub
27	Snowberry	Mountain shrub
46	Gambel Oak	Mountain shrub
47	Xeric Mountain Shrub Mix	Mountain shrub
43	Pinyon-Juniper	Forest
44	Juniper	Forest
53	Pinyon-Juniper-Oak Mix	Forest
54	Pinyon-Juniper-Sagebrush Mix	Forest
55	Pinyon-Juniper-Mountain Shrub Mix	Forest
56	Sparse Pinyon-Juniper/Shrub/Rock Mix	Forest
57	Sparse Juniper/Shrub/Rock Mix	Forest
58	Juniper/Sagebrush Mix	Forest
62	Aspen	Forest
63	Aspen/Mesic Mountain Shrub Mix	Forest
66	Engelmann Spruce/Fir Mix	Forest
67	Douglas Fir	Forest
69	Sub-Alpine Fir	Forest
78	Fir/Lodgepole Pine Mix	Forest
79	Douglas Fir/Engelmann Spruce Mix	Forest
81	Spruce/Fir/Aspen Mix	Forest
84	Douglas Fir/Aspen Mix	Forest
105	Forested Riparian	Forest
108	Conifer Riparian	Forest
91	Rock	Barren
92	Talus Slopes & Rock Outcrops	Barren
93	Soil	Barren

Table 2. Regression coefficients for variables in the best approximating model of greater sage-grouse breeding habitat selection in the Parachute-Piceance-Roan population, Colorado, 2006-2009.

Variable	Estimate (β) ± SE
Intercept	-9.769 ± 1.831
Proportion sagebrush-dominated habitat within 100 m	1.807 ± 0.2561
Proportion forest within 350 m	-9.518 ± 0.9048
Proportion mountain shrub-only habitat within 740 m	-38.47 ± 4.481
Terrain roughness within 100 m	-0.1533 ± 0.01512
Elevation (m)	0.004767 ± 0.000716
Distance to forest (m)	0.001406 ± 0.0005747

Table 3. Regression coefficients for variables in the best approximating model of greater sage-grouse summer-fall habitat selection in the Parachute-Piceance-Roan population, Colorado, 2006-2009.

Variable	Estimate (β) ± SE
Intercept	-36.186975 ± 3.081181
Proportion forest within 740 m	-16.169219 ± 1.168489
Proportion sagebrush-dominated habitat within 100 m	1.888706 ± 0.301398
Proportion mountain shrub-only within 740 m	-53.431828 ± 5.675204
Proportion riparian habitat within 1000 m	-99.478843 ± 50.591082
Terrain roughness within 100 m	-0.160485 ± 0.019555
Elevation (m)	0.016521 ± 0.001238
Aspect (transformed)	-2.548745 ± 0.281008

Table 4. Summary of vegetation and topography variables at selected scales at 1072 breeding-season locations of marked greater sage-grouse in the Parachute-Piceance-Roan population, Colorado, 2006-2009.

	SageDom[1] 100-m	SageMixGrass[1] 350-m	Forest 350-m	Mtn. shrub 740-m	Roughness[1] 100-m	Elevation (m)	Distance to forest (m)
Mean ± SE	0.742 ± 0.008	0.930 ± 0.002	0.046 ± 0.002	0.008 ± 0.000	7.68 ± 0.12	2470 ± 2.06	244 ± 4.81
Median	0.816	0.956	0.024	0.003	6.90	2473	214
(25-75% quartiles)	(0.576-0.962)	(0.904-0.983)	(0.005-0.065)	(0.000-0.012)	(4.82-9.55)	(2427-2524)	(140-315)
(5-95% quantiles)	(0.250-1.000)	(0.784-1.000)	(0.000-0.0150)	(0.000-0.030)	(2.92-15.63)	(2351-2565)	(50-525)

[1] SageDom 100-m = proportion sagebrush-dominated habitat within 100 m. SageMixGrass 350-m = proportion sagebrush + grassland + mixed sagebrush-mountain shrub habitat within 350 m. Roughness 100-m = standard deviation of the elevation of pixels within 100 m.

Table 5. Summary of vegetation and topography variables at selected scales at 1112 summer-fall locations of marked greater sage-grouse in the Parachute-Piceance-Roan population, Colorado, 2006-2009.

	SageDom[1] 100-m	SageMixGrass[1] 350-m	Forest 740-m	Mtn. shrub 740-m	Riparian 1000-m	Roughness[1] 100-m	Elevation (m)	Distance to forest (m)
Mean ± SE	0.685 ± 0.008	0.923 ± 0.002	0.087 ± 0.002	0.008 ± 0.000	0.000 ± 0.000	8.12 ± 0.11	2445 ± 2.38	196 ± 3.96
Median	0.714	0.948	0.072	0.003	0.000	7.36	2444	173
(25-75%)	(0.500-0.922)	(0.881-0.986)	(0.044-0.115)	(0.000-0.013)	(0.000-0.000)	(5.20-10.31)	(2409-2487)	(98-268)
(5-95%)	(0.177-1.000)	(0.773-1.000)	(0.012-0.215)	(0.000-0.030)	(0.000-0.002)	(3.16-15.32)	(2397-2597)	(29-440)

[1] SageDom 100-m = proportion sagebrush-dominated habitat within 100 m. SageMixGrass 350-m = proportion sagebrush + grassland + mixed sagebrush-mountain shrub habitat within 350 m. Roughness 100-m = standard deviation of the elevation of pixels within 100 m. Aspect (transformed) = extent of southern exposure (1= due south, 0 = due north).

Table 6. Updated timeline for greater sage-grouse research (seasonal habitat maps and assessment of pinyon-juniper removal) in the Parachute-Piceance-Roan population, Colorado.

Task	Initiation	Completion
Seasonal habitat use maps		
GIS analyses and seasonal model development	31 Aug 2009	COMPLETE
Collect validation location dataset	1 Sep 2009	COMPLETE
Complete final model assessment and GIS map processing.	1 Mar 2010	COMPLETE
Prepare final report on breeding habitat-use maps	15 Jul 2010	COMPLETE
Prepare final report on summer-fall habitat-use maps	15 Jul 2010	COMPLETE
Prepare final report on winter habitat-use maps	31 Mar 2010	IN PROGRESS
Assessing response to pinyon-juniper removal		
Identification of plots for pinyon-juniper removal	COMPLETE	COMPLETE
Winter track surveys, pellet collection (annually)	1 Jan	1 Mar
Remove encroaching pinyon-juniper (2010)	20 Oct	1 Dec
Analysis of winter track data (annually)	1 Mar	1 Jun
Analysis of genetic samples (annually, depends on no. samples)	1 Apr	1 Jun
Analysis of genetic data (annually)	1 Jun	1 Aug
Prepare cumulative report (annually)	1 Aug	1 Oct
Prepare cumulative final report	1 Aug 2012	1 Oct 2012

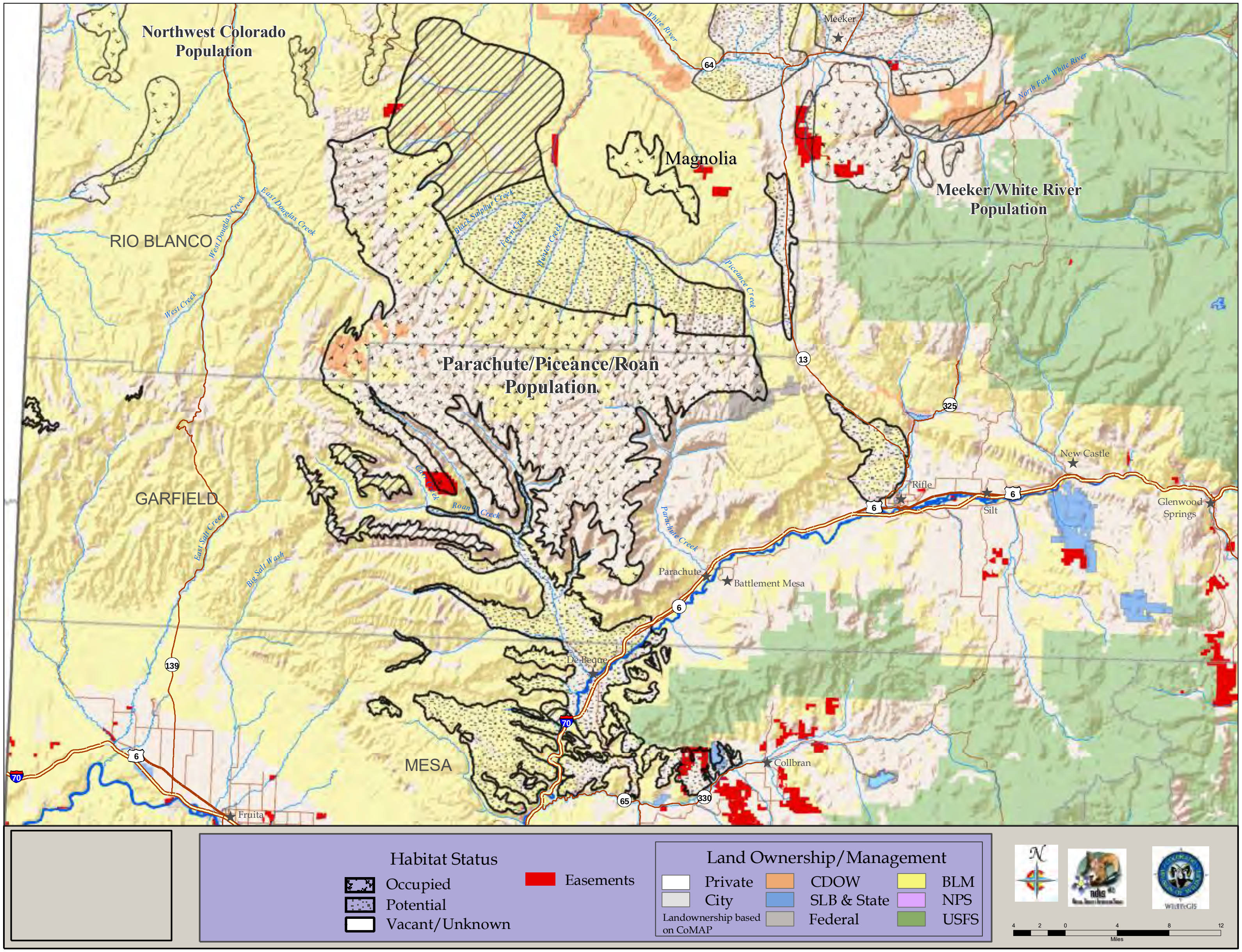


Figure 1. Distribution of the Parachute-Piceance-Roan greater sage-grouse population as of 2006, including the Magnolia portion (CGSSC 2008).

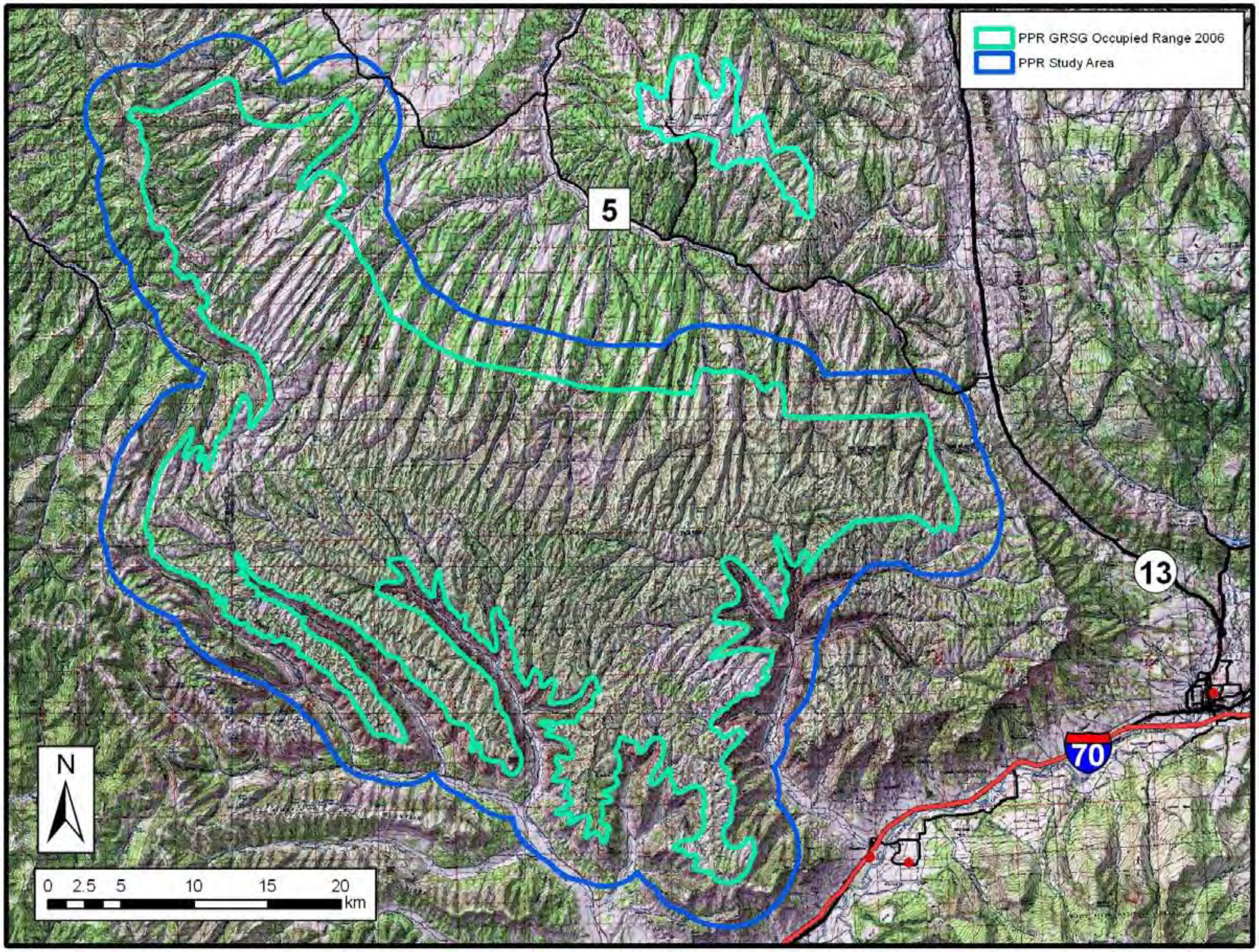


Figure 2. Occupied range as of 2006 and the study area boundary for the Parachute-Piceance-Roan greater sage-grouse population, Colorado. The study area excluded the Magnolia portion of occupied range because we did not attempt to capture or track birds there.

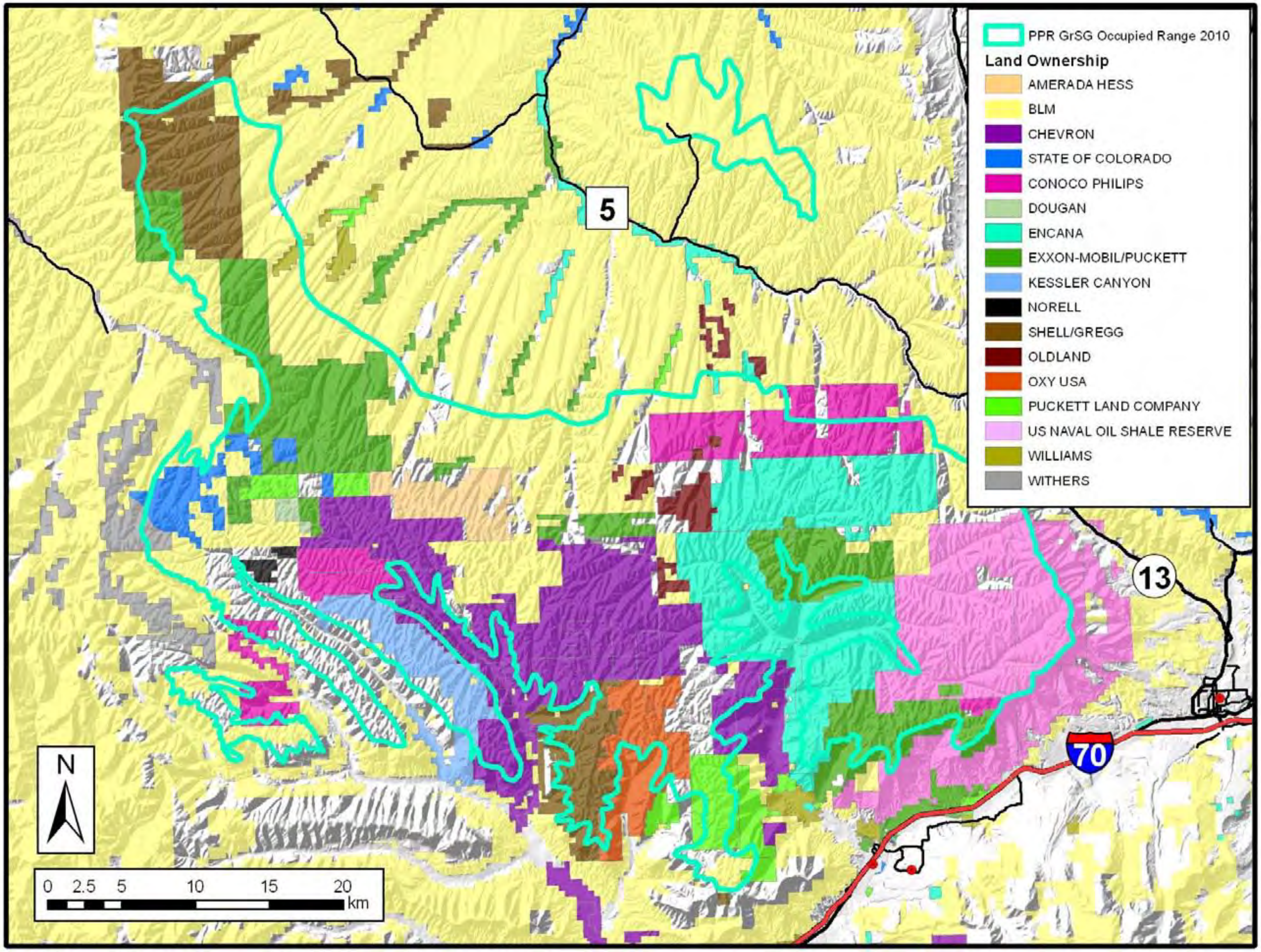


Figure 3. Surface ownership (major landowners only) in the Parachute-Piceance-Roan population of greater sage-grouse as of 2009.

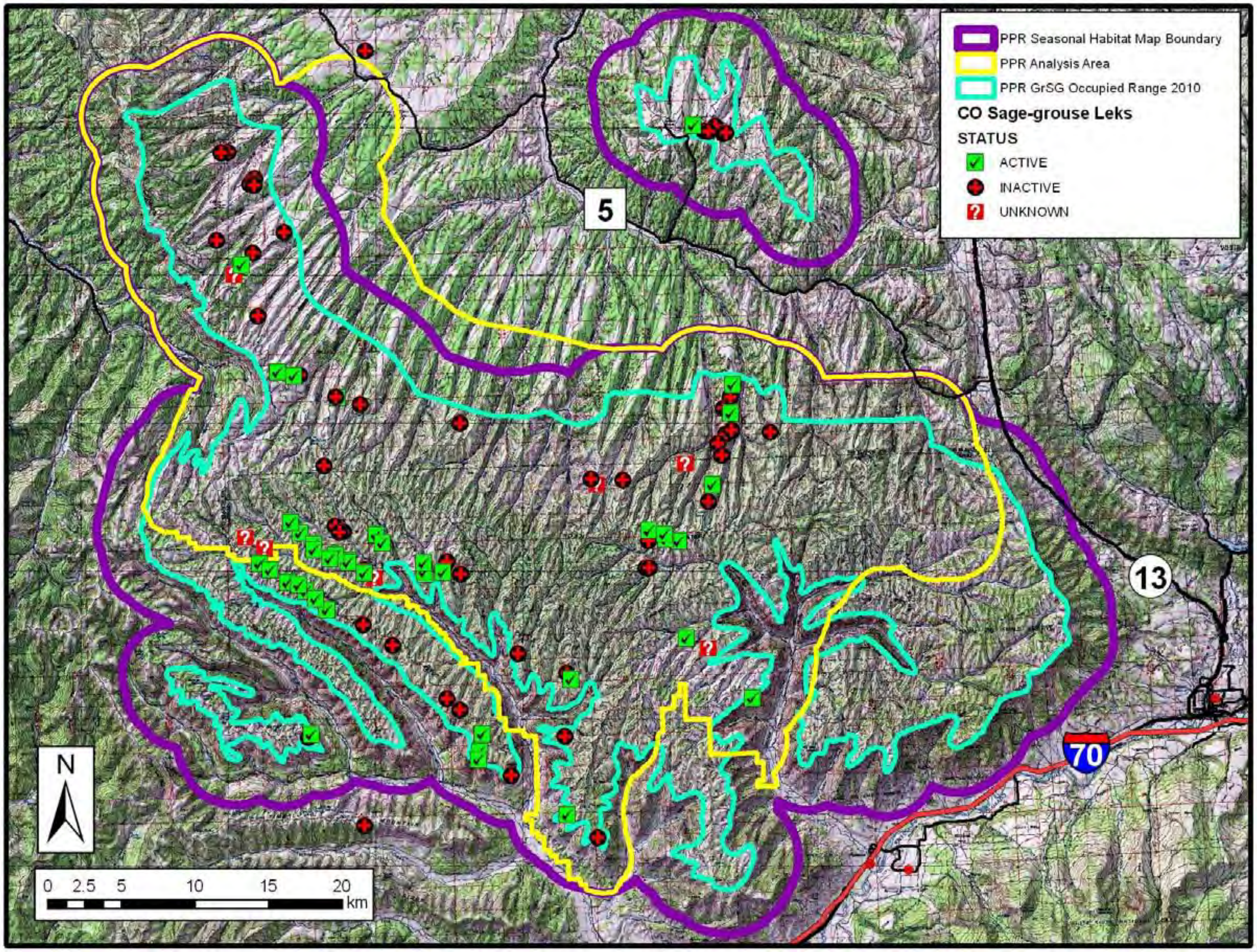


Figure 4. Occupied range as of 2010, the analysis area, and the extent of seasonal habitat mapping overlaid with active, inactive, and unknown status leks in the Parachute-Piceance-Roan greater sage-grouse population, Colorado.

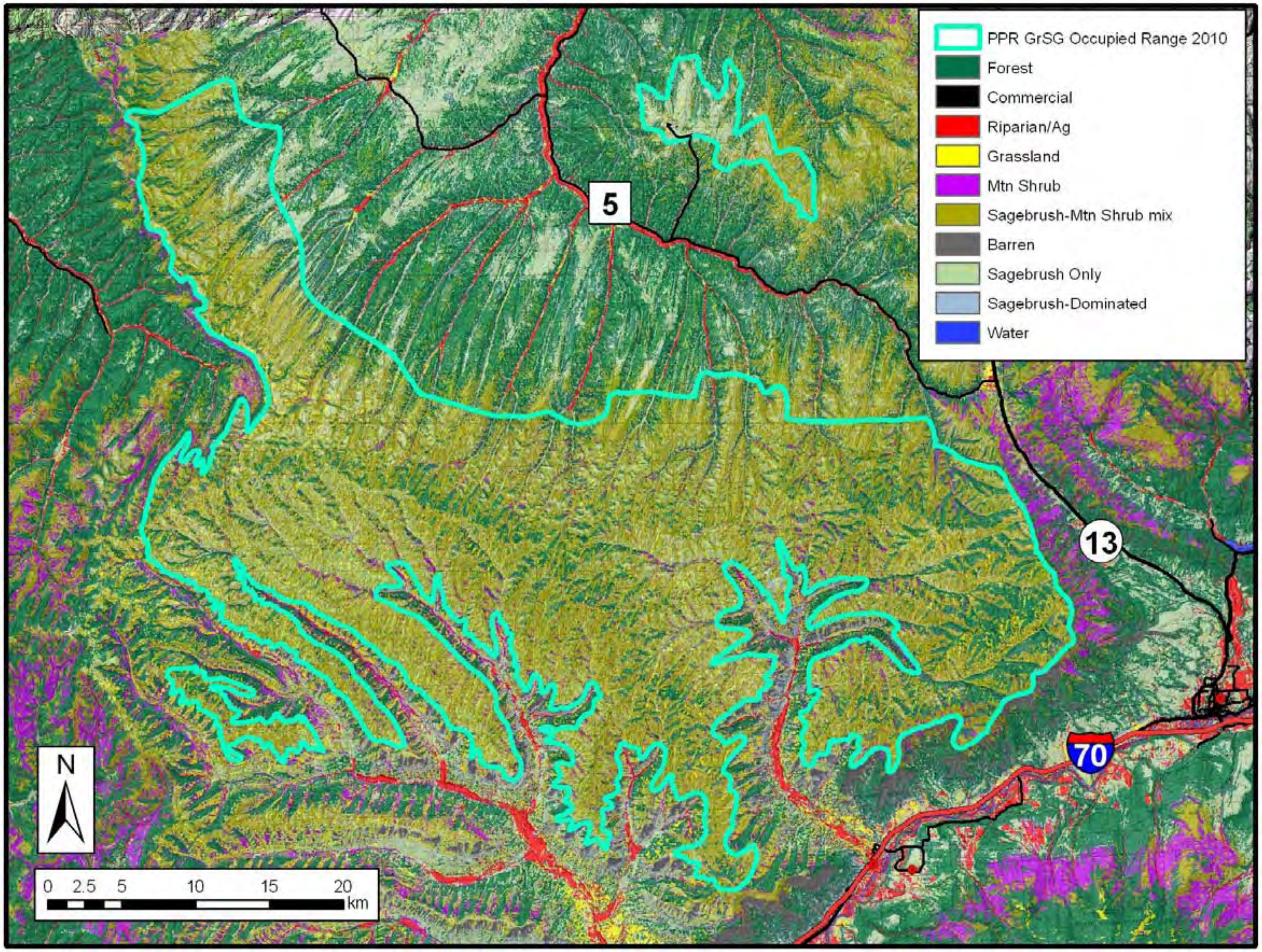


Figure 5. Major habitat types derived from cover types in the Colorado Vegetation Classification Project and occupied range as of 2010 for the Parachute-Piceance-Roan greater sage-grouse population, Colorado. See Table 1 for how CVCP cover types were grouped into habitat types.

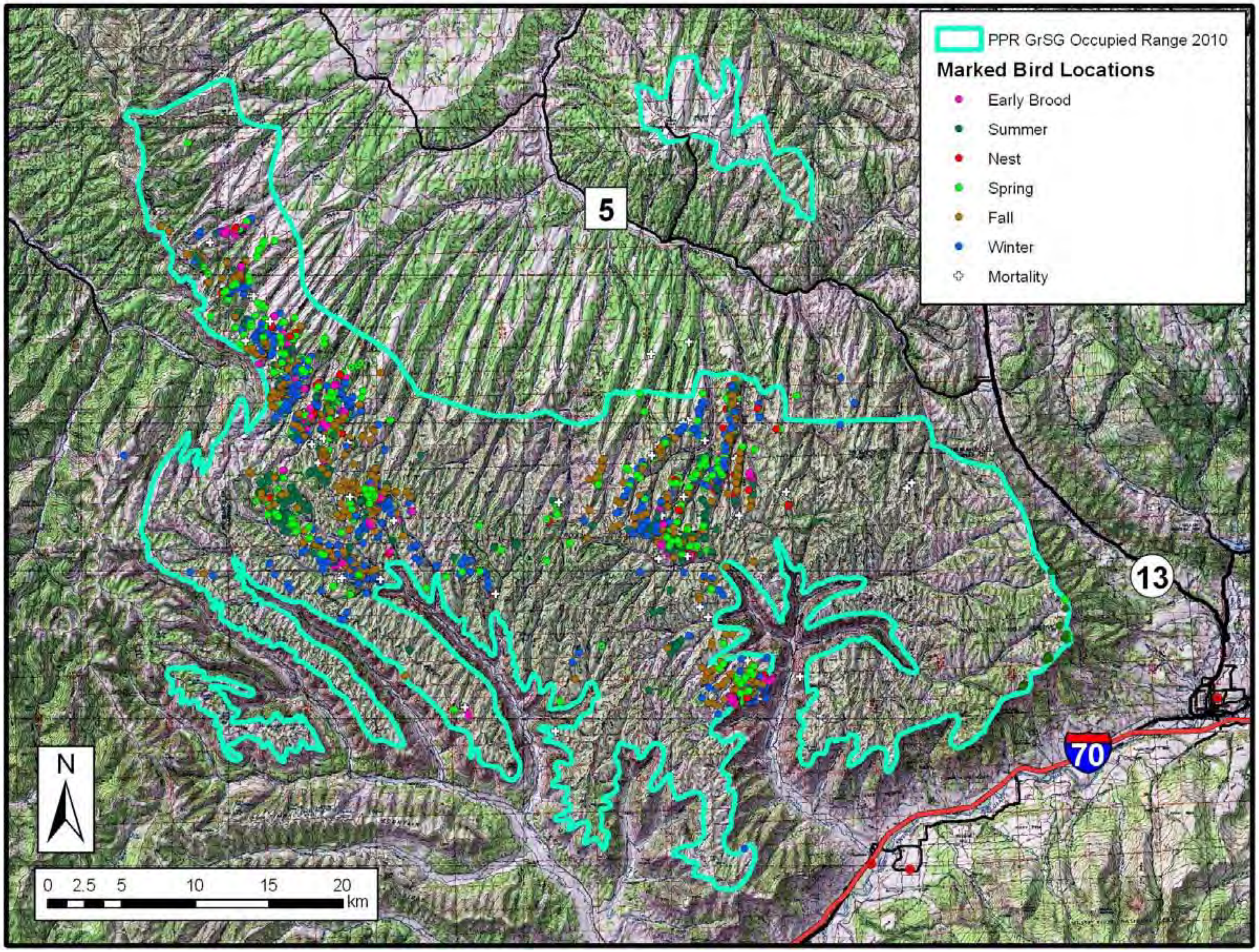


Figure 6. Locations of marked greater sage-grouse collected from 2006-2010 overlaid with occupied range as of 2010 for the Parachute-Piceance-Roan population, Colorado. Not all areas were accessible in all seasons due to land ownership or logistical constraints.

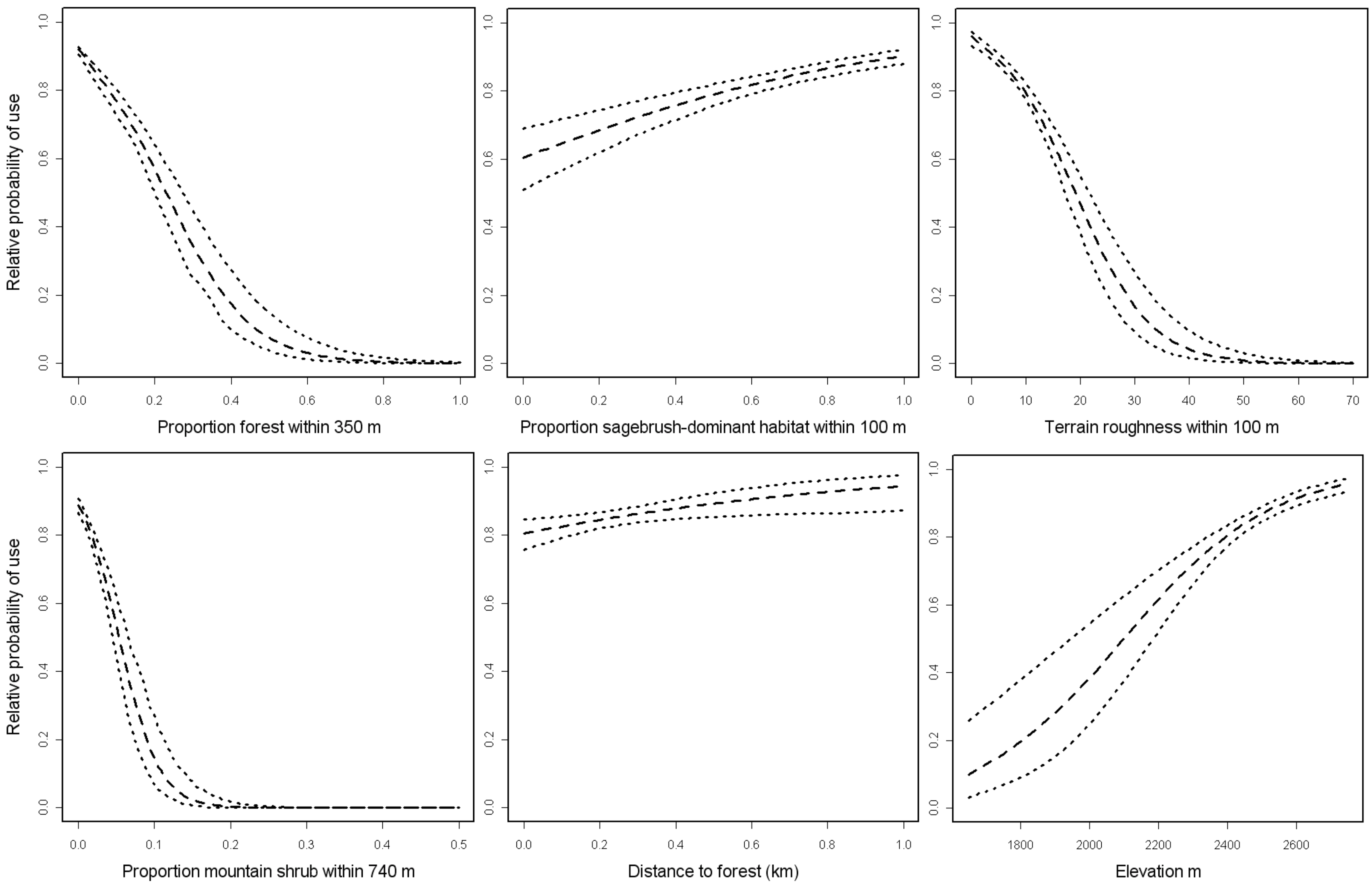


Figure 7. Relationships between landscape-level habitat variables and relative probability of use during the breeding season for greater sage-grouse in the Parachute-Piceance-Roan population, Colorado, 2006-2009. In all models, values for other variables were set to the mean value at used locations.

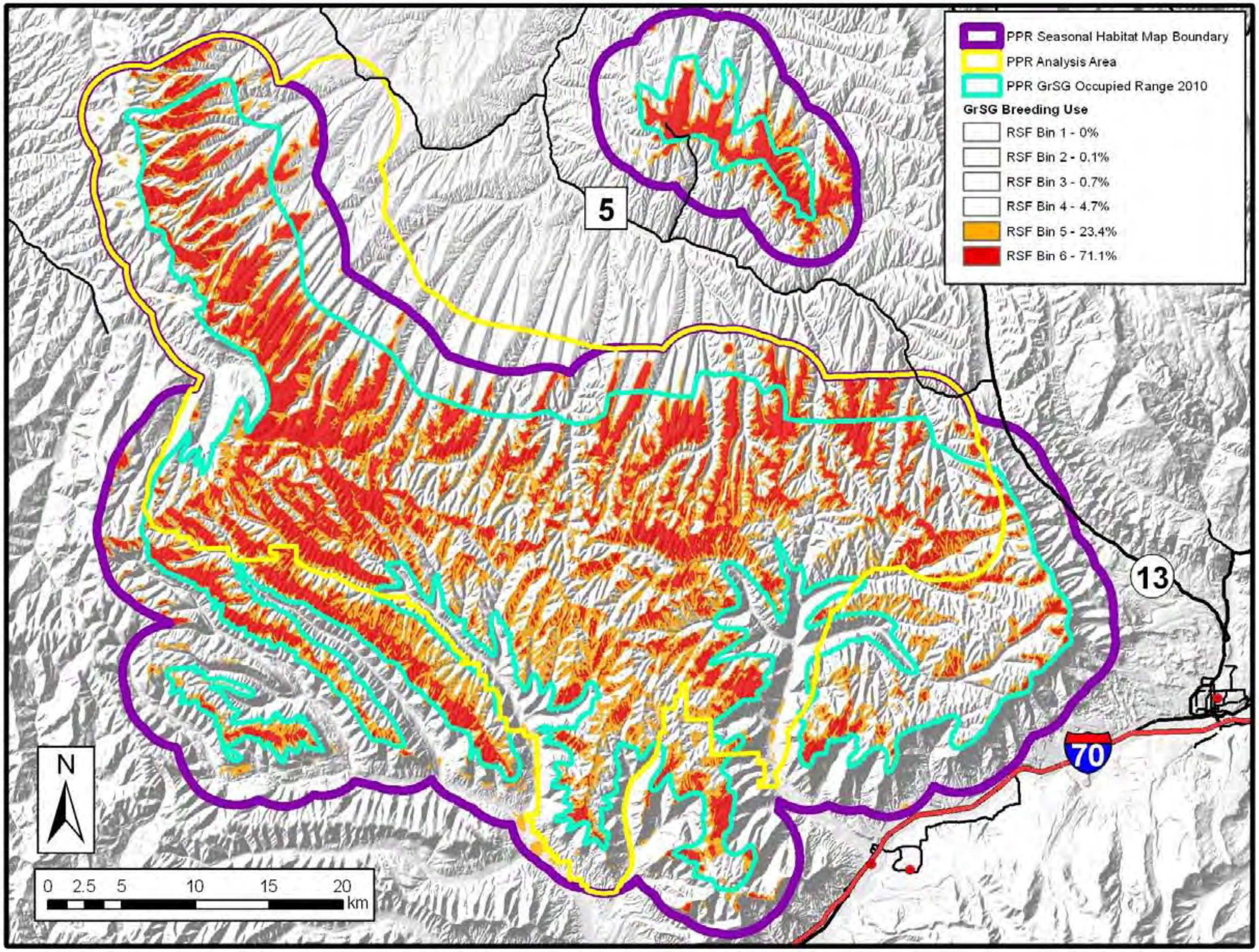


Figure 8. Breeding habitat map for greater sage-grouse in the Parachute-Piceance-Roan population based on vegetation, topography, and breeding-season locations of marked birds, 2006-2009. Model predictions may not hold outside the analysis area boundary.

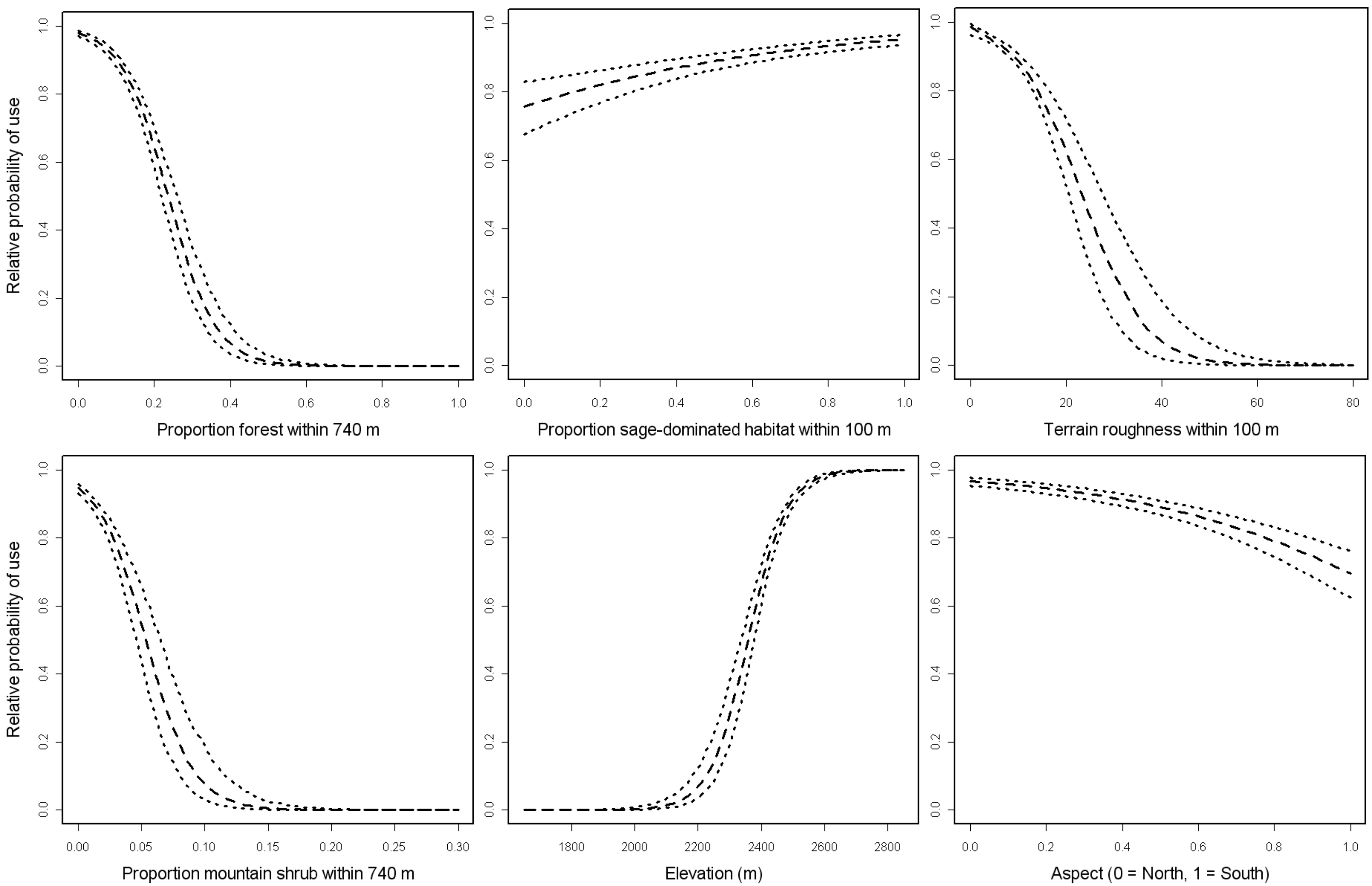


Figure 9. Relationships between landscape-level habitat variables and relative probability of use during summer and fall for greater sage-grouse in the Parachute-Piceance-Roan population, Colorado, 2006-2009. In all models, values for other variables were set to the mean value at used locations.

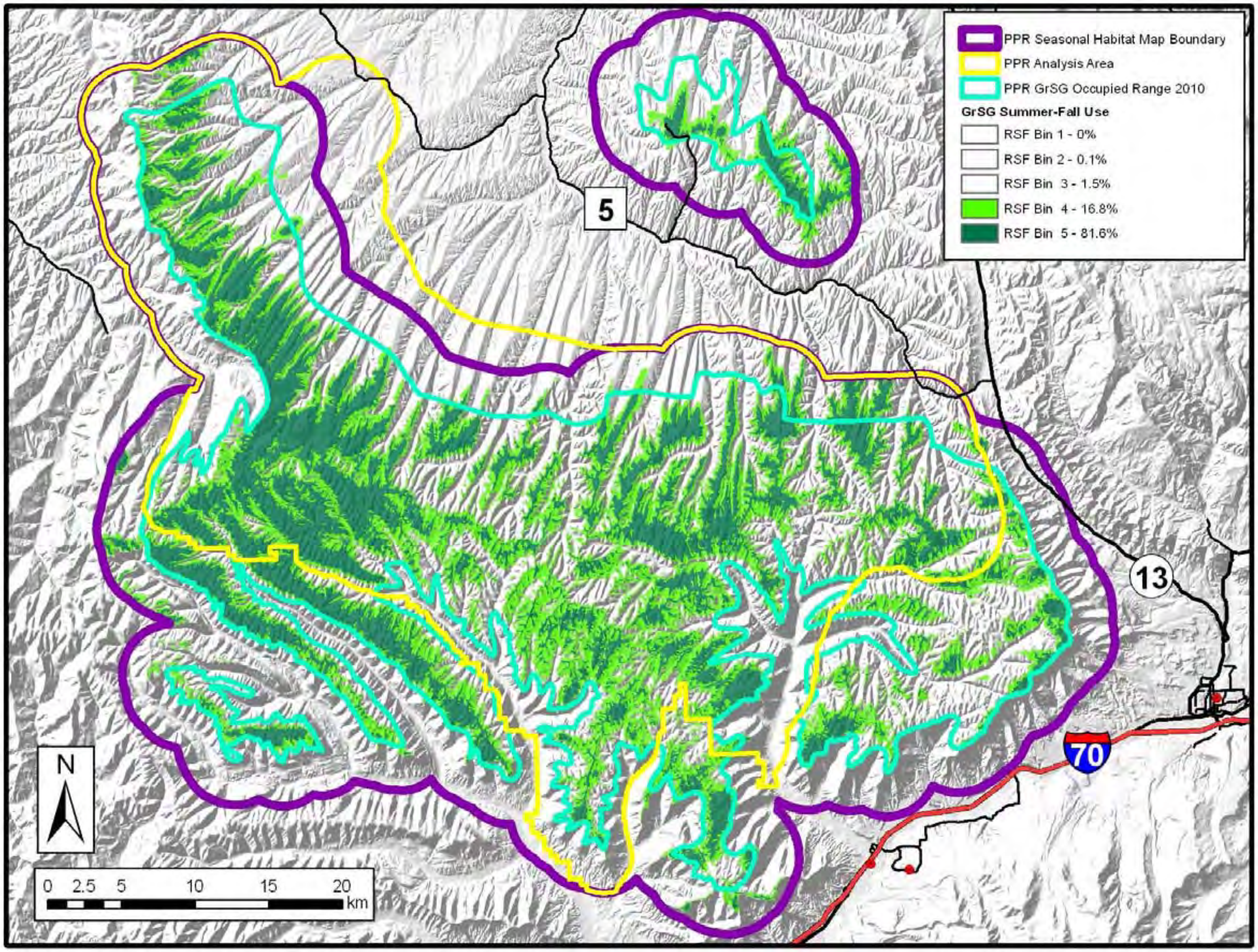
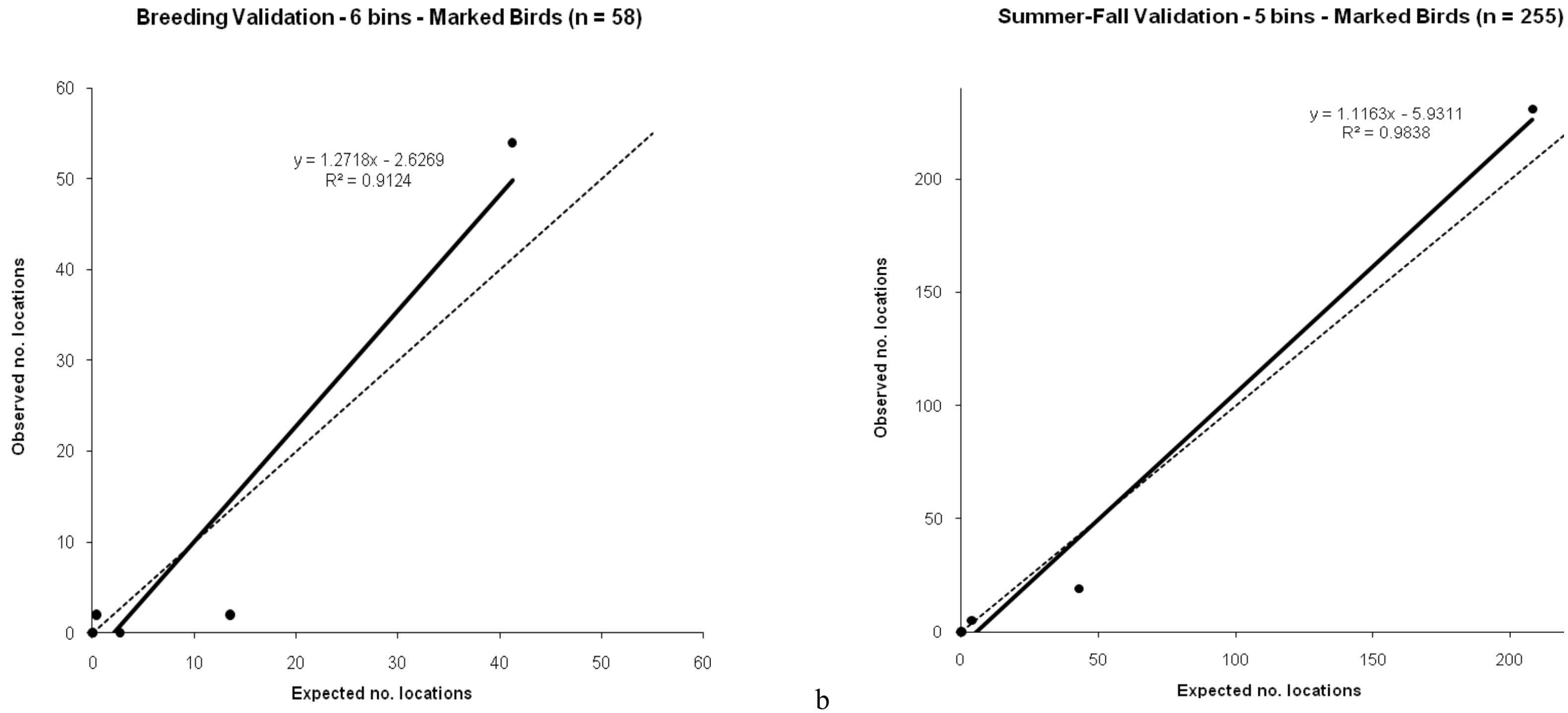


Figure 10. Summer-fall habitat map for greater sage-grouse in the Parachute-Piceance-Roan population based on vegetation, topography, and summer-fall locations of marked birds, 2006-2009. Model predictions may not hold outside the analysis area boundary.



a b

Figure 13. Regression of observed vs. expected no. of independent greater sage-grouse locations in each of 5-6 RSF bins for (a) breeding, and (b) summer-fall habitat in the Parachute-Piceance-Roan population, 2006-2009. Dashed lines shows expected pattern under perfect model fit. Breeding validation data are from spring 2010.

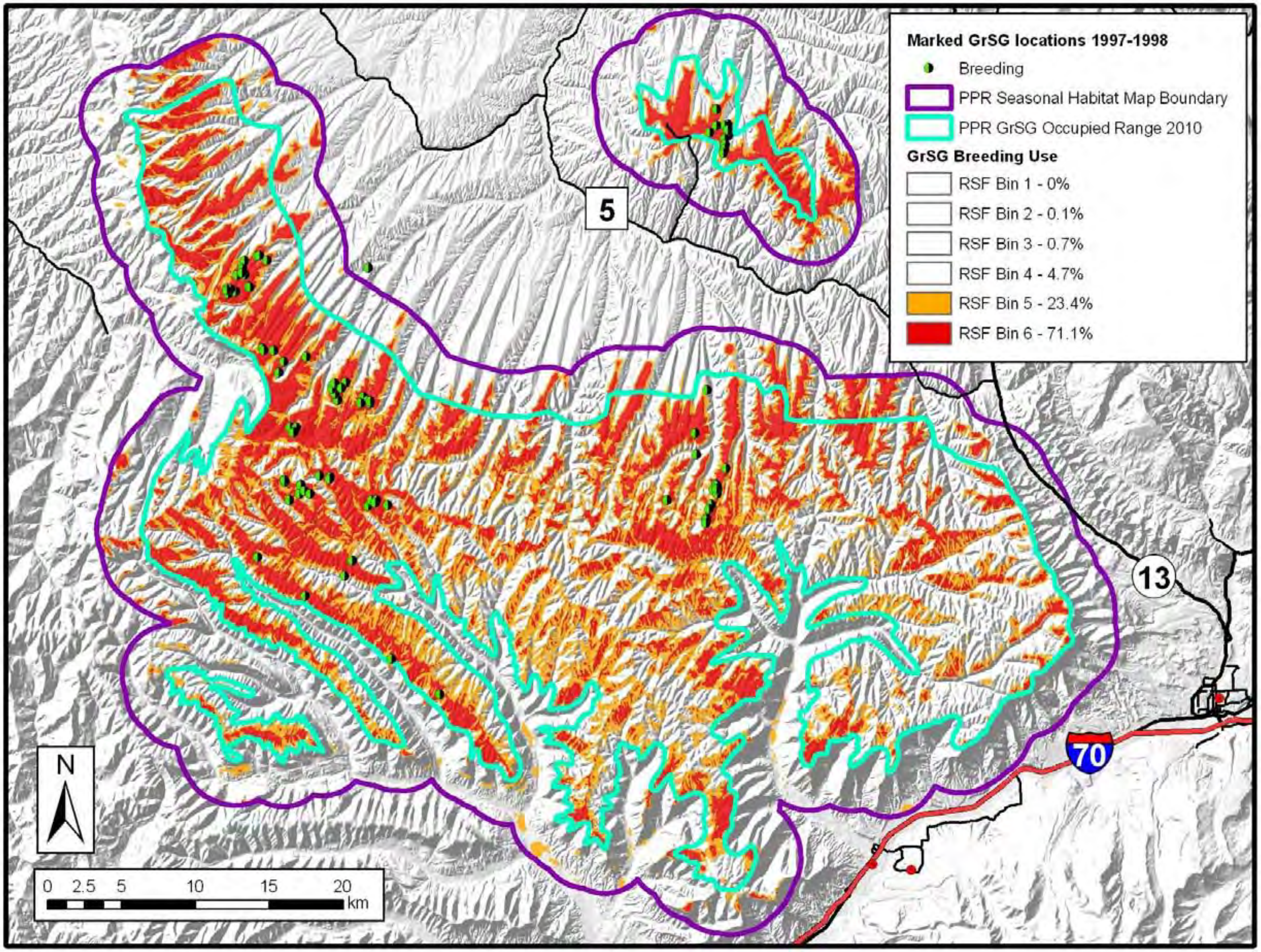


Figure 14. Breeding-season map for greater sage-grouse in the Parachute-Piceance-Roan population from 2006-2010 overlaid with 109 breeding-season locations of marked greater sage-grouse from 1997-1998. 94.5% of previous breeding locations occurred in bins 5-6.

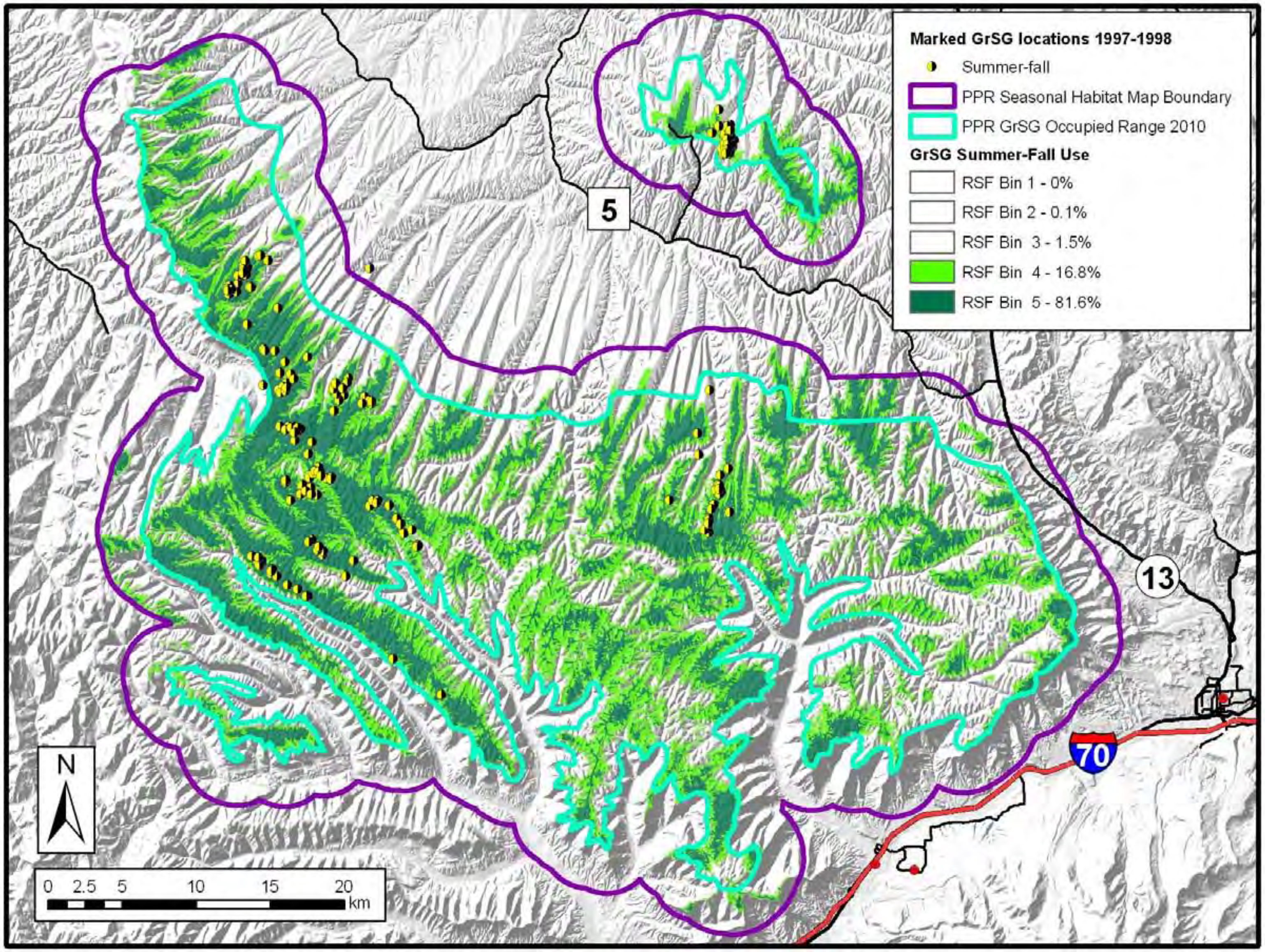


Figure 15. Summer-fall map for greater sage-grouse in the Parachute-Piceance-Roan population from 2006-2010 overlaid with 246 summer-fall locations of marked greater sage-grouse from 1997-1998. 93.5% of these locations occurred in bins 4-5.

COLORADO DIVISION OF WILDLIFE – AVIAN RESEARCH PROGRAM
PROGRESS REPORT
September 2010

TITLE: Restoring energy fields for wildlife

AUTHOR: D. B. Johnston

PROJECT PERSONNEL: B. DeVergie, J.C. Rivale, J.T. Romatze, R. Velarde

Period Covered: January 16, 2009 – January 15, 2010

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INTRODUCTION

Preserving wildlife habitat quality in oil and gas fields requires effective reclamation of impacted areas. Successful reclamation for wildlife involves overcoming the threat of weed invasion, preventing soil loss, and promoting natural plant succession so that diverse, native plant communities are established. A thorough understanding of site-specific factors, such as topography, soils, climate, and land use history, are required for making informed reclamation choices. Obtaining this kind of information for oil and gas fields, however, is difficult due to the spatial pattern of disturbance.

The disturbances caused by oil and gas fields, in contrast to many other kinds of development, are small in acreage but large in number, and each is connected via pipelines and access roads which may extend across hundreds of thousands of acres. The complexities of gathering knowledge at appropriate scales, administering recommendations for the multitude of sites, and enforcing standards over such large areas often results in reclamation that falls short of the most basic standards (Avis 1997, Pilkington and Redente 2006). Addressing these challenges is imperative, as the fragmented pattern of development means that wildlife and wildlife habitat are affected over a much larger acreage than that directly occupied by development activities (Sawyer et al. 2006, Bergquist et al. 2007, Walker et al. 2007). The goal of this study is to address the knowledge gap by replicating tests of promising reclamation techniques in many locations within an ecologically diverse oil and gas field.

The Piceance Basin is a natural gas field in northwestern Colorado which provides an ideal laboratory for conducting large-scale studies of reclamation techniques. The area is currently experiencing an unprecedented level of natural gas development, it provides critical habitat for the largest migratory mule deer herd in the United States, and it has a complex topography which ensures that a wide range of precipitation, soil development, and plant community types are represented. Furthermore, the Piceance Basin is partly but not wholly invaded by the troublesome weed cheatgrass (*Bromus tectorum*), allowing an opportunity to assess control measures for this weed in an area where such measures may have the most effect.

Cheatgrass invasion presents a serious obstacle to effective reclamation in the study area (Pilkington and Redente 2006), and the possibility exists that gas development could facilitate weed invasion into undisturbed habitat (Bergquist et al. 2007). Because of the potential for weed invasion to reduce wildlife habitat quality (Trammell and Butler 1995), several components of this research study specifically address weed control: When is it necessary? What are its ecological costs? What methods work best, and in which environments? What can be done to improve the competitive advantage of desirable vegetation?

Even in areas where weed invasion is not a problem, reclamation techniques can be improved. A particular challenge is the re-establishment of plant diversity, as many times, the outcome of reclamation efforts is a stand of grasses, which does not serve the nutritional needs of wildlife well. Several components of this research study address the question of how to best foster diverse plant communities in areas where weed pressure is non-existent or moderate.

The focus for all of the studies is on sagebrush (*Artemesia tridentata*) communities, because of the need for better techniques for re-establishing these communities (Lysne 2005), their widespread distribution, and their importance to wildlife.

APPROACH

Twelve research locations were chosen within the Piceance Basin in sagebrush habitats (Figure 1, Table 1). These twelve locations span most of the range of elevation, soil type, vegetation, and precipitation to be found in the area. The lowest elevation site, SK Holdings (SKH) lies at 1561 m (5120 ft), has alkaline, clayey soils, and is characterized by high cheatgrass cover with interspersed Basin Big Sagebrush. The highest

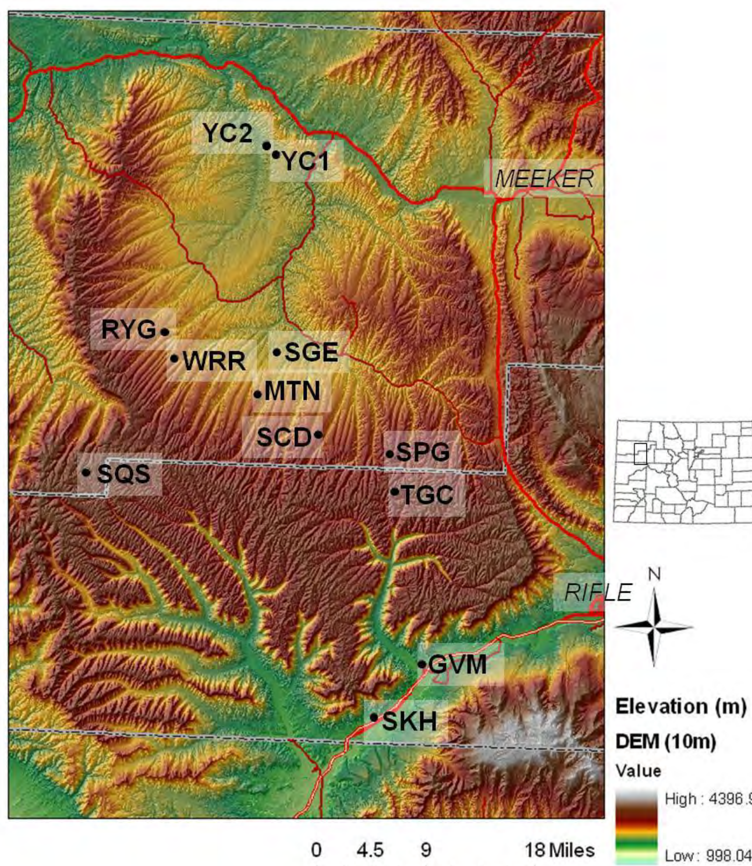


Figure 1. Location of the twelve study sites within the Piceance Basin.

elevation site, Square S (SQS), lies at 2676 m (8777 ft), has a sandy loam soil, and has a mixture of non-noxious forb, grass, and Mountain Big Sagebrush cover. Due to the extreme variability of the study sites, it proved inadvisable to conduct identical experiments at all sites. The implemented design consists of five experiments, each conducted in 2-6 locations, some of which contain treatments which are also represented in other experiments. The overlap of treatments allows the experiments to relate to one another in a way that will permit broad-scale conclusions, if appropriate, while the differences in the experiments permit tailoring of particular treatments to those portions of the landscape where they are potentially useful.

Two types of disturbances, a simulated pipeline and a simulated well pad, were created to provide templates for the experiments. The major difference relevant to reclamation in these two types of disturbances is in the length of time topsoil is stockpiled. Pipeline disturbances measured 11 m wide by 52 m long and were simulated using a bulldozer and a backhoe. Vegetation was scraped and discarded, the top 20 cm of topsoil was scraped and stockpiled, and then a 1m wide by 1m deep trench was dug. Trenches were left open 3 weeks, and then the subsoil was replaced and the topsoil spread evenly over the site. This work was completed in 6 locations in August and September of 2008. Well pad disturbances measured 31m X 52m and were simulated using a bulldozer. Vegetation was cleared, the top 20 cm of topsoil was scraped and stockpiled, and then the subsoil was cut and filled to create a level surface. The initial work was completed in July and August of 2008, and the surface was kept weed-free for one year by repeated hand-spraying of emerging plants with 2% (v/v) glyphosate. In August of 2009, the subsoil was recontoured to approximate the original contour, and the stockpiled topsoil respread evenly across the surface of the site. Simulated well pads were created in 12 locations, each with slopes of 5% or less. One experiment (called hereafter the Pipeline Experiment) was conducted on the simulated pipeline disturbances, and the remainder of the experiments was conducted on the simulated well pad disturbances. All sites were fenced with 2.4 m (8 ft.) fencing after experiments were implemented.

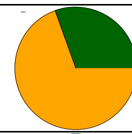
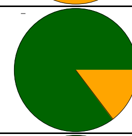
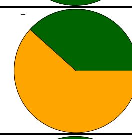
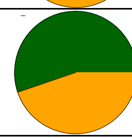
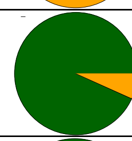
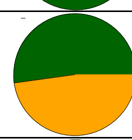
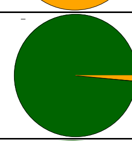
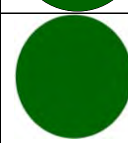
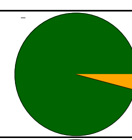
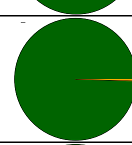
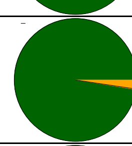
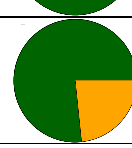
SITE CHARACTERIZATION

Vegetation at all sites was characterized by 4-7 point-intercept transects 10 m in length placed systematically in undisturbed vegetation 10 m from the edge of the disturbed area. Fifty hits per transect were recorded to species following the method outlined by Herrick (Herrick et al. 2005). Percent cover was assessed between 7/1/09 and 7/20/09, and results are summarized in Table 1.

Soils across the Piceance Basin vary widely. Soil characteristics at each study site were determined by sampling the top 20 cm from 8 undisturbed locations within 10 m of the research area between 6/15/09 and 6/17/09. Samples were aggregated for each site and analyzed for pH, electrical conductivity (EC) sodium absorption ratio (SAR), organic matter (OM), nitrate nitrogen, P, K, Zn, Fe, Mn, Cu, Ca, Mg, Na, K, and particle size distribution by the Soil, Water, and Plant testing laboratory at Colorado State University, Fort Collins, CO. Results are summarized in Appendix 1.

Rain and air temperature data were recorded at 6 sites in *2009 [*Yellow Creek 1 (YC1), Yellow Creek 2 (YC2), Ryan Gulch (RYG), Wagon Road Ridge (WRR), Grand Valley Mesa (GVM) and SKH] using RG3-M data logging rain gauges (Onset® Computer Corporation, Bourne, MA) installed on guyed posts at each site. Rain data was recorded in 2 mm intervals, and temperature data was recorded every 30 min.

Table 1. Ownership, elevation, vegetation, and experiments conducted at study sites. Relative cover is for undisturbed ground adjacent to the study area in the 2009 growing season. At sites below 7,000 ft, non-natives are primarily cheatgrass. At higher elevations, non-natives were primarily seeded pasture grasses such as bulbous bluegrass and Kentucky bluegrass.

Code	Name	Landowner	Elev. m (ft)	Experiment(s) Conducted	RelativeCover Native NonNative
SKH	SK Holdings	Williams	1561 (5120)	Pipeline Gulley	
GVM	Grand Valley Mesa	Williams	1662 (5451)	Pipeline Strategy Choice	
YC2	Yellow Creek 2	DOW	1829 (5999)	Pipeline Gulley	
YC1	Yellow Creek 1	DOW	1905 (6248)	Pipeline Gulley	
SGE	Sagebrush	BLM	2004 (6573)	Strategy Choice Competition Seed Dispersal	
RYG	Ryan Gulch	Williams	2084 (6835)	Pipeline Gulley	
MTN	Mountain Shrub	BLM	2183 (7160)	Strategy Choice	
WRR	Wagon Road Ridge	Williams	2216 (7268)	Pipeline Strategy Choice Competition Seed Dispersal	
SCD	Scandard	BLM	2342 (7681)	Mountain Top	
SPG	Sprague (formerly called Snowpile)	Conoco	2445 (8019)	Mountain Top	
TGC	The Girls' Claims	Encana	2527 (8288)	Mountain Top	
SQS	Square S	DOW	2676 (8777)	Mountain Top	

EXPERIMENT UPDATES

PIPELINE EXPERIMENT

Conducted at 6 sites: YC1, YC2, RYG, WRR, GVM and SKH (Table 1, Figure 1).

Background

The goal of the pipeline experiment is to evaluate the effectiveness of tillage treatments vs. an herbicide treatment at controlling cheatgrass and promoting establishment of native plants. Oil and gas disturbances are amenable to tillage manipulations, as the ground is already disturbed and access routes for heavy equipment have already been created. In agricultural settings, combining lower levels of herbicide with tillage treatments, such as disk cultivation, has proven effective for controlling weeds (Mulugeta and Stoltenberg 1997, Mohler et al. 2006). Soil manipulations may be particularly effective for controlling cheatgrass because cheatgrass is sensitive to seed burial (Wicks 1997), does not germinate well in even slightly compacted soil surfaces (Thill et al. 1979), and is less competitive in denser soils (Kyle et al. 2007). Tillage manipulations examined include disking (D), compaction with a heavy roller (R), compaction with a vibratory drum roller (V), disking plus compaction with a heavy roller (DR), and a control (C).

The herbicide investigated is Plateau ™ (ammonium salt of imazapic, BASF Corporation, Research Triangle Park, NC), as it has been shown to reduce cheatgrass with little effect on some perennial grasses (Kyser et al. 2007). However, it may also reduce vigor and density of established forbs (Baker et al. 2007), and little is known about its effect on germination of desirable species. Plateau was applied at 420 g/acre (6 oz./acre) along with glyphosate at 560 g/acre (8 oz./acre). The study design is split-plot factorial with Herbicide as the whole plot and Tillage treatments as subplots (Fig. 2).

Vegetation at the six study areas varied from near complete dominance of cheatgrass at SKH to an intact and nearly completely native community at WRR (Table 1). Sites were seeded the second week in October 2008 using a Tye Pasture Pleaser rangeland drill, with grasses and forbs/shrubs seeded in alternate rows. The seed mixture contained 8 native grasses, 7 native forbs, and 3 native shrubs, and was applied at 8.6 PLS/acre.

Objectives for 2009

2009 was the second year for the pipeline experiment. Our first objective was to quantify the effect of each soil tillage treatment, as well as the creation of the pipeline disturbances themselves, on the density of the soil. Our second objective was to understand the first post-treatment year response of native plants and cheatgrass to the treatments. Our final objective was to analyze data collected and draw preliminary conclusions.

Quantifying Soil Density

We used two methods to quantify soil density: sampling the soil using a drop-hammer double cylinder soil corer, and measuring the resistance of the soil to penetration using a Jornada cone penetrometer (Herrick and Jones 2002). Penetrometer measurements are much more easily obtained, but because penetration resistance depends on soil moisture, penetration resistance is poor choice for comparing differences between sites or between treatments which might alter soil moisture (Miller et al. 2001). Therefore, we used soil bulk density samples to compare sites and to compare on-disturbance vs. off-disturbance locations. We augmented this with penetrometer measurements to quantify within-site differences between the tillage plots.

Soil samples were taken in September of 2008 using a 30.5 cm (12 in.) AMS core sampler fitted with 6 abutting 5.1 cm (2 in.) long inner cylinders. Five cores were taken in undisturbed, adjacent areas to each research site, and three cores were taken from each of the two plots receiving the C soil treatment. Each soil core was divided into 6 known-volume depth increments by removing the inner cylinders and using a piece of metal flashing to separate soil from adjoining cylinders. Samples were stored in plastic bags and were analyzed in June of 2009 by drying each sample to a constant weight and dividing dry weight by the volume of the sample (Krzic et al. 2000).

Penetrometer measurements were taken in May of 2009. Five penetrometer readings were taken in each plot. The number of hammer drops required to move the penetrometer through the soil was recorded for each 5 cm depth increment from 4 cm to 29 cm, and the force required to penetrate the soil was calculated for each depth fraction in each plot. To check for differences in soil moisture among plots, which could compromise the value of penetrometer readings, we took concurrent volumetric soil moisture measurements for a depth of 0-20 cm using a Hydrosense® Time-Domain-Reflectrometry probe (Campbell Scientific, Logan, UT) in 10 locations in each plot.

Quantifying cheatgrass propagule pressure

The six study sites chosen for this experiment had cheatgrass present in varying quantities. Prior work has shown that the quantity of weed seeds, or ―propagule pressure" is important in understanding the outcome of revegetation (DiVittorio et al. 2007). We quantified cheatgrass propagule pressure at each study site using 0.1 m^2 seed rain traps constructed of posterboard covered with Tree Tanglefoot (The Tanglefoot Company, Grand Rapids, MI), a sticky resin. Eight (8) traps were set in systematically chosen locations in undisturbed vegetation surrounding each site. Cheatgrass seeds were counted and removed from traps biweekly from 5/15/09 until 8/26/09. Tanglefoot was reapplied as necessary to ensure a sticky surface. Total growing season cheatgrass propagule pressure (seeds/m^2) was calculated from these data.

Quantifying vegetation response to treatments

Seedling counts were conducted in May and July of 2009 for nine locations within each plot, which were selected systematically by throwing a hoop within each of nine cells created by placing an imaginary ―tic-tac-toe" board over each plot. In May, only cheatgrass seedling densities were recorded, and in June, both cheatgrass and native seedling densities were recorded. A 1 m wide buffer zone surrounding each plot was excluded from measurement. Because seedling density varied widely from site to site, the size of the hoop was allowed to vary from 300 to 3000 cm^2 so that an area sufficient for sampling was obtained. A total of 90 counts were done per site, and the density of seedlings was calculated for each plot from seedling counts and hoop areas.

Data analysis

Our general approach was to use analysis of variance (ANOVA) in SAS PROC MIXED (SAS Institute Inc., Cary, NC) to analyze differences in responses to treatments. Treatments were included as fixed effects, and a Site blocking term was included as a random effect. For bulk density, separate analyses were done for each depth fraction, and the fixed effect was a location variable (on or off pipeline). For penetration resistance, separate analyses were done for each depth fraction, and the fixed effects were the soil tillage treatments. For soil moisture, the fixed effects were the soil tillage treatments, and a retrospective power analysis in SAS ANALYST was also performed.

For cheatgrass seedling density and native seedling density, models with different combinations of fixed effects were compared using Akaike's Information Criterion, adjusted for small sample size (AIC_c). The models included Plateau treatment (P), the Tillage treatments (D, R, and V) and two-way interactions among them as fixed effects in various combinations (Table 2). In addition, models including penetration resistance in the 4-9 cm depth fraction (PR) in lieu of tillage variables were also considered. A total of 18 models were tested. In all models, site was included as a random effect, and an adjustment for the split-plot design was incorporated into the RANDOM statement. For cheatgrass seedling density, a REPEATED statement allowed incorporation of both May and June seedling counts into the same analysis. The magnitude of treatment effects were evaluated using ESTIMATE statements in the model with the lowest AIC_c value.

The effect of Plateau was also analyzed separately for each site, using only the Control tillage plots with individual counts as replicates within an ANOVA in SAS PROC GLM. Means are presented ± standard errors.

Results

Ambient cheatgrass propagule pressure varied from 6.3 ± 5.0 seeds/m^2 at WRR to 1676 ± 261 seeds/m^2 at SKH (Fig. 3).

The creation of the simulate pipeline disturbances increased soil bulk density by an average of 0.13 ± 0.5 g/cm^3 across depth fractions. The increase in bulk density was evident at all depth fractions except the 5-10 cm depth fraction ($p < 0.01$, Fig. 4). Bulk density also varied significantly across study sites with the discrepancy between the two most disparate sites, RYG and SKH, being 0.29 ± 0.8 g/cm^3.

The soil tillage treatments significantly affected soil penetration resistance (Fig. 5). These differences were most evident for the shallowest depth fraction measured, 4-9 cm. At that depth, the soil had 99 ± 34 N greater resistance in the V treatment than in the control, 134 ± 29 N less resistance in the D treatment than in the control, and 74 ± 29 N less resistance in the DR treatment than in the control (Fig. 5). For the 9-14 cm depth fraction, the V treatment had 163 ± 64 N more resistance than the control, and the D treatment had 171 ± 56 N less resistance than the control. For the 14-19 cm depth fraction, penetration resistance was 230 ± 107 N greater in the V treatment than in the control. Differences were not evident for any treatment at depths greater than 19 cm, and the R treatment was not significantly different from the control at any depth.

We detected no differences in volumetric soil water due to any of the tillage treatments, and the power analysis found that we had 70% power to detect differences.

The model with the most explanatory power to predict cheatgrass seedling density included the Plateau treatment, Disking, and their interaction (Table 2). In this model, an interaction occurred by which Disking reduced cheatgrass seedling density by 65.5 ± 23.4 seedlings/m^2 when Plateau was not used (Figure 6a), but had no discernable effect when Plateau was used. The Plateau itself was not significantly effective in this cross-site analysis. The next best model included PR, the Plateau treatment, and their interaction. In this model, PR had no detected effect on cheatgrass seedling density when Plateau was present, but when Plateau was absent, cheatgrass seedling density increased by 0.32 ± 0.12 seedlings for every 1 N increase in penetration resistance. Models including rolling and vibration but not disking did not perform well (Table 2).

The model with the most explanatory power to predict native seedling density was a simple model including Disking (Table 3). This model found native density to be 1.5 ± 0.8 seedlings/m^2 higher in disked plots than in undisked plots ($p = 0.06$, Figure 6b).

In the analysis of the Plateau treatment separately by site, the Plateau treatment reduced cheatgrass seedling density by 572 ± 104 seedlings/m^2 at RYG, and 439 ± 24 seedlings/m^2 at YC2. There was no detected effect of Plateau on cheatgrass seedling density at GVM, SKH, WRR, or YC1 (Figure 7a). The Plateau treatment increased native seedling density at RYG by 13.7 ± 2.7 seedlings/m^2 (Figure 7b). There was no detected effect of the Plateau treatment at GVM, SKH, WRR, YC1, or YC2.

DISCUSSION

The soil tillage treatment of disking proved helpful in controlling cheatgrass and improving native seedling density (Figure 6). The soil tillage treatment of rolling did not discernibly affect either native or cheatgrass seedling density. There was no evidence of interaction between the rolling and disking treatments.

Both disking and rolling altered the density of the soil, as evidenced by the soil penetration resistance measurements (Figure 5). However, a model substituting soil penetration resistance for soil tillage variables did not perform as well as a model including the disking variable. Although these results are preliminary, the most likely interpretation at this time is that the benefit of the disking treatment is primarily due to the action of turning the soil and thereby burying cheatgrass seeds, rather than by altering soil density.

There was no consistent effect of the Plateau treatment in this study. In a site-by-site analysis, Plateau was effective at reducing cheatgrass density at 2 of 6 sites, and effective at increasing native density at 1 of 6 sites (Figure 7). The reason for the discrepancy in effectiveness between sites is not entirely clear. At WRR, a lack of sufficient cheatgrass propagule pressure to test the herbicide is the most likely explanation (Figure 3). Lower cheatgrass propagule could be a factor in the lack of effectiveness at GVM, but it does not seem able to completely explain the results, as cheatgrass did establish in both Control and Plateau plots (Figure 7a). The four remaining sites certainly had high enough cheatgrass propagule pressure to present a fair test of the herbicide (Figure 3). The two of these where Plateau was ineffective, SKH and YC1, had Sodium Absorption Ratios (SAR) six to nine times higher than any of the other sites (Appendix 1). SAR is related to the ratio of Sodium to Calcium + Magnesium ions in the soil, has a large effect on soil structure. An excess of sodium causes soil aggregates to break down, reducing the ability of soil to absorb water and causing the formation of hard-pan crusts. These crusts were evident at YC1 and SKH, but not at any other sites. It is possible that these crusts prevented the herbicide from penetrating the soil. It is also possible that these crusts reduced cheatgrass establishment, as the density of cheatgrass seedlings at YC1 and SKH in the non-Plateau plots was not as high as the other sites with comparable cheatgrass propagule pressure (Compare Figures 3 and 7a). Biological soil crusts have been shown to prevent cheatgrass establishment (Shinneman and Baker 2009).

The lack of effect or possible negative effect of increasing soil density on cheatgrass establishment was not what was anticipated. In other work, cheatgrass has been shown to be a poorer competitor in compacted soils (Beckstead and Augspurger 2004). A possible explanation for this discrepancy involves how the treatments affected density at different depths. An ideal tillage treatment for hindering cheatgrass while favoring native plants would have created a dense surface crust with less dense soil through the rooting zone. This is the pattern of soil density with depth in undisturbed locations (Figure 4), but not following the creation of the pipeline disturbances. None of the tested tillage treatments re-created this density profile. The disking + rolling treatment was the most direct attempt to do so, but rolling compacted deeper soil layers in addition to shallower ones; the reduction in resistance at the 9-14 cm depth with disking was negated when rolling was added. In this study, the detriment of soil compaction in the rooting zone for perennial plants may have outweighed any benefit of rolling in controlling cheatgrass. To achieve a soil density profile suitable for cheatgrass control, it may be necessary to add products such as soil binding agents to the soil surface.

The Pipeline experiment will continue to be monitored for at least one more growing season. The data here, particularly the results for native density, are preliminary, as perennial plants may take 3 years or more to respond to reclamation treatments. Future results will be combined with those presented here in a repeated-measures analysis.

Table 2. Results of model selection for competing models of cheatgrass density. W_r values can be interpreted as the probability that a given model would prevail if tested again against the other models in the set. D=Disked, P=Plateau, PR= penetration resistance, R= Rolled, V= rolled with Vibration.

Parameter(s) in Model	AIC_c	ΔR	Likelihood	W_r
D, P, and P*D interaction	1459.2	0.00	1.00	**0.22**
P, PR and P*PR interaction	1460.0	0.87	0.65	0.15
P, PR	1460.6	1.47	0.48	0.11
D, P	1461.0	1.85	0.40	0.09
D, P, P*D interaction, R	1461.2	2.09	0.35	0.08
PR	1461.3	2.11	0.35	0.08
D	1461.3	2.17	0.34	0.08
P	1462.2	3.07	0.22	0.05
D, P, R	1463.1	3.92	0.14	0.03
D, R	1463.3	4.19	0.12	0.03
V	1463.8	4.64	0.10	0.02
R	1464.2	5.05	0.08	0.02
D, P, R, P*R interaction	1465.0	5.87	0.05	0.01
D, P, V, P*V interaction	1465.1	5.91	0.05	0.01
D, P, R, V	1465.3	6.14	0.05	0.01
D, R, D*R interaction	1465.6	6.42	0.04	0.01
P, R, P*R interaction	1465.8	6.67	0.04	0.01
P, V, P*V interaction	1469.6	10.46	0.01	0.00

Table 3. Results of model selection for competing models of native seedling density. W_r values can be interpreted as the probability that a given model would prevail if tested again against the other models in the set. D=Disked, P=Plateau, PR= penetration resistance, R= Rolled, V= rolled with Vibration.

Parameter(s) in Model	AIC_c	ΔR	Likelihood	W_r
D	331.7	0.00	1.00	**0.27**
PR	333.3	1.64	0.44	0.12
D, P, and P*D interaction	333.6	1.94	0.38	0.10
D, P	334.0	2.32	0.31	0.08
D, R	334.1	2.47	0.29	0.08
D, R, D*R interaction	334.2	2.55	0.28	0.07
D	335.0	3.33	0.19	0.05
R	335.0	3.34	0.19	0.05
V	335.0	3.36	0.19	0.05
PR	335.5	3.87	0.14	0.04
D, P, P*D interaction, R	336.3	4.60	0.10	0.03
D, P, R	336.5	4.88	0.09	0.02
D, P, V, P*V interaction	338.2	6.57	0.04	0.01
D, P, R, P*R interaction	338.3	6.61	0.04	0.01
P, R, P*R interaction	339.0	7.35	0.03	0.01
D, P, R, V	339.1	7.46	0.02	0.01
P, R, P*R interaction	341.4	9.75	0.01	0.00
P, V, P*V interaction	341.4	9.75	0.01	0.00

Figure 2. Layout of the Pipeline Experiment at one of six sites. D= Disked, R= Rolled, DR= Disked and Rolled, V= rolled with Vibration, C= Control.

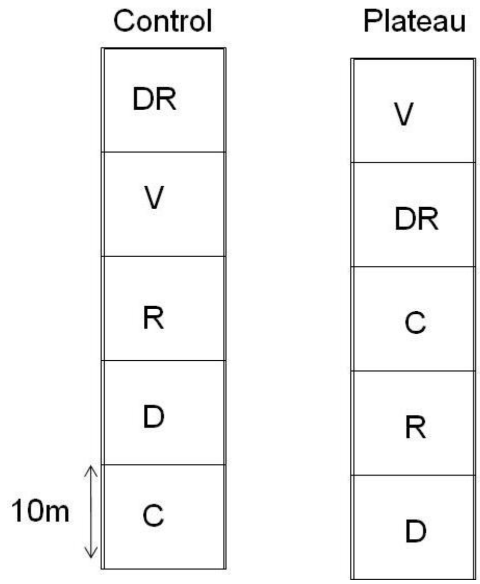


Figure 3. Ambient cheatgrass propagule pressure in undisturbed areas adjacent to each of six study sites. Error bars = SE.

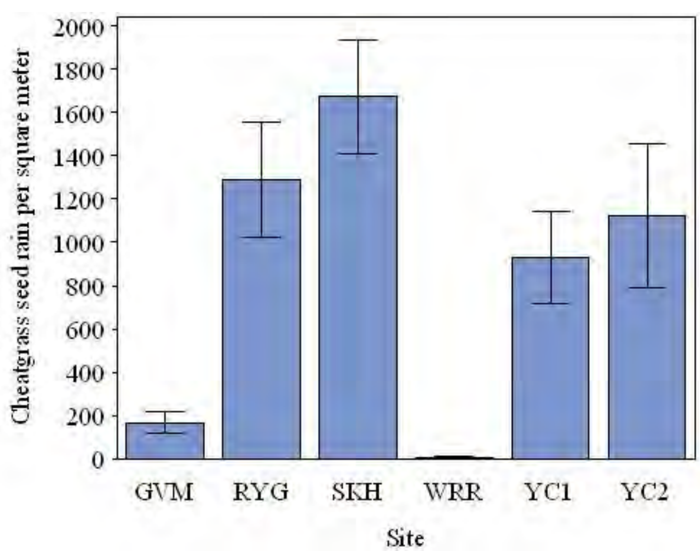


Figure 4. Effect of creating pipeline disturbances on soil bulk density profile. Error bars= SE.

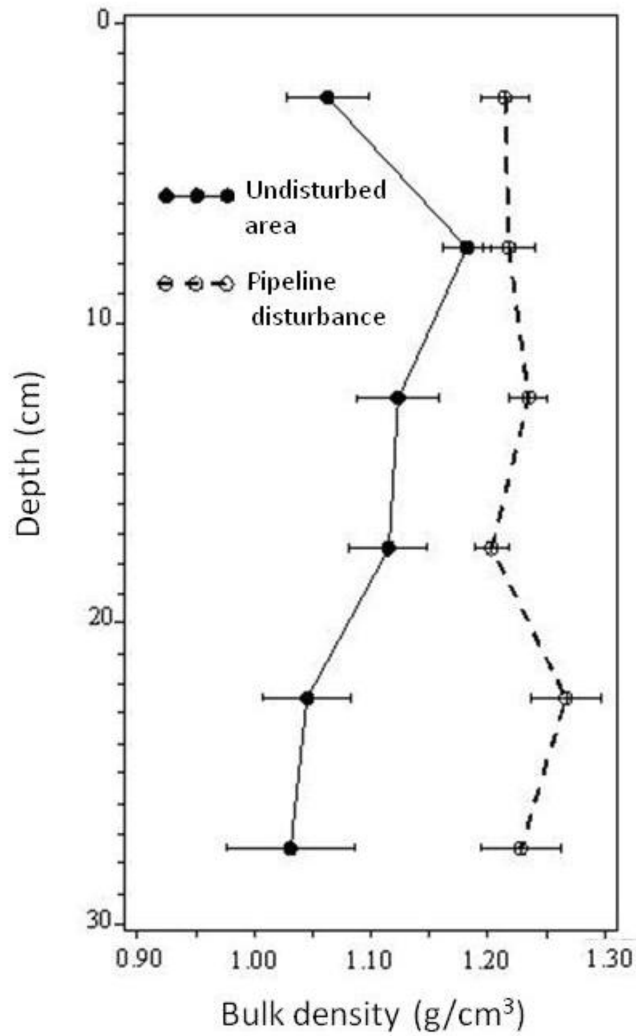


Figure 6. Effect of Disking (D), Rolling (R), and Vibratory drum rolling (V) on soil penetration resistance at a depth of 4-9 cm. Error bars = SE. C = Control.

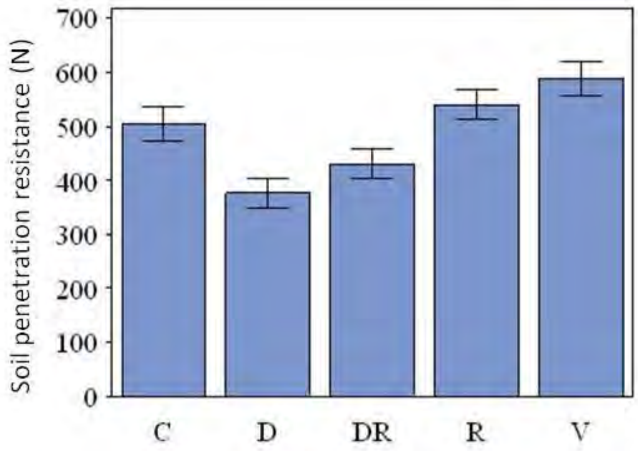


Figure 5. Response of cheatgrass seedlings (a) and native seedlings (b) to soil tillage treatments. D= Disked, R= Rolled, DR= Disked and Rolled, V= rolled with Vibration, C= Control. For cheatgrass, averages include only plots without Plateau. Error bars are SE for data normalized for site differences by subtracting the site mean and adding the overall mean to each value. Note differing Y-axis scales.

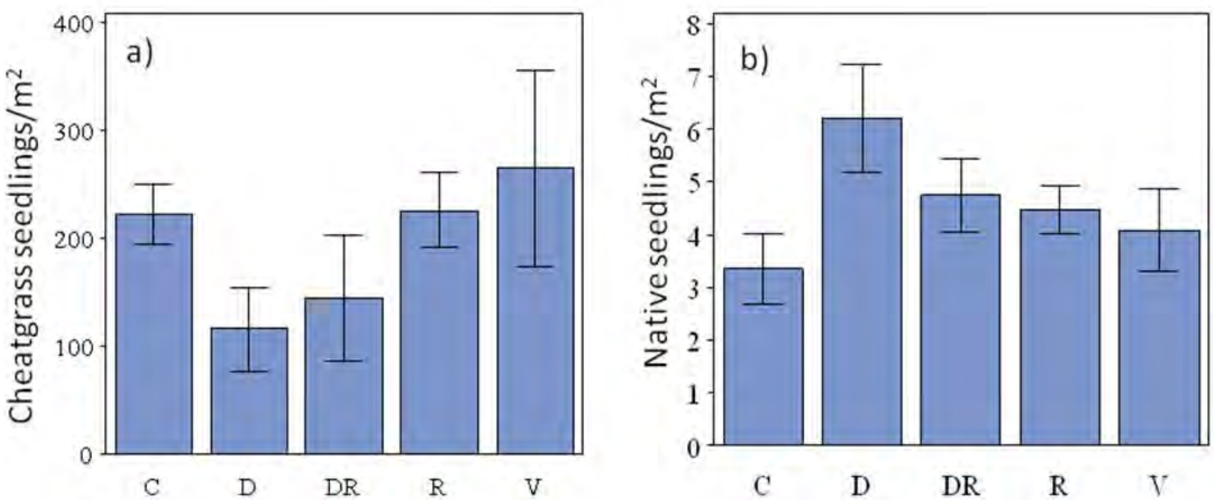
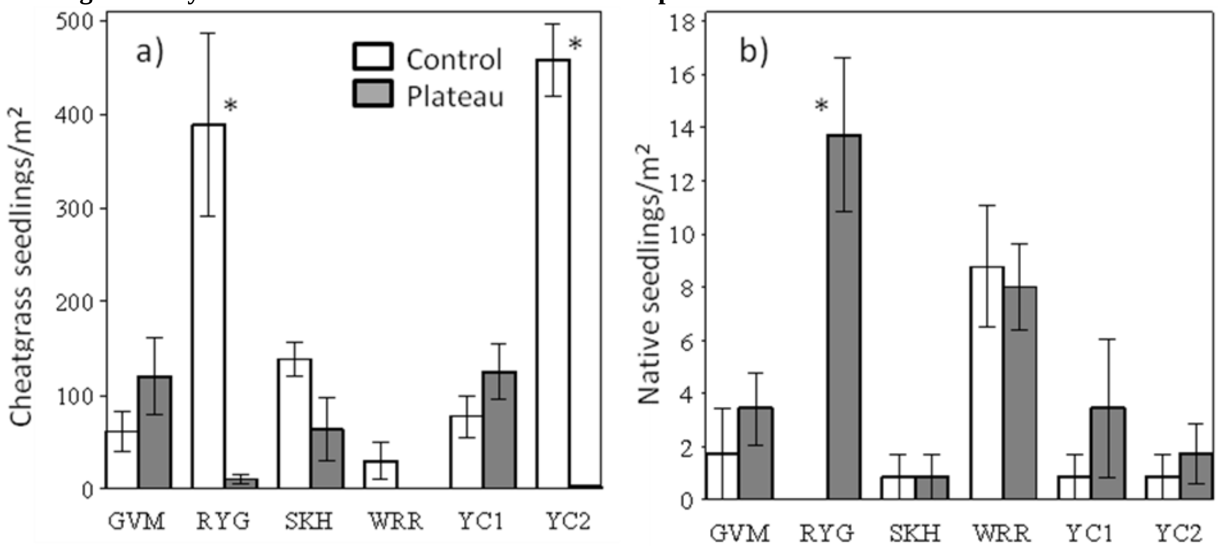


Figure 7. Response of cheatgrass seedings (a) and native seedlings (b) in late June 2009 to Plateau herbicide at six study sites. Data are counts from plots receiving the C soil tillage treatment. Error bars are SE. Stars denote significantly different means for Control vs. Plateau plots within a site at the α = 0.05 level.



MOUNTAIN TOP EXPERIMENT

Conducted at 4 sites: Scandard (SCD), Sprague (SPG; formerly called Snowpile), The Girls' Claims (TGC) and SQS.

Background

Even after decades of recovery, reclamation areas may not resemble undisturbed habitat. A common outcome is domination by grasses, even if the surrounding undisturbed area contains a desirable mixture of grasses, forbs, and shrubs (Newman and Redente 2001). Explanations for grass dominance include a loss of variability in soil resources when topsoil is redistributed, and a disproportionate influence of the grasses included in the reclamation seed mix (Redente et al. 1984). If the surrounding undisturbed area is diverse and desirable, then creating treatments which re-establish resource heterogeneity, encourage native seed dispersal, and avoid undue competition from seeded grasses may result in more satisfactory reclamation. In this study, we examine two treatments designed to create variability in soil resources and maximize establishment of seeds from the surrounding plant community: creating large holes, and using brush scraped from the well pad surface as mulch. Large holes create variability in soil depth and microsites of higher moisture availability, and have recently been shown to improve the establishment of native species in reclamation areas (Eldridge 2008). Large holes have also been shown to entrap and retain dispersing seeds (Chambers 2000). Similarly, brush mulch creates favorable microsites by causing snow to drift and creating shade, entraps dispersing seeds (Kelrick 1991), and also likely contains some viable native seed. These two treatments are applied with and without seeding in order to address the question: If the adjacent undisturbed area is desirable, how important is seeding versus creating heterogeneity and encouraging natural seed dispersal? The treatments examined include:

1) Seeding [Seeded or Not Seeded]
2) Soil Surface [Holes or Flat]
3) Brush mulch [Mulched or Not Mulched]

These treatments were implemented in a completely randomized, factorial design with 3 replications per location (Figure 8).

Study sites

The four study sites used in this experiment had predominately native plant communities and ranged in elevation from 2342 m (7681 ft) to 2676m (8777 ft) in elevation (Table 1). Species common to all study sites included Mountain Big Sagebrush, Saskatoon Serviceberry (*Amelanchier alnifolia*), Snowberry (*Symphoicarpos rotundifolius*), Prairie Junegrass (*Koeleria macrantha*), and Western Wheatgrass *Pascopyrum smithii*). The SCD site was further characterized by Bitterbrush (*Purshia tridentata*), Yellow rabbitbrush (*Chrysothamnus viscidiflorus*), Needle-and-thread grass (*Hesperostipa comata*), the non-native pasture grass Smooth Brome (*B. inermis*), Sulfurflower buckwheat (*Eriogonum umbellatum*), and the non-native Desert Madwort (*Alyssum desertorum*). The SPG site contained Yellow Rabbitbrush, Indian Ricegrass (*Achnatherum hymenoides*), Sandberg Bluegrass (*Poa secunda*), Arrowleaf balsamroot (*Balsamorhiza sagittata*), and the non-native Redstem filaree (*Erodium cicutarium*). The TGC site contained Bitterbrush, Sandberg Bluegrass, Sulfurflower buckwheat, Tailcup Lupine (*Lupinus caudatus ssp. caudatus*) and Purple Locoweed (*Oxytropis lambertii*). The SQS site was contained Rubber Rabbitbrush (*Ericameria nauseaosa*), the non-native pasture grass Bulbous Bluegrass (*Poa bulbosa*), Pearly Pussytoes (*Antennaria anaphaloides*), the non-native Flixweed (*Descurainia sophia*), and Silky Lupine (*Lupinus sericeus*).

Objectives for 2009

2009 was the first year for the Mountain Top Experiment. The goal for 2009 was to implement the treatments.

Treatment implementation

Treatments were implemented between 8/13/09 and 9/23/09. The large holes treatment (H) was created using a mini excavator to dig holes approximately 100 cm X 60 cm X 50 cm deep (Figure 9). Material removed was mounded next to each hole, and approximately 18 holes were dug per plot. This resulted in approximately 20% of the ground being allocated to holes, 30% to mounded soil, and 50% to interspaces.

The seed mix given in Table 4 was planting in all plots receiving the seeded treatment. On Flat plots, seed was drilled approximately 1 cm deep using a Plotmaster™ 400 with a hunter grain drill attachment. On Holes plots, seed was broadcast and then lightly raked to incorporate the seed into the soil. Seeding rates were the same for both seeding methods. Seed was mixed 1:1 by volume with rice hulls to help ensure even distribution of species when seeding.

The Brush mulch treatment was achieved by distributing approximately 1.2 m^3 of stockpiled woody debris to each plot receiving the brush treatment. This resulted in approximately 5% of the plot are being covered by brush. Because some topsoil was mixed with stockpiled brush, and this likely contained viable seed, an effort was made to distribute equal amounts of this topsoil to each plot. Approximately 4 liters of topsoil from brush stockpiles was scattered over each plot receiving the brush treatment.

Sagebrush seed was collected within 10 miles of each study site in November 2009 and broadcast seeded between 11/11/09 and 12/15/09.

Expected products

The Mountain Top Experiment will be monitored for at least 3 additional growing seasons. The performance of the treatments will be assessed by quantifying density, cover, and diversity of desirable vegetation in the study plots. Vegetation in adjacent, undisturbed areas will also continue to be monitored at each site. Data will be analyzed using a repeated measures analysis with treatments and their interactions as fixed effects. If the effectiveness of treatments differs across study sites, a site-by-site analysis will be done. The cost and value of large holes, brush mulching, and seeding in areas with desirable surrounding habitat will be compared and discussed.

Table 4. Seed mix used in Seeded plots of the Mountain Top experiment.

Common Name	Variety	Scientific Name	Life Form	Seeds/ m^2	PLS (kg/ha)	Seeds/ ft^2	PLS (lbs/ac)
Mountain Brome	Garnet	*Bromus marginatus*	grass	54	3.8	5	3.4
Thickspike Wheatgrass	Critana	*Elymus lanceolatus spp. lanceolatus*	grass	22	0.6	2	0.6
Slender Wheatgrass	San Luis	*Elymus trachycaulus spp. trachycaulus*	grass	65	2.2	6	1.9
Green Needlegrass	Lowdorm	*Nassella viridula*	grass	43	1.2	4	1.0
Muttongrass	VNS	*Poa fendleriana*	grass	215	0.5	20	0.4
Bluebunch Wheatgrass	Anatone	*Pseudoroegneria spicata spp. spicata*	grass	65	2.3	6	2.1
Western Yarrow	Eagle Mtn.	*Achillia millefolium*	forb	161	0.3	15	0.2
Utah Sweetvetch	Timp	*Hedysarum boreale*	forb	15	1.5	1	1.3
Palmer Penstemon	Cedar	*Penstemon palmeri*	forb	215	1.7	20	1.5
Rocky Mtn. Penstemon	Bandera	*Penstemon strictus*	forb	108	1.7	10	1.5
Silver Sage	VNS	*Artemisia cana*	shrub	323	1.3	30	1.2
Mtn. Big Sagebrush	VNS	*Artemisia tridentata spp. vaseyana*	shrub	250	0.6	23	0.5
Rubber Rabbitbrush	VNS	*Ericameria nauseosa*	shrub	22	0.2	2	0.2
			TOTAL=	**1556**	**17.8**	**145**	**15.9**

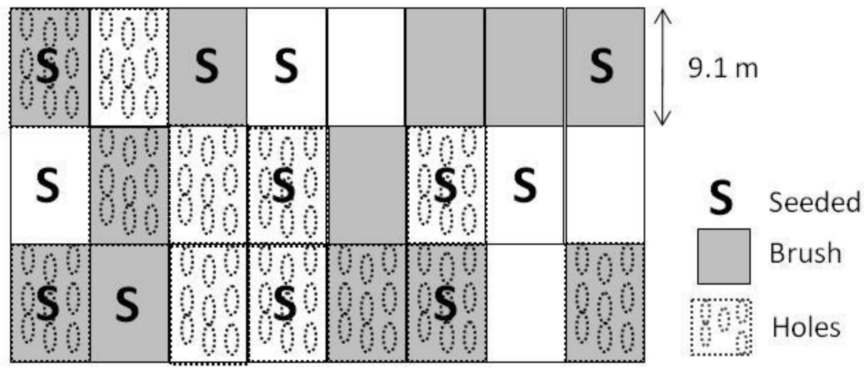


Figure 9. Layout of the Mountain Top experiment at the TGC site.

Figure 8. Implementing the Holes treatment in the Mountain Top Experiment at the TGC site.

STRATEGY CHOICE EXPERIMENT

Conducted at 4 sites: WRR , Sagebrush (SGE), GVM, and Mountain Shrub (MTN)

Background

The goal if the Strategy Choice Experiment is to compare two mutually exclusive reclamation strategies. A ―conservative" strategy is the obvious choice in areas where weed pressure is very high: plant a highly competitive seed mix, use aggressive weed control measures, and avoid contaminating the site with seed from the surrounding area. The benefit of a conservative strategy is in minimizing weed invasion and soil loss, and the cost is in a loss of plant diversity: highly competitive seed mixes, weed control, and lack of natural seed dispersal all reduce the diversity of the resulting plant stand (Marlette and Anderson 1986, Chambers 2000, Krzic et al. 2000, Baker et al. 2007). The opposite strategy, dubbed here ―optimistic", emphasizes maximizing the diversity of the plant stand but allows a higher risk of weed invasion and/or soil loss. An optimistic strategy uses highly diverse seed mixes with a minimal fraction of highly competitive grasses, avoids herbicides (many of which have a detrimental effect on forbs), and makes use of brush mulch, holes, or other mechanisms to entrap seed dispersing from the surrounding area. An optimistic strategy is the obvious choice when the surrounding plant community is desirable, and the risks of soil erosion and weed invasion are low. This study compares the results of these two strategies in situations where the choice is not clear: the risk of weed invasion is moderate, and the surrounding plant community contains both some desirable and some undesirable species. The goal of the study is to shed light on the question: What conditions mandate a conservative approach to reclamation? Treatments include:

1) Seed Mix Competition Level [High Competition (HC) or Low Competition (LC)]
2) Soil surface/mulch type [Flat/Straw or Holes/Brush]
3) Herbicide application [Plateau applied or no Plateau]

Treatments were implemented in a completely randomized, factorial design, with 3 replications in each location (Figure 10).

Study sites

We selected four study sites with light to moderate weed dominance for this experiment (Table 1). The GVM site was at 5451 ft and was dominated by Wyoming Big Sagebrush, Indian Ricegrass, Utah Juniper (*Juniperus osteosperma*), shadscale saltbush (*Atriplex contertifolia*), Tall tumble mustard (*Sisymbrium altissimum*), and cheatgrass. The SGE was at 6573 ft as was dominated by Wyoming Big Sagebrush, Sandberg Bluegrass, Western Wheatgrass, Needle-and-Thread grass, Prairie Junegrass, and Scarlet Globemallow (*Sphaeralcea coccinea*). The MTN site was 7160 ft was dominated by Wyoming Big Sagebrush, Sandberg Bluegrass, Western Wheatgrass, Needle-and-Thread grass (*Hesperostipa comata*), Prairie Junegrass, Indian Ricegrass, Bulbous Bluegrass, Spreading Phlox (*Phlox diffusa*), and Saskatoon Serviceberry. The WRR site was at 7268 ft. and was dominated by similar species to the MTN site, with the addition of a wider diversity of native forbs, including Hawksbeard (*Psilochenia acuminate*).

Objectives for 2009

2009 was the first year for the Strategy Choice Experiment. The goal for 2009 was to implement the treatments.

Treatment implementation

At GVM and MTN, the full experiment with all three treatments was implemented. At WRR and SGE, space constraints mandated implementing an abbreviated form of the experiment, and the Herbicide treatment was omitted.

Seed mixes for the HC and LC treatments are shown in Table 6. A key difference between the mixes is in the number and type of grass seeds used. In the HC mix, 344 grass seeds/ m^2 (32 seeds/ sq. ft.) were used, and these were mostly wheatgrasses, which tend to be good competitors. In the LC mix, 156 grass seeds/m^2 (15 seeds/ sq. ft.) were used, and the majority of these were less competitive species (Table 6).

On Holes/Brush plots, all species were hand-broadcast and raked, after creation of the holes but before the application of brush. On Flat/Straw plots, some seed was hand broadcast and then lightly raked, and the remained was drill seeded approximately 1 cm deep using a Plotmaster™ 400 with a hunter grain drill attachment (Table 6). Seed was mixed 1:1 by volume with rice hulls to aid in an even distribution of species.

Certified weed-free straw was applied by hand at a rate of 4.0 Mg/ha (1.8 tons/ac) to plots receiving the Flat/Straw treatment. Straw was crimped in place using a custom-built mini crimper. The Holes/Brush treatment was created using a 331 Bobcat® compact excavator to dig holes approximately 130 cm X 80 cm X 50 cm deep. Material removed was mounded next to each hole, and 18 holes were dug per plot. This resulted in approximately 1/3 of the ground being allocated to each of holes, mounds, and interspaces (Figure 11).

Plots receiving the Plateau treatment were sprayed with 140 g ai/ha of Plateau (8 oz. /acre) applied with 655 li/ha of water (70 gal. /acre) with a backpack sprayer. Dye indicator was used to ensure even application. In Plateau plots also receiving the Flat/Straw treatment, the amount of water used in the application was tripled to aid the product in penetrating the straw mulch.

After Plateau application, brush which had been cleared and stockpiled next to each site was used for plots receiving the Holes/Brush treatment. Approximately 5 m^3 of brush was applied evenly to each plot.

Sagebrush was hand-broadcast on top of snow in all plots in December of 2009.

Expected products

The Strategy Choice Experiment will be monitored for at least 3 additional growing seasons. The performance of the treatments will be assessed by quantifying density, cover, and diversity of desirable vegetation in the study plots. Vegetation in adjacent, undisturbed areas and cheatgrass propagule pressure will also continue to be monitored at each site. Data will be analyzed using a repeated measures analysis with treatments and their interactions as fixed effects. If the effectiveness of treatments differs across study sites, a site-by-site analysis will be done, and the results interpreted with respect to surrounding vegetation and cheatgrass propagule pressure. Conditions under which an optimistic strategy may be successfully employed, vs. those mandating a conservative strategy, will be discussed.

Table 5. High Competition and Low Competition seed mixes used in the Strategy Choice Experiment. On Holes/Brush plots, all seed was broadcast. On Flat/Straw plots, seed was either broadcast or drill seeded as indicated.

	Common Name	Variety	Scientific Name	type	High Comp. Mix seeds/ m^2	High Comp. Mix PLS (kg/ha)	Low Comp. Mix seeds/ m^2	Low Comp. Mix PLS (kg/ha)
drill seeded	Bluebunch Wheatgrass	Anatone	*Pseudoroegneria spicata spp. spicata*	grass			22	0.8
	Galleta Grass	Viva	*Pleuraphis jamesii*	grass	75	2.2		
	Indian Ricegrass	Rimrock	*Achnatherum hymenoides*	grass	65	1.8	11	0.3
	Muttongrass	VNS	*Poa fendleriana*	grass			54	0.1
	Slender Wheatgrass	San Luis	*Elymus trachycaulus spp. trachycaulus*	grass	75	2.5	11	0.4
	Thickspike Wheatgrass	Critana	*Elymus lanceolatus spp. lanceolatus*	grass	65	1.9		
	Western Wheatgrass	Rosana	*Pascopyrum smithii*	grass	65	2.5	5	0.2
	Utah Sweetvetch	Timp	*Hedysarum boreale*	forb	22	2.1	22	2.1
	Fourwing Saltbush	VNS CO	*Atriplex canescens*	shrub	11	1.1	11	1.1
broadcast seeded	Prarie Junegrass	VNS	*Koeleria macrantha*	grass			54	0.1
	Bluestem Penstemon	VNS	*Penstemon cyanocaulis*	forb	108	0.7	108	0.7
	Hairy Golden Aster	VNS	*Heterotheca villosa*	forb			215	1.3
	Lewis Flax	Maple Gr.	*Linum lewisii*	forb	54	0.8	54	0.8
	Many-lobed grounsel	VNS	*Packera multilobata*	forb			215	1.3
	Oregon Daisy	VNS	*Erigeron speciosis*	forb			323	0.9
	Sulphur flower buckwheat	VNS	*Eriogonum umbellatum*	forb	108	2.3	108	2.3
	Western Yarrow	VNS	*Achillia millefolium*	forb	129	0.2	129	0.2
	Winterfat	VNS	*Krascheninnikovia lanata*	shrub	22	0.8	22	0.8
	Wyoming Big Sagebrush	VNS	*Artemesia tridentat spp. Wyomingensis*	shrub	253	0.6	253	0.6
				GRASS TOT	**344**	**9.8**	**156**	**1.7**
				FORB TOT	420	5.6	1173	8.7
				SHRUB TOT	285	2.2	285	2.2
				TOTAL	**1049**	**17.6**	**1614**	**12.6**

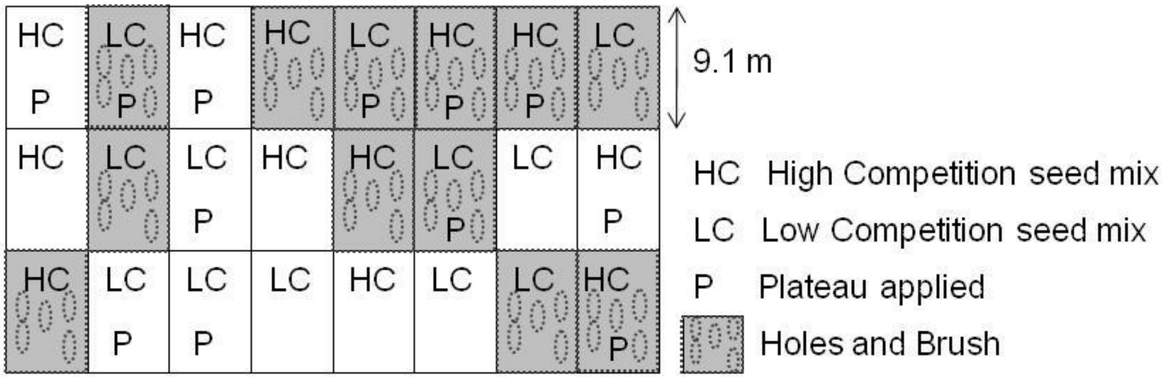


Figure 11. Layout of the Strategy Choice experiment at the GVM site.

Figure 10. The Strategy Choice Experiment at GVM, showing Flat/Straw mulch plots and Holes/Brush mulch plots.

Gulley Experiment

Conducted at 4 sites: RYG , SKH, YC1, and YC2

Background

The goal of the Gulley Experiment is to address reclamation strategies in a difficult circumstance: when weed pressure from the surrounding plant community is very high. Achieving successful reclamation in this case is difficult because most weed control strategies are short-lived. For instance, tilling soil to bury weed seeds does nothing to prevent germination of new seeds landing on the soil surface. In the Piceance Basin, input of cheatgrass seeds dispersing from the surrounding plant community is a potential problem (please see Appendix 2, ―Seed Dispersal Study"). An additional problem is that most herbicides are not completely effective, or are effective for only a short time. The best available selective herbicide for cheatgrass, Plateau, does not completely control cheatgrass when applied at rates which allow germination of desirable species (Bekedam 2004) A recent study has shown that even when Plateau is successfully employed, it can fail to prevent cheatgrass from regaining dominance within 2 years (Morris et al. 2009). It is clear that more thorough and continually effective strategies for controlling cheatgrass and other weeds are needed to allow a resistant, fully developed perennial plant community to develop.

In this study, we compare the effectiveness of two additional weed control strategies with that of Plateau application in reclamation areas surrounded by highly weedy plant communities. The first strategy is fallowing for one year with the herbicide Pendulum® AquaCap™ (pendimethalin, BASF Corporation, Research Triangle Park, NC; hereafter *Pendulum*). Pendulum is a broad-spectrum, pre-emergent herbicide, is effective for about 6 months, and is often used in orchards to maintain bare soils. Pendulum application is a drastic measure designed to eliminate as much of the existing seed bank as possible. The second strategy is surrounding the reclamation area with seed dispersal barriers to prevent weed seeds from blowing in. Seed dispersal barriers were constructed of aluminum windowscreen using a design that had been effective in a Utah seed bank study (Smith et al. 2008). Each of these treatments is tested alone and in combination with each other as well as with Plateau (Figure 12). In summary, the treatments are:

1) Fallowing [Fallowing with Pendulum for one year or No Fallowing]
2) Plateau application [Plateau applied just prior to planting or No Plateau]
3) Seed Barriers [Barriers or No Barriers]

Study sites

We selected four study sites with heavy cover of non-natives in the adjacent plant community: YC1, YC2, RYG, and SKH (Table 1). All sites were characterized by Wyoming Big sagebrush and cheatgrass, and most contained Tall Tumblemustard (*Sisymbrium altissimum*), Western Wheatgrass, Needle-and-Thread grass, Prairie Junegrass, Yellow Rabbitbrush, Desert Madwort, and Scarlet Globemallow. At RYG, Basin Wildrye (*Leymus cinereus*), Rubber Rabbitbrush, Winterfat (*Krascheninnikovis lanata*), and Netseed Lambsquarters (*Chenopodium berlandieri*) were also found. At YC1, Indian Ricegrass, Sandberg bluegrass, and Winterfat were found. YC2 contained Squirreltail (*Elymus elymoides*). SKH contained Greasewood (*Sarcobatus vermiculatus*), Redstem Filaree, and Western Salsify (*Tragopogon dubius*).

Objectives for 2009

2009 was the first year for the Gulley Experiment. The goal for 2009 was to implement the Barrier and Fallowing treatments, and to apply Plateau and plant seed in the non-fallowed plots. Plateau application and seeding in Fallowed plots will occur in 2010.

Quantifying cheatgrass propagule pressure

The degree of cheatgrass seed input from the surrounding plant community is an important covariate for this study. Cheatgrass seed input was quantified at all study locations using the techniques described in the section ―Pipeline Experiment".

Treatment implementation

These treatments were implemented in a factorial, split-split plot design with three replications in each location (Figure 12). The whole-plot factor is Fallowing (assigned randomly), the sub-plot factor is Barriers (assigned randomly within Fallow designations), and the sub-subplot factor is Plateau is (assigned randomly within Barrier designations). This design allows less power to detect differences for the Fallowing and Barrier treatments than for the Plateau treatment. This was unavoidable because of the difficulty of implementing the Fallowing and Barrier treatments at small scales.

Fallowed whole plots were treated with Pendulum at 3200 g ai/ha (3 qt/ac), applied with a boom sprayer with 330 li/ha (35 gal/ac) of water between 8/26/09 and 9/2/09. At the time of application, no germinated plants of any kind were evident at any of the sites. Once dry, the product was immediately incorporated into the soil with light disking to 5 cm (2 in) to prevent breakdown due to UV radiation.

Unfallowed whole plots were seeded by hand-broadcasting a mixture of native grasses, forbs and shrubs (Table 6). Even seed distribution was ensured by preparing batches of the seed mix for each sub-subplot and seeding plots individually. Seed was mixed 1:1 by volume with rice hulls to aid in even distribution of species. Seed was lightly raked to incorporate it into the soil after broadcasting.

Plateau sub-subplots not receiving the Fallowing treatment were treated with 140 g ai/ha (8 oz/ac) applied with 655 li/ha (70 gal/ac) of water with a backpack sprayer. Dye indicator was used to ensure even application. Plateau was applied between 8/26/09 and 9/2/09, and no cheatgrass germination was evident at the time of application.

To prevent wind and water erosion, a light tackifier was applied to all plots following Plateau application. The tackifier used was DirtGlue® (DirtGlue® Enterprises, Amesbury, MA), a water-based polymer emulsion which permits water infiltration. DirtGlue was applied with a boom sprayer at 190 li/ha (50 gal/ac) diluted 10:1 with water.

Next, Barrier subplots were surrounded by aluminum windowscreen seed dispersal barriers. Barriers were 0.6 m high and were secured to oak stakes with staples (Figures 13 and 14). One meter wide buffer strips separated Barrier subplots (Figure 12).

A difficulty with constructing a fair test of the barriers is that subplots on the edge of the experiment area are likely be subject to more seed blowing in from the edge than are subplots in the interior. We moderated this effect by hand-broadcasting cheatgrass seed within the buffer strips separating subplots. To determine how much seed to scatter, we used data on ambient cheatgrass seed rain known from our Tanglefoot seed rain traps. Because the traps were sticky and did not allow the seeds to redistribute, we scattered only half as much seed per unit area as these traps had caught. This compensated for the fact that under normal conditions roughly half of cheatgrass seeds landing in a particular location move again (Kelrick 1991); therefore our traps likely overestimated by a factor of 2. The scattered cheatgrass seed had been collected from near-monocultures within 100 m of each site between 6/15/09 and 7/10/09, when the seed was dry and nearly ready to fall. Seed was collected using a lawnmower with a bagging attachment. Viable cheatgrass seed content was estimated for each collection by gathering 5 5g subsamples, and then counting and weighing all of the fully developed, hard-coated cheatgrass seeds for each subsample.

At two of the sites, RYG and SKH, barriers were badly damaged by cow trampling after the cheatgrass seed had been broadcast. The barriers were rebuilt, and lath secured with wood screws was added to the oak stakes at all sites to better secure the windowscreen. The barrier treatments at RYG and SKH are best viewed as being functionally implemented in 2010, while those at YC1 and YC2 were effective for 2009 growing season. All of the sites were fenced to prevent damage in the future.

Locally collected sagebrush was hand-broadcast in the non-fallowed plots in December of 2009.

Expected Products

The Gulley Experiment will be monitored for at least 3 additional growing seasons. The performance of the treatments will be assessed by quantifying density, cover, and diversity of desirable vegetation in the study plots. Vegetation in adjacent, undisturbed areas and cheatgrass propagule pressure will also continue to be monitored at each site. Data will be analyzed using a repeated measures analysis with treatments and their interactions as fixed effects. If the effectiveness of treatments differs across study sites, a site-by-site analysis will be done, and the results interpreted with respect to surrounding vegetation and cheatgrass propagule pressure. The costs and benefits of the three weed control measures tested will be compared and discussed.

Table 6. Seed mix used in the Gulley Experiment.

Common Name	Variety	Scientific name	Life Form	Seeds/ m2	PLS (kg/ ha)	Seeds/ ft2	PLS (lbs/ ac)
Basin Wild Rye	Trailhead	*Leymus cinereus*	grass	43	1.3	4	1.2
Bluebunch Wheatgrass	Anatone	*Pseudoroegneria spicata spp. spicata*	grass	108	3.9	10	3.5
Galleta Grass	Viva	*Pleuraphis jamesii*	grass	54	1.6	5	1.4
Indian Ricegrass	Rimrock	*Achnatherum hymenoides*	grass	108	3.0	10	2.7
Muttongrass	VNS	*Poa fendleriana*	grass	323	0.7	30	0.7
Slender Wheatgrass	San Luis	*Elymus trachycaulus spp. trachycaulus*	grass	65	2.2	6	1.9
Squirreltail	Toe Jam Ck.	*Elymus elymoides*	grass	108	2.5	10	2.3
Thickspike Wheatgrass	Critana	*Elymus lanceolatus spp. lanceolatus*	grass	65	1.9	6	1.7
Western Wheatgrass	Rosana	*Pascopyrum smithii*	grass	65	2.5	6	2.2
Lewis Flax	Maple Gr.	*Linum lewisii*	forb	54	0.8	5	0.7
Utah Sweetvetch	Timp	*Hedysarum boreale*	forb	22	2.1	2	1.9
Western Yarrow	VNS	*Achillia millefolium*	forb	183	0.3	17	0.3
Fourwing Saltbush	VNS	*Atriplex canescens*	shrub	32	3.3	3	3.0
Rubber Rabbitbrush	VNS	*Ericameria nauseosa*	shrub	22	0.2	2	0.2
Winterfat	VNS	*Krascheninnikovia lanata*	shrub	16	0.6	1.5	0.5
Wyo. Big Sagebrush	VNS	*Artemesia tridentat spp. Wyomingensis*	shrub	250	0.6	23	0.5
			TOTAL=	**1514**	**28**	**141**	**25**

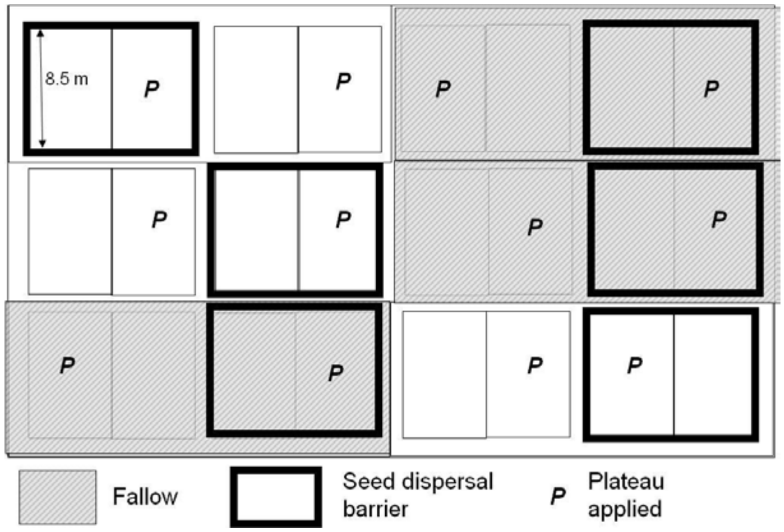


Figure 14. Layout of the Gulley Experiment at the SKH site.

Figure 12. The Barrier treatment at the SKH

Figure 13. A closeup of the Barrier treatment showing trapped cheatgrass

Competition Experiment

Conducted at 2 sites: WRR and SGE

Background

The Competition Experiment is a small-scale study to evaluate how soil additives may affect the competitive balance between native wheatgrasses and cheatgrass. Known quantities of cheatgrass seed and wheatgrass seed were planted within a simulated well pad disturbance. Two soil additives were added, with or without soil compaction.

The first soil additive is a super-absorbant polymer (SAP). SAPs have been used for many years in baby diapers and potting soil because of their ability to retain up to 400 times their weight in water. When added to degraded soils, SAPs will absorb and then gradually release water, reducing the effects of water stress (Huttermann et al. 2009). If addition of SAP reduces annual variability in soil moisture, then cheatgrass establishment may be hindered, because cheatgrass has been shown to be a more effective invader when soil moisture is more variable (Chambers et al. 2007). The SAP we are investigating is Luquasorb®, a cross-linked copolymer of Potassium acrylate and acrylic acid in granulated form (BASF, Ludwigshafen, Germany).

Another type of soil additive common in reclamation settings is soil binding agent, or tacifier, which is used to stabilize soil and facilitate binding of seed to the soil surface. The effect of tacifiers on competitive interactions is unknown. We are investigating the effects of DirtGlue® (DirtGlue® Enterprises, Amesbury, MA) because of its claimed ability to bind soil particles without reducing water infiltration.

Finally, we are examining the effects of both Luquasorb® and DirtGlue® in combination with with rolling with a heavy lawn roller. The goal of the heavy roller treatment is to determine if combining rolling with a binding agent would create a crust useful in preventing cheatgrass germination. In summary, treatments include:

1) Binding agent (BA; low, high, or no addition of BA)
2) Super-absorbant polymer (SAP; Addition of SAP or no addition)
3) Rolling (Rolled or Not Rolled)

Treatments were implemented in a factorial split-split plot design, with completely randomized whole plots (Figure 15). The subplot factor was BA, the split plot factor was SAP, and the whole plot factor was Rolling. Three replicates were implemented at each site.

Study sites

Because we wanted to control the degree of competition in this experiment, we desired study sites which were free of cheatgrass at the initiation of the experiment, but which were capable of being invaded by cheatgrass. The two study sites selected, SGE and WRR, had no apparent cheatgrass, but cheatgrass was well established on nearby roads and disturbed areas. Both SGE and WRR were within the Piceance fine sandy loam soil type (USDA Natural Resources Conservation Service Survey version 2/4/08) and had slopes of approximately 5%. For a full description, please see the section ―Strategy Choice Experiment.”

Objectives for 2009

2009 was the first year for the Competition Experiment. The goal for 2009 was to implement the treatments.

Cheatgrass seed collection and dispersal

Cheatgrass seed was collected using a lawnmower with a bagging attachment from monocultures or near-monocultures in 4 locations, each within 50 miles of the study sites. Collections were made in late June or early July when most or all of the cheatgrass in a location had fully ripened seed heads. Seed was allowed to dry and after-ripen in shallow containers in a dry, warm location for approximately 3 months. The density of apparently viable cheatgrass seeds was determined by gathering five 5g subsamples from each collection, and then counting and weighing all of the fully developed, hard-coated cheatgrass seeds for each subsample. Equal quantities of seeds from each location were mixed together, and then quantities of seed sufficient to supply 300 seeds/m^2 were prepared for each 17.8m^2 subplot. Seed was hand-broadcast in early October, 2009, and immediately lightly raked to incorporate seed into the soil. The 300 seeds/m^2 seeding rate is about 25% of the 2009 cheatgrass seed rain at heavily cheatgrass-infested sites quantified for the Pipeline Experiment, and therefore thought to be a reasonable value of cheatgrass seed density for a Piceance Basin site in the initial phases of invasion.

Treatment implementation

A mixture of native wheatgrasses was drill-seeded using a Plotmaster 400 (Table 7). Seed was mixed 1:1 by volume with rice hulls to maintain suspension of the seed mixture. For subplots receiving the SAP treatment, granulated SAP was added to the seed/rice hull mixture. At SGE, 6.7 g/m^2 of SAP was added, and at WRR, 30.8 g/m^2 was added. These rates span are near the lower and upper limits, respectively, of recommended application rates for different agricultural purposes. Next, whole plots receiving the Rolling treatment were rolled ten times with a static roller supplying a linear load of 20.8 lbs/in (36.5 N/cm). Next, BA subplots were treated by sprinkling plots using hand watering cans (Figure 16). High BA plots received 4100 li/ha (440 gal/ac) of BA, diluted 6:1 with water. Low BA plots received 1600 li/ha (175 gal/ac) of BA, diluted 17:1 with water. No BA plots received 21000 li/ha (3200 gal/ac) of plain water, an amount equivalent to the total amount of liquid applied to other plots.

Following implementation, the entire treatment area was surrounded by a barrier to prevent dispersal of cheatgrass seed out of the experiment area. A physical barrier of aluminum window screen was constructed adjacent to the plots. This barrier was 0.6 m high and supported by oak stakes. Outside of this, we applied a chemical barrier of pendimethalin herbicide (Pendulum® AquaCap™, BASF Corporation, Research Triangle Park, NC) at 3200 g a.i./ha (0.75 gal/ac) a broad spectrum pre-emergent herbicide, to a 1m- wide strip of bare ground.

Expected products

The competition experiment will be monitored for at least two additional growing seasons. The performance of the treatments will be assessed by quantifying density and cover of weeds vs. desirable vegetation. Data will be analyzed using a split-split plot, repeated measures analysis, with treatments and their interactions as fixed effects. The control over cheatgrass seed in this experiment should allow more power to detect effects than that afforded by typical reclamation trials. Costs and recommended application procedures will be discussed for any treatments promoting dominance of desirable vegetation under competition from cheatgrass.

Table 7. Seed mix used in the Competition Experiment.

Common Name	Variety	Scientific Name	Life Form	Seeds/ m2	PLS (kg/ha)	Seeds/ ft2	PLS (lbs/ac)
Slender Wheatgrass	San Luis	*Elymus trachycaulus spp. trachycaulus*	grass	150.7	5.1	14	4.5
Thickspike Wheatgrass	Critana	*Elymus lanceolatus spp. lanceolatus*	grass	150.7	4.5	14	4.0
Western Wheatgrass	Rosana	*Pascopyrum smithii*	grass	150.7	5.8	14	5.2
			TOTAL	**452.1**	**15.3**	**42**	**13.7**

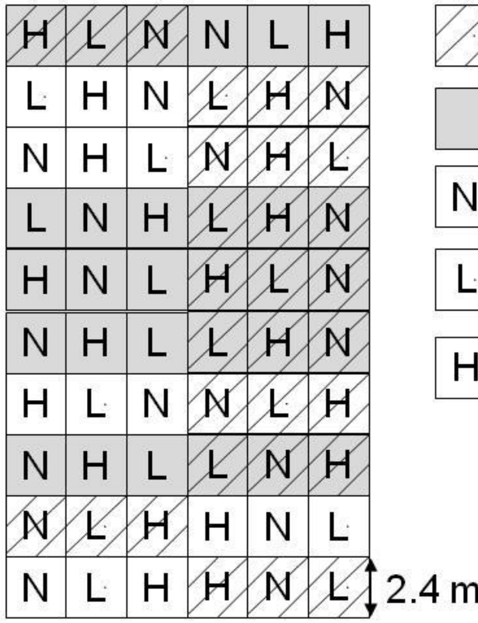


Figure 15. Layout of the Competition Experiment at the WRR site.

Figure 16. Implementing the Competition Experiment at the WRR site.

CONCLUSIONS

In 2009, we obtained and analyzed the first year of data from the Phase I of the project, an experiment on weed control techniques on simulated pipelines. Plateau herbicide was effective at 2 of 6 study sites, and disking was also useful in controlling cheatgrass.

2009 was the initial year for Phase II of the project, which included 4 experiments conducted on simulated well pad disturbances. These experiments were tailored to particular zones of the landscape, but had overlapping treatments, which will allow inference over a broad range of conditions. Questions posed by the new experiments include: How important is facilitating natural seed dispersal vs. planting seed? What conditions mandate a conservative approach to reclamation? What new weed control techniques might be effective in improving establishment of desirable plants in weedy areas? How do soil additives affect the competitive balance between weeds and desirable plants? All four experiments were successfully implemented. Future work will include monitoring all 5 experiments and determining the effectiveness of all treatments examined.

ACKNOWLEDGEMENTS

This research has been funded by donations from Encana Oil and Gas (Encana), Shell Oil Company, and Williams Production Company (Williams). Land access was provided by Williams, Encana, ConocoPhillips, the Bureau of Land Management (BLM), and the Colorado Division of Wildlife (DOW). Logistical support was provided by Ed Hallowed (BLM), Ken Holsinger (BLM), Rob Raley (Williams), Mike Gardner (Williams), Mike Reynolds (Williams), Dan Colette (Williams), Nicole Byrnes (Encana), and Justin Lovato (ConocoPhillips). Steve Hanson (Brady Construction), Reed Wold (MB Construction), and Jon Maille (J3 Environmental) oversaw construction crews. Kim Kaal (DOW) organized funding efforts, and Brett Walker (DOW) and Chuck Anderson (DOW) provided research advice. Ruth Bennett Andrew Paull, Robert Wayne, Neil LaFleur, and Katherine Kain collected field data.

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Appendix 1. Soil test results.

SITE	pH	EC (mmhos/cm)	Lime Estimate	OM (%)	NO_3-N	P	K	Zn	Fe	Mn	Cu
					ppm						
GVM	8.1	0.2	Very High	1.8	0.7	1.8	125	0.417	4.58	4.25	4.35
MTN	7.7	0.2	Low	1.3	2.6	2.5	155	0.333	7.76	2.61	2.42
RYG	7.8	0.2	Medium	2.2	4.5	4.9	238	0.469	17.0	4.03	3.66
SCD	7.3	0.2	Low	2.5	3.0	1.8	113	0.390	17.3	2.57	2.29
SGE	7.9	0.3	High	1.4	4.6	1.5	77.1	0.146	4.05	3.56	1.80
SKH	8.3	0.3	Very High	0.9	3.4	3.1	213	0.308	2.68	0.79	3.00
SPG	7.8	0.3	High	2.5	12.0	2.1	79.7	0.340	12.3	0.82	2.87
SQS	6.5	0.2	Low	1.9	11.6	3.4	336	1.280	68.3	1.89	2.23
TGC	7.0	0.1	Low	2.8	6.8	4.6	166	0.618	36.2	0.60	2.04
WRR	7.3	0.3	Low	1.8	2.4	2.8	93.2	0.269	7.27	3.27	2.19
YC1	8.1	0.3	Very High	1.8	5.8	2.5	166	0.699	6.52	3.15	2.61
YC 2	7.8	0.3	Very High	3.2	11.3	6.2	200	0.526	12.8	6.55	3.10

SITE	Ca	Mg	Na	K	SAR	Sand	Silt	Clay	Texture
	meq/L					%			
GVM	2.1	0.5	0.4	0.1	0.3	50	30	20	Loam
MTN	2.1	0.6	0.4	0.1	0.3	52	26	22	Sandy Clay Loam
RYG	2.6	0.3	0.4	0.5	0.3	68	16	16	Sandy Loam
SCD	1.8	0.6	0.3	0.1	0.3	66	14	20	Sandy Loam
SGE	2.8	0.6	0.5	0.2	0.4	60	22	18	Sandy Loam
SKH	1.4	0.2	1.8	0.3	**2.0**	52	22	26	Sandy Clay Loam
SPG	3.1	0.7	0.4	<0.1	0.3	70	12	18	Sandy Loam
SQS	1.2	0.3	0.3	0.4	0.4	68	20	12	Sandy Loam
TGC	0.5	0.1	0.4	0.1	0.6	72	12	16	Sandy Loam
WRR	3.7	0.8	0.4	<0.1	0.3	56	26	18	Sandy Loam
YC1	1.7	0.1	2.6	0.2	**2.8**	62	24	14	Sandy Loam
YC 2	3.9	0.5	0.4	0.5	0.3	70	16	14	Sandy Loam

COLORADO DIVISION OF WILDLIFE- AVIAN RESEARCH PROGRAM
PROGRESS REPORT
September 2010

TITLE: Cause-specific mortality of mountain plover (*Charadrius montanus)* chicks in eastern Colorado: Phase III. A pilot field study

AUTHORS: V. J. Dreitz and M. Riordan

PROJECT PERSONNEL: F. Knopf, K. Hosek, and L. Kennedy, Avian Research technicians; B. Smith, Northeast Region Pilot; T. Florian, Area 4 District Wildlife Manager; D. Augustine, USDA-ARS.

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

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

ABSTRACT

The mountain plover (*Charadrius montanus*) is a species of special concern in Colorado with >50% of the continental population believed to breed in the eastern half of the state. In eastern Colorado breeding plovers primarily use short-grass prairie habitats consisting of grasslands with and without black-tailed prairie dogs (*Cynomys ludovicianus*) and agricultural fields. The nesting ecology of mountain plovers has been well-studied across the species‘ breeding range and nest success is similar among the eastern Colorado short grass habitats (Dreitz and Knopf 2007). However, chick survival and brood movement patterns were found to differ between habitats and were not related to differences in prey resource availability among habitats (Dreitz 2009). Further information on cause-specific mortality of chicks is needed to understand differences in brood-rearing behavior and success among different habitats. Technological advances in radio transmitters have resulted in small (≤ 0.35 g) radio transmitters that can be used in field investigations of cause-specific mortality of mountain plover chicks (~10 g at hatch). During 2007 and 2008 we conducted captive studies evaluating transmitter attachment methods and concluded that a leg harness attachment is a suitable method, with minimal to no observed impacts on survival, physiology, growth and behavior of chicks (Dreitz 2007, 2008). Using this attachment method, we field tested the use of transmitters to address future biological questions on the mortality (or survival) of mountain plover chicks in 2009. The results of this study suggest that telemetry is a feasible technique for investigating cause-specific chick mortality. We were able to determine distance range in which we could locate transmitters, feasibility of finding below-ground transmitters, ability and distance to locate transmitters via aircraft, longevity of transmitters and/or needed adjustments in the leg harness attachment, and determine mortality causes including distinguishing between avian and mammalian predators. Predation (45%) and weather conditions (13%) were the main contributors to mortality in our study. Premature failure of transmitter battery and precipitation led to unknown fates of 42% of chicks. Body mass in wild plover chicks was found to be significantly lower than chicks reared in captivity at equivalent ages (Dreitz 2008). This finding suggests modifications to the size of the loops of the leg harness or using transmitters with longer battery longevity are needed for future field investigations.

CAUSE SPECIFIC MORTALITY OF MOUNTAIN PLOVER (*Charadrius montanus*) CHICKS IN EASTERN COLORADO: PHASE III. A PILOT FIELD STUDY

Progress Report, July 1, 2008-September 30, 2009

Victoria J. Dreitz and Maggie Riordan

PROJECT OBJECTIVES

The objective of this study was to develop and test field techniques to determine the feasibility of using transmitters attached by the leg harness method on mountain plover chicks for future studies investigating cause-specific mortality.

SEGMENT OBJECTIVES

1. To address various field technique questions on the applicability of using transmitters attached by the leg harness method on mountain plover (*Charadrius montanus*) chicks from hatch to fledging or conclusion to their fate.
    a. Assess the feasibility of locating, capturing, and placing a transmitters on ≤1 d old ‗wild' mountain plover chicks.
    b. Evaluate the loop size of leg harness transmitter attachment method on ‗wild' mountain plover chicks.
    c. Determine distances in locating transmitters in a vehicle or on foot both above- and below-ground (buried or in a burrow), and by an aircraft.
    d. Determine the feasibility of distinguishing cause of mountain plover chick mortality as predation (avian versus mammalian), starvation, weather conditions or transmitter technique failure.
2. Summarize and analyze data, publish information as a Progress Report. Publish previous captive studies (Dreitz 2007, 2008) and these findings in a peer-reviewed manuscript.

INTRODUCTION

The mountain plover (*Charadrius montanus*) is a neotropical, upland shorebird found on the xeric tablelands from Mexico to northern Montana (Knopf and Wunder 2006). Steep, constant declines in population size have been reported for mountain plovers across their range since 1966. In 1999, the USFWS petitioned for ‗threatened' status of the mountain plover, but the listing decision was found not warranted in 2003 (USFWS 2003). Nevertheless, consistent population declines have prompted conservation agencies to assess the spatial extent and potential factors contributing to declines.

Historically, mountain plovers were present across western prairies in areas of intensive grazing by bison (*Bison bison*) or prairie dogs (*Cynomys* spp.). Today, mountain plovers are still observed on areas grazed by prairie dogs, along with areas grazed by domestic cattle and sheep, and on agricultural fields (Knopf and Wunder 2006). The eastern plains of Colorado provide breeding habitat for more than half of the continental population of mountain plovers (Kuenning and Kingery 1998). Smaller, more isolated breeding areas occur throughout the western Great Plains region including Montana (Knowles et al. 1982, Olson-Edge and Edge 1987) and South Park, Colorado (Wunder et al. 2003).

The nesting ecology of mountain plovers has been well-studied across the species' breeding range including areas in Colorado (Graul 1975, Knopf and Wunder 2006, Dreitz and Knopf 2007) and Montana (Knowles et al. 1982, Knowles and Knowles 1984, Dinsmore et al. 2002). Detailed information on brood-rearing ecology has been conducted in both Colorado and Montana. Knopf and Rupert (1996) estimated daily chick survival on grassland habitat in northeastern Colorado at 10-day intervals ranging from 0.951-0.977. Lukacs et al. (2004) found that chick survival was lowest immediately after hatching and quickly increased within 4 d post-hatch on prairie dog colonies in Colorado. Dinsmore and Knopf (2005) found that fledglings tended by females had higher survival than those tended by males on prairie dog colonies in Montana. Knopf and Rupert (1996), Lukacs et al. (2004), and Dinsmore and Knopf (2005) indicated that daily survival rates increased with age of the chick. In eastern Colorado, Dreitz (2009) estimated chick survival from hatch to 30 d post-hatch to be higher on grassland with prairie dogs (0.75, CI = 0.54, 0.87), than grassland without prairie dogs (0.24, CI = 0.08, 0.45) and agricultural fields (0.23, CI = 0.14, 0.33) and the rate of brood movement off of prairie dog nest habitat was lower than grassland, but higher than agricultural fields for each year of the study. These patterns observed in chick survival and brood movements were not influenced by prey resources biomass or density (Dreitz 2009). None of the above studies determined causes of mortality in plover chicks but Knopf and Rupert (1996) speculated that on grassland the main cause is predation by swift foxes (*Vulpes velox*).

Multiple factors may influence the mortality of young birds. In general, young individuals lack experience with selective pressures such as predation, foraging efficiency, parasites, and extremes in environmental conditions which may be correlated with habitat quality. Further, these selective pressures differ spatially and temporally across the species‘ range. The distribution of individuals among habitats reflects their ability to discriminate between habitat types and to assess habitat quality. Thus, the landscape configuration and the proximity of resources provided by different habitat types of the western prairie may be critical to the reproductive output of mountain plovers. Information on the post-hatching stage is imperative for conservation efforts on mountain plovers because brood loss affects real reproductive output as well as the degree of subsequent recruitment and, in turn, the viability of the population.

Technological advances in radio transmitters have made it possible to determine the cause-specific mortality of mountain plover chicks. Average hatching mass of mountain plover chicks is 7-11 g (Graul 1975, Miller and Knopf 1993). Radios (≤ 0.35 g) placed on the chicks follow established guidelines to not exceed 5% of body mass for small (<50 g) birds (Caccamise and Hedin 1985, Gaunt et al. 1999). Various attachment methods have been evaluated in captivity suggesting that a leg harness attachment is a suitable method with minimal to no observed impacts on survival, physiology, growth and behavior (Dreitz 2007, 2008). In the spring/summer of 2009 we conducted a field study to further understand the field applications of using radio telemetry to address biological questions, particularly cause-specific mortality, on mountain plover chicks.

METHODS

Study Area

This study was conducted on the Pawnee National Grasslands (PNG) in Weld County, Colorado. Vegetation, climate, and physiography of this grassland are described by Graul (1975). Nests were found and monitored on grasslands with and without black-tailed prairie dogs (hereafter prairie dog) in 13 PNG allotments. Radio telemetry on chicks was conducted from hatching to fledging (≥32 d, Graul 1975, Miller and Knopf 1993) or until conclusion of fate.

Placement of Transmitters on Hatchlings

We located and identified ~1d old plover chicks by monitoring nests. We used egg flotation (Westerskov 1950) to age eggs and to estimate days until hatching. Estimating hatching date is difficult even when egg laying date is known because incubation (and chick development) may not start until a few days after all eggs are laid. Additionally, continuous checking of nests by observers can lead to nest abandonment or attract mammalian predators (from leaving olfactory cues) to nests. We visited nests ≤5 times to minimize these potential impacts. David Augustine (USDA-ARS) collaborated with this study by providing nest locations.

After hatching and when chicks were completely dry, chicks were captured by hand and received a radio transmitter. We attempted to place a ≤0.35 g transmitter (average battery life 20 d, pers obs.) on all hatched chicks within a brood at initial capture. Transmittered plover chicks were located almost daily and live status (alive or dead) was determined by visual observation. We attempted to recapture chicks when they were ~14 d old and ≥20.0 g to replace the 0.35 g transmitter (hereafter, small) with a 0.62 g transmitter (hereafter, large). This was necessary to keep transmitters attached; avoid transmitter attachment impacting growth, survival and behavior of the chicks; and to monitor the chicks until fledging, ≥30 d, given the battery life of the transmitters. If body mass of chicks were ≤20.0 g at ~14 d, chicks were recaptured ≤5 d later and transmitters were replaced when they were the appropriate weight. Chicks were recaptured and weighed ≤3 times during the study.

Leg Harness Attachment Method

We determined if our leg harness attachment method was a feasible method to use in a field setting. Our leg harness follows the design of Rappole and Tipton (1991) having a 2-loop harness with the transmitter between the loops (Fig. 1) in which the loops are placed over the legs such that the transmitter sits over the synsacrum. The equal-sized loops are made with a 100% polyurethane clear elastic material (Stretchrite®, purchased at most fabric stores; hereafter elastic). The elastic material is commercially available in 6.35 mm (0.25 inch) width which is decreased to 1.5 mm width. Based on information obtained on captive mountain plovers (Dreitz 2008), we used 40 mm loops for the small transmitters and 50 mm for the large transmitters (Fig. 1). Cyanoacrylate glue (Loctite Easy Squeeze Super Glue Gel) was used to affix the transmitter to the elastic material. This created a rough surface in which a small piece of felt was placed at this connection such that the felt was between the bird and the transmitter. The weight of the elastic and felt add <0.03 g to the transmitters. The transmitter harnesses were made in advance to lessen handling time of the chicks.

Locating Transmitters

Transmittered chicks were located by vehicle and on foot with collapsible 3-element hand-held Yagi antennas that were held in hand or mounted to the box of pickup trucks. We also had the opportunity to test the use of a whip-it antenna mounted on a vehicle when borrowing another CDOW researcher‘s vehicle at the end of the field season (late June). The ability to detect transmittered chicks from an aircraft was also tested.

We determined the distance in locating transmitters by placing activated transmitters (not attached to chicks) in random locations within the study area. Small transmitters were mainly used in order to determine the minimum distance we needed to be near a transmitter to locate a signal. To test the distance in which we could obtain a transmitter signal above-ground, we recorded the farthest perpendicular distance in which a signal heard by vehicle and on foot. We used vacant prairie dog holes to test how far a signal could be picked up if the transmitter was below-ground. We attached a string marked at 0.9, 1.2, 1.5 m to transmitters and dropped the transmitters in the burrows. This did not allow us to account for perpendicular distance below-ground. However, our interest was to know if a predator carried the transmitter into a burrow at what distance into the burrow could we pick up the signal. We also randomly placed activated transmitters within our study area to determine the distance and elevation a signal could be received from an aircraft. We provided general locations of where the transmitters were located to the pilot. The pilot located the transmitters and we determined the distance and evaluation we were able to pick up a signal from our known transmitter location. Additionally we determined the distance and elevation of the initial signal when locating ‗lost‘ chicks (chicks we were not able to locate on the ground) from the aircraft.

Evaluating Cause Specific Mortalities

For all known mortality events, we attempted to determine the cause of mortality as either: predation (avian and/or mammalian), weather events, transmitter technique failure, or unknown fates. We assumed a chick predation event when the transmitter was found with or without remnants of a chick or a chick was not with the adult but its sibling(s) where still present. Further, we determined an avian predation event through evidence such as location near either avian nesting area or plucking post; amount of feather remains (e.g., where all the feather plucked from the chick); condition of transmitter, especially the antennae (e.g., was the antennae twisted or straight). Mammalian predation was suggested when transmitters were cached, scat was found in the area, and/or other physical signs (e.g., teeth marks) of the carcass or transmitter (e.g. antennae still in good condition). Mortality by weather events were defined when entire carcasses of chicks were found with the transmitter. These chicks were collected and further evaluated by necropsy at a later date to confirm if the mortality was weather related or determine other cause (e.g., starvation). Transmitter technique failure is not a true mortality event but the loss of chicks as a result of our field techniques such as the transmitter attachment method or the transmitter. Lastly we defined a mortality event as unknown when there was not enough evidence to suggest one of the other 3 mortality categories.

RESULTS

Success in Attaching Transmitters

A total of 35 nests were located in 13 different allotments within the PNG. Failure occurred in 49% (n=17) of the nests by predation (n=13), abandonment (n=3), or flooding (n=1).
A total of 52 eggs successfully hatched (Table 1) with slightly higher apparent nest success (56.9%) on grassland with prairie dogs than grassland without prairie dogs (42.6%).

We placed small transmitters on 28 chicks (in 10 broods) from the nests we monitored and 3 additional chicks that were ≤ 5 days found opportunistically while doing telemetry on other chicks (Table 1, Appendix A). We were unable to place transmitters on 24 successfully hatched chicks (in 8 broods) because we completely missed hatching. Mountain plover chicks are precocial and leave the nest within hours of hatching (Knopf and Wunder 2006). Once they leave the nest it is difficult to locate them due to their mobility, size (≤ height of the vegetation), cryptic coloration, predatory behavioral defense (hunkering down), and adult behavior (e.g., fleeing area with chicks upon encroachment).

We were able to place transmitters on the 3 chicks in the brood when they were still in the nest cup for only 1 brood out of 10 broods. Mountain plover eggs hatch asynchronously usually within 10 hr (Graul 1975) but could be as long at 41 hr (Knopf and Wunder 2006). We found that if we were able to place a transmitter on ≥1 chick during hatching, we were able to place transmitters on the rest of the chicks within a brood. That is, during hatching we disturbed the nest area only to place transmitters on dried chicks. We re-checked these hatching nests > 10 hr later and placed transmitters on the remaining chicks. These remaining non-transmittered chicks were no longer in the nest cup but we were successful in capturing these chicks on our next visit except for 1 chick which took 5 attempts (over 5 d, mainly due to cold, wet weather) to capture.

We placed large transmitters on 6 chicks in 5 broods. These chicks were 13-18 d old and easy to recapture when necessary by locating them through telemetry. Of these 6 chicks, 4 chicks experienced a mortality event (all due to predation). We suspect battery failure of the transmitter for the remaining 2 chicks. The transmitter was activated for >18 d and we noted differences in the signal strength a few days prior to losing these 2 chicks.

Leg Harness Attachment Method

We designed and used the leg harness size based on the results of Dreitz's (2008) captive study. The body mass of the hatchings (0-1 d old) in the wild were comparable to those in captivity (Fig. 3). We found no evidence of transmitters falling off or hindering mobility at this age group.

Body mass of the wild chicks (*n*=7) when replacing transmitters, ~14 d old, was ≤20.0 g except for 1 chick. We abstained from placing the large transmitter on 6 chicks until they were ≥20.0 g. In 5 of the 6 chicks this occurred by day 18. We were unable to replace the transmitter on 1 chick because we were unable to locate the chick after day 14, likely the result of battery failure. On average wild chicks were ~ 10 g less than captive chicks at the time of transmitter replacement (Fig. 3). We still used the 50 mm size leg-loops on the leg harness (Fig. 1) for wild chicks ≥20.0 g which appeared to keep the transmitter attached and did not hinder mobility. However, if our criteria would have been only age, we would of needed to adjust the size of leg-loops on the leg harness to get the desired fit on the chicks.

Locating Transmitters

We evaluated the above- and below-ground distances in which we could locate a transmitter signal by randomly placing transmitters within our study and noting distances when locating chicks. We determined the minimum distance in which we could locate transmitters by foot was 0.5 km. This was particularly the case in areas with some terrain (e.g., rolling hills). The maximum distance we could locate a signal by foot was ~1.5 km. This was with ideal condition with transmitters placed aboveground (on a fence post) and very little change in the terrain. Using the vehicle we determined the distance in which we could pick up transmitter signal ranging between 1.0-1.5 km using both the Yagi-antennas mounted to the box of the pickup truck or the whip-it antenna. The advantage of the mounted Yagi-antennas is it allowed us to determine which side of the truck the chick was located. The whip-it antenna is logistically easier to set up and can be used on other types of vehicles, such as Sport Utility Vehicles, and all-terrain vehicles.

For the below-ground distances we only determine the distance from the vehicle and used both small and large transmitters. We only assessed by vehicle recognizing that we would like first locate the transmitter by vehicle prior to on foot if it was located below-ground. We located small transmitters that were placed 1.5 m below-ground at a distance of ~0.03 km from the vehicle, ~0.04 km at 1.2 m below-ground, and ~0.07 km at 0.9m below-ground. For the large transmitters the distances were ~0.02 km at 1.5 m below-ground, ~0.03 km at 1.2 m below-ground, and 0.24 km below-ground at ~0.9 m below ground.

We also determined the feasibility and distance and elevation of locating transmitters from the air. We flew a total of 3 times during the field season. On our initial flight we determined that small transmitters could be locate at a distance of ~3 km at an elevation of ~0.3 km. In addition, we noted the distance and elevation when we obtained a signal for lost chicks on subsequent flights. We located 2 predated chicks by air exploration 1.16 km and 2.19 km from their location the preceding day. The initial signal for these 2 chicks was obtained at the distance and elevation equivalent to other transmitter findings, ~3 km at an elevation of ~0.3 km from the aircraft.

Evaluating Cause Specific Mortalities

Most chicks were monitored daily. Periodically weather conditions prevented daily monitoring resulting in lapses in monitoring averaging 2 d and ranging 1-6 d.

Predation—A chick was assumed predated if its transmitter was found no longer attached to the chick (*n*=5 chicks), if its sibling was found with the parent and it could not be found (*n*=4 chicks), remnants of the chick were found (*n*=3 chicks), or if the transmitter was activated <12 d prior to receiving no signal (*n*=2 chicks). A total of 14 chicks were predated (Table 1, Appendix A). Potential predators that were observed include Swainson's hawk (*Buteo swainsoni*), golden eagle (*Aquila chysaetos*), burrowing owl (*Athene cunicularia*), swift fox (*Vulpes Velox*), western rattlesnake (*Crotalus viridis*), and ferruginous hawk (*Buteo regalis*). We were able to confirm predation by a mammalian predator for 4 chicks and avian predators for 2 chicks. One of the mammalian predation events was a cached chick ~ 0.2 m below ground (Fig. 2). Avian predation was from raptors including a burrowing owl in which a transmitter and leg bands were located <0.5 m from an owl burrow along with pellets. There was not enough evidence at the remaining suspect predation events (*n*=8) to determine mammalian or avian predation.

Weather Events— We collected whole carcasses of 4 chicks for further evaluation of cause of mortality by necropsy. The carcasses were collected in zip-loc plastic bags and placed in coolers containing frozen water bottles to keep the carcasses cool during transport, then placed in a storage freezer until necropsies could be preformed. The necropsy results concluded that 3 out of 4 chicks died due to trauma related incidents, the remaining carcass was too desiccated for a necropsy to be preformed. We believe that the trauma observed in necropsies may have been due to our transport method verses natural causes. While we tried to secure the carcasses in the coolers and the coolers in the vehicle, substantial movement (i.e., bouncing across the terrain) throughout the rest of the field day may have caused additional trauma to the chicks. These 4 carcasses were collected shortly (<48 hr) after substantial thunderstorm which may of caused the trauma (e.g., pelting rain or hail) or mortality (hypothermia) to these individuals.

Battery Failure— Initially we intended to recapture chicks at day 14 to attach the larger (0.62 g) transmitter. The battery life of the 0.35 g transmitter proved to be shorter than observed in a previous study (Dreitz unpublished data). Battery failure was discovered while observing chicks (*n*=2) whose frequencies were not being received. It was assumed that the battery failed when we could not receive a signal and the age of the chick was > 12 d (guaranteed life expectancy from Holohil Systems Ltd.). We estimate that the battery failure occurred in > 6 chicks.

Unknown Fates— We were unable to account for the fates of 7 mountain plover chicks because there was insufficient evidence to draw a conclusion. Through the duration of this study there were days telemetry was unable to transpire due to large amounts of precipitation. In these instances, chicks were not observed on subsequent days due to 1) signal location on private land in which we did not have access permission (≥ 3 transmitter chicks), 2) the possibility of predation, or 3) transmitter battery failure.

DISCUSSION

The results of this study suggest that it is possible to monitor mountain plover chicks by means of attaching radio transmitters at hatching. We were able to determine cause-specific mortalities for 58% of the chicks. However, we were not able to confirm survival of any chick to fledging age. Although we were unable to address many biological questions, this study paved the way for future work by answering necessary field questions.

Of the successful nests we monitored, 33.3% (6 out of 18 successful nests) of the chicks hatched and moved before we were able to place transmitters on them. Placing a transmitter on the tending adult 2-3 d prior to the estimated hatch date would help ensure location of the brood even if hatch day is missed. Previous studies have attached transmitters to upper back feathers of adult plovers using an adhesive, allowing the birds to rid themselves of the transmitter during molting (Miller and Knopf 1993, Knopf and Rupert 1996, Dreitz et al. 2005, Dreitz 2009). Leg harness attachment has not been attempted on adult plovers, but might be feasible and warrants further study.

The results from this field study suggest there are substantial differences in the development of captive versus wild plover chicks warranting modification to the leg harness attachment. Coupling factors of shorter battery life of transmitter and smaller body mass of wild chick at 13-18 d requires adjustment to transmitter harness size, timing of transmitter replacement, and/or the use of transmitters with longer battery life. Although minimal amount of handling is desired, it may be necessary to change transmitters more frequently to monitor chicks to >30 d post-hatch if transmitters with similar battery life are used. In this instance, we suggest replacing the transmitter at day 11 with harness loops ~43 mm (± 2 mm), and again at day 22 with ~50 mm (±2 mm) harness loops. Secondly, there may be other companies manufacturing small transmitters with longer battery life. If so, the timing of the transmitter replacement could be similar; however body size at ~14 d would necessitate a 46 mm size loops (± 2 mm) instead of 50 mm given the differences in body mass compared to captive reared chicks (Fig. 3).

We were not able to confirm that weather events were the cause of mortality in mountain plover chicks. However, we believe it may have occurred. Precocial chicks, such as mountain plovers, use considerable amounts of energy for thermoregulation and locomotion, and they need to keep their energy in balance within narrow margins to survive (Schekkerman and Visser 2001). Extreme inclement weather may increase chick mortality due to hypothermia or direct mortality (e.g. hail, pelting rain). While necropsy results did not confirm that hypothermia occurred during our study, we believe we need to further evaluate how to detect hypothermia in young mountain plover chicks both by necropsies and laboratory diagnostics.

In the past predators have been reported as a major source of mortality (Knopf and Rupert 1996), and was not dissimilar to the findings in this study with 45.2% known predation events. Distinguishing avian from mammalian predations was possible when there was enough evidence left from the predator. For instance, we suspect the incident in which we found a cached chick that the predator was as a mammal, likely a swift fox because numerous swift foxes (both adults and kits) were observed in the general location during the study. When evidence is available distinguishing between avian and mammalian is rather straightforward. However, when there is little evidence, such as a transmitter with the elastic material of both loops on the leg harness torn, determining the cause of mortality is difficult. In this case, we presume the cause of mortality to be an avian predator. However, we are not confident in our assumption and categorized this cause of mortality as an unknown predator. Even stating the cause of mortality of a cached chick was a mammal predator is speculative because the chick could have died prior to being located by the mammal predator. Continuous monitoring of chicks or observation of mortality events are the only means to determine the exact cause of mortality, both are impractical for most wildlife studies. Therefore, studies investigating cause-specific mortality are constrained to evidence found at the location the transmitter was found. Even if we monitored the chicks more frequently than daily, we do not believe this would increase our ability to distinguish between avian and mammalian predators because it is unlikely the predators would leave more evidence at the mortality site.

This study allowed us to determine many aspects of the field logistics on the applicability of using transmitters attached by the leg harness method on mountain plover chicks. A discomforting result of our study was we did not observe any chicks surviving to fledging. Various reasons, some of them listed above, may have influenced this outcome. Another reason may be that the transmitters are impacting survival in these ‗wild' chicks. Future field studies should examine this possibility. This could be accomplished by placing transmitters on only 1 or 2 chicks within a 3 chick brood. This would also need to be coupled with attachment of transmitter on the adult plover to assist in tracking and observing chicks without transmitters.

SUMMARY

Currently, radio telemetry is the principal approach to investigate various aspects of brood-rearing behavior of mountain plover chicks or chicks of other small species. In 2007 and 2008, we addressed questions of how to place a transmitter on chicks of small birds and if the transmitter impacts survival or behavior of the chicks in a captive setting (Dreitz 2007, 2008). The results from those studies suggested the leg harness technique had no to minimal impact on survival, physiology, growth and behavior (Dreitz 2007, 2008). Our field study suggests that telemetry is a potentially effective tool for

exploring cause-specific mortality of chicks; however there are aspects that still need to be examined to insure this is a viable method.

In our study, we applied the leg harness attachment method for the 0.35 g transmitters used to track mountain plover chicks in the field. Transmitters were placed on the chicks upon hatching, and tracked from that day forth. Monitoring chicks allowed the determination of cause-specific mortalities and aided in understanding movement behavior. We were able to draw conclusions on 18 of the 31 chicks included in this study. As suspected, predation was the main cause of mortality. While our sample sizes were rather small, the information gathered paves the way to take this study to a larger scale and address biological questions.

In sum, we answered our original objectives and believe that radio telemetry on mountain chicks can be used to address large scale, biological questions. We found that:

- capturing and attaching transmitters to 0-1 d old chicks is feasible,
- difference in body mass between wild and captive chicks requires adjustments to the loop size of the leg harness and/or battery life of transmitters needs to be increased,.
- the range in distance for locating transmitters above ground is 0.5-1.5 km,
- transmitters can be located below-ground, either buried or carried into a burrow,
- transmitters can be located by aircraft,
- causes of mortality can be determined with the possibility of distinguishing predation between avian or mammalian species.

Additionally, we recommend the following for future studies on chick mortality of mountain plovers:

- place transmitters on tending adults prior to hatching to locate chicks in case hatching is missed,
- locate chicks every 24 hr to determine cause of mortality,
- attempt to locate 'lost' chicks by aircraft prior to transmitter battery failure,
- investigate predator behavior more thorough to distinguishing between different types of predators,
- refine laboratory methods to determine causes of mortality from whole carcasses,
- determine if transmitters do influence chick survival in the field.

As the use of radio telemetry in avian studies progresses there is a need for further studies on the effect of the transmitter and the attachment techniques on all aspects of a species. We encourage others to critically assess the ability of using transmitters on a species before embarking on large scale studies to address biological questions.

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Table 1. Summary of mountain plover (*Charadius montanus)* chicks monitored in the spring-summer of 2009 on the Pawnee National Grassland.

	Grassland with prairie dog colonies	Grassland without prairie dog colonies
Nesting Information		
Total number of nests	17	18
Hatched (≥ 1 egg)	10	8
Failed	7	10
Egg Information		
Total number of eggs	51	54
Hatched eggs	29	23
Chick Information		
Total number of transmitters put on	11	20
Fates		
Predated	3	11
Environmental Influence	0	4
Battery Failure	0	5
Unknown	0	7

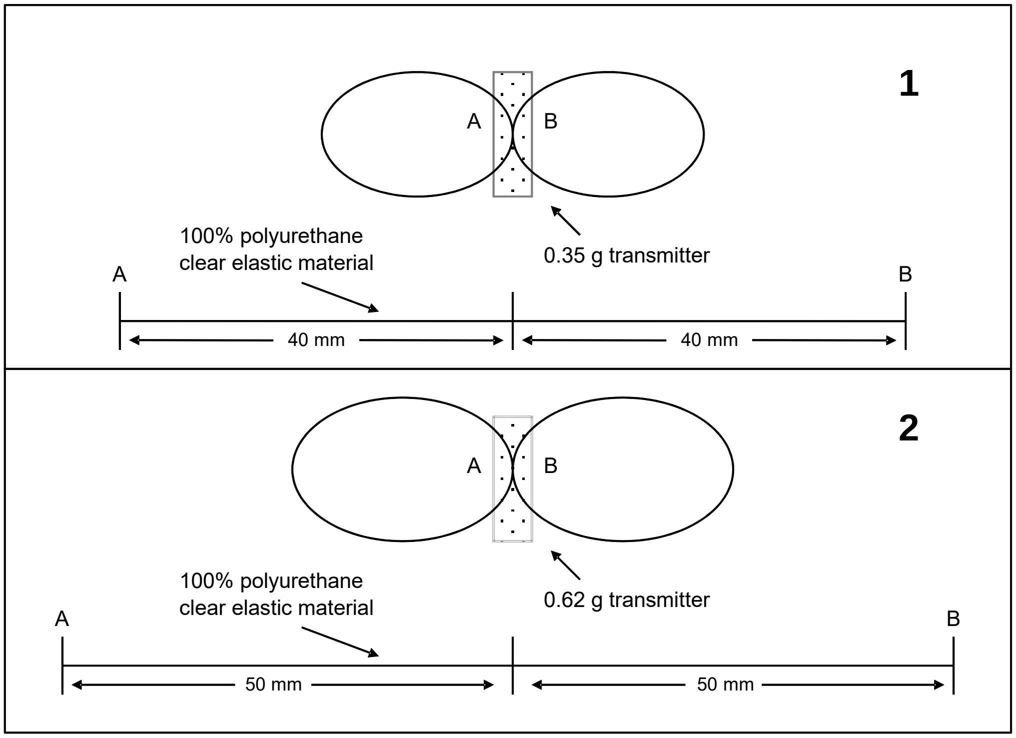

Figure 1. A modification of the leg harness attachment by Rappole and Tipton (1991). The design consists of 2-loops of equal size with the transmitter between the loops. Diagram 1 has a harness for a ≤1 d old mountain plover chick, diagram 2 is for a mountain plover chick >10 d and <20 d old.

Figure 2. Photograph showing chick dug up after being cached by a mammalian predator, such as a swift fox (*Vulpes velox)*.

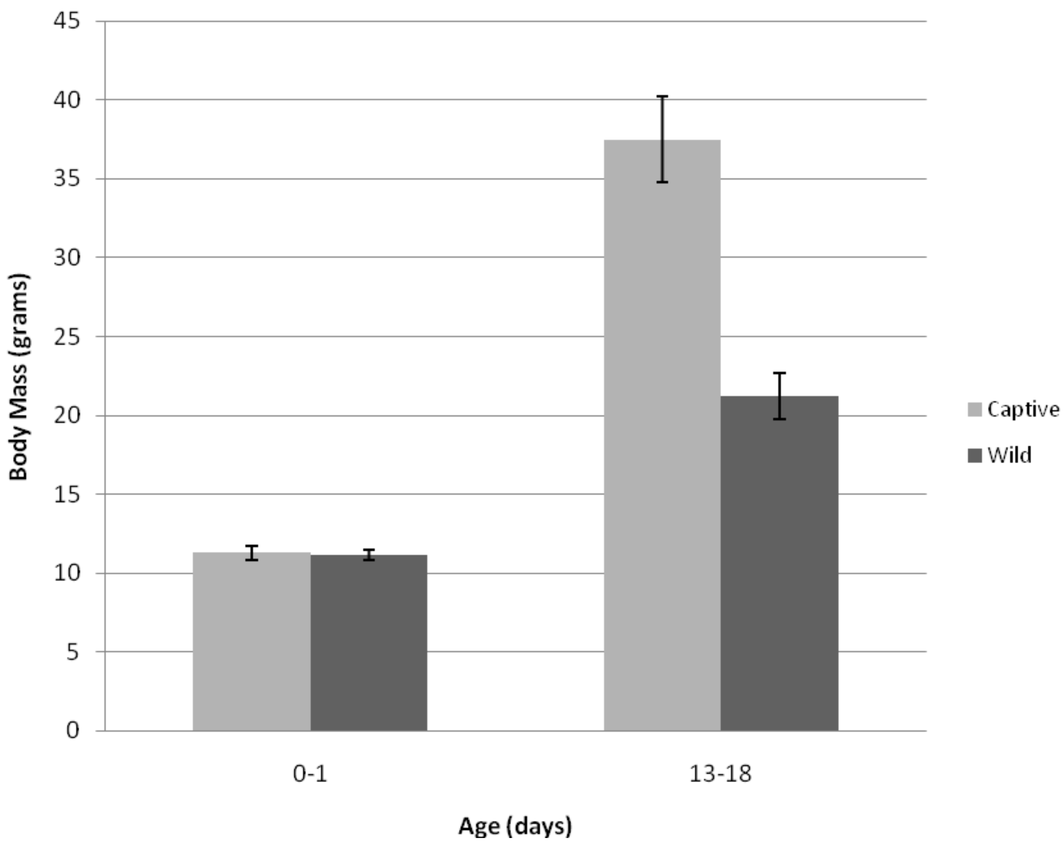

Figure 3. Graph of the body mass (g) of captive reared mountain plovers (Captive; *n*=10 body mass measurements for 0-1 d, and *n*=18 body mass measurements for 13-18 d) from Dreitz (2008) compared to mountain plovers in their natural habitat (Wild; *n*= 28 body mass measurements for 0-1 d, and *n*=7 body mass measurements for 13-18 d) from this study.

Appendix A. Summary of concluding fates of radio marked mountain plover (*Charadius montanus*) chicks in the spring- summer of 2009 on the Pawnee National Grassland.

Nest	Frequency	Age[1]	Habitat[2]	Fate	State[3]
403	092	14	GR-GR	Battery Failure	
	204	6	GR-GR	Death[4]	Chick on ground- bad weather preceding days
	636	18	GR-GR	Predation- Unknown	Transmitter on ground fully intact
406	054	17	GR-GR	Predation- Unknown	
	405	5	GR-GR	Predation- Unknown	
	678	4	GR-GR	Predation- Unknown	
432	116	23	GR-GR	Predation- Mammalian	Broken harness and auxillary bands
	367	7	GR-GR	Battery Failure	
	421	21	GR-GR	Predation- Unknown	
438	103	10	GR-GR	Predation- Mammalian	Lower half remains of chick
	154	2	GR-GR	Predation- Unknown	
439	167	8	GR-GR	Predation- Unknown	
	320	15	GR-GR	Battery Failure	
	517	15	GR-GR	Unknown	
443	444	17	PD-PD	Predation- Mammalian	
	492	12	PD-GR	Battery Failure	
	554	3	PD-PD	Predation- Unknown	Transmitter without harness material attached
448	477	4	GR-GR	Death[4]	Chick on ground- bad weather preceding days
	193	2	GR-GR	Death[4]	Chick on ground, still warm
	462	19	GR-GR	Battery Failure	
450	080	5	GR-GR	Unknown	
	217	5	GR-GR	Unknown	
	229	5	GR-GR	Unknown	
455	595	8	GR-GR	Battery Failure	
	529	12	GR-GR	Predation- Avian	Intact harness near fence post by avian pellets
457	243	9	PD-GR	Death	Desiccated corpse
	392	10	PD-C	Unknown	
	661	1	PD-PD	Predation- Avian	Antenna curled up, next to owl burrow
Unknown 1	281	10	GR-GR	Predation- Mammalian	Found buried under 6 inches of mud
Unknown 2	305	4	GR-GR	Unknown	
Unknown 3	343	1	GR-GR	Unknown	

[1] Age at mortality, or when last observed.
[2] Habitat at hatching - habitat at last observation. Grassland with prairie dogs (PD), Grassland (GR), or Crop field (C).
[3] Condition of chick or transmitter at final location.
[4] Necropsy performed and concluded a trauma related death.

COLORADO DIVISION OF WILDLIFE - AVIAN RESEARCH PROGRAM
PROGRESS REPORT
September 2010

TITLE: Evaluating relationships between hunting regulations, habitat conditions, and duck hunting quality on State Wildlife Areas in northeastern Colorado

AUTHORS: J. P. Runge and J. H. Gammonley

PROJECT PERSONNEL: T. Kroening, B. Smith, E. Gorman, M. Stratman

Period Covered: July 1, 2009 – January 31, 2010

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ABSTRACT

The lower South Platte River corridor has historically supported the highest numbers of wintering ducks and highest hunter numbers and duck harvest of any region in Colorado. There is concern that harvest pressure has led to reduced numbers of wintering ducks and low harvest success, particularly on State Wildlife Areas (SWAs), which could in turn lead to lower hunter satisfaction and declining hunter recruitment and retention. The goal of this study is to determine the extent to which a set of more restrictive hunting regulations influence duck hunter success, hunter activity, hunter satisfaction, and duck distribution, compared to a set of less restrictive hunting regulations, on selected state wildlife areas (SWAs) along the South Platte River (SPR) corridor. We will also examine how the influence of regulations on these responses varies among SWAs with differing habitat conditions. The 2009-2010 regular duck season was the second field season of the project. In 2008 we selected 3 pairs of SWAs representing different habitat conditions along the SPR corridor, and assigned 1 SWA in each pair a set of restrictive hunting regulations (hunting access permitted only on weekends, Wednesdays, and legal holidays; reservations required for a limited number of parties; and the property is closed to the public after 2 p.m.), with no restrictive regulations on the other SWA in each pair. We established check stations at each of the SWAs and required all waterfowl and small game hunters to check out during the regular duck season. We interviewed all hunters and recorded information on their hunting experience and methods, harvest success, and satisfaction. We also conducted monthly aerial counts of waterfowl along the SPR corridor. During the 2009-2010 duck season, we obtained information from 1291 hunting parties on study SWAs, of which 975 were duck hunting parties. Activity varied from a high of 536 duck hunting parties and 946 duck hunter-days at Jean K. Tool/Brush SWAs (unrestricted) to a low of 11 duck hunting parties and 21 duck hunter-days at Overland Trail SWA (restricted). Season-long harvest success, measured as ducks bagged per hunter per party per day, was lowest on Atwood SWA (unrestricted) at 0.2, slightly better at Jean K. Tool/Brush SWAs (unrestricted, 0.4) and Overland Trail SWA (restricted, 0.5), was 1.2 on Bravo SWA (restricted), and was highest at Red Lion SWA (unrestricted, 1.6) and Jackson Lake SWA (restricted, 2.1). Hunting parties‘ satisfaction with hunter crowding levels, habitat conditions, property-specific regulations, and their overall hunt experience averaged slightly satisfied or satisfied on all study SWAs; hunters tended to be dissatisfied with duck numbers on on-channel properties and satisfied with duck numbers on off-channel properties. Numbers of migrating/wintering ducks in the SPR were back to average in 2009-2010 after a relative low in 2008-2009. This study is expected to continue for 4 years, with a cross-over of regulation assignments to study SWAs occurring in 2011.

EVALUATING RELATIONSHIPS BETWEEN HUNTING REGULATIONS, HABITAT CONDITIONS, AND DUCK HUNTING QUALITY ON STATE WILDLIFE AREAS IN NORTHEASTERN COLORADO

Progress Report, July 1, 2009 – January 31, 2010

Jonathon P. Runge and James H. Gammonley

PROJECT OBJECTIVES

The goal of this study is to determine the extent to which a set of more restrictive hunting regulations influence duck hunter success, hunter activity, hunter satisfaction, and duck distribution, compared to a set of less restrictive hunting regulations, on selected state wildlife areas (SWAs) along the South Platte River (SPR) corridor. We will also examine how the influence of regulations on these responses varies among SWAs with differing habitat conditions. Specific objectives include:

1. Compare duck hunter success (ducks bagged per hunter) on selected SWAs with different hunting regulations and habitat conditions.

   Hypothesis 1: Average hunter success will be higher on properties with more restrictive hunting regulations than on properties with similar habitat conditions where hunting regulations are less restrictive.

   Hypothesis 2: Average hunter success will be lower on properties with more restrictive hunting regulations than on properties with similar habitat conditions where hunting regulations are less restrictive.

   Hypothesis 3: Differences between the two types of areas will be statistically indistinguishable.

2. Compare hunter activity (hunter use-days, party size, hunting methods, number of hours per day when hunters are present on the property) on selected SWAs with different hunting regulations and habitat conditions.

   Hypothesis 1: Properties with more restrictive hunting regulations will have less intensive use than properties with similar habitat conditions where hunting regulations are less restrictive.

   Hypothesis 2: Differences between the two types of areas will be statistically indistinguishable.

3. Compare self-reported indices of waterfowl hunter satisfaction on selected SWAs with different hunting regulations and habitat conditions.

   Hypothesis 1: Average indices of hunter satisfaction will be significantly higher on properties with more restrictive hunting regulations than on properties with similar habitat conditions where hunting regulations are less restrictive.

   Hypothesis 2: Average indices of hunter satisfaction will be lower on properties with more restrictive hunting regulations than on properties with similar habitat conditions where hunting regulations are less restrictive.

   Hypothesis 3: Differences between the two types of areas will be statistically indistinguishable.

4. Correlate overall duck numbers, climate data (temperature, precipitation), and indices of habitat conditions (river flows, percent of area flooded, percent of area frozen) with results from objectives 1-4.

   Prediction: These measures will explain a high proportion of the variation observed over space and time in the response variables for Objectives 1-4.

5. Based on results from objectives 1-4, develop recommendations for future duck hunting management of SWAs along the South Platte River corridor.

Because the purpose of restrictive regulations is to reduce disturbance to waterfowl on SWAs, it will also be necessary to restrict activities of other small game hunters. Although not the focus of this study, we will also measure the harvest, activity, and satisfaction of small game hunters on SWAs along the SPR.

SEGMENT OBJECTIVES

1. Collect information on hunting activities, harvest, and satisfaction levels from all waterfowl and small game hunting parties on 7 SWAs along the SPR corridor during the 2009-2010 regular duck hunting season.

2. Conduct monthly aerial surveys of waterfowl numbers and distribution along the SPR corridor throughout the 2009-2010 regular duck hunting season.

INTRODUCTION

About 50% of Colorado's annual statewide duck harvest occurs in 5 counties (Logan, Morgan, Sedgwick, Washington, and Weld) along the lower South Platte River (SPR) corridor in northeastern Colorado (U.S. Fish and Wildlife Service, unpublished harvest survey results). Over 60% of Colorado duck hunters hunt in this area, and a majority of these hunt exclusively or regularly on public lands (Colorado Division of Wildlife 2006). There are >25 State Wildlife Areas (SWAs) and State Trust Lands located in the SPR corridor from Greeley to the state line, and duck hunting is a major activity and management emphasis on many of these areas. The Colorado Division of Wildlife (CDOW) historically has managed to provide a range of duck hunting opportunities on SWAs along the SPR corridor. Some properties have no restrictions on hunting beyond the statewide regulations, and the management emphasis is on maximizing hunting opportunity. On other properties, the CDOW has attempted to address issues of hunting quality in part through property-specific restrictions in hunting regulations. Property-specific restrictions include requiring reservations for access, day closures (portions of the week when no hunting is allowed), limits on the number of individuals in hunting parties, and assigned areas. Use of hunting restrictions has been largely on an ad hoc, property-specific basis. No rigorous evaluation has been conducted on the effectiveness of restrictive hunting regulations on duck distribution or on hunter success, activity, or satisfaction.

Since the 1980s the annual midwinter index of ducks counted in the SPR corridor has averaged less than half the number counted during the 1970s. Although the possibility exists that detection probability decreased over those years, it is unlikely that it decreased by 50%; thus winter (early January) abundance of ducks in the SPR has likely declined. Although overall duck harvest during 1999-2006 has been comparable to historic levels, in recent years there have been increasing concerns about the quality of duck hunting along the SPR corridor, particularly on SWAs. There is a desire to increase wintering populations of ducks, increase harvest success (i.e., average number of ducks bagged per hunter trip), and recruit and retain more duck hunters. It has been suggested that disturbance from excessive hunting activity along the SPR corridor has led to decreased use of this area by ducks, poor harvest success, over-crowding and interference among hunters on public areas, and unsatisfactory experiences for duck hunters. This concern is supported by the results of a 2005 national duck hunter survey (National Flyway Council and Wildlife Management Institute 2006), in which 66% of Colorado duck hunters surveyed (n = 488) reported they believed hunting pressure had become worse compared to 5 years prior to the survey, 65% of hunters believed crowding was worse at hunting areas, 53% reported more interference from other hunters, and 50% believed ducks were more concentrated on fewer areas. Dissatisfaction with duck hunting could in turn result in declining duck hunter recruitment and retention. Concerns over the quality of duck hunting along the SPR have led to proposals to increase hunting restrictions in this area.

Recent monitoring of duck hunter activity and harvest on South Platte SWAs indicates that patterns of public use and duck harvests are variable among SWAs and on individual SWAs among years. Voluntary reporting data suggest that average duck harvest/hunter trip was similar between public areas with restrictive hunting regulations and areas without restrictive regulations in 2004-2005 and 2005-2006, but higher in unrestricted areas in 2006-2007. Patterns of hunter use and harvest success may vary among properties in relation to the property size and the habitat types present on the property (e.g., shallow marsh impoundments, river channel, warm-water sloughs). Harvest success, particularly on properties adjacent to the river channel, was weather-dependent: harvest success increased during colder, wetter duck seasons, and within a duck season harvest success was higher when temperatures were colder. Ducks use large reservoirs that act as refuge areas within the SPR corridor, and ducks often move to feeding areas after dark. Duck use of the river is limited until low temperatures cause reservoirs to freeze and the river provides the only available open water.

It is generally acknowledged that disturbance from hunting activity can influence the distribution of ducks at a variety of spatial scales (Baldassarre and Bolen 1994). Ducks quickly find refuge areas when hunting seasons begin, and alter their spatial and temporal activity patterns to avoid hunted areas (Cox and Afton 1998a, Fleskes 2002), although refuge size and habitat conditions may influence their use and value to waterfowl (Rave and Cordes 1993, Cox and Afton 1998b, Rave 1999, Cox and Afton 1999). Numerous studies have documented anthropogenic disturbance to waterfowl (Dahlgren and Korschgen 1992, Madsen 1995, Madsen and Fox 1995, Fox and Madsen 1997, Madsen 1998a, 1998b; Evans and Day 2001, 2002; Pease and Butler 2005). Most studies that examine hunting impacts compare bird use, usually measured by counts, on sanctuary or refuge areas (i.e., no hunting or other disturbance) to hunted areas, rather than comparing different levels or types of hunting disturbance. On a Danish wetland where hunting was permitted only once every 1-3 weeks, Bregnballe and Madsen (2004) determined the proportion of waterfowl occupying the wetland just prior to hunts that returned within 1-2 days after hunts, and found that response to hunting disturbance was variable among species and within species in relation to habitat conditions. Using a similar approach, Bregnballe et al. (2004) concluded that restricting hunting to the afternoon did not adequately reduce disturbance to maintain bird numbers and diversity. In addition, most studies focus exclusively on bird responses, but do not document changes in hunter activity, success, or satisfaction in relation to creation of refuges. Madsen (1998b) noted that following creation of refuge areas on 2 Danish wetlands, hunter numbers declined on hunted portions of one area, and numbers did not decline but were redistributed on the other wetland; hunter success was not reported. Hockin et al. (1992) and Hill et al. (1997) reviewed literature on studies investigating disturbance to birds from human activity and reported that most results were anecdotal, with only a small minority of studies having some sort of experimental design that compared control and treatment areas. They recommended increased use of manipulative studies to more rigorously assess impacts of disturbance or the effectiveness of controls on disturbance.

Relationships between federal frameworks for hunting (e.g., Flyway-specific season lengths and bag limits) and resulting duck harvests have been investigated at national and regional scales (Martin and Carney 1977), but few studies have been conducted to examine the influence of local-scale hunting regulations on hunter success or satisfaction. Hunting parties were assigned 1 of 3 alternative bag limit regulations (a 2-bird limit, Flyway-specific regulations, or point system) and their performance and satisfaction were measured on a state game area during one season in Michigan (Mikula et al. 1972). However, this study did not examine impacts of regulations other than bag limit restrictions, and variation across years or among areas was not investigated. During 1963-1970, the CDOW, in cooperation with the U.S. Fish and Wildlife Service, conducted intensive studies examining how local duck populations and duck hunters responded to various experimental duck hunting regulations in the San Luis Valley

(Hopper et al. 1975). However, this study did not did not directly compare results to more restrictive regulatory approaches, and did not examine harvest success or hunter satisfaction in relation to hunting regulations at a more local scale.

Given the interest in reducing duck hunting pressure in the SPR corridor, there is a need to evaluate how more restrictive hunting regulations impact duck numbers and distribution, and hunter success and satisfaction, at local and regional scales. Here we detail results from the first year of a management experiment in SWAs along the SPR corridor that examines this issue.

STUDY AREA AND METHODS

This study is being conducted in the SPR corridor between Greeley and the state line (Fig. 1). An intensive evaluation of hunting restrictions is being conducted on 7 SWAs.

On 7 non-randomly selected SWAs (see table below), we are using a quasi-experimental cross-over design to examine the influence of hunting restrictions on selected response variables. Properties were selected to represent the range of wetland habitat types on SWAs along the SPR, including areas off the river channel with shallow, seasonally-flooded wetland impoundments near large reservoirs; small properties on the river channel that have little other wetland habitat; and larger properties on the river channel that have more diverse wetland habitats. For each pair of properties with these habitat conditions, each member of the pair was assigned a different set of hunting regulations. On ―Unrestricted" properties, no additional hunting restrictions are applied for waterfowl and small game hunting beyond the regulations that apply throughout eastern Colorado. A set of additional regulations are applied to ―Restricted" properties, intended to limit hunting disturbance while still providing some hunting opportunity. These regulations include: (1) reservations are required for hunting access (a limited number of parties on the property, with no more than 4 hunters per party); (2) all parties must leave the property by 2 p.m.; (3) hunting is allowed only on Saturdays, Sundays, Wednesdays, and legal holidays; and (4) hunting parties are assigned to specific areas on the property. These restrictions apply to waterfowl and small game hunting during the regular duck hunting season, but not to deer and spring turkey hunting. Restricted (R) and Unrestricted (U) regulations will be applied to the selected properties for 6 years as described in the table below. A cross-over design will be used to account for site-specific influences on response variables of each pair of properties.

		Hunting Season Regulations (R = Restricted, U = Unrestricted)					
Type	**State Wildlife Area**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Off river channel	Jackson Lake	R	R	R	U	U	U
	Red Lion	U	U	U	R	R	R
On-channel small property	Overland Trail	R	R	R	U	U	U
	Atwood	U	U	U	R	R	R
On-channel large property	Bravo	R	R	R	U	U	U
	Jean K. Tool & Brush	U	U	U	R	R	R

Check stations were established at these 7 SWAs, and access to these areas was from designated parking areas only. During the regular duck hunting season, all waterfowl and small game hunters were required to check out at the check station before leaving the property. A check station attendant recorded information on the hunters, their harvest, hunting methods, and measures of satisfaction (Appendix A). Voluntary hunter check-out cards requesting the same information were also provided in case a check station attendant was not present when hunters checked out.

Similar to 2008, significant ice buildup was noted on the ponds at Jackson and Red Lion SWAs during the third week in November. For comparative purposes, data from before November 20 and on or after November 20 are summarized separately for these 2 SWAs. After December 6, check station attendants were no longer assigned to these properties, and we relied on hunters filling out voluntary check-out cards.

While conducting quality control on the data, we noted that 51 hunters were deliberately giving inaccurate numbers regarding the number of years they had hunted in the SPR corridor, e.g., on one day they would say they had hunted the corridor for 1 year, then the next day claim they had hunted the SPR corridor for 5 years. Information from these hunters that was not verifiable by the technicians was excluded from the analysis. Additionally, any parties that hunted both Jean K. Tool and Brush on the same day were consolidated into 1 hunting party for the day. This type of quality control did not occur with the data reported in the 2009 progress report, thus we expect more hunting parties that hunted both areas in a single day.

Aerial surveys of the SPR corridor from Greeley to the state line were conducted monthly during the regular duck hunting season (October 8, November 5, December 3, and January 8) to provide an index to overall waterfowl numbers and distribution in the region. Observers recorded numbers and locations of ducks and geese on the river and associated sloughs, as well as ponds and reservoirs in the SPR corridor. For the December and January counts, photographs were taken of a subset of areas counted, number of waterfowl in each photograph were tallied and used to determine a visual correction factor (VCF) to the raw number counted from the air. We used the December VCF to adjust the raw counts in October and November and report the VCF-corrected data here because they are a more accurate depiction of true numbers of waterfowl available to hunters than are the raw counts. VCFs are the factor by which one adjusts the count. Thus a 1.0 VCF would indicate accurate counting, whereas a 1.5 VCF would indicate that the count underestimated the actual birds present and needed to be increased 50%.

RESULTS AND DISCUSSION

During the 2009-10 waterfowl hunting season, we obtained harvest and satisfaction measures from 1291 hunting parties. Of these, 975 (76%) were duck hunting parties. We interviewed 838 duck hunting parties, and 137 additional duck hunting parties left checkout cards at unmanned check stations. Jean K. Tool and Brush SWAs had the highest use, with 536 duck hunting parties and 946 duck hunter-days, and Overland Trail SWA had the lowest use, with 11 duck hunting parties and 21 duck hunter-days (Table 1). Note that these numbers are uncorrected for hunting parties that did not report.

Overall, 35% of duck hunters at the 7 study SWAs were in their first year of hunting the lower SPR corridor (versus 32% in 2008-09), 15% had hunted the area for 2 years (11% in 2008-09), 9% for 3 years (10% in 2008-09), 4% for 4 years (6% in 2008-09), and 37% for 5 years or more (41% in 2008-09). Most (83%) of the duck hunters surveyed hunted mainly public lands, 5% hunted mainly private lands, and 12% said they hunted both equally. The average duck hunting party size was 1.5 on all areas (Table 1). Across all 7 SWAs, 74% of all parties used standard decoys and 42% used spinning wing decoys; the use of standard decoys was high (>65%) on all properties unlike the previous year when river channel properties experience only 26-44% of parties using decoys (Table 1). Dogs were used by 35% of hunting parties, and 78% of hunting parties reported using duck calls, both very similar to 2008-2009 percentages.

A total of 1499 ducks was reported harvested on the 7 study SWAs. Season-long harvest success was measured as ducks bagged per hunter per party per day over the 2009-2010 regular duck season. From interview data, hunters at restricted areas experienced greater success than unrestricted areas, with Overland Trail success greater than Atwood (0.5 vs. 0.2 ducks per hunter per day), Bravo greater than Jean K Tool/Brush (1.2 vs. 0.4), and Jackson Lake greater than Red Lion until freeze-up (2.1 vs. 1.6) as well as after freeze-up (0.5 vs. 0.4). Except for Atwood SWA, all of these averages were higher than 2008-09.

Frequency distributions of ducks shot per hunter per day showed that small on-channel properties (Atwood and Overland Trail SWAs) had the largest proportion of 0 ducks bagged and very small proportions of >2 ducks bagged (Fig. 2). Hunters experienced proportionally fewer 0 bag days on the large on-channel properties (Jean Tool, Brush, and Bravo SWA) and proportionally more days with >2 ducks bagged (Fig. 3). As expected, the off-channel properties (Red Lion and Jackson Lake SWAs) experienced the greatest hunter success, with fewer 0 bag days and more days with >2 ducks bagged per hunter (Fig. 4). In all habitat types, hunters in restricted areas experienced greater success both in terms of having less 0 bag days and in having more days with 2 ducks or more shot per hunter (Figures 2-4). Averaged across all study areas, daily bag per hunter was not exceptionally high during the first week of hunting season but did exhibit a prolonged period of success during the second week. A small peak occurred the first day of the second season, after which random events (likely weather-related) seemed to drive hunting success (Fig. 5).

Hunter satisfaction with the level of crowding from other hunters was consistently higher at restricted areas, although mean satisfaction with crowding measures were high at all areas, ranging from an average of 4.2 (out of 5) at Red Lion SWA to an average of 4.9 at Atwood SWA (Table 2). Satisfaction with bird numbers was highest at the off-channel SWAs of Red Lion and Jackson Lake (3.5 at each) and lowest at Jean K Tool/Brush SWAs (2.5) (Table 2). Average satisfaction with habitat conditions was in the 4.1-4.2 range for all areas except Red Lion and Jackson SWAs where it was measured at 4.4. Satisfaction with property-specific hunting regulations was higher at the SWAs with fewer regulations when considered pair-wise, with highest average satisfaction at Atwood SWA (4.5) and lowest at Bravo SWA (3.6) (Table 2). Overall satisfaction levels ranged from 3.5 (Jean K Tool/Brush and Atwood SWAs) to 4.0 (Red Lion SWA).

We estimated correlation coefficients between satisfaction measures of crowding, hunting regulations, overall satisfaction, and average ducks shot per hunter per day. Correlation coefficients provide a rough estimate of the effect these factors have upon one another. A correlation coefficient of 1.0 suggests a perfect positive correlation between two factors, and -1.0 suggests a perfect negative correlation between two factors. A correlation coefficient of 0.0 suggest no correlation whatsoever between two factors. As in 2008-09, the highest correlation coefficients were between average ducks shot per hunter per day and overall satisfaction (range of 0.14-0.64, Table 3). Satisfaction with hunting regulations and overall satisfaction were also moderately correlated (range: 0.05 – 0.65, Table 3). Crowding issues did not exhibit high degrees of correlation with overall satisfaction (range: -0.07 – 0.29, Table 3).

Estimates of ducks in the count area during aerial surveys of the South Platte corridor increased from 14,845 in October to 47,615 in November and 67,205 in December, peaking at 87,119 in January (Figure 6). As in other years, >90% of ducks observed were on large reservoirs and other wetlands along the SPR corridor during October and November, while >50% of ducks observed were on the SPR and associated sloughs during December and January. The January (mid-winter) 2010 count was consistent with previous indices of abundance, as opposed to the January 2009 count, which was below average. VCFs were estimated at 1.5 for the December flight and 1.2 for the January flight.

Other game harvested and recorded as part of the study included 70 quail, 57 Canada goose, 55 rabbit, 27 squirrel, 24 pheasant, 15 coot, 6 dove, and 3 light goose (Table 4). Four parties specifically targeted coyotes, but none were harvested. Species-specific harvest of duck included 440 mallard (29%), 255 green-winged teal (17%), 198 northern shoveler (13%), 142 gadwall (9%), 139 wigeon (9%), 90 blue-winged teal (6%), 57 northern pintail (4%), 37 wood duck (2%), 22 ring-necked duck (1%), 16 redhead (1%), 15 goldeneye (1%), 13 merganser (1%), 7 bufflehead (<1%), 6 scaup (<1%), 6 canvasback (<1%), 5 ruddy duck (<1%), and 51 ducks for which species was not indicated (Table 4).

Compliance with the study was lowest at the Brush checkout station with 87% of vehicles with small game and duck hunters checking out. Red Lion had a 89% compliance rates, Bravo 91%, Jean K Tool and Overland Trail 92%, Atwood 93%, and Jackson Lake 97% (Table 5).

This study is expected to continue for 4 more years; the cross-over of assignments of regulations to study SWAs will occur in the 2011-2012 hunting season. Data collection will resume in October 2010. Both dissension and support for the study were noted in 2010. An appendix with such comments as well as comments regarding habitat conditions is included with this report (Appendix B).

ACKNOWLEDGMENTS

Area 3 Field Operations personnel provided crucial support for technicians and equipment in this project as well as providing solutions for the movement and storage of checkout stations. Area 3 personnel also provided valuable assistance in communication with hunters. Brian Smith and Marty Stratman assisted with aerial waterfowl counts. Ed Gorman assisted with production of a supplemental brochure for the public describing the study and the regulations on the 7 study SWAs. Chris Johnson and Dawn Browne created maps for the brochure, and Loyse Hinkle & staff assisted with providing information to the public on the Division of Wildlife website.

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Table 1. Statistics associated with duck hunting parties on selected State Wildlife Areas along the South Platte River corridor during 2009-2010. Percent statistics are the percent of parties that used decoys, spinning wing decoys, dogs, or duck calls.

State Wildlife Area	Total parties	Total hunter days	Avg. number in party	Avg. total duck harvest	Avg. ducks /hunter /day	% parties using decoys	% spinning wing	% dogs	% duck calls
Interviews									
Atwood (U)	41	62	1.5	0.3	0.2	78	22	37	83
Overland Trail (R)	10	20	2.0	0.7	0.5	90	60	60	90
Jean K Tool /Brush (U)	503	895	1.8	0.7	0.4	67	33	35	75
Bravo (R)	63	126	2.0	2.1	1.2	70	49	33	73
Red Lion (U)	114	246	2.2	3.4	1.6	87	58	35	82
Jackson Lake (R)	107	237	2.2	4.6	2.1	96	72	34	94
Check-out Cards									
Atwood (U)	9	13	1.4	0.2	0.2	88	0	44	78
Overland Trail (R)	1	1	1	0	0	0	0	0	100
Jean K Tool /Brush (U)	33	51	1.5	0.7	0.5	78	44	44	79
Bravo (R)	15	26	1.7	1.2	0.8	71	29	67	71
Red Lion (U)	3	4	1.3	0	0	100	100	67	100
Jackson Lake (R)	0	0	-	-	-	-	-	-	-
Total: Interviews & Cards									
Atwood (U)	50	75	1.5	0.3	0.2	80	18	38	82
Overland Trail (R)	11	21	1.9	0.6	0.4	82	55	55	91
Jean K Tool /Brush (U)	536	946	1.8	0.7	0.4	67	34	35	76
Bravo (R)	78	152	1.9	1.9	1.1	70	45	40	73
Red Lion (U)	117	250	2.1	3.3	1.5	87	59	36	82
Jackson Lake (R)	107	237	2.2	4.6	2.1	96	72	34	94
After ice-up									
Red Lion (U)	28	53	1.9	0.5	0.4	63	46	35	68
Jackson Lake (R)	47	99	2.1	0.9	0.5	88	55	29	82

Table 2. Average satisfaction measures of duck hunting parties on selected State Wildlife Areas (SWAs) along the South Platte River corridor during 2009-2010. Scale is 1 through 5, with 1 being the least favorable and 5 being the most favorable. SWAs are designated as Restricted (R) or Unrestricted (U) based on property-specific regulations.

State Wildlife Area	Total parties	Crowding	Bird numbers	Habitat conditions	Hunting regulations	Overall
Interviews						
Atwood (U)	41	4.9	2.7	4.2	4.5	3.5
Overland Trail (R)	10	4.4	2.6	4.2	4.0	3.6
Jean K Tool /Brush (U)	503	4.4	2.5	4.1	4.3	3.5
Bravo (R)	63	4.7	2.9	4.2	3.6	3.9
Red Lion (U)	114	4.2	3.5	4.4	4.3	4.0
Jackson Lake (R)	107	4.2	3.5	4.4	4.1	3.9
Check-out Cards						
Atwood (U)	9	4.7	2.2	3.9	3.9	3.6
Overland Trail (R)	1	1.0	1.0	2.0	3.0	3.0
Jean K Tool /Brush (U)	33	4.1	2.1	3.9	4.1	3.7
Bravo (R)	15	4.6	2.5	4.3	3.6	3.5
Red Lion (U)	3	4.0	2.7	3.7	3.0	3.7
Jackson Lake (R)	0					
Total: Interviews & Cards						
Atwood (U)	50	4.8	2.6	4.1	4.4	3.5
Overland Trail (R)	11	4.1	2.5	4.0	3.9	3.5
Jean K Tool /Brush (U)	536	4.3	2.5	4.1	4.3	3.5
Bravo (R)	78	4.6	2.8	4.2	3.6	3.8
Red Lion (U)	117	4.2	3.5	4.4	4.2	4.0
Jackson Lake (R)	107	4.2	3.5	4.4	4.1	3.9
After ice-up						
Red Lion (U)	28	4.6	2.9	4.0	4.1	3.5
Jackson Lake (R)	47	4.7	3.2	4.3	4.3	3.5

Table 3. Correlation coefficients between some of the satisfaction factors measured from duck hunting parties at selected State Wildlife Areas along the South Platte River corridor during the 2009-2010 regular duck season.

SWA	Factor	Crowding	Hunting regulations	Avg. ducks /hunter /day
Atwood (U)	Hunting regulations	0.20		
	Avg. ducks /hunter /day	0.03	0.05	
	Overall	0.13	0.05	0.14
Overland Trail (R)	Hunting regulations	0.17		
	Avg. ducks /hunter /day	0.20	0.39	
	Overall	0.05	0.65	0.64
Jean K Tool /Brush (U)	Hunting regulations	0.08		
	Avg. ducks /hunter /day	0.05	0.13	
	Overall	0.08	0.27	0.31
Bravo (R)	Hunting regulations	-0.12		
	Avg. ducks /hunter /day	0.00	0.17	
	Overall	0.14	0.06	0.40
Red Lion (U)	Hunting regulations	0.02		
	Avg. ducks /hunter /day	-0.16	0.05	
	Overall	-0.07	0.18	0.46
Jackson Lake (R)	Hunting regulations	0.31		
	Avg. ducks /hunter /day	-0.03	0.17	
	Overall	0.29	0.42	0.52

Table 4. 2009-2010 harvest totals for all small game and duck species reported at the 7 study SWAs during the regular duck season.

Species	Number harvested	Species	Number harvested
Ducks		*Geese*	
Mallard	440	Canada goose	57
Green-winged teal	255	Snow goose	3
Northern shoveler	198	Total geese	60
Gadwall	142		
Wigeon	139		
Blue-winged teal	90	*Small game*	
Northern pintail	57	Quail	70
Wood duck	37	Rabbit	55
Ring-necked duck	22	Squirrel	27
Redhead	16	Pheasant	24
Goldeneye	15	Coot	15
Merganser	13	Dove	6
Bufflehead	7	Snipe	4
Scaup	6		
Canvasback	6		
Ruddy duck	5		
Unspecified duck	51		
Total ducks	1,499		

Table 5. Statistics for vehicles using study SWA parking lots during 2009-2010 regular duck season. Note that vehicle numbers do not match up with party numbers in Tables 1 and 2 because some parties use multiple vehicles.

Check station	Checked out	No check-out	Compliance	Recreational use	Fishing	Parking only	Deer hunting
Atwood	112	9	93%	4	0	1	28
Overland	12	1	92%	0	0	0	5
Brush	226	35	87%	37	57	2	33
Jean K Tool	488	41	92%	32	4	3	23
Bravo (both)	84	8	91%	4	0	0	17
Red Lion	162	20	89%	6	1	0	0
Jackson Lake	162	5	97%	4	1	0	0
Overall	1,246	119	96%	87	63	6	106

Figure 1. South Platte River corridor from Greeley to the state line, showing State Wildlife Areas included in the study.

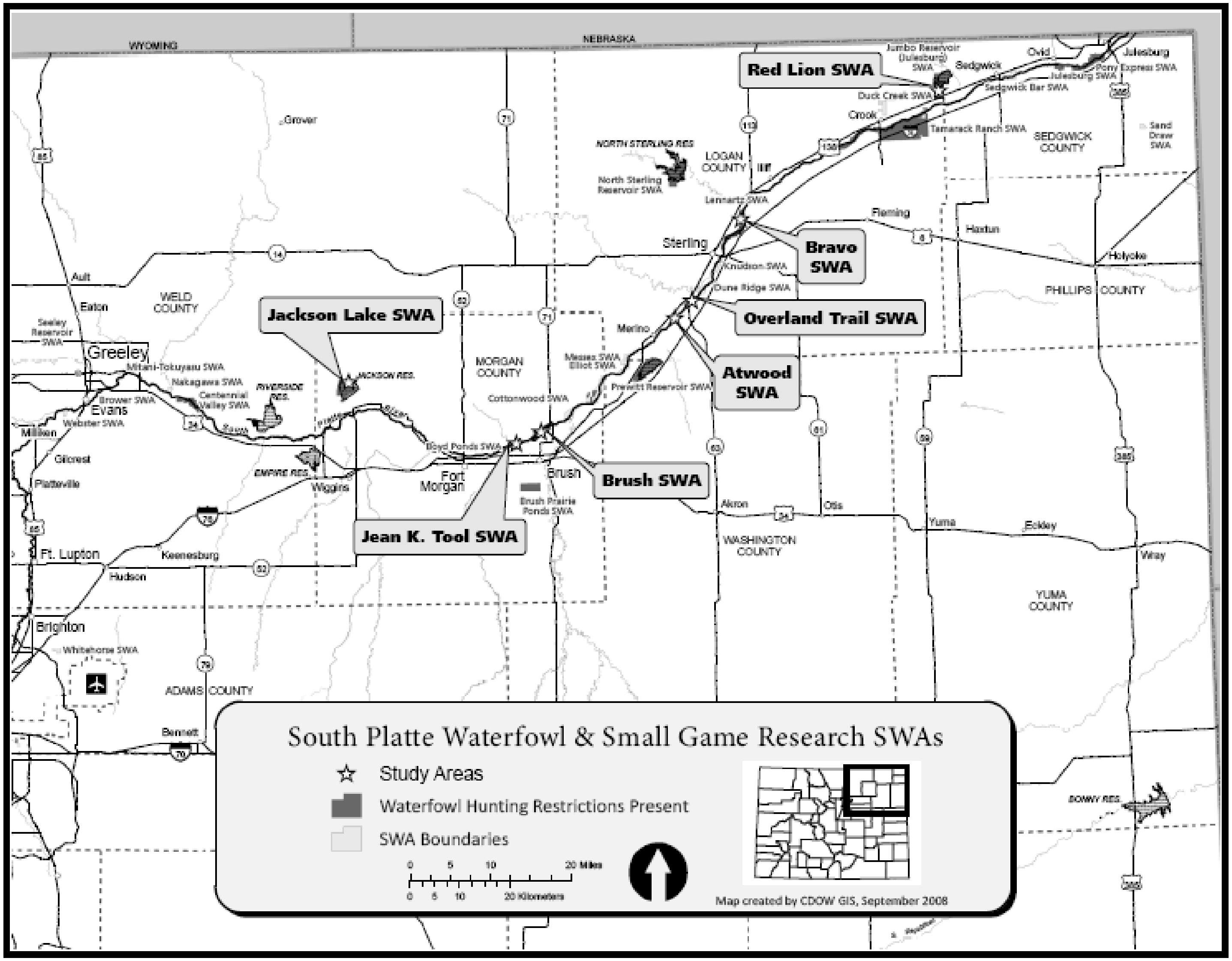


Figure 2. Distribution of ducks shot per hunter per day for parties hunting Atwood (Unrestricted) and Overland Trail (Restricted) SWAs during the 2009-2010 regular duck season.

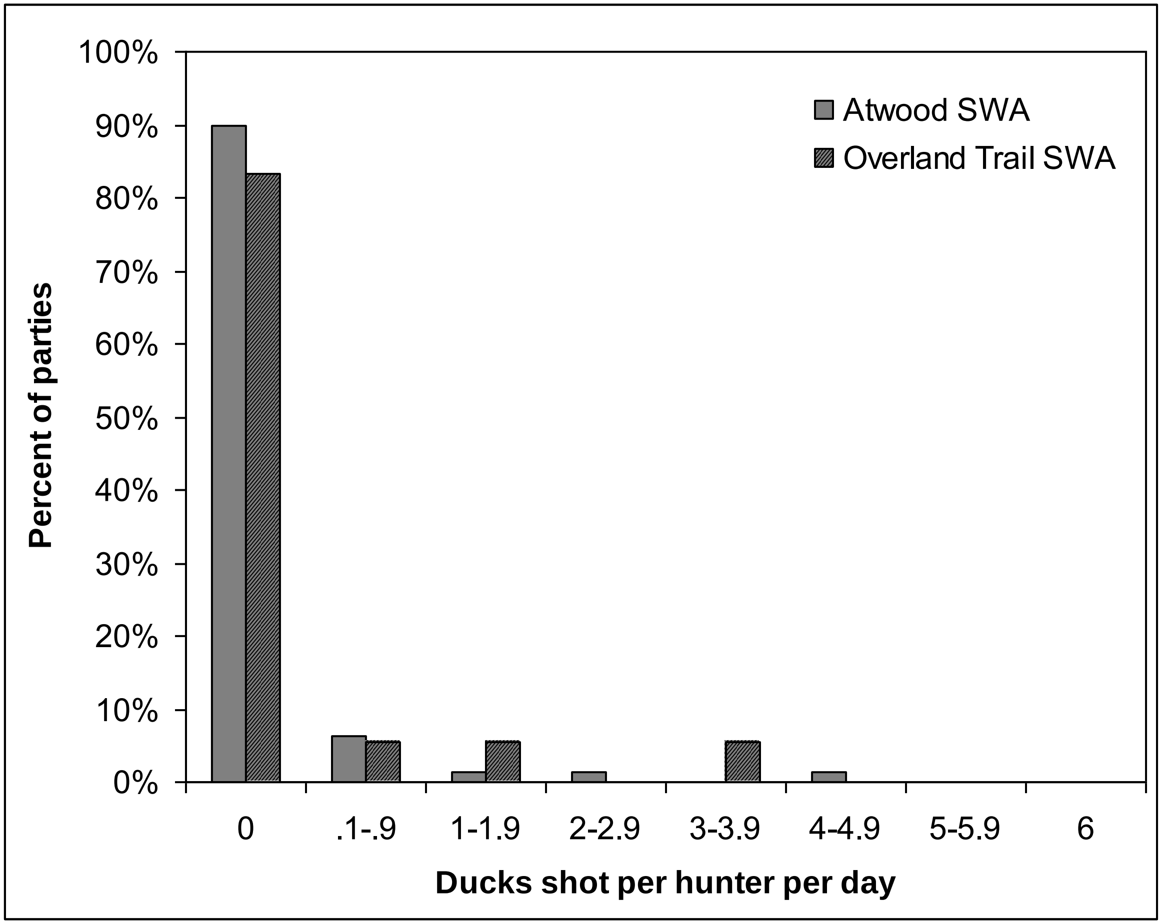


Figure 3. Distribution of ducks shot per hunter per day for parties hunting Jean K. Tool/Brush (Unrestricted) and Bravo (Restricted) SWAs during the 2009-2010 regular duck season.

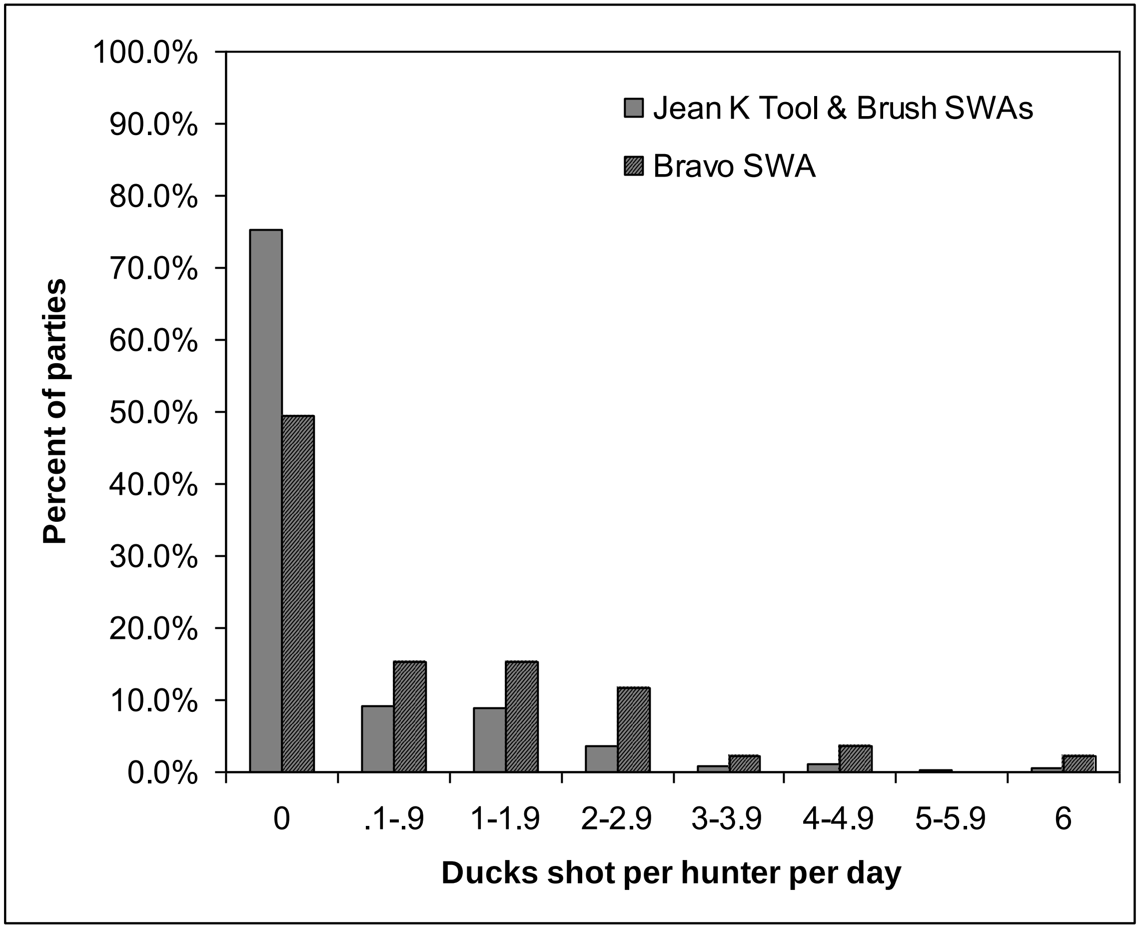


Figure 4. Distribution of ducks shot per hunter per day for parties hunting Red Lion (Unrestricted) and Jackson Lake (Restricted) SWAs during the 2009-2010 regular duck season.

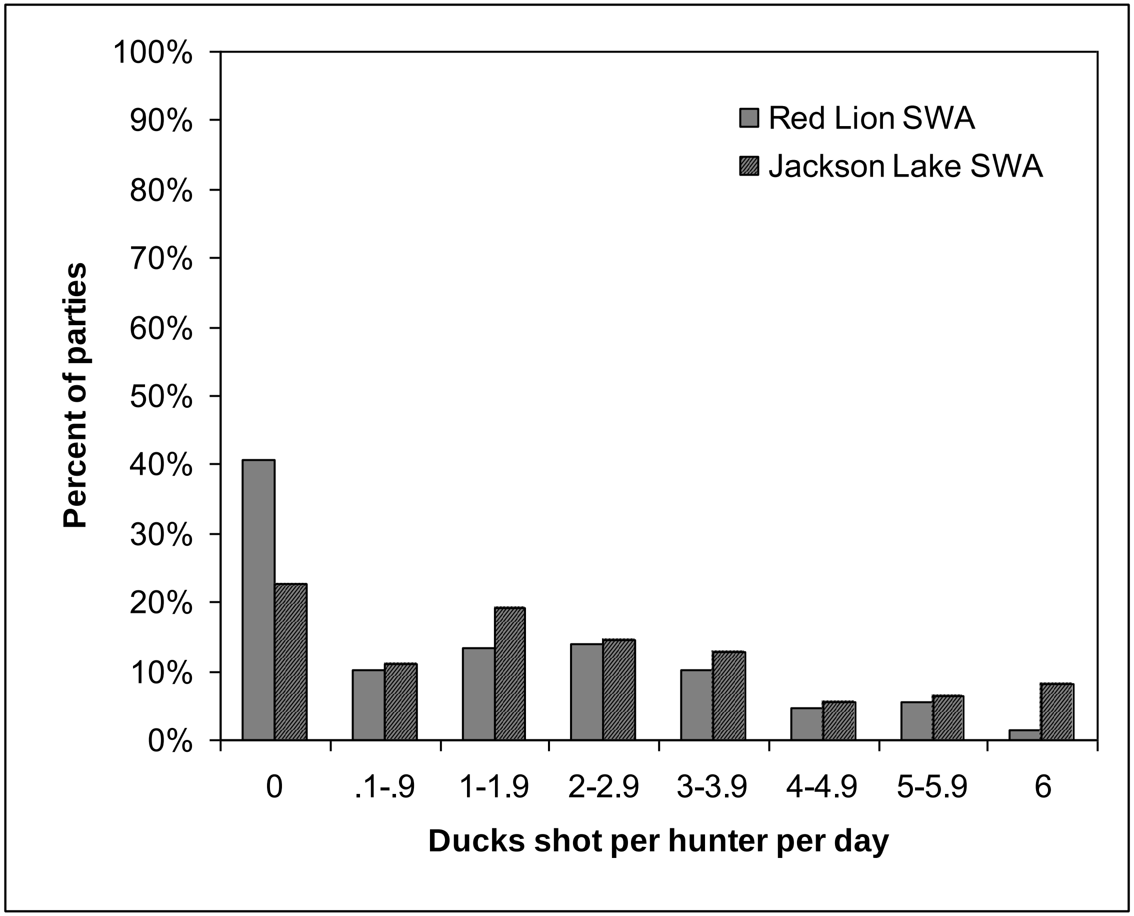


Figure 5. Chronology of duck hunting success on 7 SWAs along the South Platte River corridor during the 2009-2010 regular duck season.

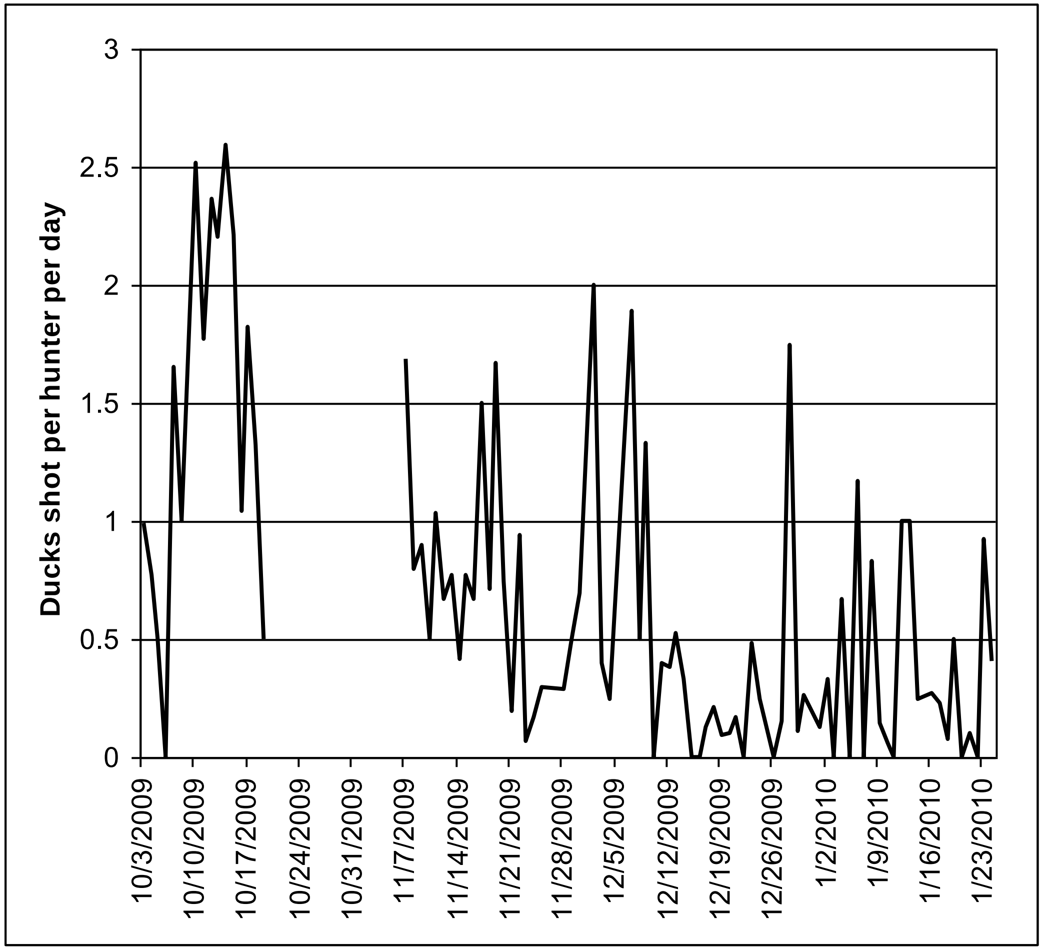
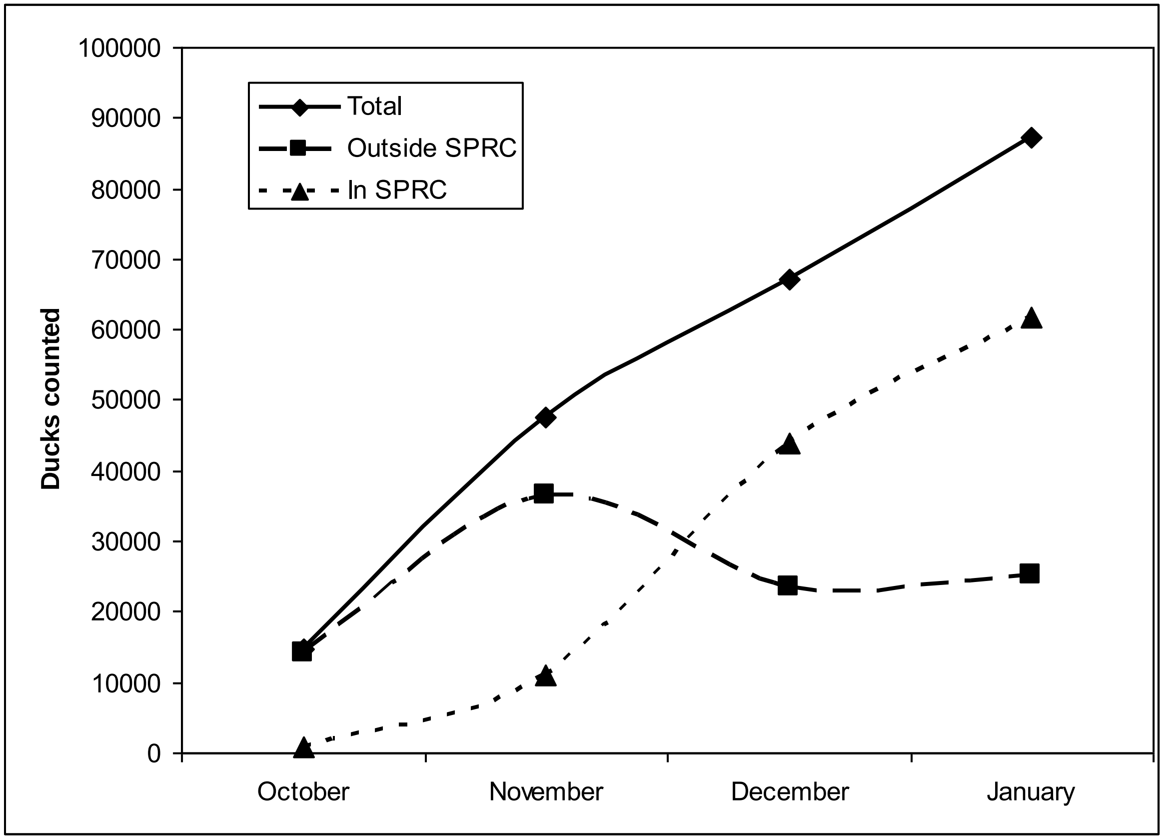


Figure 6. Estimates of duck numbers in the South Platte River corridor (SPRC) from October 2009 through January 2010.



Appendix A. Information collected from waterfowl and small game hunters on selected State Wildlife Areas along the South Platte River during the 2009-2010 regular duck hunting season.

South Platte River Corridor State Wildlife Area Hunting Study

State Wildlife Area ____________________________ Date __________________ Initials _________
Number in hunting party ____ Party arrival time ___________ Party departure time ____________
License plates ____

CID number	Sex	Years out of last 5 hunted on SPR?	Mostly public	Mostly private	Equal

Target Species:

Harvest:

	Male	Female	Unknown	Notes
Mallard				
Blue-winged/Cinnamon teal				
American wigeon				
Gadwall				
Northern shoveler				
Northern pintail				
Wood duck				
Pheasant				
Bobwhite quail				

Decoys (# dozen)? _____ Spinning-wing decoys (#)? ______ Dogs (#)? ______ Calls (Y/N)?_______
____

Rank the following from 1 to 5 for today's hunt:

Crowding problems (1 = no crowding problems, 5 = extreme crowding problems) ________

Bird numbers seen (1 = no birds seen, 5 = abundant numbers of birds seen) ________

Habitat conditions on the area (1 = very poor, 3 = average, 5 = excellent conditions) ________

Hunting regulations on the SWA (1 = very dissatisfied, 3 = neutral, 5 = very satisfied) ________

Overall satisfaction with the hunt (1 = very dissatisfied, 3 = neutral, 5 = very satisfied) ________

Notes:

Appendix B. A selection of comments obtained from hunters at the 7 check stations, 2009-2010 regular duck season.

SWA	Date	Hunt area	Notes
Atwood	11/15/2009		Located several good sized coveys.
Atwood	11/22/2009		Dog busted one covey of 8-10 Bobwhite.
Atwood	11/25/2009		Hunter doesn't like reservation system.
Atwood	12/2/2009		Hunter wants to have a complete brochure for all S. Platte SWAs.
Bravo	10/3/2009	North	Dissatisfied with days available for reservations. Unable to hit weather
Bravo	10/3/2009	North	Somewhat unhappy with reservation system
Bravo	11/7/2009	Bravo North	Crowding problems from youth hunting area; located too close.
Bravo	11/7/2009	Bravo South	Don't like reservations.
Bravo	11/7/2009	Bravo South	More water in the past; very, very satisfied.
Bravo	11/8/2009	Bravo South	The regulations are not beneficial to limit duck hunting since most of the ducks are migratory. Very inconvenient and difficult to make a reservation.
Bravo	11/14/2009	34 Bravo North	The Pike 34 lot was washed out again ruining slough habitat.
Bravo	11/25/2009	Bravo North CR-34 and South	Reported reservation problems for CR 370lot1
Bravo	11/28/2009	CR-36	Dike at slough is washed out.
Bravo	12/9/2009	Bravo North	Hunter was not happy with reservation system.
Bravo	12/16/2009	Bravo South	Hunter didn't like reservation system and likes to hunt after 1:30 p.m.
Bravo	12/19/2009	Bravo South Lot 1	Hunter saw one small covey.
Bravo	12/19/2009	South Bravo	Hunters did not have a reservation. They were target shooting down by the river.
Bravo	12/26/2009	Bravo North CR-36	Reservations on Bravo CR-34. Hunter felt that the river was unhuntable.
Bravo	12/27/2009		Hunter called on 12/23/09 to reserved Bravo Lot 34 for 12/27/09 and 12/30/09. He received confirmation letter for 12/30/09 but not for 12/27/09. He looked for a ranger at all stations without luck. He wasn't sure if he should hunt without the confirmation letter so he hunted Bravo instead and took one quail.
Brush	10/3/2009		Don't care for people fishing while trying to hunt for duck

Brush	11/14/2009		Not respectful people.
Brush	11/15/2009		Should model walk-in access program after Kansas and Nebraska, i.e. no additional license changes and Montana's permits to landowners
Brush	11/19/2009	Brush East	Hunter walked into the woods to the west, shot off one time and walked back to truck and left. Not sure what he was doing, but he seemed weird. Did not approach him.
Brush	11/23/2009	North lot	Hunters did not like checking out
Brush	11/28/2009		Habitat needs more cover.
Brush	11/30/2009		Hunting regulations are confusing.
Brush	12/13/2009	Brush North	Got into large covey and lost them.
Brush	12/19/2009	Main and South Brush	Hunter would like to go back to using lead shot.
Brush	12/19/2009	Main and South Brush	Hunter would like to see more food plots.
Brush	12/19/2009	Snyder	Hunters don't like checking out and they don't like the reservation system.
Brush	12/20/2009		Hunters feel that the birds need more to eat in their habitat.
Brush	12/27/2009	South Brush	Hunters worked about 15 geese. Hunters would like to hunt a half hour after sunset rather than a half hour before sunrise.
Brush	1/13/2010		Pass shooting geese from field east of parking lot
Brush	1/18/2010		Hunter feels that it is hard to find information about the hunting regulations.
Jackson	10/3/2009	Zone 3	1 guy left at 7:50. Complained about sky busting in unit 1 and 2 and early shooting
Jackson	10/3/2009	Zone 6	Poor Feed
Jackson	10/3/2009	Zone 1	Some sky busting and shot early, complained about being peppered with shot from unit 1
Jackson	10/3/2009	Zone 2	These guys were shooting 15 minutes before shooting hours; lots of sky busting
Jackson	10/4/2009	Zone 8	Tried to cancel ended up in zone 3
Jackson	10/7/2009	Zone 6	Boundary lines are too close
Jackson	10/7/2009	Zone 3	Like no reservations. Don't like sky busting
Jackson	11/8/2009	Zone 6	Perimeter cover fair.
Jackson	11/11/2009	Zone 3	Like to hunt evenings.
Jackson	11/11/2009	Zones 5 & 6	One hunter had a reservation for zone 5 and the other for zone 6.

Jackson	11/15/2009	Zone 4	Reservation assigned hunters to Area 4 but hunted Area 6. May have misunderstood map?
Jackson	11/22/2009	Zone 5	Hunters feel reservations are difficult to get
Jackson	11/25/2009	Zone 6	Hunters saw a lot of ducks in Area 9 but none were flying over or into the ponds.
Jean K Tool	11/11/2009		Would like it to be a bit more accessible toward west. Would like weekend reservations here at JK Tool.
Jean K Tool	11/13/2009		Hunter doesn't like reservation system.
Jean K Tool	11/21/2009		Hunter felt that the habitat conditions for the small game were very poor.
Jean K Tool	11/21/2009		Past hunting land type not specified.
Jean K Tool	11/22/2009		Hunter feels that there needs to be more knowledge about deer season dates. Please place on website the open and closed dates. Also post more new signs about dates on deer season only. Very young boy with hunter without a gun.
Jean K Tool	11/23/2009		Extreme crowding on the west end.
Jean K Tool	11/23/2009	West end	Lots of sky busting.
Jean K Tool	11/26/2009	JK Tool/North Brush	Hunter feels that habitat on the north side looks good but there were no signs of birds at all.
Jean K Tool	11/30/2009	West side	Hunters believe that DOW should start planting more stuff for the wildlife like doves and rabbits.
Jean K Tool	11/30/2009	West	Jump shooting on west side of JK Tool. One youth walking with group.
Jean K Tool	12/13/2009		West side had crowding problems between two parties.
Jean K Tool	12/27/2009	East side	Hunters were very upset with the high water level. They felt that hunting was extremely dangerous and that they could not even put out decoys.
Jean K Tool	1/16/2010	JKT & Brush	Need more areas like this for hunters--like the bigger properties
JKTBrush	1/24/2010	JK Tool/East Brush	Hunter felt that there were extreme crowding problems at East Brush, but none at JK Tool.
Overland Trail	12/12/2009		People were coming over from private. Don't like to check out by two.

Overland Trail	12/30/2009		Hunter saw a couple of coveys and shot one bird but lost it across the slough.
Overland Trail	1/1/2010		Hunters would like to see prescribed burning along the river bottom.
Red Lion	10/3/2009		Complaint about hunters sky busting and not allowing ducks to come in
Red Lion	10/3/2009		Complaint about sky busters not allowing birds to come in
Red Lion	10/3/2009		Complaint about sky busters not allowing ducks to come in
Red Lion	10/16/2009		Too much grazing along ponds, hard to find place to hide
Red Lion	11/9/2009		Private farms to the west holding all the birds.
Red Lion	11/14/2009		Hunter didn't think that pheasant hunting regulations were posted very well.
Red Lion	11/14/2009		Hunter wants grazing to stop.
Red Lion	11/16/2009		Hunter wants more quail habitat.
Red Lion	11/18/2009		Hunter feels that ducks need more grain.
Red Lion	11/18/2009		Hunter felt that the water levels were very high.
Red Lion	11/19/2009		Hunter would like to see food put out on the hunting plots and more hunting regulations.
Red Lion	11/22/2009		On Red Lion lake with canoe.
Red Lion	11/25/2009		Hunter said it was a great spot and would be back soon.
Red Lion	11/26/2009		Hunters were shooting in a.m. about thirty minutes before opening hours. They appeared to be duck hunters on Jumbo.
Red Lion	11/28/2009		Hunters want to know why there was less milo planted then in previous years.
Red Lion	11/28/2009		One youth walking. Frozen ponds, difficult to keep open. No departure time given.
Red Lion	12/22/2009		Hunter says that overall nice area but not much game and he would like to see more native plants.
Unknown	10/3/2009		Put checkout box at other parking lots

COLORADO DIVISION OF WILDLIFE - AVIAN RESEARCH PROGRAM
PROGRESS REPORT
September 2010

TITLE: Intermountain duck habitat management pilot study—North Park

AUTHOR: J. P. Runge

PROJECT PERSONNEL: J. H. Gammonley, J. Haskins, B. Sullivan, B. Weinmeister, J. Yost

Period Covered: June 11, 2008 – May 14, 2010

OBJECTIVES

The two main objectives of this project are to improve duck production in Colorado and investigate techniques for improving wetland management while incorporating uncertainty surrounding ecological processes such as density-dependence and nest site fidelity in several species of ducks that commonly breed in Colorado.

INTRODUCTION

Duck production can serve as an index of wetland value, thus monitoring the effect of habitat conservation for ducks is important. Intermountain valleys such as North Park and the San Luis Valley account for the vast majority of ducks produced in Colorado. These areas therefore provide ample opportunity to investigate methods for increasing duck production, and correspondingly, wetland value.

Many management options exist for modifying wetlands for waterfowl production, and they are generally related to setting back the successional stage of the wetland. The operational theory behind such work is that waterfowl production in wetlands increases along with vegetation structure following a disturbance. However, at a certain point in the successional arc, vegetation become too thick, and ducks choose to nest elsewhere. Thus management tools such as grazing, burning, and disking can remove vegetation and maintain high duck production over the long term. The downside to such management tools is that they can set succession back far enough that it takes several years for ducks to begin nesting in substantial numbers. The challenge to managers then is to find an optimal disturbance schedule that maximizes duck production over a number of years, while minimizing management costs.

This research focuses on establishing that optimal disturbance schedule for different wetland habitats in North Park and the San Luis Valley. The first step is to investigate and quantify how duck production responds to disturbance events. Two ecological processes may influence duck production and optimal disturbance schedules: density dependence and nest site fidelity. Theoretically, as nest density increases, per capita production may decrease due to depleted food resources. Also, dense conglomeration of nesting birds may attract predators, which could result in decreases in nest success. Thus it may be prudent to manage for an optimal nest production rates rather than maximizing nest density.

High nest success may result in greater return rates for nesting females (i.e., high nest site fidelity). This would result in a positive feedback loop in which greater return rates would cause a population to reach optimal nest density faster than if no nest site fidelity occurred. With high nest site fidelity and high nest success, nesting populations may become too dense thus invoking the negative feedback of density dependence. This study will attempt to estimate nest site fidelity and the form of density dependence in breeding intermountain ducks, use these estimates to determine optimal nest density and success, and determine whether such optimal states can be obtained in a cost-effective manner.

Because this study uses optimal decision making policies while incorporating ecological processes, it is a form of adaptive resource management (ARM; Williams et al. 2007). It is important to note, however, that unlike much adaptive management work, this study requires several years to quantify answers to management questions due to successional dynamics. Even with this delay in feedback, ARM can improve effectiveness of habitat conservation programs by integrating research and management in a decision making framework.

STUDY AREA AND METHODS

During 2008 and 2009, we conducted a pilot study investigating methods for estimating duck production. To obtain an estimate of production, we measured information on nest success and density. Nest searching was conducted in the North Park wetland complexes Lake John Annex (CDOW), Hebron Slough (BLM), and the Arapaho National Wildlife Refuge (USFWS). Targeted wetlands for study in North Park included Hebron Slough (BLM), Case Flats (USFWS), Illinois River oxbows and sloughs (USFWS), and Lake John Annex (CDOW). Details pertaining to each study area are described in Table **1**. In North Park, 3-4 observers dragged a rope through vegetation to flush hens from nests (Earl 1950). The observers either walked through nesting areas or drove ATVs. Nest locations were marked with surveyors' pin flags and revisited weekly to determine nest success. Eggs were candled to determine incubation stage (Weller 1956). Nest searches took place 1-3 times per summer on each study unit.

In July and August of 2008 and 2009, we initiated and continued banding efforts in North Park in an ongoing attempt to estimate survival and recovery rates and decompose recovery into constituent harvest and reporting rates. Ducks were caught in bait traps, rocket-netted, or caught in dip nets from airboats. Captured ducks were fitted with standard aluminum USGS legbands. Two out of every three female mallard, gadwall, and blue-winged/cinnamon teal were fit with nasal tags (Lee 1960) to aid in estimation of site fidelity (i.e., resightings of nasal-marked females on study sites in subsequent years). One out of every three females of these species received a leg band only. This will allow estimation of hunter recovery rates of nasal marked vs. non-nasal marked waterfowl. All males of these species, and all captured ducks of other species, were also legbanded. Following marking, ducks were released immediately at the capture site.

In May-June 2009, we collected information regarding vegetation cover (vegetation height-density as measured with Robel poles [Robel et al. 1970]), depth of dead vegetation, primary and secondary dominant vegetation types, and hydrological characteristics (water depth, % area covered by water) in focal wetlands and nesting areas. We established 50 random points in a given wetland unit via GIS sampling. At each random point we outlined a circular plot 4m in radius ($50.27m^2$ plot). At each cardinal point of the resulting circle, we recorded depth (in cm) of dead vegetation and water depth (if any) as well as recording Robel visual obstruction values. Dead vegetation included any vegetation that was lying over, but may still have had an unbroken stalk, the goal being to estimate an index for cover available to ducks initiating nests in May-June. We recorded primary and secondary vegetation types in the 50.27m plot, the % of plot covered in visible water, and the % of plot that was bare ground.

Analysis.—Estimates of daily nest survival were conducted in program MARK (White and Burnham 1999). For the 2008 data, we fit two models, one based upon dominant vegetation in the vicinity of the nest, one with all nests pooled. For the 2009 data, we fit several models investigating the variation among the different management units. Additionally, we included the dominant vegetation around the nest as a factor affecting nest success, the depth of dead vegetation at each nest as an individual covariate, the average depth of dead vegetation at 50 random points as a patch-level covariate and the nest density in each management unit as a patch level covariate. Further detailed analysis regarding species and other environmental covariates will be undertaken as part of a final report once more data are collected.

Litter depth was similarly used as a patch level environmental variable to investigate its association with nest density (nests/ha.) in a given management unit. Two models were fit, one with litter depth only, and one with litter depth and litter depth^2, the latter to investigate whether nest density increases then decreases as litter depth increases. Litter depth was log-transformed as an input variable to ensure normality in results.

RESULTS AND DISCUSSION

Nesting.—During summer 2008, we located 53 active nests at the Lake John Annex. Twenty-five were mallard, 12 were blue-winged/cinnamon teal, 8 were lesser scaup, 3 were northern shoveler, 3 were canvasback, 1 was American wigeon, and 1 was gadwall. Forty-three of these nests were located in bulrush and Baltic rush, 7 were in grasses, 1 was in saltgrass, 1 was in greasewood, and 1 was located on the edge of bulrush and grass habitat. Overall apparent nest success was 58% (not including the 3 nests that were abandoned just after they were found). Of the two models run, the model with vegetation differences fit best, and daily nest survival was estimated at 0.977 (95% CI: 0.961-0.986) for Baltic rush and bulrush-associated nests and 0.916 (95% CI: 0.832-0.960) for nests associated with grass and greasewood. For 35 day nesting periods these estimates correspond to 44.3 and 4.6% nest success, respectively. Two hundred and twenty-one eggs were known to have hatched in the Lake John Annex area during the summer of 2008. Of these, 205 hatched in Baltic rush and bulrush habitats and 16 in grass habitats. In terms of species, 99 eggs hatched were mallards, 51 were blue-winged/cinnamon teal, 40 were lesser scaup, 16 were canvasback, and 15 were northern shoveler. Conducting pilot work for future years, we found 4 nests on unit A6 of ANWR, 1 on unit C11, 0 on unit C5, C6, and C8/10. We did not follow these nests as these were pilot efforts meant to identify areas that could be included in future work on the Refuge.

During summer 2009, we found 144 nests, 129 of which were active. Details of which management units nests were found on, and which species nested in those units can be found in Table 2. Apparent nest success for all the nests found in 2009 was 61.6%. None of the explanatory variables investigated (e.g., dominant vegetation, litter depth, nest density, etc) explained daily nest survival rates better than a model expressing nest survival as constant across all area and habitat factors. The estimate from this model was 0.955 (95% CI: 0.943-0.964), which corresponds to 19.8% nest success for a 35 day nesting period.

Average dead vegetation depth (i.e., litter) explained nest density well. As mentioned above, litter depth was log-transformed; the intercept of the relationship was estimated at -5.46 (SE: 1.07) with the slope estimated at 0.381 (SE:0.09). Due to the log-transformation, the relationship is easier communicated with a graphical depiction (Figure 1). A 2nd model including a litter depth^2 variable returned nonsensical results and likely needs more data to be fit correctly.

Three hundred and sixty-seven eggs were known to hatch in the study area during 2009. Table 3 details area and species-specific relationships for hatched eggs. One hundred and thirty-seven eggs hatched from nests associated mainly with Baltic rush (52 active nests found), 93 from nests associated with wetland grasses and sedges (31 nests), 51 from upland grasses (8 nests), 44 from bulrush (23 nests), 18 from greasewood (2 nests), 16 from rye (4 nests), and 8 from spike rush (3 nests). No eggs hatched from nests found that were associated with sage (1 nest), willow (1 nest), or no vegetation at all (1 nest).

On units 12 and 13 of ANWR, and the D Meadow (west) unit of Hebron Sloughs, 0 nests were found.

Banding.—In 2008, we banded 741 ducks in North Park. Sex, age, and species-specific details are given in Table 4. Nasal tags were placed on 57 gadwall females (32 in ANWR, 11 in Hebron Sloughs, 1 in Lake John, 13 in Walden Reservoir), and 77 mallard females (31 in ANWR, 30 in Hebron Sloughs, 15 in Lake John, 1 in Walden Reservoir) for a total of 134 nasal tags.

In 2009, we banded 1068 ducks in North Park (Table 5). Nasal tags were placed on 22 blue-winged/cinnamon teal females (15 in ANWR, 7 in Lake John), 49 gadwall females (33 in ANWR, 16 in Lake John), and 131 mallard females (48 in ANWR, 28 in Hebron Sloughs, 55 in Lake John) for a total of 202 nasal tags.

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Figure 1. Estimated relationship between depth of dead vegetation and duck nest density, based upon results from North Park, 2009. Points are the different management units measured and the line is the relationship modeled between average depth of dead vegetation and duck nest density.

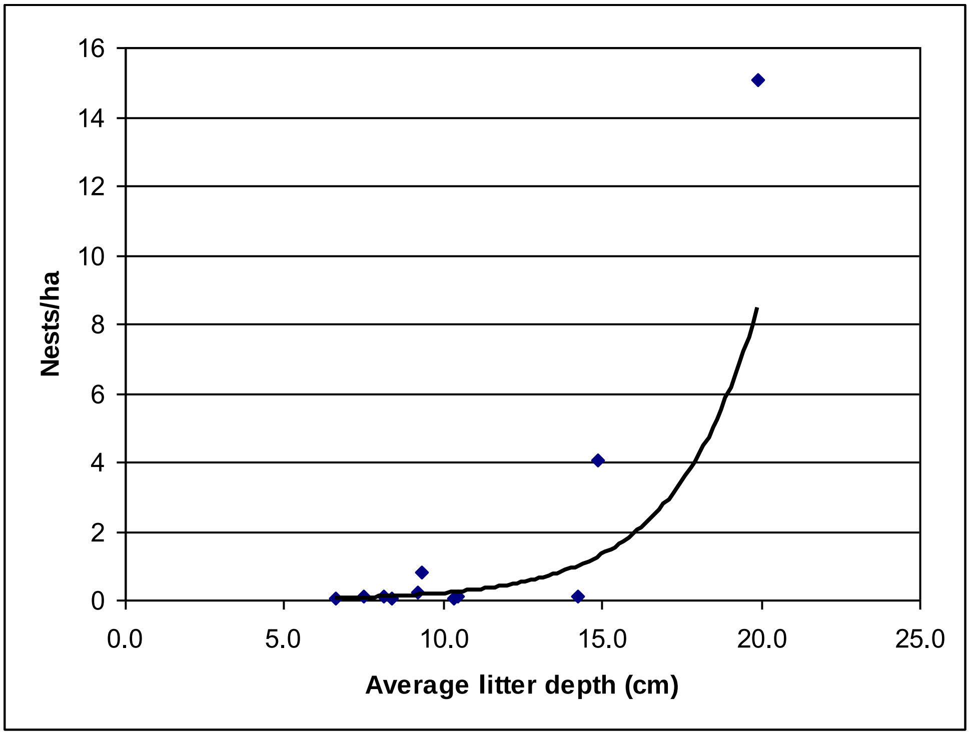

Table 1. Description of sampled wetland units.

Mgmt. Unit	Area	Hectares	Dominant vegetation	Percent of vegetation plots containing water in spring 2009
25a	ANWR	27.07	Grasses and sedges	39%
25b	ANWR	26.64	Grasses and sedges	10%
26	ANWR	55.97	Baltic rush	34%
27a	ANWR	20.60	Grasses and sedges	9%
27b	ANWR	29.33	Grasses and sedges	26%
12	ANWR	25.32	Grasses and sedges	5%
13	ANWR	39.38	Baltic rush	16%
A5	ANWR	214.24	Baltic rush	44%
A6	ANWR	38.43	Baltic rush	46%
C12w	ANWR	184.64	Grasses and sedges	10%
D2	Hebron	25.99	Grasses and sedges	28%
D1	Hebron	22.83	Grasses and sedges	10%
LJ East	Lake John	8.38	Baltic rush/bulrush	50%
LJ West	Lake John	1.26	Bulrush	51%

Table 2. Number of nests found in North Park 2009 by species and management unit.

Unit	Area	BCTE	CANV	GADW	LESC	MALL	NSHO	UNSP	Total
25a	ANWR	2		1					3
25b	ANWR	1		1					2
26	ANWR			2		4	1	1	8
27a	ANWR	1							1
27b	ANWR	1		3					4
A5	ANWR	12		6	1	2	5	1	27
A6	ANWR	9		11	3	3	4	1	31
A9	ANWR			2				0	2
C12w	ANWR	2					4	1	7
D2	Hebron Slough	1		5					6
LJ East	Lake John	5		2	9	9	1	8	34
LJ West	Lake John	6	1	1	1	7	1	2	19
Total		40	1	34	14	25	16	14	144

ANWR = Arapaho National Wildlife Refuge, BCTE = blue-winged or cinnamon teal, CANV = canvasback, GADW = gadwall, LESC = lesser scaup, MALL = mallard, NSHO = northern shoveler, UNSP = unknown species.

Table 3. Number of eggs confirmed to hatch in North Park 2009 by species and management unit.

Unit	Area	BCTE	GADW	LESC	MALL	NSHO	UNSP	Total
25a	ANWR	9						9
25b	ANWR	9	6					15
26	ANWR		10		9			19
27a	ANWR	9						9
A5	ANWR	19	8		12	10		49
A6	ANWR	43	34			15		92
C12w	ANWR	9				9		18
D2	Hebron Slough	10	18					28
LJE	Lake John	10	6	32	7		25	80
LJW	Lake John	9	7	9	23			48
Total		127	89	41	51	34	25	367

ANWR = Arapaho National Wildlife Refuge, BCTE = blue-winged or cinnamon teal, GADW = gadwall, LESC = lesser scaup, MALL = mallard, NSHO = northern shoveler, UNSP = unknown species.

Table 4. Number of ducks banded in North Park, July-September, 2008.

		Female					Male					Unknown				
Region	Species	AHY	HY	L	U	Tot.	AHY	HY	L	U	Tot.	AHY	HY	U	Tot.	Grand Total
ANWR	AMWI	1				1		2			2					3
	BCTE	1				1										1
	BWTE						1		1		2					2
	CANV							1			1					1
	CITE						1				1					1
	GADW	21	16	26	1	64	11	24	14		49					113
	LESC	1	2			3		1	3		4					7
	MALL	23	14	10	1	48	106	32	5	45	188		1	3	4	240
	NOPI	2				2	2				2	2			2	6
	NSHO	1	4	3		8	1	3			4					12
	REDH							1			1					1
ANWR Total		50	37	39	2	128	122	64	23	45	254	2	1	5	8	390
Hebron	AGWT	1				1										1
	AMWI		3			3	3				3					6
	BWTE						1				1					1
	CANV		1			1		1			1					2
	GADW	6	12	2		20	5	11	4		20		1		1	41
	MALL	24	14	2	2	42	74	15	9		98					140
	NOPI							1			1					1
	NSHO	1	1			2										2
	REDH	1				1	2				2					3
	RUDU						1				1					1
Hebron Total		33	31	4	2	70	86	28	13		127		1		1	198
Lake John	AMWI							1			1					1
	BCTE		2			2		1			1					3
	CANV							1			1					1
	GADW	1	1			2	1				1					3
	LESC							1			1					1
	MALL	8	1	12	1	22	10	4	10	7	31					53
	NSHO		8			8		10			10					18
	REDH		1			1		1			1					2
Lake John Total		9	13	12	1	35	11	19	10	7	47					82
Walden Res.	AMWI				1	1										1
	BWTE							1			1					1
	CANV		3			3		1			1					4
	GADW	5	15		1	21	13	3			16					37
	MALL		3			3	2				2					5
	NOPI							1			1					1
	NSHO	4				4	10	8			18					22
Walden Res. Total		9	21		2	32	25	14			39					71
Grand Total		101	102	55	7	265	244	125	46	52	467	2	2	5	9	741

Table 5. Number of ducks banded in North Park, July-August, 2009.

		Females					Males					
Region	Species	AHY	HY	L	U	Total	AHY	HY	L	U	Total	Grand Total
ANWR	AGWT		8	1		9	46	11			57	66
	AMWI	19				19	20	1			21	40
	BCTE	5	14	1		20	8	16	2		26	46
	CITE						1				1	1
	GADW	36	4	7		47	73	2	5	1	81	128
	LESC			1		1						1
	MALL	33	34	6	1	74	59	30	5		94	168
	NOPI		2			2		1			1	3
	RNDU						2				2	2
ANWR Total		93	62	16	1	172	209	61	12	1	283	455
Hebron	AGWT	3	16	2		21	35	20	4		59	80
	AMWI								1		1	1
	BCTE		1	3		4		2	3		5	9
	BWTE							1			1	1
	MALL	12	20	13		45	11	36	3		50	95
Hebron Total		15	37	18		70	46	59	11		116	187
Lake John	AGWT		1			1	1				1	2
	AMWI		6	1		7		7			7	14
	BCTE	2	6			8	4	2	3		9	17
	CANV		5	2		7			1		1	8
	CITE						1				1	1
	GADW	13	6	6		25	63	5	2		70	95
	LESC		1			1	1		1		2	3
	MALL	39	42	2		83	154	36	5		195	278
	NOPI		3			3						3
	NSHO		1			1		1			1	2
	REDH		1	1		2		1			1	3
Lake John Total		54	72	12		138	224	52	12		288	426
Grand Total		162	171	46	1	380	479	172	35	1	687	1068

For Tables 4 and 5, the following abbreviations are defined as: AHY = after hatch year, HY = hatch year, L = local (i.e., duckling), U = unknown sex or age, ANWR = Arapaho National Wildlife Refuge, AGWT = American green-winged teal, AMWI = American wigeon, BCTE = blue-winged or cinnamon teal, BWTE = blue-winged teal, CANV = canvasback, CITE = cinnamon teal, GADW = gadwall, LESC = lesser scaup, MALL = mallard, NOPI = northern pintail, NSHO = northern shoveler, REDH = redhead, RNDU = ring-necked duck.

COLORADO DIVISION OF WILDLIFE - AVIAN RESEARCH PROGRAM
PROGRESS REPORT
September 21, 2010

TITLE: Population dynamics of resident Canada geese along the Front Range of Colorado

AUTHOR: J. H. Gammonley

Period Covered: June 1, 2003 – September 1, 2010

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

ABSTRACT

Populations of resident Canada geese (*Branta canadensis*) were established along Colorado's Front Range corridor beginning in the 1950s and 1960s, providing recreational hunting and viewing opportunities. Human-goose conflicts have increased over time, but information is lacking on current population growth rate or how vulnerable these resident geese are to harvest during hunting seasons. The purpose of this study is to obtain current estimates of population size and survival, recruitment, and harvest rates; describe seasonal movements; and document the spatial and temporal distribution of harvest of resident Canada geese along the I-25 urban-suburban (Front Range) corridor. This information will be used to develop a population model and management plan for resident Canada geese along the Front Range.

Canada geese were banded in 3 Front Range sub-areas: Northern Front Range, Denver Metro, and Southern. During 2003-2008, 10,478 Canada geese were legbanded at breeding and molting areas; 1,534 adult geese were also neckbanded. During annual banding operations, 6,621 previously marked geese were recaptured. Based on recaptures of double-marked geese, neckband loss was significant, and some legband loss also occurred. Through September 2009, 1,589 (15.2%) banded Canada geese had been reported to the USGS Bird Banding Laboratory as shot during hunting seasons. A larger percentage of geese marked in the Northern Front Range sub-area (25.6%) was reported harvested than geese marked in the Denver Metro (7.3%) or Southern (10.5%) sub-areas. Most (93.7%) hunter recoveries occurred in study area counties, and 76.2% of recoveries occurred in the Northern Front Range sub-area. Canada geese banded along the Front Range were disproportionately harvested early and late during hunting seasons. Across all hunting seasons, 60% of recoveries of marked resident Canada geese occurred during September-October and February, when 27% of the hunting season days occurred, whereas only 40% of recoveries occurred during November-January, when 73% of the hunting season days occurred. This pattern contrasts to the temporal pattern of overall harvest of Canada geese (resident and migrant geese combined) in study area counties; only 24% of total harvest occurred during September-October and February, and 76% of harvest occurred during November-January.

Additional band recoveries are being incorporated into the data set, and recovery and recapture information will be used to estimate population size, survival, harvest, and fidelity rates during 2011. Plot surveys to resight neckbanded geese and estimate numbers of geese in the study area will continue through spring 2011. This information will be used to estimate demographic parameters and examine seasonal movements of Canada geese along the Front Range. After all results are analyzed, manuscripts will be prepared and submitted for publication.

POPULATION DYNAMICS OF RESIDENT CANADA GEESE ALONG THE FRONT RANGE OF COLORADO

Progress Report, June 1, 2003 – September 1, 2009

James H. Gammonley

INTRODUCTION

Canada geese (*Branta canadensis*) historically nested in small numbers on the eastern plains of Colorado (Bailey and Niedrach 1965), but by 1932 the only known breeding population consisted of about 17 geese near Denver; this flock grew to about 1,000 geese by 1964 (Szymczak 1967). Efforts by the Colorado Division of Wildlife (CDOW) to establish a resident breeding population of Canada geese along the Front Range foothills north of Denver began in 1957, when 40 geese were released on College Lake near Fort Collins (Szymczak 1975). Goose "restoration" in this area was initially focused on the Fort Collins-Loveland and Boulder-Longmont areas. Local populations grew quickly, and by 1967 goslings from these areas, as well as the Denver area, were removed annually for release in other areas in Colorado and surrounding states where additional resident breeding populations were desired. Despite these removals of young birds, the estimated size of local populations exceeded 1,600 in the Fort Collins-Loveland area and 800 in the Boulder-Longmont area by 1973 (Szymczak 1975). Most recently, goslings from the Denver and northern Front Range areas were released at several sites near Pueblo during 1996-2000, in an effort to establish a local breeding population in Pueblo County. Currently, resident Canada geese occupy most suitable habitat in and around the urban/suburban corridor along Interstate 25 from north of Fort Collins to south of Pueblo. Formal breeding population surveys were never designed and implemented, but "post-production" counts have been made at a number of sites where brood-rearing and molting geese traditionally congregate in several Front Range areas. Assuming these counts provide an accurate index of population status, resident Canada goose numbers in these areas continued to increase through the 1980s, and by the late 1990s appeared to have stabilized, with reduced annual production of young.

Resident Canada geese provide an important resource for consumptive and non-consumptive users, but conflicts between geese and humans also occur. Complaints from the public about nuisances caused by Canada geese occurred even while early efforts to expand the Front Range population were underway (Szymczak 1967, Szymczak 1975), and public concerns have increased over time. In addition, the human population along Colorado‘s urban Front Range corridor has greatly expanded since efforts to establish resident Canada goose populations were initiated. Given expanding populations of Canada geese and the increasing human population in Colorado, there will likely be increasing demands for effective management approaches to reduce human-goose conflicts, while maintaining a resident goose population along the Front Range urban corridor. Management of resident Canada goose populations in urban and suburban areas has developed into a significant issue in many parts of the United States, and more aggressive population control measures have been advocated in some areas (Conover and Chasko 1985, Conover 1987, Ankney 1996, Cooper 1997, Smith et al. 1999, U.S. Fish and Wildlife Service 2002).

In addition to providing opportunities for sport harvest as a means for influencing the abundance and distribution of geese, the CDOW has used numerous methods to attempt to address local goose problems and maintain numbers of resident Canada geese. Local problems are addressed primarily through non-lethal methods (hazing, use of chemical deterrents, habitat management), as well as educational materials and technical assistance to prevent problems. In the past, the CDOW also annually trapped geese along the Front Range during the molting period and released them in other areas in Colorado or other states. Since the 1970s, the CDOW has moved over 15,000 Canada geese using this method, primarily from the Front Range area. However, this method is costly and time-consuming, with limited effectiveness in either controlling local goose numbers or addressing site-specific problems

(Smith et al. 1999). In addition, there are no longer sites where there is a desire to use trap and transport of goslings to establish new local breeding populations. More recently, CDOW received a permit from the U.S. Fish and Wildlife Service to oil or addle eggs in Canada goose nests. During 2002-2009, an average of 1,653 eggs in 304 nests were treated statewide, with most nest control occurring along the Front Range (unpublished CDOW records).

Future management of resident Canada geese along Colorado‘s Front Range urban corridor would benefit from an improved understanding of the dynamics of this population, and the influence of management actions on population parameters. The objectives of this study were to obtain current estimates of population size and survival, recruitment, and harvest rates; describe seasonal movements; and document the spatial and temporal distribution of harvest of resident Canada geese along the I-25 urban-suburban (Front Range) corridor. This information will be used to develop a population model and management plan for resident Canada geese along the Front Range. In this report I summarize banding, recapture, and recovery results.

STUDY AREA

The study area included the urban-suburban corridor along Interstate 25 in Adams, Arapahoe, Boulder, Denver, Douglas, El Paso, Jefferson, Larimer, Pueblo, and Weld counties in central Colorado. I initially divided the overall study area into 3 sub-areas: the Northern Front Range sub-area included Boulder, Larimer, and Weld counties; the Denver metropolitan sub-area included Adams, Arapahoe, Denver, Douglas, and Jefferson counties; and a Southern sub-area included El Paso and Pueblo counties. These 3 sub-areas were identified because of differences in variables that may influence local population dynamics of resident Canada geese, including landscape features, numbers and distribution of resident Canada geese, and hunting pressure. In addition, interchange of geese among these sub-areas, as well as movements to areas outside the overall study area, were of interest.

Canada goose hunting regulations differed among and within the 3 Front Range sub-areas and the remainder of the eastern plains of Colorado over the course of the study (Table 1). A Northern Front Range Zone was established prior to the study; in this zone, additional early season hunting days are available, that are not available in the remainder of the eastern plains. This zone was spatially expanded beginning with the 2006-07 hunting season, primarily to provide more early season hunting opportunity near the Denver metro area. During 2003-04 through 2005-06, a relatively restrictive season was in place in Pueblo County; these restrictions were eliminated beginning in 2006-07, and regulations in Pueblo County were the same as in the rest of the eastern plains.

METHODS

Canada geese were captured at 30-40 breeding and molting sites throughout the study area during June and July, 2003-2008. The Northern Front Range sub-area included banding sites in and near Boulder, Fort Collins, Greeley, Loveland, Longmont, and Windsor; the Denver sub-area included banding sites in and near Aurora, Denver, Englewood, Golden, Lakewood, and Wheatridge; and the Southern sub-area included banding sites in and near Colorado City, Colorado Springs, Fountain, and Pueblo. At most banding sites, kayaks were used to drive flightless geese from water bodies into net corrals on the shoreline. Captured geese were classified by age (adult or juvenile) and sex and fitted with standard, individually coded U.S. Geological Survey (USGS) aluminum legbands. Some adult geese were also fitted with plastic, individually coded green neckbands with white alpha-numeric codes. Captured geese were released at the capture site after processing.

Information on marked resident Canada geese was obtained from 3 sources: (1) recaptures of previously marked geese during annual banding operations, (2) hunter-reported recoveries of marked geese shot or found dead during hunting seasons, and (3) resightings of neckbanded geese throughout the year. Recapture data were collected during annual banding operations. Band recovery data were obtained from the USGS Bird Banding Laboratory. Neckbanded geese were observed during surveys of 94 randomly selected plots throughout the study area. Each year, plots were surveyed 3 times during April-May, and monthly during August-January. Additional observations of neckbanded geese were obtained from opportunistic sightings and reports by volunteer observers to the Bird Banding Laboratory.

Legband and neckband loss are important issues, because marker loss can have significant impacts on the estimation of parameters of interest (survival rates, harvest rates, etc.) unless rates of marker loss are estimated and accounted for in mark-recapture models (Nichols and Hines 1993, Coluccy et al. 2002). Geese that were marked with both legbands and neckbands provide an opportunity to estimate band loss. When these geese that were originally double-marked were recaptured in subsequent years, they were checked to see if they retained both marks or had lost either their neckband or legband (geese that lost both marks could not be identified).

RESULTS

During 2003-2008, 10,478 Canada geese were legbanded in the study area, including 4,190 in the Northern Front Range sub-area, 4,830 in the Denver Metro sub-area, and 1,458 in the Southern sub-area; 1,534 (19%) of the adult legbanded geese were also neckbanded (Table 2). No banding was conducted in the Southern sub-area in 2003. The total number of geese captured during trapping operations increased each year. The number of newly banded geese slowly declined after 2004, however, as recaptures comprised an increasing proportion of the total number of geese captured each year (Tables 2, 3).

Neckband loss was significant, and some loss of legbands also occurred (Table 4). During 2004-2008, we annually recaptured 156-232 geese that were originally double-marked with both legbands and neckbands. From 2.6% (2004) to 19.8% (2008) of these geese that still retained legbands had lost their neckbands when recaptured, and an additional 6.0% (2008) to 20.3% (2005) had cracked or broken neckbands. Annual observed legband loss in recaptured, double-marked geese that still retained their neckbands ranged from 0% (2005) to 4.5% (2004).

As of September 2009, 1,589 (15.2%) of the Canada geese banded along the Front Range during this study had been reported to the USGS Bird Banding Laboratory as shot during hunting seasons (Tables 5,6,7), including 681 direct recoveries (recovered during the first hunting season following banding) and 908 indirect recoveries (recovered during later hunting seasons). These recoveries included 14.7% of adult geese marked only with legbands, 16.8% of adult geese marked with both legbands and neckbands, and 15.3% of juvenile geese marked with legbands. Over 6 hunting seasons (2003-04 to 2008-09), a larger percentage of geese marked in the Northern Front Range sub-area (25.6%) were reported harvested than geese marked in the Denver Metro (7.3%) or Southern (10.5%) sub-areas (Table 8). Of geese marked in the Northern Front Range sub-area that were reported shot during hunting seasons, 95% were recovered in the Northern Front Range sub-area. Similarly, 91.5% of hunter recoveries of geese marked in the Southern sub-area occurred in the Southern sub-area. Geese marked in the Denver Metro sub-area were most likely to be harvested outside the sub-area; 51.8% and 8.2% of recoveries of Denver-banded geese occurred in the Northern Front Range and Southern sub-areas, respectively. Geese marked in the Denver Metro sub-area were also more likely to be harvested outside the overall study area (14.1% of recoveries). Most (95.6%) hunter recoveries were in the Central Flyway portion of Colorado, with most (79.7%) of these recoveries occurring in the Northern Front Range portion of the study area (Table 8).

Resident Canada geese were disproportionately harvested early and late during hunting seasons. Across all hunting seasons, 60% of recoveries of marked resident Canada geese occurred during

September-October and February, when 27% of the hunting season days occurred, whereas only 40% of recoveries occurred during November-January, when 73% of the hunting season days occurred (Table 9). This pattern contrasts to the temporal pattern of overall harvest of Canada geese (resident and migrant geese combined) in study area counties; only 24% of harvest occurred during September-October and February, and 76% of harvest occurred during November-January (Table 10).

An additional 45 banded geese have been reported to the USGS Bird Banding Laboratory as dead due to causes other than hunting, including being struck by a motor vehicle (20), found dead on a highway (13), killed by a dog or other animal (3), and unspecified injuries (9). An additional 42 geese were reported as found dead during hunting seasons, and 87 geese were found dead outside of hunting seasons.

DISCUSSION

Additional band recoveries are being incorporated into the data set, and recovery and recapture information will be used to estimate population size, survival, harvest, and fidelity rates during 2011. Plot surveys to resight neckbanded geese and estimate numbers of geese in the study area will continue through spring 2011. This information will be used to estimate demographic parameters and examine seasonal movements of Canada geese along the Front Range. A population model will be developed for Front Range resident Canada geese. After all results are analyzed during 2011, manuscripts will be prepared and submitted for publication. Results of this study will be used to develop recommendations for future management of Front Range Canada geese.

ACKNOWLEDGMENTS

Valuable assistance with field work and data management was provided by Craig Garner, Mike Grooms, Lacrecia Johnson, Emma Kaiser, Susan Kelsall, Matt Reddy, Matt Schenk, Melanie Spies, Tanner Weisgerber, and Stacy Wolff. CDOW personnel and volunteers provided valuable assistance with annual trapping and marking of geese, and their contributions were critical to the success of this project. I thank municipal parks managers and private landowners for providing access to banding sites. This study was reviewed and approved by the CDOW Animal Care and Use Committee.

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Table 1. Dark goose hunting regulations along the Front Range and eastern plains of Colorado during this study. During 2003-04 through 2005-06, the Northern Front Range Zone included all areas in Adams, Boulder, Clear Creek, Denver, Gilpin, Jefferson, Larimer and Weld counties bounded on the north by the Colorado-Wyoming state line, on the east by Interstate 25, on the south by Interstate 70, and on the west by the Continental Divide and the Lariner-Jackson county line. During 2006-07 through 2008-09, the zone was expanded to include Boulder, Larimer and Weld counties from the Continental Divide east along the Wyoming border to Highway 85, south on Highway 85 to the Adams County line, and all lands in Adams, Arapahoe, Broomfield, Clear Creek, Denver, Douglas, Gilpin, and Jefferson counties. The remainder of the eastern plains included all lands east of the Continental Divide, except North Park, South Park, the San Luis Valley, Pueblo County, and the Northern Front Range zones.

	Northern Front Range Zone			Pueblo County Zone			Remainder of Eastern Plains		
Hunting season	Season dates	Days	Bag limit	Season dates	Days	Bag limit	Season dates	Days	Bag limit
2003-04	Oct 4–12 & Nov 15–Feb 8	95	3	Dec 6–Feb 8	65	2	Nov 15–Feb 8	86	3
2004-05	Oct 2–10 & Nov 20–Feb 13	95	3	Dec 4–Feb 13	72	2	Nov 20–Feb 13	86	3
2005-06	Oct 1–9 & Nov 19–Feb 12	95	3	Dec 3–Feb 12	72	3	Nov 19–Feb 12	86	3
2006-07	Sep 30–Oct 8 & Nov 25–Feb 18	95	3	Zone eliminated; same regulations as Remainder of Eastern Plains			Nov 25–Feb 18	86	3
2007-08	Sep 29–Oct 8 & Nov 17–Feb 17	103	4				Nov 17–Feb 17	93	4
2008-09	Oct 4–15 & Nov 15–Feb 15	105	4				Nov 15–Feb 15	93	4

Table 2. Summary of Canada goose bandings and recaptures along the Front Range during 2003-2008.

	Year						
	2003	2004	2005	2006	2007	2008	Total
BANDED SAMPLE							
Neckbanded/Legbanded Adults							
Northern Front Range	191	136	108	124	68	35	662
Denver Metro	166	96	136	134	69	54	655
Colorado Springs/Pueblo	-	21	42	65	64	25	217
Subtotal	357	253	286	323	201	114	1,534
Legband Only Adults							
Northern Front Range	439	579	519	226	315	223	2,301
Denver Metro	823	694	325	310	498	587	3,237
Colorado Springs/Pueblo	-	51	135	447	230	171	1,034
Subtotal	1,262	1,324	979	983	1,043	981	6,572
Legbanded Juveniles							
Northern Front Range	193	221	249	160	198	206	1,227
Denver Metro	74	239	138	161	162	164	938
Colorado Springs/Pueblo	-	40	17	43	59	48	207
Subtotal	267	500	404	364	419	418	2,372
Total Banded	1,886	2,077	1,669	1,670	1,663	1,513	10,478
RECAPTURES							
Neckbanded/Legbanded Adults							
Northern Front Range	-	74	73	64	76	63	350
Denver Metro	-	82	84	109	125	149	549
Colorado Springs/Pueblo	-	0	15	29	41	45	130
Subtotal	-	156	172	202	242	257	1,029
Legband Only Adults							
Northern Front Range	-	191	370	378	340	291	1,570
Denver Metro	-	377	637	639	671	962	3,286
Colorado Springs/Pueblo	-	0	47	100	316	273	736
Subtotal	-	568	1,054	1,117	1,327	1,526	5,592
Total Recaptured	-	724	1,226	1,319	1,569	1,783	6,621
Total Geese Captured	1,886	2,801	2,895	2,989	3,232	3,296	17,099

Table 3. Summary of recaptures by year of banding, for Canada geese banded along the Front Range.

Year of banding	Number banded	Year of recapture				
		2004	2005	2006	2007	2008
2003	1,886	724	556	353	282	240
2004	2,077	-	670	478	378	350
2005	1,669	-	-	488	329	229
2006	1,670	-	-	-	580	389
2007	1,663	-	-	-	-	575

Table 4. Observed legband and neckband loss for Canada geese marked with both legbands and neckbands and recaptured along the Front Range.

	Year of recapture				
	2004	2005	2006	2007	2008
Number of double-marked geese recaptured[1]					
Year banded: 2003	156	108	66	50	36
2004	-	74	52	33	32
2005	-	-	84	50	37
2006	-	-	-	97	62
2007	-	-	-	-	65
Total	156	182	202	230	232
Number with missing neckband (%)					
Year banded: 2003	4 (2.6)	9 (8.3)	12 (18.2)	6 (12.0)	6 (16.7)
2004	-	3 (4.1)	7 (13.5)	5 (15.2)	9 (28.1)
2005	-	-	7 (8.3)	2 (4.0)	8 (21.6)
2006	-	-	-	6 (6.2)	14 (22.6)
2007	-	-	-	-	9 (13.8)
Total	4 (2.6)	12 (6.6)	26 (12.9)	19 (8.3)	46 (19.8)
Number with cracked/broken neckband (%)					
Year banded: 2003	15 (9.6)	27 (25.0)	5 (7.6)	7 (14.0)	2 (5.6)
2004	-	10 (13.5)	5 (9.6)	4 (12.1)	1 (3.1)
2005	-	-	6 (7.1)	7 (14.0)	3 (8.1)
2006	-	-	-	12 (12.4)	5 (8.1)
2007	-	-	-	-	3 (4.6)
Total	15 (9.6)	37 (20.3)	16 (7.9)	30 (13.0)	14 (6.0)
Number with missing legband (%)					
Year banded: 2003	7 (4.5)	-	-	3 (6.0)	1 (2.8)
2004	-	-	-	1 (3.0)	-
2005	-	-	1 (1.2)	2 (4.0)	-
2006	-	-	-	-	1 (1.6)
2007	-	-	-	-	1 (1.5)
Total	7 (4.5)	0 (0.0)	1 (0.5)	6 (2.6)	3 (1.3)

[1] Does not include geese that had already lost their neckband in a previous year.

Table 5. Summary of reported hunter recoveries by year of banding, for adult Canada geese marked with legbands, along the Front Range.

		Hunting season of recovery						
Year of banding	Number banded	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	Total
2003	1,262	28	56	43	24	15	14	180
2004	1,324	-	102	67	52	28	27	276
2005	979	-	-	83	58	34	18	193
2006	983	-	-	-	49	38	43	130
2007	1,043	-	-	-	-	55	52	107
2008	981	-	-	-	-	-	82	82
Total	6,572	28	158	193	183	170	236	968

Table 6. Summary of reported hunter recoveries by year of banding, for adult Canada geese marked with both legbands and neckbands, along the Front Range.

		Hunting season of recovery						
Year of banding	Number banded	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	Total
2003	357	18	16	9	2	1	0	46
2004	253	-	34	6	6	7	4	57
2005	286	-	-	29	24	7	5	65
2006	323	-	-	-	16	13	13	42
2007	201	-	-	-	-	21	15	36
2008	114	-	-	-	-	-	11	11
Total	1,534	18	50	44	48	49	48	257

Table 7. Summary of reported hunter recoveries by year of banding, for juvenile Canada geese marked with legbands, along the Front Range.

		Hunting season of recovery						
Year of banding	Number banded	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	Total
2003	267	16	21	5	5	1	2	50
2004	500	-	33	21	13	7	10	84
2005	404	-	-	29	27	14	16	86
2006	364	-	-	-	30	23	16	69
2007	419	-	-	-	-	18	30	48
2008	418	-	-	-	-	-	27	27
Total	2,372	16	54	55	75	63	101	364

Table 8. Location of harvest for Canada geese marked along the Front Range of Colorado during June, 2003-2008, and reported as shot by hunters during the 2003-04 through 2008-09 goose seasons (direct and indirect recoveries combined).

	Area of banding							
	Northern Front Range		Denver Metro		Southern		Total	
Area of harvest	N[1]	%[2]	N	%	N	%	N	%
Colorado								
Northern Front Range	1,017	95.0	183	51.8	1	0.7	1,201	76.2
Denver Metro	20	1.9	80	22.7			100	6.3
Colorado Springs/Pueblo	7	0.6	29	8.2	140	91.5	176	11.2
Northeast	2	0.2	8	2.3	2	1.3	12	0.8
Southeast	4	0.4	1	0.3	7	4.6	11	0.7
San Luis Valley	2	0.2	1	0.3	2	1.3	5	0.3
South Park	1	0.1	1	0.3			2	0.1
Western Colorado[3]	4	0.4	33	9.3			37	2.3
Alberta	2	0.2	1	0.3			3	0.2
Connecticut	2	0.2					2	0.1
Iowa			1	0.3			1	0.1
Kansas			2	0.6			1	0.1
Louisiana			1	0.3			1	0.1
Montana			1	0.3	1	0.7	2	0.1
Nebraska	2	0.2	1	0.3			3	0.2
New Mexico	3	0.3	3	0.8			5	0.3
New York			2	0.6			2	0.1
Ontario	1	0.1					1	0.1
Oregon	1	0.1					1	0.1
Quebec			1	0.3			1	0.1
Texas			4	1.1			4	0.3
Wyoming	3	0.3					3	0.2
Total recoveries	1,071	100.0	353	100.1	153	100.1	1,577	100.0
Total banded sample	4,190		4,830		1,458		10,478	

[1] Number of band recoveries.
[2] Percentage of total band recoveries for the area of banding considered.
[3] Pacific Flyway portion of Colorado.

Table 9. Timing of annual harvest of Canada geese marked along the Front Range of Colorado during June, 2003-2008, and harvested in study area counties (Adams, Arapahoe, Boulder, Denver, Douglas, Elbert, El Paso, Jefferson, Larimer, Pueblo, Weld).

	Hunting season						
Period	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	Total
September/October[1]							
Hunting days[2]	11 (11%)	11 (11%)	11 (11%)	11 (11%)	12 (11%)	14 (13%)	70 (12%)
Reported harvest	13 (23%)	83 (34%)	90 (31%)	89 (32%)	77 (29%)	54 (16%)	406 (27%)
November/December							
Hunting days	40 (41%)	42 (43%)	43 (44%)	37 (38%)	45 (43%)	47 (44%)	254 (42%)
Reported harvest	13 (23%)	29 (12%)	42 (15%)	59 (21%)	67 (25%)	68 (20%)	278 (19%)
January							
Hunting days	31 (32%)	31 (32%)	31 (32%)	31 (32%)	31 (32%)	31 (29%)	186 (31%)
Reported harvest	18 (32%)	52 (21%)	50 (19%)	59 (22%)	44 (17%)	76 (23%)	299 (20%)
February							
Hunting days	15 (15%)	13 (13%)	12 (12%)	18 (19%)	17 (16%)	15 (14%)	90 (15%)
Reported harvest	12 (21%)	81 (33%)	105 (35%)	77 (26%)	77 (29%)	134 (40%)	486 (33%)
Total hunting days	97	97	97	97	105	107	600
Total harvest	56	245	304	284	265	332	1,486

[1] Includes youth waterfowl weekend and Northern Front Range zone (zone includes portions of the Northern Front Range and Denver portions of the study area).
[2] Number of days in the period when the dark goose hunting season was open.

Table 10. Timing of annual harvest of all Canada geese (including resident and migrant geese) in study area counties (Adams, Arapahoe, Boulder, Denver, Douglas, El Paso, Jefferson, Larimer, Pueblo, Weld) during the 2003-2008 hunting seasons in Colorado.

	Hunting season						
Period	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	Total
September/October[1]							
Hunting days[2]	11	11	11	11	12	14	70
	(11%)	(11%)	(11%)	(11%)	(11%)	(13%)	(12%)
Harvest estimate[3]	965	242	1,000	886	-	-	3,093
	(2%)	(1%)	(2%)	(2%)			(2%)
November/December							
Hunting days	40	42	43	37	45	47	254
	(41%)	(43%)	(44%)	(38%)	(43%)	(44%)	(42%)
Harvest estimate	21,610	8,231	19,996	26,100	-	-	75,937
	(33%)	(21%)	(39%)	(61%)			(38%)
January							
Hunting days	31	31	31	31	31	31	186
	(32%)	(32%)	(32%)	(32%)	(32%)	(29%)	(31%)
Harvest estimate	31,451	19,125	16,664	8,489	-	-	75,729
	(48%)	(49%)	(33%)	(20%)			(38%)
February							
Hunting days	15	13	12	18	17	15	90
	(15%)	(13%)	(12%)	(19%)	(16%)	(14%)	(15%)
Harvest estimate	11,384	11,136	12,998	7,349	-	-	42,867
	(17%)	(29%)	(26%)	(17%)			(22%)
Total hunting days	97	97	97	97	105	107	600
Total harvest	65,409	38,734	50,660	42,823	-	-	197,626

[1] Includes youth waterfowl weekend and Northern Front Range zone (zone does not include entire Central Flyway portion of Colorado).
[2] Number of days in the period when the dark goose hunting season was open.
[3] Harvest estimates obtained from U.S. Fish and Wildlife Service harvest surveys; harvest estimates for 2007-08 and 2008-09 were not available at the time of this report.