AVIAN PROGRAM

SEPTEMBER 2011

WILDLIFE RESEARCH REPORT

WILDLIFE RESEARCH REPORTS

SEPTEMBER 2011

AVIAN RESEARCH PROGRAM

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

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Colorado Division of Parks and Wildlife

September 2011

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COLORADO PARKS AND WILDLIFE - AVIAN RESEARCH PROGRAM
PROGRESS REPORT
September 2011

TITLE: Demography and dispersal of Gunnison sage-grouse

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Period Covered: August 1, 2010 - August 31, 2011

ABSTRACT

In 2005, the Colorado Division of Wildlife (currently Colorado Parks and Wildlife, CPW) initiated a research project to evaluate the demography and movement patterns in two Gunnison sage-grouse (*Centrocercus minimus*, 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 (2005). 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 have 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 summarizes the final year of field work on this project and the initial stages of data analysis.

DEMOGRAPHY AND DISPERSAL OF GUNNISON SAGE-GROUSE
Progress Report, August 1, 2010 - August 31, 2011
Michael L. Phillips

PROJECT OBJECTIVES

1. Acquire current estimates of demographic rates (nest success, juvenile survival, and adult survival) and estimates of variation (temporal and spatial) for 2 populations of GUSG.

2. Model nest survival using nest-site vegetation structure and various spatial and temporal factors (e.g., time of nest initiation, nest age, and population) as covariates.

3. Model juvenile, yearling and adult survival using life history and various spatial and temporal factors as covariates (e.g., age, sex, time of year, population and area within a population).

4. Record movement patterns of GUSG and use the information to develop landscape use, movement models and spatial models of demographic parameters.

5. Use the above estimates to update and refine a population viability analysis (PVA) developed for the GUSG Rangewide Conservation Plan (Gunnison Sage-grouse Rangewide Steering Committee, 2005) and to develop a spatially-explicit population model (SEPM) specific to GUSG.

6. Use estimates of demographic parameters and model output to develop and evaluate the projected consequences of alternative management plans.

SEGMENT OBJECTIVES

1. Complete final season of field work: a) record radiotelemetry locations every 1-3 days to determine movement patterns (August-September 2010), b) replace transmitters on juveniles, yearlings and adults as needed (September 2010), and c) record radiotelemetry locations approximately once a month during October 2010 - May 2011 to record movements and survival of adult and juvenile GUSG.

2. Compile and error check telemetry data in preparation for development of landscape use, movement models and spatial models of demographic parameters.

3. Compile and error check nest and nest-site vegetation data in preparation for analysis of nest survival.

4. Compile and error check juvenile, yearling and adult survival in preparation of survival analyses, update of a PVA model, and development of a SEPM for GUSG.

INTRODUCTION

Our ability to conserve Gunnison sage-grouse (*Centrocercus minimus*, GUSG) will depend on our ability to restore and manage a biologically relevant mosaic of habitats. Population viability analysis (PVA) and spatially explicit population models (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 landscape features 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 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 has been documented (Apa 2004).

This study will lead to a refinement of a PVA developed for the Gunnison Sage-grouse Rangewide Conservation Plan (GUSG RCP, 2005) and the development of 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 more current GUSG demographic data, 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.

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).

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 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

All trapping and handling procedure followed the CPW Sage-grouse Trapping and Handling Protocol previously approved by the Animal Care and Use Committee. 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, National Brand and Tag Company) 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.

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 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 CPW 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 or ruffed grouse. Juveniles were handled as quickly as possible to minimize stress. The brood was released where they were originally captured. We estimated a 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 CPW 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 (Dalke et al. 1963, 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 1-3 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 shrub height and canopy cover were determined using line-intercept (Canfield 1941). Shrub species was separated into 3 categories: *Artemisia tridentata* spp., other sagebrush species and non-sagebrush shrubs (e.g., antelope bitterbrush). Total shrub cover included all 3 categories. 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 at 5 m intervals 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 (Daubenmire 1959).

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 use nest survival models (Dinsmore et al. 2002) in Program MARK (White and Burhnam 1999) to estimate rates of daily nest survival and examine the relationship between nest success and vegetation and temporal covariates. We will calculate adult and yearling monthly and annual survival using known fate models in Program MARK (White and Burhnam 1999). We will calculate daily chick survival for chicks up to 30 days old also using known fate models in Program MARK (White and Burhnam 1999). If there is significant movement 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).

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

During the spring of 2010 (March-May 2010), we tracked 63 birds (5 males and 58 females), including individuals radio-marked in previous field seasons. 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 (42.6%). Twenty-six were destroyed by predation and one was abandoned. Half of the yearling nests hatched (3/6), while 41.5% of the adult nests hatched (17/41). Twenty-three adult nests were destroyed by predation and one was abandoned. We radiomarked 51 chicks from the 20 nests that hatched. Four chicks were radiomarked for a CPW captive breeding research project. However, the chicks were not incorporated into the captive breeding project so they were added to the demography and dispersal project, bringing the total number of chicks to 55. By September 2010, 16.4% (9/55) of the chicks were confirmed alive, 60.0% (33/55) were confirmed mortalities and the remaining 23.6% (13/55) were missing. These estimates are consistent with trends in previous field seasons (Fig.1). Through August 2011, 5.5% (3/55) GUSG radiomarked as chicks in 2010 were confirmed still alive.

Since 2005, we radiomarked 167 females, 33 males and 215 juveniles (not including missing individuals) and monitored 210 nests in the Gunnison Basin population. We have not observed dispersal movements among radiomarked individuals (i.e., movements beyond the population distribution). However, individuals in the Gunnison Basin exhibit considerable variation in the distances traveled. For example, the amount of area used by females with broods can vary from 0.6-14.1 mi^2 ($\bar{y}$ = 6.1 ± 4.2). We observed relatively long distance movements within the Gunnison Basin. For example, in 2010 we trapped and marked a female in the northwest section of Gunnison Basin. She spent the breeding season very close to where she was captured. She successfully hatched a brood, but it was lost to predation a few weeks after hatch. The following winter, she was found in the southeast corner of the Basin, > 35 miles from where she spent the breeding season. She returned to the same area the following spring.

San Miguel

During the 2010 field season 8 female and 4 male GUSG were tracked in San Miguel population. Nineteen males were counted on leks near the Miramonte Reservoir. Therefore, our sample represented approximately 15% of the GUSG in this portion of the San Miguel population. We observed 4 mortalities (2 females and 2 males) from February - May 2010. This is above average adult mortality for this time period. Normal mortality is 10-20%. Four of the remaining 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.

Since 2007, we have radiomarked 11 females, 15 males and 8 juveniles. We monitored 20 nests (6 of these were renesting attempts). Individuals in the Miramonte segment of the San Miguel population did not exhibit any long-distance movements. All remained within 1-2 miles of the Miramonte Reservoir. Nest success has been low (4/20 nests hatched). Of the 8 juveniles that hatched, all were taken by predators within 10 days (i.e., we did not observe any juvenile recruitment). Adult survival has been variable over time, but has been relatively low for sage-grouse (ranging from 55-70%). Most mortalities were due to predation.

This illustrates that predation is a problem in the Miramonte area. In March 2011, the CPW initiated a predator control project. We contracted with Wildlife Services (USDA) to eradicate as many predators as possible from this segment of the San Miguel population. The project is being supervised by CPW Biologists, Jim Garner and Brad Banulis (Area 18, Montrose, CO). They radiomarked 5 females in 2011. Three nests were destroyed by predation. The other 2 nests hatched. The first brood had 5 chicks and the second brood had 6 chicks. They radiomarked 2 chicks from the first brood and 3 chicks in the second brood. The 2 radiomarked chicks in the first brood were killed by predators. The 3 chicks in the second brood are still alive. A second season of predator control is planned for 2012. CPW biologists will evaluate the project and determine future plans after the 2012 field season.

SUMMARY

We have completed 6 field seasons of data collection in the Gunnison Basin (including 1 year of pilot data and 1 year of baseline data) and 4 field seasons of data collection in the San Miguel population. The demographic parameters recorded in the Gunnison Basin during 2010-2011 were consistent with previous field seasons. The increased mortality during the winter of 2007-2008 is the exception. In the San Miguel population we observed 4 mortalities out of 20 GUSG being tracked during the winter of 2007-2008 (8 near the Miramonte Reservoir area and 12 in Dry Creek Basin). Three of the mortalities were in the Miramonte Reservoir area and 1 was in Dry Creek Basin. This illustrates the potential for significant spatial variation in demographic rates that have not been previously documented for GUSG. Juvenile survival also exhibits similar general pattern across years with the majority of mortality occurring within the first 6-8 weeks after hatch (Fig. 1, Table 1).

The impact of predation in the San Miguel population is of concern. Low nest success and no juvenile recruitment among radiomarked juveniles are reflected in the declining lek counts since 2006. The lek counts are at the threshold of 25% of the target population goal (pp. 134 ff and 243 ff) that warrants an evaluation of predator control (see also Research, Objective #4, p. 250). A predator control project is being conducted for the Miramonte segment of the San Miguel population.

Future Plans

Data collection was completed in May 2011. While intensive ground radiotelemetry was completed in September 2010, monthly radiotelemetry locations were recorded throughout the winter and spring of 2011. In 2009, Amy Davis joined the project as a graduate student at Colorado State University

(CSU) under the mentorship of Dr. Paul Doherty. Amy successfully completed her candidacy exam at CSU in the fall of 2010. Phillip Street completed his work on the project as a Research Associate with CSU. The schedule for the remainder of the study is as follows:

2011: Construct and test nest survival model using nest-site vegetation as covariates.
Construct and test models of juvenile, yearling and adult survival.
Construct and test preliminary landscape use models.
Construct and test preliminary PVA and SEPM models; create and validate GIS database.

2012: Refine and finalize landscape use models.
Refine and finalize PVA and SEPM models.
Write final reports and management recommendations.
Prepare and submit manuscripts for publication.
Amy Davis defends her doctoral dissertation.

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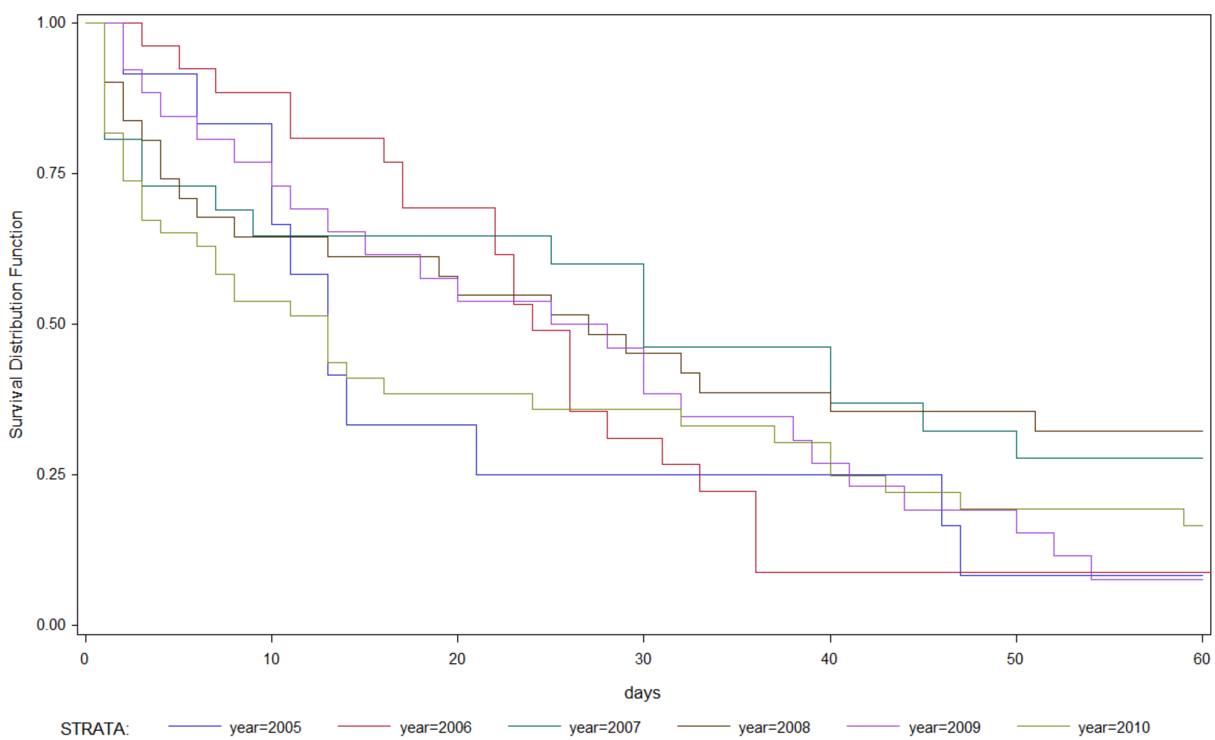
Table 1. Comparison of juvenile survival rates in the Gunnison Basin in 2005-2010.

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

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



COLORADO PARKS AND WILDLIFE- AVIAN RESEARCH PROGRAM
Progress Report
September 2011

TITLE: Gunnison sage-grouse captive-rearing

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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. Department of Agraiculture 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 Parks and Wildlife (CPW) 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 CPW 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. Fourteen females were captured in the Gunnison Basin. They were added to 36 previously marked females and were available for egg collection and to serve as potential surrogate for domestically-reared chicks. Forty-seven of 50 females (94.0%) initiated a nest. The 3 females who did not initiate a nest died before a nest was detected (20 April, 27 April, and 5 May). Eggs were collected from 14 females. Five of the 8 females that had eggs collected during laying, successfully hatched (62.5%). All of the 6 females who were forced to abandon, initiated a renest and 3 of the 6 hatched successfully (50.0%). Excluding females forced to abandon for egg collection purposes (n=6), 62.5% (25/40) initial and 50.0% (5/10) of the renests were successful. Thirty-seven eggs were collected from 5 incubating females, and 38 eggs were collected from 9 laying females. Thirty-two eggs were collected from 5 captive-reared females. All eggs laid were collected, and no females were allowed to incubate. Seventy-one of 107 eggs artificially incubated hatched (66.4%). Of the 36 eggs that did not hatch, 14 were infertile, and 4 were malpositioned (head down, away from air cell). If those eggs are censored from the

analysis, our hatch success of viable eggs is 79.8% (71/89). Chick survival appeared to be higher in 2011. Fifty-two of 71 chicks that hatched successful survived to introduction (73.2%). Fifteen wild broods were augmented with 51 captive-reared chicks over 19 separate introductions. Overall adoption success (defined as successful if the chick is with the surrogate brood 24-36 hours post-introduction) was 35.3% (*n* = 18/51). Within Treatment I (7-days), our adoption success was 60% (15/25), although 1 chick was lost due to exposure, and 2 surrogate broods, including 7 domestic chicks were depredated within 24 hours of release, accounting for most of our failed adoptions. Apparent survival of the domestically reared chicks was 0% (0/39). Four of the 51 chicks were censored from the analysis after the transmitters fell off. Eight of the remaining 47 were missing and their fate is unknown.

GUNNISON SAGE-GROUSE CAPTIVE-REARING
Progress Report, April 1, 2010 – August 31, 2011
L. A. Wiechman, A. D. Apa, and M. L. Phillips

PROJECT OBJECTIVES

1. Evaluate various husbandry techniques and develop protocols for hatching and maintaining juvenile and adult GUSG in captivity.
2. Compare 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. Further develop captive breeding techniques for adult and chick 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- (2010-11), 3- (2010 only), 5- (2010-11), and 7- (2010 only) weeks of age.

INTRODUCTION

Gunnison sage-grouse (*Centrocercus minimus;* GUSG) 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 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 several of the small populations. 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. The Pinyon Mesa and Dove Creek populations have received 40-50 birds each. Transplants are planned for the Crawford and Monticello, Utah populations. 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 CPW 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. Department of Agriculture 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 CPW 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 CPW 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 AREA

Our study occurred in two areas, the Gunnison Basin (GB) and in Fort Collins (FTC), Colorado. GB is an intermontane basin that includes parts of Gunnison and Saguache Counties, Colorado. FTC is located in Larimer County, Colorado. In 2010, the study was allocated to the Kezar Basin/Sapinero Mesa (KBSM) areas on the western edge of the Gunnison Basin. The KBSM site provided for the capture of surrogate females and broods while we used females captured in other areas of the GB for collecting eggs. In 2011, our study was conducted across the GB in 8 study sites: Sapinero Mesa (SM), Kezar Basin (KB), South Beaver (SB), Chance Gulch (CG), South Parlin/Razor Dome (SP), North Parlin (NP), Flat Top Mountain (FT), and the Ohio Creek area (OC). Elevation ranged from 2,290 to 2,900 m.

Grouse were hatched in a newly constructed incubation building that provides egg storage, incubation, and hatching (Fig. 1A) and raised at the CPW Foothills Wildlife Research Facility (FWRF) in FTC and moved to the NWRC in FTC and raised to an introduction treatment age. All captive grouse were held in aviaries at the NWRC. The aviary, as described in Oesterle et al. (2005) is 38 x 19 x 4-14 m in size. Both ends are bounded by a 4-m high chain link fence. To prevent the risk of being severely injured or killed (if grouse flew into the fence), a 3.2 cm mesh knotless nylon net was placed in front of the chain link fence that ran from the ceiling to the ground. Eight wood shelters (0.6 x 0.6 x 0.46 m) where distributed throughout the aviary to provide additional cover.

METHODS

Our methods for husbandry of eggs and chicks followed techniques already established in previous CPW 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 CPW, the University of Idaho and Colorado State University Animal Care and Use Committees (ACUC): Huwer (CSU ACUC # 02-023A-01; Thompson et al (U. Idaho ACUC # 2005-45). This current project received CPW ACUC approval (ACUC #03-2009) and ACUC review and approved from the NWRC (# QA-1625).

This is a 3-year project. The first year focused on raising chicks and maintaining them in captivity through their first year. In the second and third years we expanded our focus to include the introduction of captive-reared chicks to surrogate brooding females and assessing mating behavior and breeding effort and success in captivity.

Captive Breeding

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 documented in the GB, 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 captive GUSG 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 all captive females were laying eggs, females were no longer allowed access to males. The males were released into the larger male aviary following the cessation of breeding activity.

Surrogate Female Capture

Female GUSG were captured in GB using the spot-lighting technique and long-handle hoop nets (Giesen et al. 1982, Wakkinen et al. 1994). 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 scale. 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, National Brand and Tag Company) was attached to a leg for individual identification. The females were released at the point of capture. All trapping and handling procedure followed the CPW Sage-grouse Trapping and Handling Protocol previously approved by the CPW ACUC. Birds were released by placing them under a sagebrush or in adjacent cover.

Nest Monitoring

GB – We monitored radio-marked female movements and nesting activity every 1 – 2 days between the hours of 0700 and 1200. 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 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 3-7 days. Following incubation activity, we ascertained nest fate.

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.

NWRC – In 2010, we ascertained whether captive females would initiate and incubate a nest by monitoring 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 Production/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 - In 2010, 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. In 2011, all eggs were collected and marked. Eggs were transported to the CPW FWRF where they were stored in a cooler at 10-15° C (50^{o}-60^{o} 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.

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 CPW FRWF in Fort Collins. The eggs were stored in a cooler at 10-15° C (50^{o}-60^{o} F) and turned twice/day (Harvey 1993).

Incubators and hatchers were set up at the CPW FWRF and CPW 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 to Fort Collins CPW FWRF in a temporary incubator (maintained at 35-37.5° C; GQF Manufacturing; Foam Hova-Bator) and immediately transferred to an incubator at the CPW 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.

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.

Chick Husbandry

At 7 days of age, chicks were moved to an aviary at the NWRC. Within the aviary, the chicks were housed in a smaller artificial brood-rearing pen. We provided three artificial brood-rearing pens. The artificial brood-rearing pen consisted of an enclosed "coop" and outdoor pen (Fig. 5). The enclosed coop was factory manufactured and 1 x 1 x 1.2 m in size. Chicks could move freely from the coop to the outside pen. The coop was equipped with additional heat from heat lamps and herptile heating pads. The coop was maintained at a constant temperature (37 º C) during day and night. The chicks were confined in the coop from sunset to sunrise or during inclement weather. Otherwise, the chicks were allowed free access between the two facilities.

The artificial brood-rearing pen also consisted of an outside fenced area. The 1.8 x 1.8 m outside pen was enclosed with 0.6 – 1.2 m tall 1.3 cm mesh wire fencing. Additional heat was provided in the outside pen (e.g. heat lamp). Over the next 21 days, the outdoor pen was gradually enlarged (2-3 times larger) to provide additional space. Additional space was provided to habituate grouse with ever-increasing space to explore and feed. The entire pens were moved to unsoiled ground approximately every 2 weeks to avoid unsanitary conditions due to feces accumulation. The bottom of the coop and feeding dishes were washed and sanitized daily.

Due to the presence of West Nile Virus (WNv) in Larimer County (Colorado Department of Public Health 2009) and the documented risk to greater sage-grouse (Walker 2008), precautions were taken to protect GUSG from infection. Three levels of protection were provided to the grouse. The first level was standing water treatment by the NWRC. The NWRC staff regularly treated standing water with *Bacillus thuringiensis* (BTI). The second precaution taken was with a mosquito trap with attractant (Mosquito Magnet®) that provided levels of protection up to a 60 m radius from the trap. The last and most direct effort to prevent exposure of the captive-reared GUSG to WNv was complete protection through the use of a mosquito proof enclosure (Fig. 5). Grouse occupied the enclosure (11 x 4 x 2 m) from late-June until the chicks were transported to Gunnison for release. The enclosure provided for complete confinement during dusk, dawn and the night while providing for limited access during the times of the day when mosquitoes are less active. The enclosure was constructed of a PVC plastic pipe frame covered by black mosquito netting fabric (42 holes/cm²).

Chicks were provided a diet of invertebrates of various ages/sizes; house crickets (*Achela domesticus*), mealworms (*Tenebrio* spp.), flightless less fruit flies (*Drosphila melanogaster or D. hydei*), waxworms (larval stage of the Phralidae family of moths), 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 GB. 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. However, in 2011, we constructed a temporary hoop barn similar to the one in Fig 5, on CPW land at Miller's Ranch. Chicks we transported to GB the same way as 2010, but chicks were given 8-32 hours to rest in the hoop barn prior to release. We provided food (sage and crickets), water, and shelter in the hoop barn, similar to what was provided in FTC.

Success is defined in 2 phases: adoption and introduction. "Adoption success" is defined as the immediate outcome of the introduction attempt. An adoption will be determined as successful if the introduced chicks are with the surrogate female or another female within 24 hours. If any released chicks are not with the surrogate female, the introduction will be designated as 'failed' and decisions will be made whether to take action and recapture the chicks, and attempt the introduction again, or to allow the chicks more time to find a surrogate brood or flock. We will monitor for "introduction success" by measuring the survival of the release.

We used 4 treatment levels in 2010, but concluded that the sample sizes were inadequate for evaluating potential differences. In 2011, only Treatments I and III were 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. 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.

Fall Capture and Release in Captivity

Two male GUSG were captured using the spot-lighting technique and long-handle hoop nets (Giesen et al. 1982, Wakkinen et al. 1994). Males and females were trapped in the Gunnison Basin population. Fall trapping was conducted in October. Adult grouse were placed in a small animal crate (60 x 40 x 30 cm) with padding on the floor to provide more secure footing. Grouse were transported to the Fort Collins NWRC facility the morning after capture. We used a soft-release method. The door was opened and the grouse moved from the transport crate under their own volition into a slightly modified aviary as describe by Oesterle et al. (2005).

Nursery grown potted big sagebrush (*Artemisia tridentata spp.*) and black sagebrush (*A. nova*) were planted or placed throughout the aviary to provide native food and cover. Additional Wyoming big sagebrush (*A. t. wyomingensis*) was harvested from native stands for additional food and cover. A seed mix consisting of western yarrow (*Achillea millefolium*), Utah northern sweetvetch (*Hedysarium boreale*), maximilian sunflower (*Helianthus maximiliani*), mountain lupine (*Lupinus argenteus*), alfalfa (*Medicago sativa*), white sweetclover (*Melilotus alba*), and Great Basin wildflower mix (Table 1) was planted in the aviary to provide fall and spring forbs for food. GUSG were presented dietary items *ad libitum*. Food items made available included Purina Mills Gamebird Chow® (maintenance diet), superworms (*Zophobas morio*), and potted and wild grown big and black sagebrush. Water was provided and supplemented with Vita-Max (Table 2).

Winter Flock 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 shelter to encourage refoliation in an attempt to reduce costs associated with the purchase of new plants.

RESULTS AND DISCUSSION

Captive Breeding

2010

Captive-reared males began to display in late-January and the wild males began to display in February. However, 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 3).

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 4). 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 5). In a couple of instances, females would enter the male aviary, and illustrate breeding "interest" (precopulatory postures) but not breed with the males. The wild female was observed in the male aviary but was never observed copulating (Table 3). 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.

2011

The wild male and captive-reared males began to display in March. However, we delayed breeding interaction with the females until 11 April to reflect lek and nesting activity observed in the GB. Five females were allowed access to the wild male and 1 captive-reared male for a total of 16 days between 11 April and 27 April for ≥ 1 hour each day ($\bar{x}$ = 66 minutes) (Table 6). The other 2 captive-reared males ("Pink" and "Orange") were separated and not permitted to breed. We observed the captive-reared male ("Red") as the dominant male prior to female interaction (Table 7).

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 8). In a couple of instances, females would enter the male aviary, and illustrate breeding "interest" (precopulatory postures) but not breed with the males.

Surrogate Female Capture

2010

Twenty-two females were captured and radio-marked in the KBSM. Trapping occurred over 12 trapping nights with 1–2 trapping crews. Adult female mass was 1,199 ± 34 ($\bar{x}$ ± SE) (n=8) was higher ($t_{2,12}$ = 2.18; P = 0.023) than yearling females at 1,097 ± 20 g (n=13) (Table 9). These females were available to become surrogate brood hens for the captive-rearing study.

2011

Fourteen females were captured and radio-marked in the GB. Captures occurred over 9 trapping nights with 1–2 trapping crews. Adult and yearling female mass was 1,293 ± 24 ($\bar{x}$ ± SE) (n=11) and 1,153 ± 31 g (n=3) (Table 10), respectively. Twelve of 14 radio-marked females (2 grouse left study area and were censored from any further analysis) were monitored for nesting and available as surrogate brood females. Those 12 grouse were added to 10 grouse from the 2010 season, as well as 28 radio-marked females captured from 2005–2010 for a separate study of GUSG demographics and movement patterns. All 50 radio-marked females were available for egg acquisition and surrogate broods.

Nest Monitoring
2010

GB – Three females (#0804, #0820, #0805) were monitored for egg collection. All three females established nests. Renesting was documented for 33% (n = 1/3) of the females. Female #0804 had an unsuccessful renesting attempt.

KBSM – Of the 22 grouse captured, 15 were available as surrogates (6 grouse left study area, 1 was depredated prior to documenting any nesting attempt). Thirteen of 15 females (86.7%) initiated nests (Table 11). Four of 13 females had successful (30.8%) 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.

NWRC – 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 12). 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 13). These chicks remained in the flight pens to be raised by the maternal females.

Each nest had logistical issues. Two females (#1199-09 and #1193-09) 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.

2011

GB – Female movements were monitored daily to establish nesting behavior. All females were monitored for egg collection. In 2011, 47 of 50 females (94.0%) initiated a nest (Table 14). The 3 females who did not initiate a nest died before a nest was detected (20 April, 27 April, and 5 May). Eggs were collected from 14 females. Nine of 14 females had eggs collected while laying (Table 14). Eggs were replaced with decoys and eggs left were marked inconspicuously, so we could determine the number of eggs laid after our collection. One of those 9 females was forced to depredate as she nested <5 m from the county road. The other 5 females were all incubating within the 1st seven days of incubation.

Five of the 8 females that had eggs collected during laying, successfully hatched (62.5%). All of the 6 females who were forced to abandon, initiated a renest and 3 of the 6 hatched successfully (50.0%). Excluding females forced to abandon for egg collection purposes (n=6), 62.5% (25/40) initial and 50.0% (5/10) of the renests were successful (Table 14).

Egg Production/Collection
2010

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 an incubating female (#0804), 6 eggs were collected from female #0805 during egg laying and 1 egg while she was incubating. The last 7 eggs were collected from female #0820 during incubation (Table 15). Eggs were transported to the CPW FWRF on 27 April, 29 April, and 7 May.

NWRC - Thirty-eight of 56 eggs laid were collected (Table 16). Overall, 59 eggs were collected and artificially incubated. A 60th egg was found, but 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 issues with existing eggs in the incubators.

2011

GB – Nesting behavior was documented on or about 21 April with incubation beginning approximately 24 April. Seventy-five GUSG eggs were collected from 14 females. All females were chosen opportunistically and all females were adults. Thirty-seven eggs were collected from 5 incubating females, and 38 eggs were collected from 9 laying females (Table 17).

NWRC - Thirty-two eggs were collected from 5 captive-reared females (Table 18). All eggs laid were collected, and no females were allowed to incubate.

Egg Storage and Incubation
2010

Mass of eggs collected from wild females (42.73 g ± 0.48; $\bar{x}$ ± SE) was heavier ($t = 2.02_{2,41}$; $P <$ 0.0000) than eggs collected from captive-reared females 39.81g ± 0.34. 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 g ± 0.14 while the percent mass loss for eggs collected in the wild was 11.11 g ± 0.31. The combined mean percent mass loss was 10.88 g ± 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 g ± 0.49 which was heavier ($t = 2.02_{2,40}$; $P = 0.0016$) than captive-produced chick mass which was 29.95 g ± 0.39. 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 g ± 0.37) and 2010 (32.07 g ± 0.49). 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 g ± 0.39).

2011

A more comprehensive and detailed explanation of egg mass loss is in progress and will be available in early 2012.

Egg Hatching

2010

Overall hatch success was 78% (*n* = 46/59) (Table 19). Hatching began on 22 May and continued through 17 June. 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). We defined eggs that were incubated within ≤ 7 days of being laid as being 'good' eggs and eggs incubated ≥ 8 days after being laid as 'bad' eggs. Hatch success for 'good' eggs was 82% (42/51) and 'bad' eggs was 50% (4/8). Of the 4 chicks that hatched, 2 had hatch deformities (crooked necks and splayed legs) and died shortly after hatch.

Thirteen eggs did not hatch. Two of the eggs appeared to be infertile without any vascular development, and development stopped early in incubation in 4 eggs. Two chicks were fully developed and malpositioned (head down, away from air cell), preventing successful pipping. Five embryos showed varying stages of development from early limb and eye development (~ 2 weeks) to almost complete development (25 days) with no draw-down from the inner membrane.

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 every day for the first 10 days (Table 20). After day 10, chicks were weighed opportunistically, and at day-14, -17, -21, -28, and -35 if possible (Fig. 1). Chicks were also weighed when they were transported to the GB for introduction.

2011

Overall hatch success was 66.4% (71/107) (Table 21). Of the 36 eggs that did not hatch, 14 were infertile, and 4 were malpositioned (head down, away from air cell). If those eggs are censored from the analysis, our hatch success of viable eggs is 79.8% (71/89). Eight eggs contained a "blood ring", a concentration of vascular development where development ceases around 4-7 days into development. Two eggs were pipped externally and after over 40 hours of movement, the chicks died before hatching completely. The causes of the other 8 failed hatches are either unknown or results are still pending. A more comprehensive and detailed explanation of hatch success is in progress and will be available in early 2012.

Chick Husbandry

2010

Initially, post-hatch mortality of chicks appeared to be relatively low (Table 22). 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 23). 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 nothing 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 24). On 27 May, Dr. Lisa Wolfe (CPW) 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 CPW 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 25). 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.

2011

Chick survival in captivity appeared to be higher in 2011. Fifty-two of 71 chicks that hatched successful survived to introduction (73.2%; Table 26). Two chicks hatched with a ruptured umbilicus causing their intestines to hemorrhage. One of the chicks was euthanized, while the other was surgically repaired but died 1 day later. Two chicks were euthanized due to a leg malformation that could not be corrected. Three chicks were euthanized. Two chicks died of trauma, and 6 chicks died due to problems associated with *Klebsiella spp*. bacteria. Two chicks died from complications related to bacteria, but not the yolk-associated *Klebsiella* as seen in most of the case. The causes of the other 6 chick mortalities are either unknown or pending histopathology results. A more comprehensive and detailed explanation of chick survival and cause of mortality is in progress and will be available in December, 2011.

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
2010

Three wild broods were augmented with 27 captive-reared chicks over 10 separate introductions (Table 27). Overall adoption rate (defined as successful if the chick is 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).

2011

Fifteen wild broods were augmented with 51 captive-reared chicks over 19 separate introductions. Overall adoption success (defined as successful if the chick is with the surrogate brood 24-36 hours post-introduction) was 35.3% (*n* = 18/51). Within Treatment I (7 days), our adoption success was 60% (15/25), although 1 chick was lost due to exposure, and 2 surrogate broods, including 7 domestic chicks were depredated within 24 hours of release, accounting for most of our failed adoptions. Our adoption success was lower within Treatment III with 11.5% (3/26).

To date, none of the 51 released chicks are confirmed to be still alive. Eight of the 51 chicks are missing and the fates of 4 chicks are unknown as their collars fell off.

Winter Flock Husbandry
2010

Thirteen grouse (8 F and 5 M) were kept and fed over the 2010-11 winter. Two wild adult males captured on 30 September 2010 were kept in a separate aviary during the fall and early winter. 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. Through the winter, a total of 390 big sagebrush plants (220 potted and 170 harvested) were fed to captive GUSG.

On 22 August, a female (#1195-09) was found dead. Gross necropsy results indicated the presence of a fungal infection associated with *Aspergillus* spp., when coupled with stress could be the cause of mortality (Dr. Lisa Wolfe *pers. comm*.). On 15 September, a female (#1198-09) was found dead. The previous day, she had been examined by CPW vets, and had purged a clear liquid. Gross necropsy results indicated "…marked dilation and koilin degeneration in the ventriculus, likely causing gastrointestinal stasis…" The cause of this was unknown. A puncture wound found in the skull surrounded by bone proliferation. The histopathology report would indicate that the female also had West Nile virus. On 24 November, a wild male was found dead. Gross necropsy results yielded no immediate cause of death and histopathology reports indicated a fungal infection associated with *Aspergillus* spp., when coupled with stress could be the cause of mortality (Dr. Lisa Wolfe *pers. comm*.). On 22 December, a female (#1199-09) was found dead. Gross necropsy results yielded no immediate cause of death and histopathology reports are pending. On 22 December, the other male was found dead. Gross necropsy results indicated multiple granulomas throughout airsacs and lungs (severe aspergillosis). Histopathology reports confirmed the presence of a fungal infection associated with *Aspergillus* spp. The remaining males were separated from the females in December, and will remain separated.

From 1 October 2010 through 31 December 2010, nine captive-reared domestic grouse were provided 175 – 200 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 300 – 400 g of chow daily and consumed 75 – 100% of the chow provided. Chow was also provided to the wild-reared GUSG, but they did not consume any measureable amount of chow. Entering the 2011 captive breeding season, we had 4 males (3 domestic and 1 wild) and 5 females (all domestic).

Staffing

2010

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. Trapping efforts only took place in KBSM in order to not conflict with the ongoing CPW research project investigating GUSG demography.

2011

Seven temporary staff were hired for the 2011 field season effects. Three technicians were stationed in GB to conduct trapping, telemetry, and brood augmentation in GB. 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. Field work was initiated on 1 April.

Current Status

The captive GUSG flock of 5 females, 3 males, and 1 juvenile are continuing to be held at the NWRC. Construction has begun at the CPW FWRF to augment the existing flight pens to house the captive flock by the end of September, where they will be cared for and held indefinitely. We will continue to analyze data from the 2011 field season and create a final report encompassing 2009-2011, as well as recommendations for future plans, research, and management.

SUMMARY

We continued to build on our knowledge of captive-rearing and husbandry of Gunnison sage-grouse. In 2010, bacterial infections continued to result in substantial chick mortality post-hatch. The construction of a new incubation and hatching facility (Fig. 3) 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. Preliminary data suggest that in 2011 chick survival in captivity increased and mortalities associated with bacteria decreased.

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.

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.

Reducing chick augmentation treatments from 4 separate introduction ages to 2 introduction ages (5-10 days and 30-35 days), simplified logistics and made introductions easier. Having a larger number of surrogates available appears to be crucial so we were not causing undue stress by making several repeated visits to broods in order to release more chicks (only 4 of 19 surrogate brood had to be used for both introductions). A final report will be available in December of 2011.

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Table 1. Common and scientific name of plant species in the Great Basin Wildflower mix planted in Gunnison sage-grouse aviary.

Common Name	Scientific Name
bachelor button	*Centaurea cyanus*
lance-leaved coreopsis	*Coreopsis lanceolata*
plains coreopsis	*Coreopsis tinctoria*
yellow cosmos	*Cosmos sulphureus*
eastern purple coneflower	*Echinacea purpurea*
Siberian wallflower	*Erysimum marshalii*
California poppy	*Eschscholiza californica*
blanket flower	*Gaillardia pulchella*
baby snapdragon	*Linaria maroccana*
scarlet flax	*Linum grandiflorum*
Lewis blue flax	*Linum lewsii*
corn poppy	*Papaver rhoeas*
annual phlox	*Phlox drummondii*
upright prairie cornflower	*Ratibida columnaris and R. columnifera*
blackeyed Susan	*Rudbeckia hirta*

Table 2. Analysis of concentrations of the following vitamins and minerals are guaranteed in Vita-Max per 0.45 kg of product (a vitamin supplement for poultry) used for captive-reared Gunnison sage-grouse.

Vitamin or Mineral	Guaranteed Analysis per 0.45 kg
Vitamin A	2,8000,000 IU
Vitamin D_3	386,640 IU
Vitamin E	18,640 IU
d-Pantothenic Acid	18,640 mg
Ascorbic Acid (Vitamin C)	20,000 mg
Niacinamide	50,176 mg
Riboflavin	6,656 mg
Pyridoxine HCl	6,855 mg
Thiamine HCl	3,790 mg
Folic Acid	1,024 mg
MSBC (Vitamin K3)	932 mg
Biotin	160 mg
Vitamin B_{12}	16 mg
Potassium	1.57%
Sodium	0.46%
Magnesium	0.009%

Table 3. 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)	Average 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

* Too dark to see female's leg band.

Table 4. 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 5. 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	93	3	7*

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

Table 6. Captive Gunnison sage-grouse female breeding history at the National Wildlife Research Center, Fort Collins, Colorado, USA, 2011.

Female ID	Band ID	Access to Males (Days)	Average Access Time (min.)	Number of Males Copulated	Total Copulations
1200-09	Red-Green	16	66	1	5
2972-09	Red-Orange	16	66	1	3
1196-09	Blue	16	66	1	2
1197-09	Red-White	16	66	1	1
1193-09	Pink	16	66	1	1

* Too dark to see female's leg band

Table 7. Captive Gunnison sage-grouse male breeding history at the National Wildlife Research Center, Fort Collins, Colorado, USA, 2011.

Male ID	Female Access (Days)	Access Time (min.)	Different Females Bred	Total Copulations
Red	16	66	5	12
Wild	10	66	0	0

Table 8. Captive Gunnison sage-grouse female breeding occasions at the National Wildlife Research Center, Fort Collins, Colorado, USA, 2011.

Female ID	Band ID	Date	Time	Male
1200-09	Red-Green	11-Apr	0706	Red
1200-09	Red-Green	17-Apr	0643	Red
2972-09	Red-Orange	17-Apr	0806	Red
1200-09	Red-Green	17-Apr	0813	Red
1193-09	Pink	19-Apr	0637	Red
1197-09	Red-White	23-Apr	0648	Red
1200-09	Red-Green	23-Apr	0651	Red
1196-09	Blue	23-Apr	0704	Red
1200-09	Red-Green	26-Apr	0739	Red
1196-09	Blue	27-Apr	0710	Red
2972-09	Red-Orange	27-Apr	0713	Red
2972-09	Red-Orange	27-Apr	0721	Red

Table 9. Capture information for female Gunnison sage-grouse captured in Kezar Basin/Sapinero Mesa, 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
1033	4/18	SOUTH BEAVER	F	A	1074

[1]A = Adult, Y = Yearling

Table 10. Capture information for female Gunnison sage-grouse captured in Gunnison Basin, Colorado, USA, 2011.

Female ID	Capture Date	Lek of Capture	Sex	Age[1]	Weight (g)
1149	4/1	SOUTH PARLIN	F	A	1253
1150	4/1	SOUTH PARLIN	F	A	1183
1160	4/2	SOUTH PARLIN	F	A	1326
1162	4/4	SOUTH PARLIN	F	A	1276
1163	4/4	SOUTH PARLIN	F	A	1231
1164	4/5	SOUTH PARLIN	F	Y	1099
1165	4/7	CHANCE GULCH	F	Y	1206
1166	4/8	CHANCE GULCH	F	A	1466
1167	4/8	CHANCE GULCH	F	A	1271
1168	4/9	CHANCE GULCH	F	A	1209
1169	4/9	SOUTH PARLIN	F	Y	1154
1170	4/9	SOUTH PARLIN	F	A	1307
1171	4/9	NORTH PARLIN	F	A	1334
1172	4/20	SAPINERO	F	A	1368

[1]A = Adult, Y = Yearling

Table 11. Gunnison Sage-grouse female nest success in Kezar Basin/Sapinero Mesa, 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

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

Table 12. 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 13. 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 14. Gunnison sage-grouse female nest success in Gunnison Basin; Colorado, USA, 2011.

Female ID	Age	Initiation Date	Hatch Date	Nest Fate[1]	Total Eggs Laid	Eggs Collected	Eggs Hatched
1041	A	24-Apr	21-May	S	7	0	6
1150	A	24-Apr	21-May	S	7	0	7
1053	A	24-Apr	21-May	U	3+	0	0
1014	A	25-Apr	22-May	S	9	0	9
1166	A	25-Apr	22-May	EA / U	6+	4	0
1052	A	26-Apr	23-May	S	8	0	8
1044	A	26-Apr	23-May	S	7	0	7
1042	A	26-Apr	23-May	EA / FD	8	8	N/A
1043	A	26-Apr	23-May	EA / FD	8	8	N/A
1045	A	27-Apr	24-May	S	8	0	8
1047	A	28-Apr	25-May	EA /S	8	4	4
1160	A	28-Apr	25-May	S	8	0	8
1015	A	30-Apr	27-May	U	5+	0	0
1165	Y	30-Apr	27-May	U	1+	0	0
1171	A	30-Apr	27-May	U	7	0	0
1048	A	30-Apr	27-May	EA / FD	8	8	N/A
1038	A	1-May	28-May	S	8	0	7
1046	A	1-May	28-May	S	7	0	7
1029	A	1-May	28-May	U	3+	0	0
1030	A	1-May	28-May	U	N/A	0	0
1162	A	1-May	28-May	U	N/A	0	0
1170	A	1-May	28-May	U	7+	0	0
1013	A	2-May	29-May	S	8	0	7
1034	A	2-May	29-May	S	7	0	5
1055	A	2-May	29-May	S	6+	0	6+
1033	A	2-May	29-May	U	N/A	0	0
1054	A	2-May	29-May	EA / U	5+	4	0
1163	A	2-May	29-May	U	7	0	0
1027	A	3-May	30-May	S	10	0	9
1040	A	3-May	30-May	U	N/A	0	0
1001	A	4-May	31-May	EA / S	8	4	4
1021	A	4-May	31-May	S	8	0	8
1149	A	5-May	1-Jun	U	N/A	0	0
1059	A	5-May	1-Jun	S	6	0	5
1036	A	6-May	2-Jun	EA / S	7+	4	1+
1018	A	7-May	3-Jun	S	8	0	7
1035	A	7-May	3-Jun	EA / U	7+	4	0
1025	A	8-May	4-Jun	S	8	0	8
1026	A	9-May	5-Jun	EA / S	8	4	2
1008	A	10-May	6-Jun	EA / FD	5	5	N/A
1167	A	10-May	6-Jun	EA / FD	8	8	N/A
1051	A	11-May	7-Jun	S	7	0	7
1061	A	13-May	9-Jun	S	4+	0	2
1043	A	14-May	10-Jun	U	7+	0	0
1172	A	16-May	12-Jun	S	7	0	6
1042	A	17-May	13-Jun	S	6	0	6

1166	A	21-May	17-Jun	S	6	0	5
1170	A	22-May	18-Jun	U	3+	0	0
1028	A	23-May	19-Jun	S	4+	0	4+
1056	A	23-May	19-Jun	EA / S	9	4	3
1048	A	24-May	20-Jun	U	Unknown	0	0
1058	A	26-May	22-Jun	S	6	0	5
1008	A	30-May	26-Jun	S	2+	0	2+
1167	A	3-Jun	30-Jun	U	5	0	0
1051	A	N/A	LAYING	EA / FD	6	6	N/A
1162	A	N/A	LAYING	U	3+	0	0

[1] S = Successful, U = Unsuccessful, EA = Egg Acquisition, FD = Forced Depredation

Table 15. Number and allocation of eggs collected in the Gunnison Basin, Colorado, USA, 2010.

Location	Female ID	Age	# of Eggs	Incubating or Laying	Date Collected	Renested[1]	Renest Fate
S. Parlin	0804	Adult	8	Incubating	27-Apr	Y	Unsuccessful
S. Parlin	0805	Adult	6	Laying	29-Apr	N	n/a
S. Parlin	0805	Adult	1	Incubating	7-May	N	n/a
S. Parlin	0820	Adult	7	Incubating	29-Apr	N	n/a
Total			22				

[1] Y = Yes, N = No

Table 16. 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 17. Number and allocation of eggs collected in the Gunnison Basin, Colorado, USA, 2011.

Location	Female ID	Age	# of Eggs	Incubating or Laying	Date Collected	Renested[1]	Renest Fate
Sapinero	1001	Adult	4	Laying	3-May	N	n/a
GSWA	1008	Adult	5	Incubating	10-May	Y	Successful
N. Parlin	1026	Adult	4	Laying	3-May	N	n/a
S. Beaver	1035	Adult	4	Laying	23, 29-Apr (1, 2), 4-May (2)	N	n/a
S. Parlin	1036	Adult	4	Laying	5-May	N	n/a
S. Parlin	1042	Adult	8	Incubating	29-Apr	Y	Successful
S. Parlin	1043	Adult	8	Incubating	29-Apr	Y	Unsuccessful
S. Parlin	1047	Adult	4	Laying	22-Apr (3), 27-Apr(1)	N	n/a
N. Parlin	1048	Adult	8	Incubating	5-May	Y	Unsuccessful
C. Gulch	1051	Adult	6	Laying	23-Apr (2), 28-Apr (4)	Y	Successful
Flat Top	1054	Adult	4	Laying	30-Apr	N	n/a
Flat Top	1056	Adult	4	Laying	30-Apr (2), 5-May (2)	N	n/a
C. Gulch	1066	Adult	4	Laying	22-Apr	Y	Successful
N. Parlin	1067	Adult	8	Incubating	14-May	Y	Unsuccessful
Total			75				

[1] Y = Yes, N = No

Table 18. Number of captive females and eggs laid at the National Wildlife Research Center, Fort Collins, Colorado, USA, 2011.

Captive Females	Eggs Laid	Eggs Collected	Eggs Incubated
5	32	32	0

Table 19. 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 20. 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 21. Total Gunnison sage-grouse egg artificial incubation at the Foothills Wildlife Research Facility, Fort Collins, Colorado, USA, 2011.

Captive Females	Eggs Collected	Eggs Incubated	Eggs Hatched	Eggs 'Dead in Shell'	Possible Infertile Eggs	Chicks Yielded
5	107	107	71	16	14	51

Table 22. 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%	21	45.65%	42.89	1.79

Table 23. 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 24. 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 25. 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 at death	Gross Diagnosis	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 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 d	Splayed Legs	unk	0	9.90%	10.29	28.25	1.18	No
CU-5	D-25-10	5/28	5/29	1100	1 d	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 d	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 d	Bacterial[1]	<1	6.07	8.82%	9.07	52	2.17	No
804-14	D-5-10	5/22	5/26	1030	4 d	Bacterial[1]	unk	0	8.57% *	9.76	46	1.92	No
804-19	D-4-10	5/22	5/27	2000 - 0630	5 d	Bacterial[1]	unk	0	8.59% *	9.78	43.5	1.81	No
804-15	D-3-10	5/22	5/27	745	5 d	Bacterial[1]	unk	0	8.55% *	9.73	43.5	1.81	No
805-33	D-18-10	5/27	6/1	1430	5 d	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 d	Bacterial[1]	unk	0	11.52% *	11.93	42	1.75	No
820-28	D-13-10	5/26	6/2	2230 - 0455	7 d	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 d	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 d	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 d	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 d	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 d	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 25 (continued).

Egg ID	Chick ID	Hatch	Mortality Date	Time of Death	Age 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 pip and hatch	Assisted Hatch
804-13	D-2-10	5/22	5/23	1730	1 d	Suffocation	unk	0	9.44% *	10.72	34.25	1.43	No
CN1-e	D-48-10	6/4	6/6	~1350	2 d	Trauma	N/A	8**	N/A	N/A	N/A		N/A
820-22	D-9-10	5/25	6/11	1600	17 d	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 d	Unknown	N/A	8**	N/A	N/A	N/A		N/A
CN1-a	D-49-10	6/4	6/8	~1800	3 d	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 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 26. Gunnison sage-grouse chick mortality totals at the Foothills Wildlife Research Facility, Fort Collins, Colorado, USA, 2011.

Trauma	Splayed Leg	Euthanized	Bacteria	Other / Unknown	Total Mortalities
2	0	3	6	8	19

Table 27. 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 28. 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 (Y = yes, N = no)	Chick ID	Hatch Date	Hatch Time	External Pip Date	External Pip Time	Hatching Time (hrs)	Hatching Time (days)	Hatch Weight (grams)	Projected Weight Loss Percentage (27 days)	Status as of 7/1 (Alive, Dead, Introduced)	Age as of 7/1 (days)	Mortality Date	Mortality Time	Age at Death / Stop in Egg Development (days)	Mortality 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
805-34	Y	D-20-10	5/27	1110	5/25	1845	40.42	1.68	34.6	10.67	Introduced	36				

Table 28 (continued).

Egg ID	Hatch (Y = yes, N = no)	Chick ID	Hatch Date	Hatch Time	External Pip Date	External Pip Time	Hatching Time (hrs)	Hatching Time (days)	Hatch Weight (grams)	Projected Weight Loss Percentage (27 days)	Status as of 7/1 (Alive, Dead, Introduced)	Age as of 7/1 (days)	Mortality Date	Mortality Time	Age at Death / Stop in Egg Development (days)	Mortality Cause
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
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

Table 28(continued).

Egg ID	Hatch (Y = yes, N = no)	Chick ID	Hatch Date	Hatch Time	External Pip Date	External Pip Time	Hatching Time (hrs)	Hatching Time (days)	Hatch Weight (grams)	Projected Weight Loss Percentage (27 days)	Status as of 7/1 (Alive, Dead, Introduced)	Age as of 7/1 (days)	Mortality Date	Mortality Time	Age at Death / Stop in Egg Development (days)	Mortality Cause
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						

Figure 1. Individual captive-reared Gunnison sage-grouse chick mass gain for the first 35 days of life in Fort Collins, Colorado, USA, 2010.

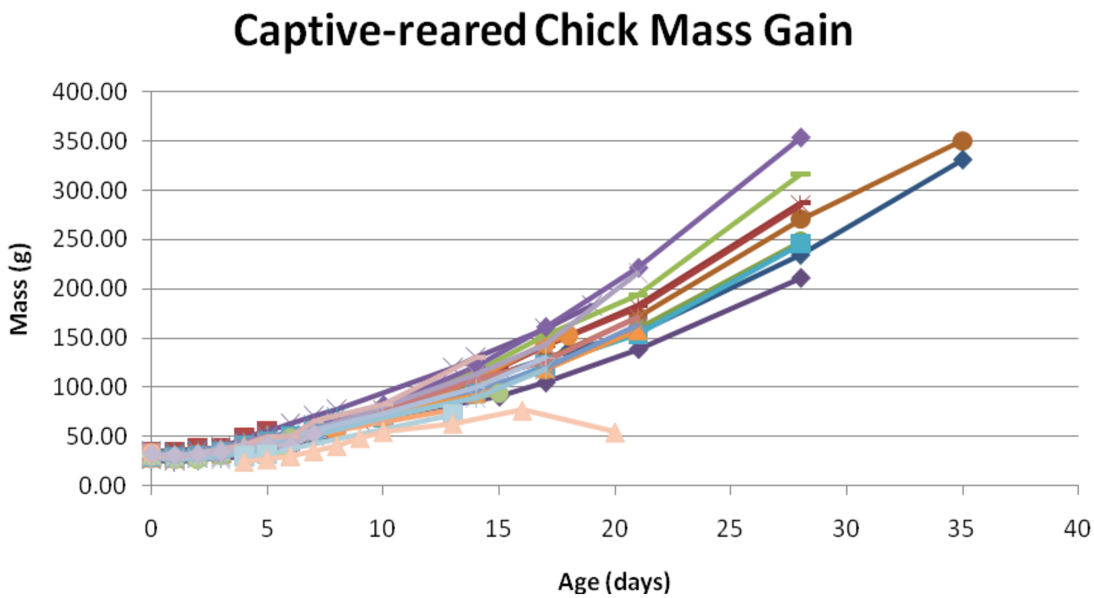

Figure 2. West Nile virus / Mosquito exclosure.

Figure 3. CPW 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 PARKS AND WILDLIFE - AVIAN RESEARCH PROGRAM
PROGRESS REPORT
September 2011

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

AUTHOR: J. H. Gammonley, A. D. Apa, and M. L. Phillips

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

Period Covered: September 1, 2010 – August 31, 2011

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 Gunnison sage-grouse (*Centrocercus minimus*) is classified as warranted for listing 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 Parks and Wildlife (CPW) 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. 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 ecological sites, and a total of 392 30-m line transects were selected and sampled across all study sites. Results from 2010 sampling were summarized in an interim report, and vegetation measures were compared to established guidelines for Gunnison sage-grouse. To examine temporal variation in vegetation measures, all transects were measured again in 2011, with field work completed in August. A final report will be completed by February 2012.

BASELINE HABITAT MONITORING FOR GUNNISON SAGE-GROUSE IN THE GUNNISON BASIN, COLORADO

Progress Report, September 1, 2010 – August 31, 2011

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

PROJECT OBJECTIVES

1. Collect baseline information on vegetation structure and composition across the Gunnison basin, and compare these measures to established guidelines for Gunnison sage-grouse.

2. Examine spatial and temporal variation in vegetation measures, and develop recommendations for establishing a long-term habitat monitoring program to guide management decisions for Gunnison sage-grouse in the Gunnison Basin.

SEGMENT OBJECTIVES

1. Summarize field data collected during 2010 in an interim report.

2. Complete a second year of data collection, using the same sampling plots and methodologies as in 2010.

INTRODUCTION

The Gunnison sage-grouse (*Centrocercus minimus*) is classified as warranted for listing 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 Parks and Wildlife (CPW) 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. Several large sub-areas within the Gunnison Basin were identified based on existing locations of radio-marked Gunnison sage-grouse. These areas were further stratified based on ecological sites, and during May-August 2010 a total of 392 30-m line transects were selected and sampled across all study sites.

Following examination of the results of the 2010 monitoring effort, stakeholders agreed that a second year of monitoring would be valuable, to address annual variation in vegetation measures. This additional data would be used to make recommendations on the design of a potential long-term habitat monitoring program to help guide management decisions.

STUDY AREA AND METHODS

This study was focused on the Gunnison Basin, where the largest remaining population of Gunnison sage-grouse occurs. During 2005-2010, a large-scale demographic and movements study was conducted throughout the Gunnison Basin (Phillips 2011). Based on preliminary results from this study, we identified 7 areas within the Gunnison Basin; in each sub-area, breeding sage-grouse movements were relatively independent from other sites: Chance Gulch, Flat Top, Kezar, North Parlin, Ohio Creek, Sapinero, and South Parlin. Spatial data and descriptions of ecological sites were obtained from the Natural Resources Conservation Service staff in Gunnison and soil data were obtained from SSURGO for Gunnison County. The target ecological sites for sampling were Dry Mountain Loam and Mountain Loam. These ecological sites were not well represented in Flat Top, therefore baseline monitoring was not conducted in Flat Top.

In 2010, line transects were randomly placed in each of the 2 ecological sites within each of the 6 study areas. A total of 392 30-m lime transects was established. Monitoring methods followed techniques from Herrick et al. (2005a, 2005b) and the Gunnison sage-grouse conservation plan (Gunnison Sage-grouse Rangewide Steering Committee 2005) with some modifications (Appendix).

RESULTS AND DISCUSSION

Results of the 2010 sampling were summarized in a report by M. Williams and A. Hild (Appendix). There were differences in vegetation measures among study areas and between ecological sites, but across all transects most vegetation measures (averages) were within the habitat guidelines for Gunnison sage-grouse.

All transects established in 2010 were sampled again during May-August 2011. A crew of 6 technicians was hired and trained by M. Williams, using the same field methods as in 2010. All data have been checked and entered. Data analyses are being conducted, and a final report is expected in early 2012.

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Appendix

Characteristics of Gunnison Sage-Grouse Habitat in Dry Mountain Loam and Mountain Loam Ecological Sites of the Gunnison Basin

Mary I. Williams[1] and Ann L. Hild[2]
Department of Renewable Resources, University of Wyoming, Laramie

Introduction

Gunnison sage-grouse (*Centrocercus minimus*) are a significant species impacting management of federal and state lands in western Colorado. The species is listed as sensitive by the Bureau of Land Management (BLM) and a management indicator species by the US Forest Service (USFS). Low genetic diversity, genetic drift from small population sizes, habitat issues (loss, degradation, and fragmentation), interactions with predators, and drought impacts are the most significant threats facing Gunnison sage- grouse (GUSG) (Gunnison Sage-grouse Rangewide Steering Committee 2005). By far, the greatest threat is loss and associated fragmentation and degradation of sagebrush habitat to urban and commercial development.

The Steering Committee of the GUSG Rangewide Conservation Plan (RCP) recognizes the need to use information from research and monitoring to evaluate the effects of management, identify gaps in knowledge, and to develop alternative management plans in order to meet population and habitat goals of the RCP (Gunnison Sage-grouse Rangewide Steering Committee 2005). Vegetative habitat guidelines are established for GUSG (see Appendix A: Gunnison Sage-Grouse Structural Habitat Guidelines), but comprehensive habitat monitoring is needed to better understand how the guidelines apply to sage-grouse populations at various stages of their life cycle and how methods used by land management agencies (e.g., Bureau of Land Management [BLM] and Natural Resource Conservation Service [NRCS]) assess ecological site characteristics that are related to sage-grouse habitat.

One of the frequent questions facing western land management agencies is the potential influence of livestock grazing on sagebrush steppe and sage-grouse populations. There is little scientific data linking grazing practices to sage-grouse population levels (but see Kuipers 2004). Few studies clearly document structural habitat response to livestock grazing or to seasonal habitat requirements of GUSG. A variety of grazing practices may benefit GUSG by altering vegetative structural habitat to fulfill guidelines outlined in the RCP. Essential to any attempt in documenting the impacts of altered grazing practices on GUSG is a detailed vegetation inventory, permanent monitoring locations, and carefully defined monitoring methodologies that provide baseline pre- treatment data. This report documents baseline monitoring efforts conducted during June and August 2010 across the Gunnison Basin.

Goals and Objectives

As an initial step to document characteristics of sagebrush steppe and GUSG habitat, current soil and vegetation were monitored in six sage-grouse study sites in Gunnison County, CO between June and August 2010. The goals of this project are to provide 1) baseline monitoring of Gunnison Basin ecological sites and 2) facilitate design of an experimental study to examine potential manipulation of livestock grazing in the Gunnison Basin intended to improve habitat for GUSG.

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The objectives of this research are to 1) develop geospatial database of livestock allotment boundaries, soils, elevation, ecological sites, and GUSG habitat areas to guide sampling of soil and vegetation conditions, 2) record baseline soil and vegetation characteristics within ecological sites using standardized methods, 3) provide summary of baseline data within each ecological site, 4) provide recommendations for design of subsequent experiments be implemented to assess relationship of livestock grazing with GUSG populations in the six study sites, and 5) write and submit any noted trends or relationships of baseline data to GUSG populations to a peer-reviewed scientific journal.

Materials and Methods

Study Area

Gunnison Basin of Colorado (lat 38°32'N, long 106°55'W) is comprised of BLM, USFS, State of Colorado, Curecanti Recreation Area (NPS), and private lands (Fig. 1). Within the Basin, Gunnison sage-grouse (GUSG) occur on seven documented sites with an average elevation of 2586 m – Chance Gulch, Flat Top, Kezar, North Parlin, Ohio Creek, Sapinero, and South Parlin (Table 1). The Gunnison Basin lies within the 30 to 40 cm precipitation zone of Natural Resources Conservation Service (NRCS) Major Land Resource Area (MLRA) 48A-Southern Rocky Mountains which extends into New Mexico and Utah. Spatial data and descriptions of ecological sites were obtained from the NRCS staff in Gunnison and soil data were obtained from SSURGO for Gunnison County (Soil Survey Staff 2010). The target ecological sites for sampling were Dry Mountain Loam (DML) and Mountain Loam (ML) (Appendix B: Ecological Site Descriptions). These ecological sites were not well represented in Flat Top, therefore baseline monitoring was not conducted in Flat Top (Table 1). Dry Mountain Loam and ML are primarily distinguished by slope and aspect. Dry Mountain Loam sites are typical on south, west, and southwest facing alluvial fans, hills, and ridges with slopes averaging 5 to 45%. These sites have sandy loam, sandy clay loam, loam, and clay loam soil textures and typically support Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) and cool-season bunchgrasses. Mountain Loam sites are common to north, east, and northeast terraces, fans, and valleys with slopes averaging 5 to 10%. Mountain Loam sites have loam, sandy loam, and gravelly sandy loam soil textures and support Wyoming big sagebrush and cool-season grasses.

Data Collection

Soil and vegetation characteristics were measured on 392 30 m line transects stratified by ecological site in each study site (Appendix C: Gunnison Sage-Grouse Study Sites and Ecological Sites). Site characteristic data from shrub-steppe ecological sites similar to Dry Mountain Loam (DML) and Mountain Loam (ML) were used to estimate the number of transects needed to detect a 5% minimal change in soil and vegetation characteristics (Herrick et al. 2005a; Williams 2010). Conservative estimates for our study sites were 20 30 m transects in DML and 45 30 m transects in ML. Transect locations were generated randomly in each study site in a Geographic Information System (GIS) and visited on the ground to verify they were located on the targeted ecological sites. Transects located in areas that were occupied by radio-collared GUSG were given higher monitoring priority than transects located outside these areas. General locations of GUSG were obtained from the lead technicians of the sage-grouse telemetry effort supported by Colorado State University and CDOW – Phillip Street (Change Gulch, Ohio Creek, North Parlin, and South Parlin) and Lief Wiechman (Kezar and Sapinero). Location and direction (azimuth) of transect were marked with a GPS unit and a photograph was taken of each transect.

Monitoring methods follow techniques from Herrick et al. (2005a, 2005b) and the RCP (2005) with some modifications (Table 2). These monitoring methods were used because they are accepted quantitative measurements of rangelands and are frequently used to conduct baseline inventories, evaluate site stability and wildlife habitat, and generate indicators of ecosystem attributes. There will be some overlap in measurements. The recommended minimal structural habitat measurements for GUSG are shrub canopy cover, sagebrush height, grass cover, forb cover, grass height, and forb height which are traditionally estimated using Daubenmire methods (RCP 2005). Daubenmire frames (20 x 50 cm) were placed every 5 m along each transect to record ocular estimates of cover (sagebrush, grass, forb, bare ground, and litter), plant height (sagebrush, grass, and forb), and plant composition. Daubenmire cover estimates were placed into one of six cover classes: 0-5%, 5-15%, 15-25%, 25-50%, 50-75%, and 75-100%. Midpoint value of each cover class was used to estimate cover. A single sagebrush, grass, and forb were measured in or near each Daubenmire frame. Sagebrush canopy height, excluding inflorescence, was measured to the nearest cm. The tallest vertical point where the bulk of grass and forb canopy mass occurred was measured to the nearest cm. Line-point intercept was used to measure the type and amount of cover (plant canopy and basal, bare ground, litter, rock, moss, and lichen) and top canopy height (to the nearest cm) in 1 m increments along the transect. Every plant species and ground type intercepted on a vertical point (pin flag) was recorded.

Plant basal and canopy gaps, shrub density, and soil stability were also measured on each transect (Table 2). Plant basal and canopy gap sizes measured by gap intercept methods can characterize songbird habitat within shrub-steppe ecological sites (Williams et al. 2011). Gap size may also be an important characteristic of sage-grouse habitat. Gap intercept measured spaces (> 20 cm) between plant canopies and bases. Shrub density (number of individuals per ha) was measured in a 2 x 30 m belt transect and categorized into four height classes (< 10 cm, 11 – 50 cm, 51 – 100 cm, and > 100 cm). Soil stability was sampled at 3 locations along each transect at 5, 15, and 25 m. Stability was determined on a scale of 1 (unstable) to 6 (stable).

Data Summary and Analysis

Soil and vegetation characteristics were averaged for each transect and summarized by study site (Chance Gulch, Kezar, North Parlin, Ohio Creek, Sapinero, and South Parlin) and ecological site (Dry Mountain Loam and Mountain Loam). Plant species composition and data summary tables are in Appendix C: Gunnison Sage-Grouse Study Sites and Ecological Sites. General linear models (GLM) and mean comparisons were used to test for differences in characteristics between ecological sites (fixed effect) across the study sites (random factor). Study sites were treated as random factors because their geographic locations and abiotic characteristics would likely affect ecological site characteristics (Table 1). Residuals were assessed for meeting the assumptions of GLM. When models detected differences (alpha ≤ 0.05), means were separated using Fisher's Protected LSD test.

We estimated sample sizes and compared traditional (Daubenmire) and standardized (line-point intercept) methods used to measure plant cover and height. For sample size calculations, we used grass and forb canopy cover data from the North Parlin study site to estimate number of 30 m transects needed for 5, 10, and 20% minimum detectable change (MDC). Sample sizes were estimated using methods outlined in Herrick et al. 2005b. Daubenmire and line-point intercept cover and height data were compared with t-tests, correlation coefficients (r), and coefficient of variation (CV; alpha ≤ 0.05).

Results

Study Sites

Study sites did not differ in sagebrush cover or forb height, but differed in all other monitored characteristics (Table 3). Chance Gulch and South Parlin had similar characteristics: shorter vegetation, lower shrub density (shrubs > 50 cm tall), and less litter cover values than the four other sites. South Parlin had the lowest grass and forb cover of all sites. Among the remaining four sites, forb cover was greater in Kezar and North Parlin than in Sapinero and South Parlin, whereas plant canopy and grass cover were greatest in Ohio Creek. Kezar, North Parlin, and Ohio Creek had greater density of tall shrubs (> 50 cm tall) than Chance Gulch and South Parlin. In sites with dense plant communities, canopy and basal gaps were small. For example, Ohio Creek had greater plant canopy cover and smaller canopy gaps than at Sapinero and South Parlin. Across all sites, soil stability values were less than 3 and were lowest at Ohio Creek and Sapinero.

In comparison to the structural habitat guidelines (Appendix A: Gunnison Sage- Grouse Structural Habitat Guidelines), most study site characteristics were within the breeding, summer, and winter guidelines. Exceptions were grass height in Chance, North Parlin, and South Parlin.

Ecological Sites

Across the Gunnison Basin, Mountain Loam (ML, *n* = 305) ecological sites are more common than Dry Mountain Loam (DML, *n* = 87) sites. We blocked the effect of study site differences to examine trends in ecological sites across the Basin. Using study sites as blocks, we found differences between the two ecological sites (DML and ML) in plant canopy, bare ground, litter, and shrub cover, sagebrush and plant height, and density of shrubs 11-50 cm tall (Fig. 2). Shrub communities in ML were taller and more dense than DML. Bare ground was more frequent in DML. Cover and height of sagebrush, shrubs, grasses, and forbs of both ecological sites were within the minimal GUSG habitat guidelines (Appendix A). In both sites canopy gaps ranged from 50 to 52 cm and basal gaps ranged from 88 to 92 cm. Soil stability values were low (1 to 2) and values < 3 were common in both sites. Values 5.5 and above generally are more resistant to erosion (Pellant et al. 2005). Species composition was similar between the sites (Table C5). The dominant shrubs, grasses, and forbs were Wyoming big sagebrush, rabbitbrush (*Chrysothamnus viscidiflorus*), antelope bitterbrush (*Purshia tridentata*), muttongrass (*Poa fendleriana*), Sandberg bluegrass (*Poa secunda*), Letterman's needlegrass (*Achnatherum lettermanii*), Indian ricegrass (*Achnatherum hymenoides*), spiny phlox (*Phlox hoodii*), hollyleaf clover (*Trifolium gymnocarpon*), fleabane (*Erigeron speciosus*), and mat penstemon (*Penstemon caespitosus*).

Dry Mountain Loam (DML) sites were uncommon in Change Gulch, Kezar, and Sapinero (Table 1 and Figs C1, C2, and C6). Most cover and height measures on DML sites were within the breeding and summer habitat guidelines for Gunnison sage-grouse (RCP 2005). Cover was adequate for DML and ML in four study sites: the exceptions were Kezar DML and Sapinero ML (Fig. 3). Grass and forb height were below the guideline in both ecological sites, but were at least above 3 cm (Fig. 4). Dry Mountain Loam sites in Kezar fell consistently short of the sagebrush cover and height guideline, but these estimates are based on very few transects (*n* = 4) in DML at Kezar.

Sample Size Estimates

We used available data from the 2010 baseline collection to estimate needed sample sizes to detect change in vegetation characteristics in the Basin. Using the grass and forb cover data from North Parlin study site, at least 54 30 m transects are required for a 20% change in grass cover and 310 30 m transects to detect changes in forb cover in North Parlin (Table 4). Several more transects would be needed to detect a 5 or 10% change in cover. In 2010, two 2-person crews established and surveyed 74 30 m transects over the course of 18 days in North Parlin.

Daubenmire and Line-Point Intercept Comparisons

Cover and height estimates in the Basin differed between the two monitoring methods (Daubenmire and line-point intercept (LPI; Fig. 5). Cover measures were correlated between the two methods ($r \geq 0.360$, $P \leq 0.05$), but sagebrush was 5%, grass was 10%, and litter was 30% larger using LPI than Daubenmire methods. Line-point intercept estimates for these cover characteristics were also higher in precision (low CV) than Daubenmire estimates: sagebrush LPI = 51%, Daubenmire = 61%; grass LPI = 47%, Daubenmire = 55%; litter LPI = 38%, Daubenmire = 73%. Daubenmire estimates of bare ground were approximately 25% larger with a lower CV than LPI estimates (LPI CV = 68%, Daubenmire CV = 41%). Forb cover estimates did not differ between the two methods. Both methods estimated cover within the habitat guidelines for Gunnison sage- grouse (Appendix A).

Sagebrush height was correlated between the two methods, but was at least 7 cm greater using Daubenmire than LPI (Fig. 5). Grass and forb height estimates were not correlated between the methods. Daubenmire estimates of grass height were on average, 2 cm larger and estimates of forb height were 4.5 cm larger than LPI. Sagebrush, grass, and forb heights estimated by Daubenmire had smaller CVs than LPI. There was a 7% difference in variation between Daubenmire and LPI estimates for both sagebrush and grass height. Forb height CV, in contrast, was 58% using Daubenmire and 167% using LPI. Sagebrush, grass, and forb height met the guidelines when monitored using Daubenmire but LPI estimates of grass and forb height fell short of breeding habitat (Appendix A).

Discussion

Baseline monitoring of Gunnison sage-grouse habitat in the Gunnison Basin has occurred in past years, but not to the extent as reported in this document. Differences in cover, height, and shrub density between Dry Mountain Loam (DML) and Mountain Loam

(ML) ecological sites are probably a function of aspect and should be anticipated given soil differences between the two sites. Across the Basin, ML sites supported taller and more dense shrub communities. In comparison to the habitat guidelines for GUSG, cover and height estimates were within the breeding and summer to fall habitat guidelines, especially in cover and sagebrush height for both ecological sites across the Basin. Under current management activities in the Basin, the majority of guidelines were met despite lower than average precipitation in 2010 (WRCC 2010).

Significant correlations between Daubenmire and line-point intercept (LPI) cover and height estimates provide evidence that standard monitoring techniques (e.g., LPI) can substitute for traditional methods (e.g., Daubenmire). However, differences in cover and height between Daubenmire and LPI should not be overlooked. Daubenmire cover estimates are often lower and less precise than LPI estimates (Symstad et al. 2006). Line- point intercept is the least biased and most objective method over ocular estimates (Bonham 1989), but not as efficient as quadrat-based methods in recording minor and rare plant species (Elzinga et al. 1998). Daubenmire methods detected more plant species than LPI in our study, but the advantage to LPI was having a quantitative and more precise measure of cover by species (Fig. 5 and Table C5).

Sagebrush, grass, and forb height estimates using Daubenmire were greater and more precise than LPI estimates, however, these differences were likely a function of measuring technique and number of observations. In LPI, the top canopy height of intersected plants was measured whereas the tallest vertical position of a plant's bulk mass was measured in or near every Daubenmire frame. A simple modification to LPI that includes measuring height of understory canopy layers will likely reduce variation in grass and forb heights.

At the time of this report, DML and ML ecological site maps and descriptions are in draft form until approved by NRCS. Additional years of baseline monitoring will help to isolate differences in these sites' response to variable climatic conditions. By documenting variation due to climate, researchers will be able to discern differences due to imposed treatments (such as grazing management) in the future.

Recommendations

Baseline monitoring of soil and vegetation characteristics should commence over the next two years prior to designing an experimental treatment (e.g., livestock grazing) and/or alter management activities. If Daubenmire methods are used exclusively to measure cover and height, it is important to note that line-point intercept (LPI) can generate more ecological site indicators related to a range of monitoring objectives than ocular methods (Godinez-Alvarez et al. 2009) and can be used to detect and discern quantitative changes in plant species cover that are important to wildlife (e.g., food forbs). The number of transects to detect only a 10% change in vegetative characteristics would require a more intensive survey than the one reported here. Data collected on the same transects in subsequent years will help capture annual variation in site characteristics and can be used to refine our sample size estimates. Accounting for annual variation will most likely reduce the number of transects needed to detect vegetation change. In addition, data from multiple years coupled with Gunnison sage-grouse demography and movement can be used to make informed management decisions to benefit sage-grouse and their habitat.

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Table 1. Ownership and descriptive abiotic characteristics of Gunnison sage-grouse study sites located in the Gunnison Basin, Colorado. Climate data from the Western Regional Climate Center (2010). Precipitation and temperature are mean (min, max). Transects (30 m) are number sampled during June and August 2010 in Dry Mountain Loam (DML) and Mountain Loam (ML).

	Chance Gulch	Flat Top	Kezar	North Parlin	Ohio Creek	Sapinero	South Parlin
Lat Long	38°28'N 106°51'W	38°42'N 106°54'W	38°23'N 107°07'W	38°32'N 106°43'W	38°40'N 106°59'W	38°23'N 107°12'W	38°26'N 106°42'W
Elevation (m)	2557	3163	2480	2659	2596	2608	2594
Climate							
Precip (cm)	28 (18, 46)	43 (25, 58)	30 (18, 43)	43 (20, 69)	25 (15, 46)	30 (18, 43)	28 (18, 46)
Temp (C)	3 (-7, 13)	0.5 (-9, 9)	2 (-9, 13)	0.5 (-8, 10)	3 (-7, 13)	2 (-9, 13)	3 (-7, 13)
Area (ha)							
Total	9001	6419	8543	4607	6202	5705	13077
Public	7902	4886	6806	4266	3804	5226	10894
Private	1099	1533	1737	341	2398	479	2183
DML	2	6	131	1013	831	-	655
ML	7780	130	6771	3748	2628	5013	10335
Transects *n*							
DML	-	-	4	29	35	-	19
ML	66	-	42	45	37	52	63

Table 2. Biological and physical indicators generated from Gunnison Basin monitoring methods (adapted from Herrick et al. 2005a, 2005b and Pellant et al. 2005).

Monitoring Method	Protocol	Quantitative Indicator	Qualitative Indicator	Biological and Physical Interpretation
Soil stability	Measure surface soil stability at 3 random locations	Stability ranked 1 (unstable) to 6 (stable)	Soil surface resistance to erosion	Soil aggregate stability key indicator of soil quality and rangeland health; closely related to soil organic matter, biotic activity, resistance to erosion, and infiltration capacity
Line-point intercept with height (LPI)	Measure intercepting cover; measure height of top canopy	Canopy and basal plant cover; litter, rock and ground cover; bare ground; plant composition; plant height; live to dead canopy	Water flow patterns; bare ground; litter movement; plant community composition and distribution; plant functional and structural groups; plant mortality/decadence; litter amount; invasive plants; structure	Basal cover slows water movement; bare ground correlated with runoff and erosion; changes in plant composition related to changes in infiltration and functional and structural groups; live to dead proportion related to plant mortality and decadence; cover and height related to wildlife habitat
Basal gap intercept	Measure intercepting gaps between plant bases	Proportion of basal gaps > 20, 50, 100, 200 cm; basal gap size	Water flow patterns; litter movement; plant community composition and distribution; horizontal structure	Water gains energy as it moves across large basal gaps; redistribution or loss of litter increases with large basal gaps; changes in basal gaps are related to changes in plant distribution which affect structure
Canopy gap intercept	Measure intercepting gaps between plant canopies; measure height of intersecting shrubs	Proportion of canopy gaps > 20, 50, 100, 200 cm; canopy gap size; shrub canopy height	Bare ground; vertical and horizontal structure with height measurements	Wind and water erosion risk increases with increases in canopy gap
Daubenmire	List plant species height and cover in 7 quadrats along transect	Percent frequency of plant species; species cover; species height	Frequency; species composition; vegetation condition and trend; species distribution	Species composition dictated by ecological site potential and environmental conditions; presence of food sources for wildlife
Shrub density belt	Number of shrubs by species and height class in 2 x 30 m belt transect	$Shrubs \cdot ha^{-1}$ < 10, 11-50, 51-100, > 100 cm tall; ratios; shrub height by species	Shrub composition; vertical and horizontal structure; shrub mortality/recruitment/decadence; distribution and heterogeneity	Density associated with wildlife habitat; changes in density affect wind and water erosion, infiltration and nutrient cycling

Table 3. Soil and vegetation characteristics (± SE of the mean) for six Gunnison sage-grouse study sites in Colorado, measured in 2010. Characteristic means with the same letter do not differ across study site ($P \geq 0.050$). Cover and height measured by line point intercept, shrub densities by height measured in 2 x 30 m belt transect, and gap measured by gap intercept methods.

	Chance Gulch (*n* = 66) Mean (SE)	Kezar (*n* = 46) Mean (SE)	North Parlin (*n* = 74) Mean (SE)	Ohio Creek (*n* = 72) Mean (SE)	Sapinero (*n* = 52) Mean (SE)	South Parlin (*n* = 82) Mean (SE)
Cover (%)						
Canopy	56.5 (1.4)bc	56.8 (2.6)bc	59.3 (1.6)b	64.8 (1.8)a	55.5 (2.4)bc	53.9 (1.3)c
Bare ground	18.2 (1.3)bc	23.8 (1.9)a	15.5 (1.2)cd	15.0 (1.3)cd	12.9 (1.9)d	21.8 (1.4)ab
Litter	47.6 (2.3)c	51.4 (3.0)bc	61.0 (2.3)a	58.3 (2.2)ab	57.7 (3.5)ab	45.2 (1.8)c
Sagebrush	22.8 (1.3)	26.3 (2.5)	24.6 (1.3)	23.9 (1.7)	25.8 (1.7)	24.6 (1.2)
Grass	31.7 (1.5)b	32.0 (2.0)b	31.5 (1.5)b	39.1 (2.0)a	33.0 (2.1)b	25.0 (1.5)c
Forb	5.9 (0.7)bc	7.3 (0.9)ab	9.0 (1.0)a	6.1 (0.9)bc	4.0 (0.9)c	4.7 (0.6)c
Shrub	32.9 (1.8)b	36.0 (3.1)b	37.2 (1.6)b	42.4 (2.3)a	38.4 (2.0)ab	36.7 (1.3)b
Height (cm)						
Sagebrush	22.4 (1.2)b	32.2 (2.0)a	30.5 (1.5)a	28.4 (1.6)a	28.1 (1.5)a	22.6 (1.5)b
Grass	7.8 (0.4)b	9.6 (0.7)a	8.1 (0.4)b	8.9 (0.4)ab	9.0 (0.5)ab	7.7 (0.5)b
Forb	2.8 (0.6)	4.0 (0.8)	3.5 (0.4)	5.0 (0.9)	3.6 (0.9)	2.5 (0.7)
Shrub density (no. ha^{-1})						
Total	17762 (919)	16004 (892)	16879 (531)	19546 (929)	17182 (1230)	19032 (923)
< 10 cm tall	3886 (529)ab	2887 (569)b	3414 (358)b	2322 (378)b	5252 (1185)a	5405 (526)a
11-50 cm tall	12626 (655)b	10985 (603)bc	11209 (459)bc	14846 (815)a	10104 (536)c	12700 (685)b
51-100 cm tall	1239 (179)bc	2046 (268)a	2189 (208)a	2333 (274)a	1806 (264)ab	913 (123)c
> 100 cm tall	11 (8.1)c	87 (40)a	68 (20)ab	44 (18)abc	21 (7)bc	15 (7)c
Gap (cm)						
Canopy	50.1 (1.9)bc	53.6 (2.9)ab	52.4 (2.5)ab	45.9 (1.7)c	58.3 (3.1)a	53.4 (2.0)ab
Basal	89.5 (6.3)c	91.9 (5.6)bc	85.5 (4.6)c	89.1 (4.7)c	109.6 (4.9)a	104.5 (4.9)ab
Soil stability	2.4 (0.2)a	2.3 (0.2)ab	2.1 (0.1)abc	1.8 (0.1)c	1.8 (0.2)c	2.4 (0.1)a

Table 4. Number of 30 m transects to detect 5, 10, and 20% changes in forb and grass cover. Sample size estimates based on forb and grass cover from North Parlin study site in the Gunnison Basin, Colorado collected in 2010. Sizes estimated for Dry Mountain Loam (DML) and Mountain Loam (ML) ecological sites. Median is the median number of transects across site.

	Minimum Detectable Change (%)		
	5	10	20
Grass ML	918	230	57
Grass DML	526	132	33
Grass	869	217	54
Grass Median	869	217	54
Forb ML	4970	1243	311
Forb DML	4426	1107	277
Forb	4956	1239	310
Forb Median	4956	1239	310

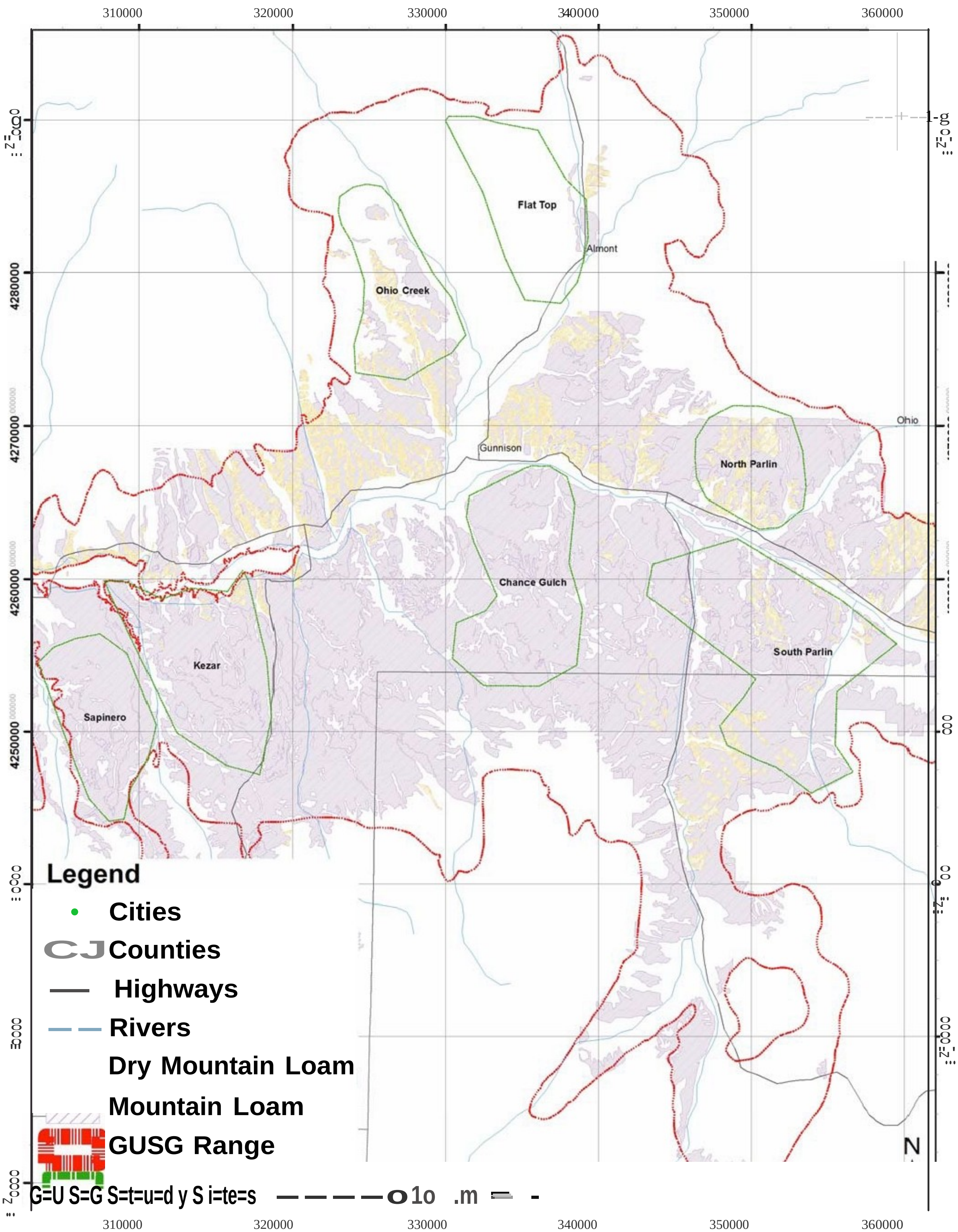

Figure 1. Baseline monitoring of soil and vegetation characteristics were measured in six study sites (Chance Gulch, Kezar, North Parlin, Ohio Creek, Sapinero, and South Parlin) within the Gururison sage-grouse range of Gunnison Basin, Colorado between July and August 2010.

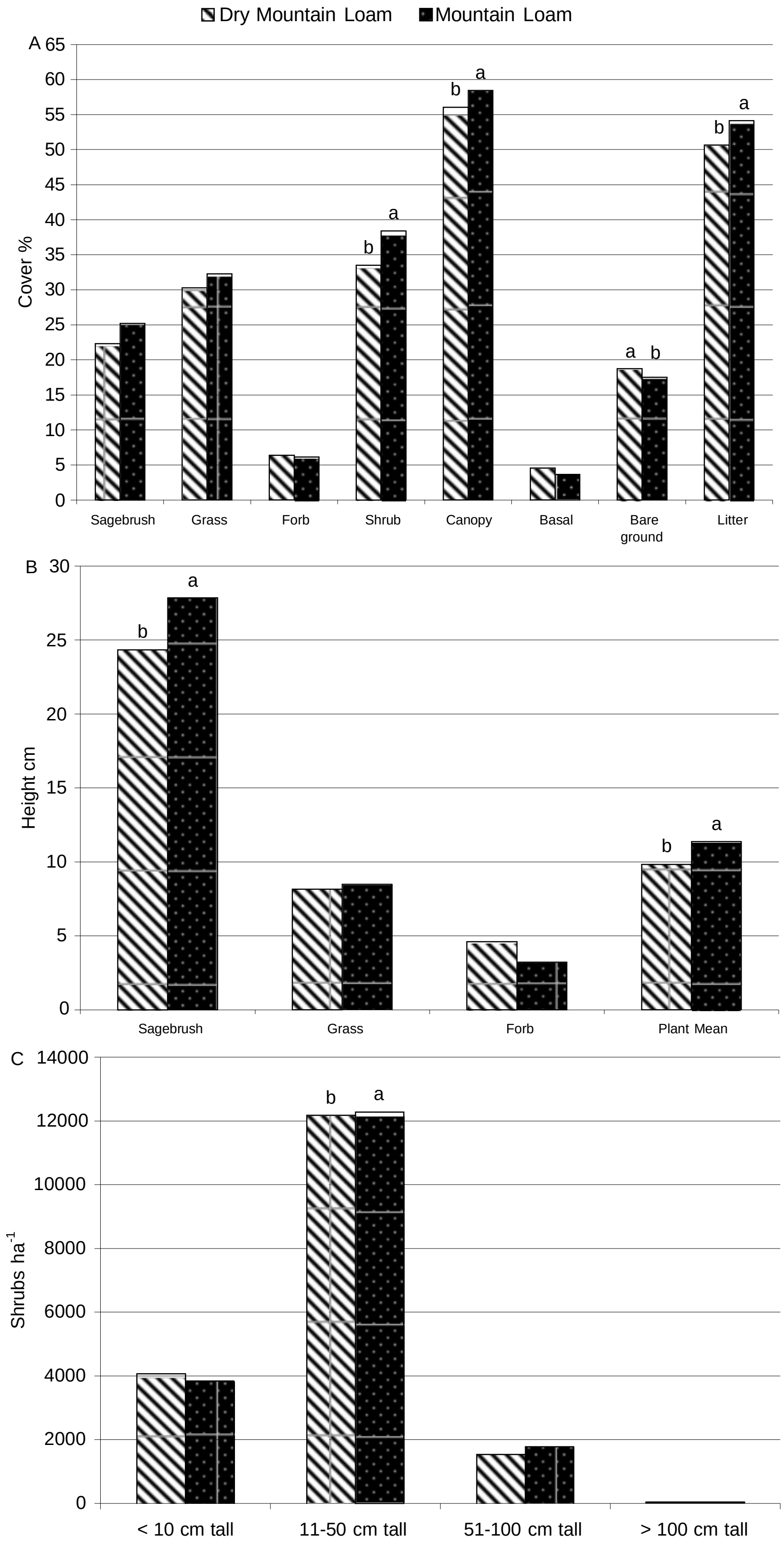

Figure 2. Dry Mountain Loam and Mountain Loam ecological site vegetative characteristics: cover (A), height (B), and shrub density (C) across six Gunnison sage-grouse study sites in the Gunnison Basin, Colorado measured in 2010. Canopy, shrub, bare ground, and litter cover and sagebrush and plant mean height were statistically different between the sites ($P \geq 0.050$).

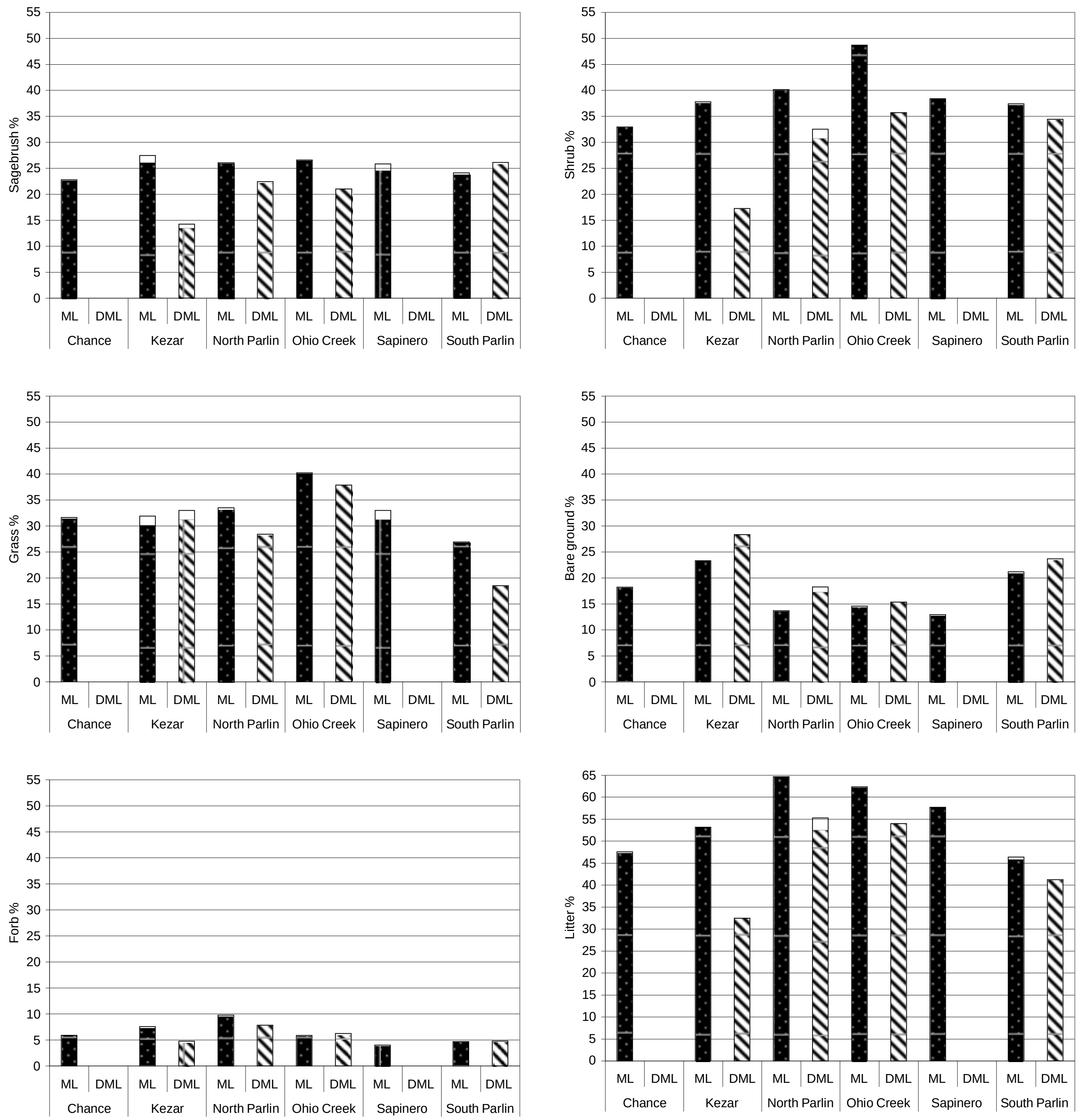

Figure 3. Cover of Dry Mountain Loam (DML) and Mountain Loam (ML) ecological sites in six Gunnison sage-grouse study sites, Colorado.

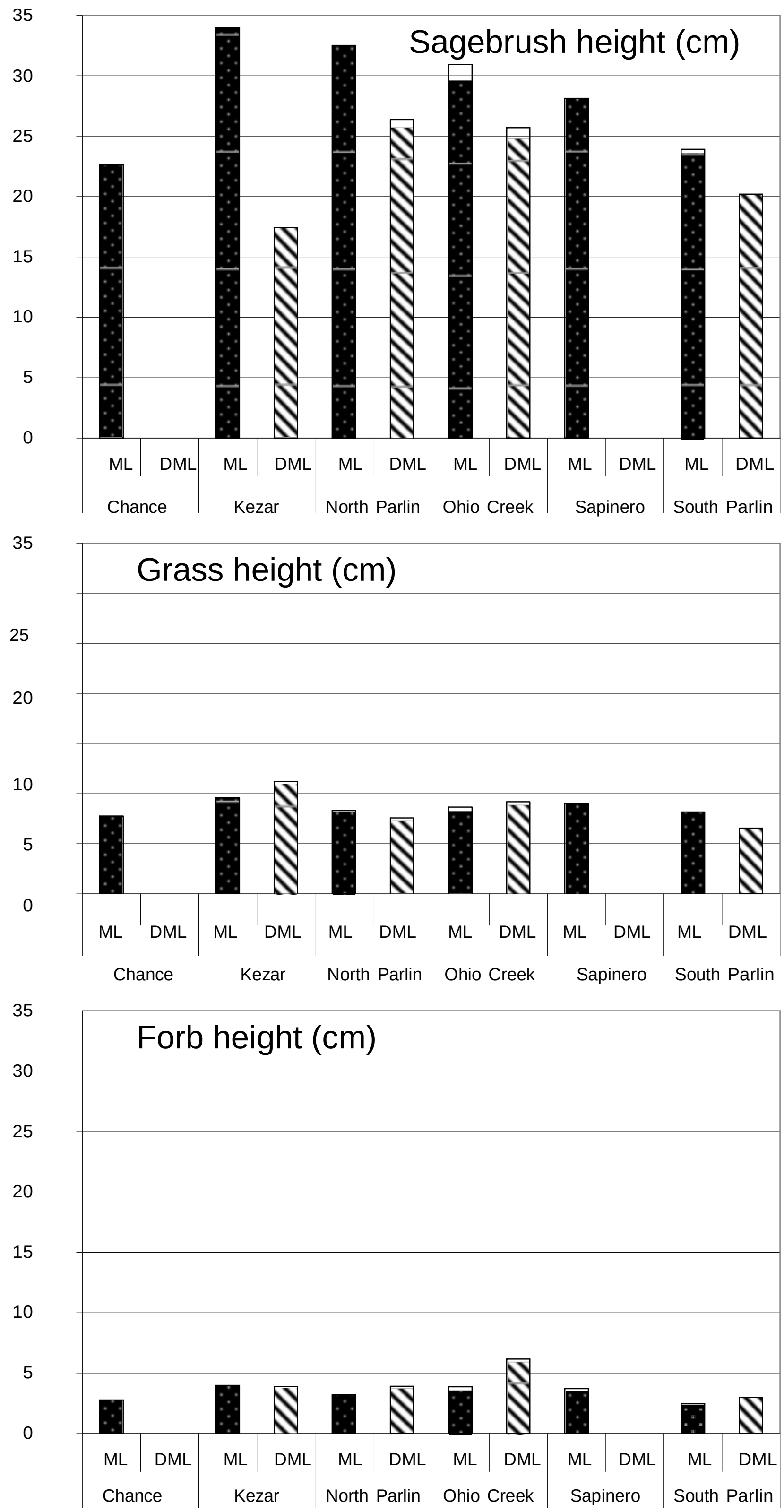

Figure 4. Sagebrush, grass, and forb height in Dry Mountain Loam (DML) and Mountain Loam (ML) ecological sites in six Gunnison sage-grouse study sites, Colorado.

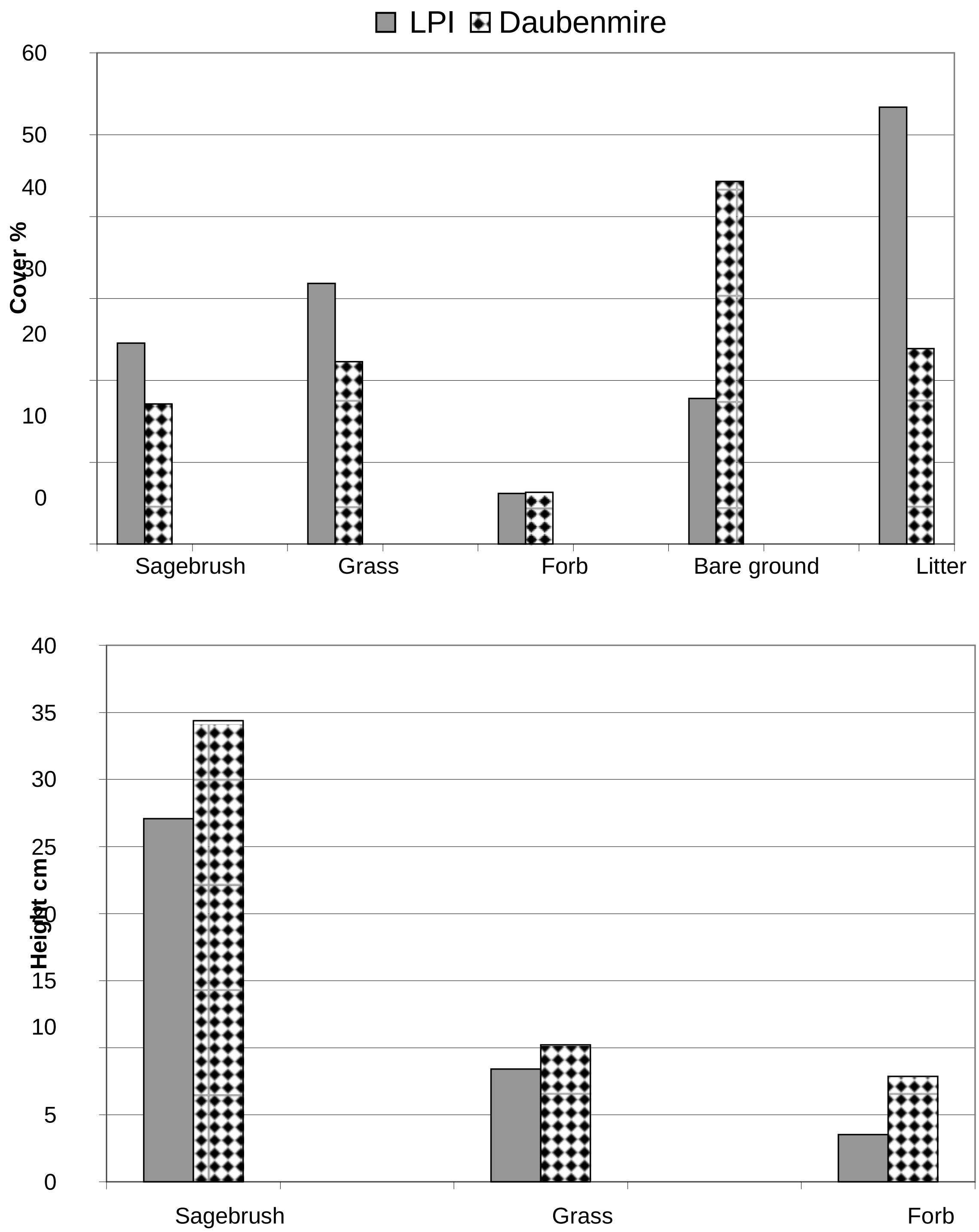

Figure 5. Cover and height of Gunnison sage-grouse habitat measured by Daubenmire and line-point intercept (LPI) methods on 392 30-m transects in 2010. Sagebrush, grass, bare ground, and litter cover and sagebrush, grass, and forb height were statistically different between the two methods ($P \geq 0.050$).

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, 2011

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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 one manuscript has been submitted for publication; all other dissertation chapters and associated manuscripts will be completed in 2012.

COLORADO DIVISION OF PARKS AND WILDLIFE – AVIAN RESEARCH PROGRAM
PROGRESS REPORT
September 2011

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

AUTHORS: M. B. Rice

PROJECT PERSONNEL: B. Petch, K. Eichhoff, J. Gammonley, A. Apa, B. Walker, M. Phillips

Period Covered: July 1, 2010 – August 31, 2011

ABSTRACT

The use of identifying core habitat areas and prediction maps for a species provides a vital tool for communication with private landowners and partner agencies. In the case of sage grouse, the recent listing of warranted but precluded warrants protection under the Endangered Species Act, but listing is currently precluded by higher priority species. This has increased the need for information on where this bird resides in Colorado and why it associates with that habitat. In Colorado, we have a large database of radio-telemetry studies from 1997-2008 from 11 studies across the northwestern portion of the state that we can use for mapping. We utilized mixed effects models which allow us to model correlations that may exist in grouped data, in the case of our model, individuals and subpopulations. Our study area was divided into 1km^2 grids where sage grouse locations were counted across the landscape as the response variable. We used a generalized linear mixed model (GLMM) in program R using vegetation variables as fixed effects and individual birds and populations as random effects to predict sage grouse location counts for each of three seasons. We found that both individual and population groupings accounted for variation within all 3 seasonal models (breeding, summer, and winter). All three seasonal models predicted sage-grouse presence in the currently delineated populations for Colorado. About 34% of the northwestern counties of Colorado are considered highly suitable habitat in each of the 3 seasons. As more development occurs in this portion of Colorado, it will become more critical to know where management actions can be accomplished and possible restoration can be explored across the range. These seasonal models provide this overall range map that managers and biologists can use for identification and further exploration when dealing with greater sage-grouse issues.

MODELING THE PROBABILITY OF GREATER SAGE-GROUSE PRESENCE ACROSS ITS DISTRIBUTION IN COLORADO
Progress Report, July 1, 2010 – August 31, 2011
Mindy B. Rice

PROJECT OBJECTIVES

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

SEGMENT OBJECTIVES

1. Develop various biologically relevant models in the telemetry database of sage grouse locations and use GIS to predict the probability of sage grouse locations in Colorado based on vegetation.

2. Provide initial prediction model for evaluation and validation before adding North Park data into model.

INTRODUCTION

Predicting species distribution across a broad geographic range can be challenging due to variability within and among regions or populations. Some studies indicate high levels of transferability of predictions among regions (Vanreusel et al. 2006) and others that argue against a uniform program for species with a large geographic range (McAlpine et al. 2008). In wildlife management for multiple populations across a large range, we need to try to develop predictive species distribution maps with small scale details but applicability across the landscape of the population (McAlpine et al. 2008). One of the more important uses for broad range potential distribution maps is for use by wildlife managers and biologists on the ground. The use of identifying core habitat areas for a species provides a vital tool for communication to private landowners and partner wildlife professionals.

The greater sage-grouse (GRSG) is a species of conservation concern due to historical population declines and range contraction (Schroeder et al. 2004) and provides an example of a species needing high quality seasonal habitat maps in the state of Colorado. Energy development is one of the major habitat concerns for GRSG as some of the largest energy reserves are in regions characterized by sagebrush habitat and public land (Harju et al. 2010). Examining conflicts between energy development and priority GRSG habitat may be essential to the future management of the species (Doherty et al. 2010). Currently, GRSG modeling has focused on season specific locations and often leks, spring breeding grounds, are a key source of information for the breeding season (Walker et al. 2007, Doherty et al. 2011). In addition, most of the current modeling methods use some form of logistic regression with a presence/absence framework, but absences are often based on random locations as proving the absence of a location can be difficult (Aldridge and Boyce 2007, Homer et al. 1993, Doherty et al. 2008, Doherty et al. 2011). Utilizing the frequency of animal locations as a continuous variable has become another option for modeling habitat associations when absence is unknown across a species range (Hall et al. 2008, Marzluff et al. 2004). In the case of sage grouse in Colorado, multiple populations exist that are separated geographically and may exhibit regional differences in habitat preferences as well as seasonal differences. In addition, we have a large dataset for GRSG that provides information for seven populations across the northwest Colorado range. Strategy 9.1.1.9 in the Colorado Greater Sage Grouse Conservation Plan called for seasonal habitats to be mapped and to provide statewide guidance on GRSG management (CGSSC 2008).

Currently, Colorado utilizes an occupied range map based on observations from field personnel updated on a 4 year rotation. This map provides a generalized spatial extent of GRSG activity in Colorado, but there is no association between the habitat encompassed by the occupied range and GRSG habitat use. In addition, most of the data is based on lek locations and any details are not incorporated into the overall shape.

One of the current challenges in habitat mapping is to use detailed information collected on individual birds to predict distributions at a broader scale (Klar et al. 2008). Generalized linear mixed models can take into account variation due to grouping variables such as individuals and populations. By incorporating random effects in the model, variation that may exist between genotypes, species, regions or time periods can be investigated (Bolker et al. 2008). By accounting for differences between these populations as well as incorporating more detailed information on individual birds, we can provide a more accurate and valid assessment for the probability of presence for sage grouse across multiple populations at a larger scale. It is the goal of this project to map seasonal habitats of GRSG in northwest Colorado at a $1km^2$ scale while accounting for variation in the data caused from grouping variables. The ultimate goal is to provide seasonal GRSG maps for managers and biologists to target prime areas of suitable habitat for future management and restoration projects.

STUDY AREA

The study area included Eagle, Garfield, Jackson, Moffat, Rio Blanco, and Routt counties in northwestern Colorado. This area is occupied by 6 populations of GRSG (Figure 1): North Park (NP), Middle Park (MP), North Eagle/South Routt (NESR), Meeker, Parachute/Piceance/Roan (PPR), and Northwest (NW) which includes 3 subpopulation zones with Northwest Zone 1 (NW_1), Northwest zone 3 (NW_3), and Northwest zone 5 (NW_5).

METHODS

Greater Sage-grouse Location Database Compilation

Telemetry locations of GRSG were compiled from 1997 to 2010 (Table 1). These data were not originally obtained with the goal of a habitat use analysis. This analysis used all GRSG telemetry studies in the state opportunistically with the idea of combining and summarizing overall GRSG habitat use patterns. Only individual GRSG that had $\geq$3 telemetry locations using VHF radio transmitters were included in the dataset used to develop distribution models (i.e., GPS locations were not used). All locations were projected to NAD83 UTM 13 and cross checked with the original data as well as with the other datasets to exclude duplicates. For each location, we included the population, individual, sex, age, date of location, year, season, and UTM coordinates. Some studies did not include sex or age in their datasets which resulted in a restricted set of information that included age and sex. Therefore, age and sex were not used in this modeling effort at the overall range scale. For those datasets that did contain age and sex information, 91.3% were female, 8.7% were male, 64.9% were adult, and 35.1% were juvenile. Seasons were temporally classified as follows: the breeding period was March through July, the summer period was July through September, and the winter period was December through February. Location data from October and November were not included as these months were considered transition periods. Populations were separated based on management zones as well as clustering (Figure 1). For these analyses location data was available from all populations except NP; contemporary location data are currently being collected for the NP population.

GIS layers and variables

I used GIS data layers in order to assess vegetation associations of GRSG. The vegetation data were obtained from the Colorado Division of Wildlife's basinwide vegetation layer with a resolution of 30m. This vegetation layer was constructed with landsat imagery at a 25m resolution as part of the Colorado

Vegetation Classification Project (CVCP) between the Colorado Division of Wildlife, Bureau of Land Management, and US Forest Service (white paper 2003). At the broad scale, I included proportions of sagebrush, pinyon juniper, agriculture, shrubland, urban, alpine, riparian, grassland, forest, bare, forest shrubland, mountain shrubland, and salt desert shrubland as variables in the model. Urban was removed as a variable because GRSG locations did not include any measure of this variable. Each of the vegetation categories were reduced from a larger set of vegetation types found in the basinwide dataset based on input from GRSG experts in Colorado as we were looking at a broader classification of habitat utilized by sage grouse (Table 2). I overlaid the 6 county study area with a grid of $1km^2$ cells. I used this scale to account for locational error associated with multiple methodologies over numerous years for the collection of radio-telemetry datasets. Only cells that contained GRSG were included in model building as I had no information about the presence or absence of GRSG in other cells. Within each grid cell, the number of GRSG locations were counted and used as the response variable for the models.

Vegetation was used to model GRSG habitat because the birds mostly rely on sagebrush for food and cover which may indicate dependence on vegetation types (Homer et al. 1993). GRSG require sagebrush throughout the year however the amount and composition of sagebrush in the landscape may differ among breeding, summer, and winter seasons (Connelly et al. 2000). In addition, other studies have demonstrated that vegetation type is an important influence on GRSG distribution (Connelly et al. 2000, Doherty et al. 2008). More localized studies have indicated that there are other variables that may be important predictors of GRSG distribution, such as elevation, slope, and aspect, but these variables likely operate at finer scales ($< 1km^2$).

Variables for the vegetation were extracted using Hawth's tools and converted to proportion of vegetation type within each grid cell where GRSG locations were recorded. The database was split into seasonal datasets based on breeding, summer, and winter locations. I calculated Pearson correlation coefficients for the vegetation variables for each seasonal dataset separately. All explanatory variables were standardized to have a mean of 0 and standard deviation of 1 to address possible convergence issues (Bolker et al. 2008, Zuur et al. 2009). Each model was run separately with the count of GRSG as the response variable. All variables for each season were included in the base model for that season, minus variables removed due to correlation (Pearson Correlation Coefficient ≥ 0.50). For the breeding model, the proportion of mountain shrubland variable was dropped due to high correlation with other variables. This resulted in using proportions of sagebrush, salt desert shrubland, forested shrubland, alpine, agriculture, grassland, shrubland, pinyon juniper, forest, bare ground, and riparian in the full model. In the winter model, proportions of salt desert shrubland, mountain shrubland, and agriculture were removed due to high correlations with other variables. This resulted in a full model that included proportions of sagebrush, forest, forested shrubland, grassland, pinyon juniper, bare ground, and riparian. For the summer model, I removed proportion of mountain shrubland due to high correlation with other variables. This resulted in a full model that included proportions of sagebrush, agriculture, grassland, salt desert shrubland, shrubland, pinyon juniper, bare ground, riparian, forest, forested shrubland, and alpine.

Data analysis

I used a generalized linear mixed model (GLMM) with random effects to investigate whether there was variance that could be explained by similarity in grouping variables. GLMM is a multivariate approach appropriate to separate potential effects of co-varying factors on the model (Martinez-Abrain et al. 2003). By associating common 'random' effects to observations sharing the same level of a classification factor, mixed effects models correctly represent the covariance structure induced by grouping data (McAlpine et al. 2008). Bolker et al. 2008 provide a summary of GLMM utilization by ecologists.

I investigated two grouping variables that might influence the data. The first variable accounted for multiple locations from each individual GRSG. The assumption is that the location of a bird at one point in time has influence on where that bird goes at a second point in time. By including marked individuals as a grouping variable, I could account for the influence of any resulting autocorrelation on the model. The second grouping variable of interest was the influence of population on the model. I assumed relationships between GRSG and vegetation variables in the same population would be more similar than those in another population and evaluated the variance attributed to this autocorrelation. Ignoring such dependence can lead to inaccurate and invalid conclusions (Olea 2009).

The response variable used in the models was a count based on the number of GRSGlocations in a grid cell, with the proportion of vegetation classes as fixed effects and individual and population as random effects. I used zero-truncated poisson regression to model these relationships since only grids with counts > 0 were included (Zuur et al. 2009). Due to the occurrence of overdispersion I used the quasi-poisson distribution with a log link (Zuur et al. 2009). Overdispersion occurs when the variance is larger than the mean which is often the case in ecological data (VerHoef and Boreng 2007). All models were run with the lmer function in the lme4 library in program R. Before each seasonal model was run, I investigated the effects the random variables alone had on the resulting model by including each grouping variable by itself as a random effect (bird, population) with no fixed effects. I then included both random effect groups to investigate which grouping variables were influencing the model the most and whether their inclusion as a random variable was necessary. For all 3 seasons, the best model based on random effects included both the individual and population grouping variables (Table 3).

The minimum adequate model (MAM) was obtained by removing from the full model those fixed variables that did not have a significant effect on the model (Vall-llosera and Sol, 2009). At each step of analysis the least significant variable in the model based on the lowest t- value was removed (Vanreusel et al. 2007, Burdett et al. 2010, Aldridge and Boyce 2007). Each model was compared using AIC and the model with the highest AIC weight was considered the best model for that season (Burnham and Anderson 2002, Koper and Manseau 2009). The top model for each season was applied to the vegetation proportion raster layers in ESRI ArcMap and the probability layer was calculated using raster calculator. This resulted in a layer for each seasonal model that shows the probability of GRSG presence from 0 to 1. In order to standardize the probabilities for comparison between seasons and to provide a more useful map for management, probability values were combined based on quantile breaks in the data resulting in four categories of highly suitable, suitable, marginal, and unsuitable (Sawyer et al. 2009, McAlpine et al. 2008). I also provide the continuous probability surface as this may be the most versatile method of viewing the models (Appendix A). In addition, proportions of habitat categories were calculated based on the population boundaries in Figure 1.

For validation, I used bootstrapping using 5000 bootstrap samples to estimate the 95% confidence interval values for the explanatory values in each season's top model (Roberts and Fan 2004). Bootstrapping provides realistic estimates of the predictive performance of a model by resampling data (Wintle et al. 2005). Bootstrapping techniques are appropriate to evaluate the model and predictions when using a single dataset (Guisan and Zimmerman 2000). Parameter estimates that fell within the confidence limits were considered reliable estimates for that model (Crowley 1992).

RESULTS

There were 17,405 GRSG radio-telemetry locations from 1414 individual GRSG available in Northwest Colorado from 1997-2010 (Table 1). Of the total locations, 79% were during the breeding season, 6% during the winter and 15% in the summer. Counts within grid cells where GRSG locations were present ranged from 1-167 during the breeding season, 1-26 during the winter season, and 1-70 for the summer season. The initial analysis consisted of evaluating the random effect variables and their ability to explain the data model without any fixed effects. The individual and population variables both contributed to the variance in each seasonal model (Table 3). This indicates that by including individual and population as random effects in the models, we can identify the explanatory variables that actually affect seasonal habitat (Vall-llosera and Sol, 2009). The variances associated with these variables will be discussed in detail with each seasonal model.

In each season, sagebrush had the highest average proportion of vegetation of all types (Table 4). The highest proportion of sagebrush was during the winter season followed by the breeding season. The second highest vegetation type found in notable quantities during the winter period was salt desert shrubland. The second highest vegetation type during the summer and breeding period was mountain shrubland, which was removed from model building due to its high correlations with sagebrush.

For the breeding season model, the best model with an AIC weight of 0.66 included salt desert shrub, agriculture, grassland, shrubland, pinyon-juniper, forest, forested shrubland, bare ground and alpine (Table 5). During the breeding season, GRSG are negatively associated with all of the variables except for a slightly positive association with grassland and alpine. The largest effect on the model was the negative relationship with forest followed by the negative relationships with forested shrubland and pinyon-juniper. The resulting probability map was broken into 4 quantile groupings resulting in the following quantile cutoffs: 0.1773, 0.7142, 0.9807, 1.0 (Figure 2). NP, NW Zone 3, and MP had > 90% of their population acreage as suitable or highly suitable habitat (Table 6). The NW zone 5 and Meeker populations also had > 85% of their population area as suitable or highly suitable. PPR had the least amount of suitable or highly suitable habitat with 67%. In all of the NW counties, 35% was considered highly suitable, 24% suitable, 22% marginal, and 19% unsuitable (Table 6). The individual and population random variables accounted for a combined 54% of the variance in the model with most of this variation at the individual level (40%). Residual variance attributed to the explanatory variables in the model was 46% (Table 3).

The best winter model included only a positive relationship with sagebrush (Table 7). The four groupings resulted in quantile cutoff values of 0.5749, 0.6630, 0.8054, and 1.0 (Figure 3). The highest proportion of suitable and highly suitable habitat was found in MP and NW zone 3 (Table 6). PPR had only 73.5% of suitable and highly suitable habitat. In all of the NW counties 32.8% was considered highly suitable, 26.5% suitable, 21.8% marginal, and 18.9% unsuitable in the winter model. Individual and population grouping variables contributed 45.5% of the variance in the model whereas the explanatory variables accounted for 54.5% of the residual variance (Table 3). Once again, the individual bird grouping variable contained the most variation with 26.5%.

The best summer model included agriculture, grassland, pinyon juniper, forest, and bare (Figure 4; Table 8). Although 4 models had AIC weights of 0.19, I chose the one with the fewest explanatory variables to provide the simplest explanation. GRSG were positively associated with grassland and negatively associated with the other variables. The quantile groupings cutoffs for the management map were 0.2870, 0.7736, 0.9547, and 1.0. The resulting probability map indicated 99.6% highly suitable and suitable habitat in NP and NW zone 3 with 94.6% (Table 6). NESR and PPR had the lowest probability of highly suitable and suitable habitat. The summer model had 34.4% highly suitable, 24.4% suitable, 21.9% marginal, and 19.0% unsuitable. The variance associated with the individual and population groupings was 39% with most of the variation at the individual level (34%). The residual variance associated with the explanatory variables was 61% (Table 3).

When the highly suitable and suitable habitat were combined from all three seasons (e.g. any cell with highly suitable and suitable ranking for winter AND summer AND breeding seasons), the NW zone 3 and NP had the largest proportion with 0.2816 and 0.1815 respectively. The highest proportion of highly suitable and suitable habitat within current BLM leases are in PPR (0.5817), NW zone 3 (0.2636), and NP (0.3737).

DISCUSSION

This analysis combined the GRSG radio-telemetry data available to model the probability of GRSG presence across 6 counties in Colorado. These seasonal maps represent the basic vegetation associations for GRSG in this region while accounting for any autocorrelation within individuals and populations. The purpose of this map is to provide baseline seasonal maps that managers or biologists can use in conservation planning for GRSG.

All three seasons indicate at a minimum suitable habitat within the current estimated GRSG range in Colorado (Appendix B). All three models also have a similar proportion of highly suitable, suitable, marginal, and unsuitable habitat within northwestern Colorado. The summer model is mostly driven by negative associations with pinyon-juniper, forest, and bare ground, which have been described in other habitat studies (Connelly et al. 2000, Connelly et al. 1988). My model supports previous results that indicate that GRSG are more tolerant of other vegetation types in the summer period (Connelly et al. 2000).

The breeding model was driven by numerous negative associations with the strongest negative associations with forest, forested shrubland, and pinon-juniper. The absence of tall shrubs and trees appears to be critical for lekking (COGRSG CP). There was a positive association with grassland which has been shown to be an important component of GRSG nest sites (Connelly et al. 2000). The model for winter was based solely on the positive relationship with sagebrush. This indicates that GRSG are much more tied to sagebrush in the winter as sagebrush fell out of both the summer and breeding models. Due to using only grid cells with GRSG locations present, all cells had sagebrush as a component (range of proportions of sagebrush in breeding season is 0.0069-1.0, during the winter season is 0.0250-1.0, and during the summer season is 0.0156-1.0). Therefore, we would expect that sagebrush would have little effect on explaining the difference between location counts if all counts were associated with sagebrush. The fact that sagebrush is driving the winter model indicates its extreme importance in winter. Sagebrush has also been found to be the main selection criteria for GRSG during winter in other studies (Connelly et al. 2000, Doherty et al. 2008).

Traditional methods of habitat selection for GRSG have been focused on the presence/absence study design, often using pseudo-absences or random locations to model the specie's distribution (Aldridge and Boyce 2007, Doherty et al. 2007). This type of modeling method is common among other species as well (Copeland et al. 2006, Kaczensky et al. 2008). Modeling the frequency of GRSG locations as a continuous variable while accounting for messy data provides a unique method for managing GRSG on a large scale where the knowledge of species absence may be unconfirmed. When utilizing a presence/absence approach, often the "random" or absence locations fall into vegetation categories that a species would not be located, but may exist across a large landscape (e.g. urban). So observed locations can be a subset of a sample of available or random locations which can cause overlap in environmental variables in a logistic regression framework (Boyce et al. 2002). Our method compared each grid that contained a location to all other grids with a location, so this method investigates those grids that have few locations to those that have many locations. This type of modeling approach allows comparisons between landscapes that are known to contain birds to see if there are patterns to why certain vegetation is utilized more than others. It's a unique way to utilize large datasets collected across a species' range over time and can provide biologists a large scale utilization map. This type of data is common to state agencies and is often overlooked as useful because the studies were not originally designed for habitat analysis, it has been collected over a long period, and the data can be messy. By utilizing a count based modeling approach, it is possible to account for messy data and provide landscape scale habitat assessments to biologists on the ground.

One characteristic common to all seasonal models is the effect of individual and population as random effects on model results. In all 3 models, more than 35% of the variation was explained by variation attributed to similarities within individual birds and within populations. Most of that variation was from the individual grouping. I would expect for individuals to account for a majority of the variation as most locations from a single individual may fall in the same $1km^2$ grid cell. This means that all locations from an individual may be in the same set of grid cells with a larger resolution resulting in more autocorrelation within individuals. Failure to account for this autocorrelation can lead to incorrect conclusions regarding effects of variables and the rank of those variables (McAlpine et al. 2008). For comparison to utilizing random effects, I ran a generalized linear model (GLM) with a poisson distribution and no random effects for the breeding model (Appendix C). I found that all variables except alpine would have been included in the model and most of the effect sizes of the variables were larger than those found in the GLMM. The GLM also had a negative grassland and sagebrush effect whereas the GLMM had no sagebrush effect and a positive grassland effect. This indicates that ignoring the grouping variables in your data can have a large effect on the resulting model and prediction map.

Each of the seasonal models indicates a high probability of GRSG in areas currently populated (Appendix B). This in itself provides a good validation for the models overall, but additional validation has been done with bootstrapping. The bootstrapping confidence intervals for all 3 seasonal models indicated that variable estimates were robust with 95% confidence. In addition, the all 3 seasonal models predicted habitat in the North Park population where no locations were included in this analysis. This provides further evidence that these models are robust and useful for management purposes.

At this broad scale, small differences between individual choices and population choices will not be detected. For example, the breeding season map includes lek attendance by males and nesting and early brood rearing by females that can be found in either heavy cover or open areas. This map will not decipher between these various behaviors. Another issue with these probability maps is that what a GRSG chooses directly around itself may be different from its location in a landscape. For example, taking measurements in a 1 m vegetation plot indicates a bird chooses pinyon juniper for cover. Expand the scale to a 1 km grid cell and the vegetation in that grid cell might be 90% sagebrush and 10% pinyon juniper indicating that individual prefers sagebrush. At the broad scale of these models, detecting specifics for individual birds or individual locations are not possible.

All 3 seasonal models provide managers and biologists on the ground a useful tool for interpreting general GRSG habitat characteristics for management actions at a large scale. It also provides maps that have been tested and validated so they can have confidence in broad scale decisions that may be made based on the map. Future analyses will investigate multiple scale issues and how it effects GRSG habitat predictions. This will include mapping habitat at the individual population scale and comparing it to the overall northwest prediction map.

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Table 1. Statewide datasets combined for the model dataset from 1997-2010.

Breeding season

Investigator	# of records	Date range	# of birds	Population	UTM
T. Apa	9341	3/2001 to 1/2008	449	NW	12
J. Beck	254	4/1997 to 12/1998	19	PPR	12
M. Cowardin	333	2/2001 to 3/2002	37	MP	13
B. Holmes	65	4/2010 to 9/2010	3	meeker	13
S. Huwer	441	3/2000 to 8/2002	50	MP	13
B. Miller	653	4/2006 to 1/2008	45	PPR	12/13
L. Rossi	405	10/2003 to 9/2007	47	NESR	13
T. Thompson	360	4/2000 to 2/2008	63	NW	12
B. Walker	1485	12/2007 to 7/2010	90	NW	12
TOTAL	13729		803		

Winter season

Investigator	# of records	Date range	# of birds	Population	UTM
T. Apa	624	3/2001 to 1/2008	137	NW	12
J. Beck	80	4/1997 to 12/1998	18	PPR	12
M. Cowardin	3	2/2001 to 3/2002	1	MP	13
B. Holmes	65	4/2010 to 9/2010	3	meeker	13
B. Miller	67	4/2006 to 1/2008	17	PPR	12/13
L. Rossi	25	10/2003 to 9/2007	8	NESR	13
T. Thompson	215	4/2000 to 2/2008	41	NW	12
	1014		225		

Summer season

Investigator	# of records	Date range	# of birds	Population	UTM
T. Apa	1721	3/2001 to 1/2008	232	NW	12
J. Beck	140	4/1997 to 12/1998	17	PPR	12
M. Cowardin	3	2/2001 to 3/2002	1	MP	13
B. Holmes	32	4/2010 to 9/2010	2	meeker	13
S. Huwer	61	3/2000 to 8/2002	17	MP	13
B. Miller	239	4/2006 to 1/2008	36	PPR	12/13
L. Rossi	264	10/2003 to 9/2007	41	NESR	13
T. Thompson	202	4/2000 to 2/2008	40	NW	12
	2662		386		

Table 2. vegetation classification from the Colorado Division of Wildlife's basinwide vegetation layer and the groupings for our sage grouse model.

Original ID number	Original vegetation class	Sage grouse model vegetation class
1	Urban	Urban
2	Residential	Urban
3	Commercial	Urban
4	Agriculture	Agriculture
5	Dryland agriculture	Agriculture
6	Irrigated agriculture	Agriculture
7	Orchard	Agriculture
9	Grass/forb rangeland	Grassland
10	Snakeweed/shrub mix	Shrubland
11	Grass dominated	Grassland
12	Forb dominated	Grassland
13	Grass/forb mix	Grassland
18	Foothill and mountain grasses	Grassland
19	Disturbed rangeland	Grassland
20	Sparse grass	Grassland
21	Shrub/brush rangeland	Shrubland
22	Sagebrush	Sagebrush
23	Saltbush	Salt desert shrub
24	Greasewood	shrubland
25	Sagebrush/gambel oak mix	Sagebrush
27	Snowberry	Shrubland
28	Snowberry/shrub mix	Shrubland
29	Bitterbrush	Shrubland
30	Salt desert shrub	Salt desert shrub
31	Sagebrush/greasewood	Sagebrush
32	Shrub/grass/forb mix	Shrubland
33	Sagebrush/grass mix	Sagebrush
34	Rabbitbrush/grass mix	Shrubland
35	Sagebrush/mesic mountain shrub	Sagebrush
38	Bitterbrush/grass mix	Shrubland
40	Sagebrush/rabbitbrush mix	Sagebrush
43	Pinon juniper	PJ
44	Juniper	PJ
46	Gambel oak	Mountain shrubland
47	Xeric mountain shrub mix	Mountain shrubland
48	Mexic mountain shrub mix	Mountain shrubland
49	Serviceberry/shrub mix	Mountain shrubland
50	Upland willow/shrub mix	Mountain shrubland
51	Manzanita	Shrubland
53	PJ-oak mix	PJ
54	PJ-sagebrush mix	PJ
55	PJ-mtn shrub mix	PJ
56	Sparse PJ/shrub/rock mix	PJ
57	Sparse juniper/shrub/rock mix	PJ
58	Juniper/sagebrush mix	PJ
59	Juniper/mountain shrub mix	PJ

62	Aspen	Forested shrubland
63	Aspen/mesic mountain shrub mix	Forested shrubland
65	Ponderosa pine	Forest
66	Englemann spruce/fir mix	Forest
67	Douglas fir	Forest
68	Lodgepole pine	Forest
69	Sub-alpine fir	Forest
70	Spruce/fir regeneration	Forest
71	Spruce/lodgepole pine mix	Forest
72	Bristlecone pine	Forest
73	Ponderosa pine/douglas fir mix	Forest
75	Limber pine	Forest
77	Lodgepole/spruce/fir mix	Forest
78	Fir/lodgepole pine mix	Forest
79	Douglas fir/englemann spruce fir mix	Forest
80	Mixed forest land	Forest
81	Spruce/fir/aspen mix	Forest
84	Douglas fir/aspen mix	Forest
86	Lodgepole pine/aspen mix	Forest
87	Spruce/fir/lodgepole/aspen mix	Forest
88	Ponderosa pine/mesic mountain	Forest
90	Barren land	Bare
91	Rock	bare
92	Talus slopes and rock outcrops	bare
93	Soil	bare
94	Disturbed soil	bare
96	Alpine meadow	Alpine
97	Alpine forb dominated	Alpine
98	Alpine grass dominated	Alpine
99	Alpine grass/forb mix	Alpine
100	Subalpine shrub community	Alpine
101	Snow	Alpine
102	Subalpine meadow	Alpine
103	Subalpine grass/forb mix	Alpine
104	Riparian	Riparian
105	Forested riparian	Riparian
106	Cottonwood	Riparian
108	Conifer riparian	Forest
109	Shrub riparian	Riparian
110	Willow	Riparian
111	Exotic riparian shrubs	Riparian
112	Herbaceious riparian	Riparian
113	Sedge	Riparian
114	Water	Riparian

Table 3. Random effects influence on the model without explanatory variables included for each season for Greater sage grouse based on AIC values.

Grouping variable(s)	breeding	winter	summer
Bird	10127	659	1777
Population	20423	853	3028
Population and bird	10039*	652*	1776*

* Lowest AIC value indicating the best grouping variables to use in the GLMM

Table 4. Average values within each seasonal dataset for each vegetation class, elevation, and slope. All vegetation categories are in proportion values.

Variable	Breeding	Summer	Winter
Agriculture	0.0168	0.0251	0.0100
Grassland	0.0471	0.0602	0.0214
Shrubland	0.0390	0.0326	0.0362
Sagebrush	0.6897	0.6309	0.7082
Salt desert shrub	0.0234	0.0119	0.1279
Pinyon juniper	0.0401	0.0411	0.0189
Mountain shrub	0.0942	0.1332	0.0367
Bare	0.0164	0.0089	0.0191
Forest shrub	0.0197	0.0309	0.0147
Forest	0.0031	0.0055	0.0003
Alpine	0.0006	0.0011	0.0004
Riparian	0.0110	0.0186	0.0062

Table 5. a) Breeding season models tested with the best model selected based on the highest AIC weight. (variables are abbreviated as follows: sb=sagebrush, ag=agriculture, gl=grassland, sd=salt desert shrub, sh=shrubland, pj=pinyon juniper, f= forest, fs=forested shrub, ms=mountain shrub, b= bare, a=alpine). b) coefficients for the top breeding model.

a).

Variable	# variables	AIC	AIC weight
sb, sd, ag, gl, sh, pj, f, fs, b, a, r	12	8581	0.0894
sd, ag, gl, sh, pj, f, fs, b, a, r	11	8579	0.2429
sd, ag, gl, sh, pj, f, fs, b, a	10	8577	0.6604
sd, ag, gl, sh, pj, f, fs, b	9	8586	0.0073

*top model based on AIC weight

b).

Variable	Beta	SE	t-value	Bootstrap CI	
				Lower	Upper
Int	1.6062	0.6119	2.625	1.594	1.750
sd	- 2.5139	0.5557	- 4.524	- 3.587	- 1.117
ag	- 2.3508	0.5392	- 4.360	- 2.526	- 0.273
gl	0.7767	0.6313	1.230	- 1.135	2.232
sh	- 1.4719	0.5866	- 2.509	- 3.711	- 0.059
pj	- 4.0375	0.5191	- 7.778	- 4.305	- 2.010
f	- 6.5052	1.8570	- 3.503	- 9.299	- 1.900
fs	- 4.3974	0.8102	- 5.427	- 4.614	- 0.687
b	- 2.8574	0.9011	- 3.168	- 4.268	- 0.748
a	1.0354	0.8928	1.160	- 2.004	3.1

Table 6. Percentage of highly suitable (HS), suitable (S), marginal (M), and unsuitable (US) habitat in each of the eight populations in the northwestern region of Colorado based on seasonal models.

		Breeding				Winter				Summer			
Population	Acreage	HS	S	M	US	HS	S	M	US	HS	S	M	US
PPR	602,230	27.83	39.13	32.24	0.81	22.08	51.44	24.54	1.94	40.54	23.51	35.34	0.61
NW1	187,736	45.40	30.20	22.45	1.95	51.48	29.28	16.57	2.67	48.42	34.83	15.33	1.43
NW3	812,374	75.27	20.67	4.06	0.0	75.89	17.05	6.51	0.55	64.98	29.58	5.36	0.08
NW5	502,340	49.22	38.02	12.60	0.16	52.83	32.12	13.54	1.51	35.81	43.55	20.19	0.46
NP	414,871	77.12	20.81	2.06	0.0	68.43	14.22	11.78	5.56	79.58	19.98	0.42	0.02
NESR	246,344	36.93	33.29	26.14	3.63	47.41	34.78	14.53	3.28	31.82	38.71	26.06	3.41
MP	273,815	62.48	30.52	5.97	1.03	73.72	19.85	5.94	0.97	45.77	40.46	12.67	1.10
Meeker	97,466	52.96	35.63	10.12	1.28	54.30	32.78	10.19	2.73	43.56	44.36	11.34	0.75

Table 7. a) Winter season models tested with the best model selected based on the highest AIC weight. (variables are abbreviated as follows: sb=sagebrush, gl=grassland, sh=shrubland, pj=pinyon juniper, f= forest, fs=forested shrub, ms=mountain shrub, b= bare, a=alpine). b) coefficients for the top winter model.

a).

Variable	# variables	AIC	AIC weight
sb, gl, sh, pj, f, fs, b, a, r	10	626	0.0005
sb, gl, pj, fs, b, a, r	9	625	0.0008
sb, gl, pj, fs, b, a, r	8	623	0.0021
sb, gl, pj, fs, b, a	7	621	0.0057
sb, gl, pj, fs, a	6	619	0.0154
sb, gl, pj, fs	5	617	0.0419
sb, gl, pj	4	615	0.1139
sb, pj	3	613	0.3095
sb	2	612	0.5103*

*top model based on AIC weight

b).

Variable	Beta	SE	t-value	Bootstrap CI	
				Lower	Upper
Int	0.6735	0.2305	2.923-	0.459	0.836
sb	1.2173	0.2675	4.550	1.172	1.4442

Table 8. a) Summer season models tested with the best model selected based on the highest AIC weight. (variables are abbreviated as follows: sb=sagebrush, ag=agriculture, gl=grassland, sd=salt desert shrub, sh=shrubland, pj=pinyon juniper, f= forest, fs=forested shrub, ms=mountain shrub, b= bare, a=alpine). b) coefficients for the top summer model.

a).

Variable	# variables	AIC	AIC weight
sd, sb, ag, gl, sh, pj, f, fs, b, a, r	12	1702	0.0262
sd, ag, gl, sh, pj, f, fs, b, a, r	11	1700	0.0713
sd, ag, gl, sh, pj, f, fs, b, r	10	1699	0.1176*
sd, ag, gl, sh, pj, f, fs, b	9	1698	0.1938
ag, gl, sh, pj, f, fs, b	8	1698	0.1938
ag, gl, sh, pj, f, b	7	1698	0.1938
ag, gl, pj, f, b	6	1698	0.1938
gl, pj, f, b	5	1704	0.0097

*top model based on AIC weight

b).

Variable	Beta	SE	t-value	Bootstrap CI	
				Lower	Upper
Int	1.1586	0.3643	3.180	1.256	1.508
ag	- 0.9729	0.9891	- 0.984	- 2.247	0.978
gl	1.6303	1.2225	1.334	- 0.712	4.650
pj	- 2.5974	1.2807	- 2.028	- 3.876	0.234
f	- 4.6101	3.5002	- 1.317	- 10.123	1.115
b	- 3.7371	3.4692	- 1.077	- 8.867	- 0.766

Figure 1. The eight populations of Greater Sage grouse in Northwestern 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.

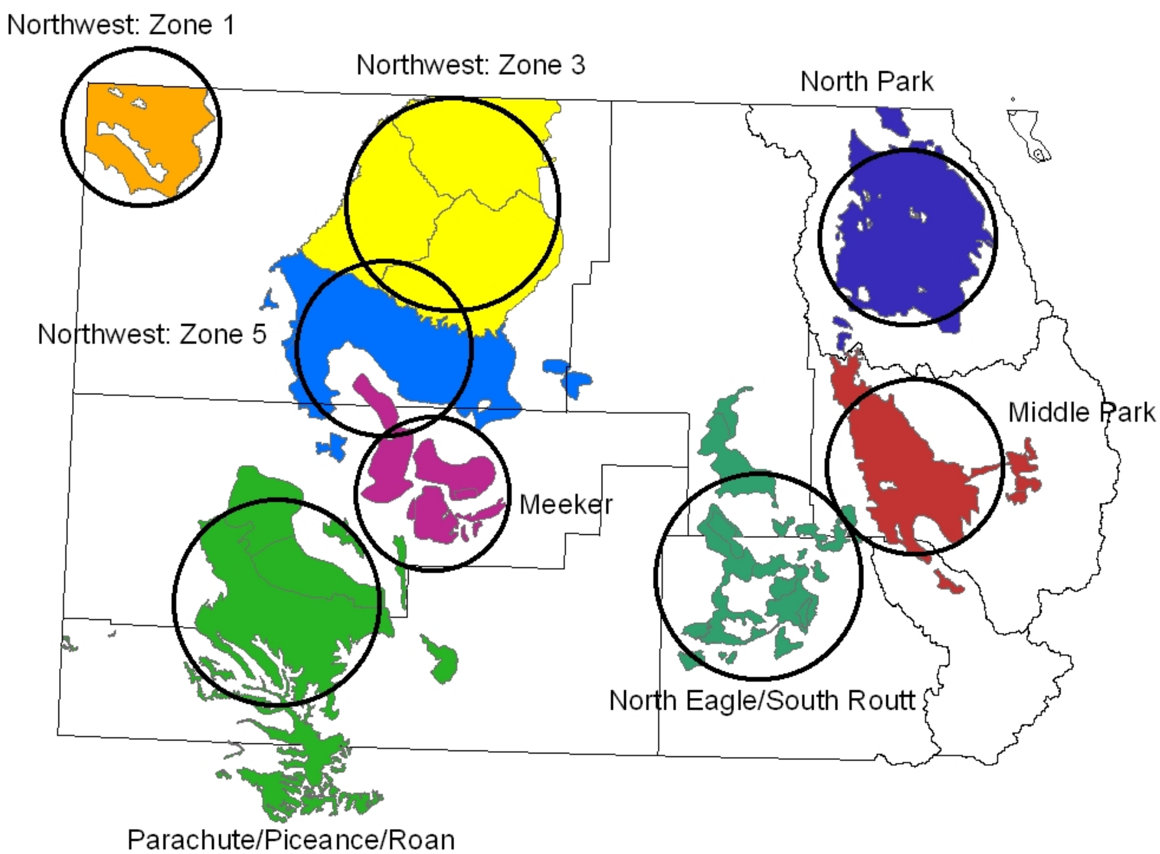


Figure 2. Probability of sage grouse presence in Northwest Colorado during the breeding season.

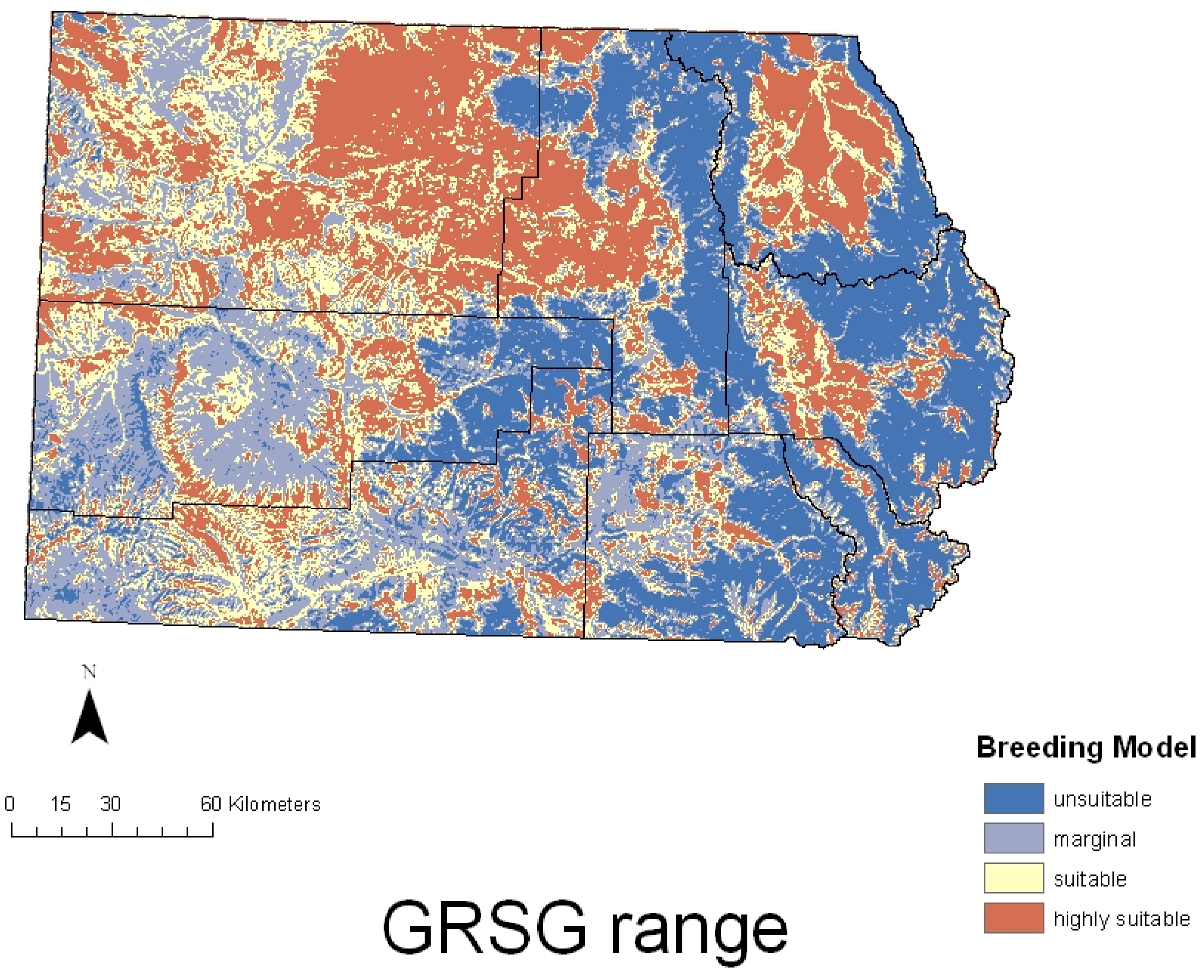


Figure 3. Probability of sage grouse presence in Northwest Colorado during the winter season.

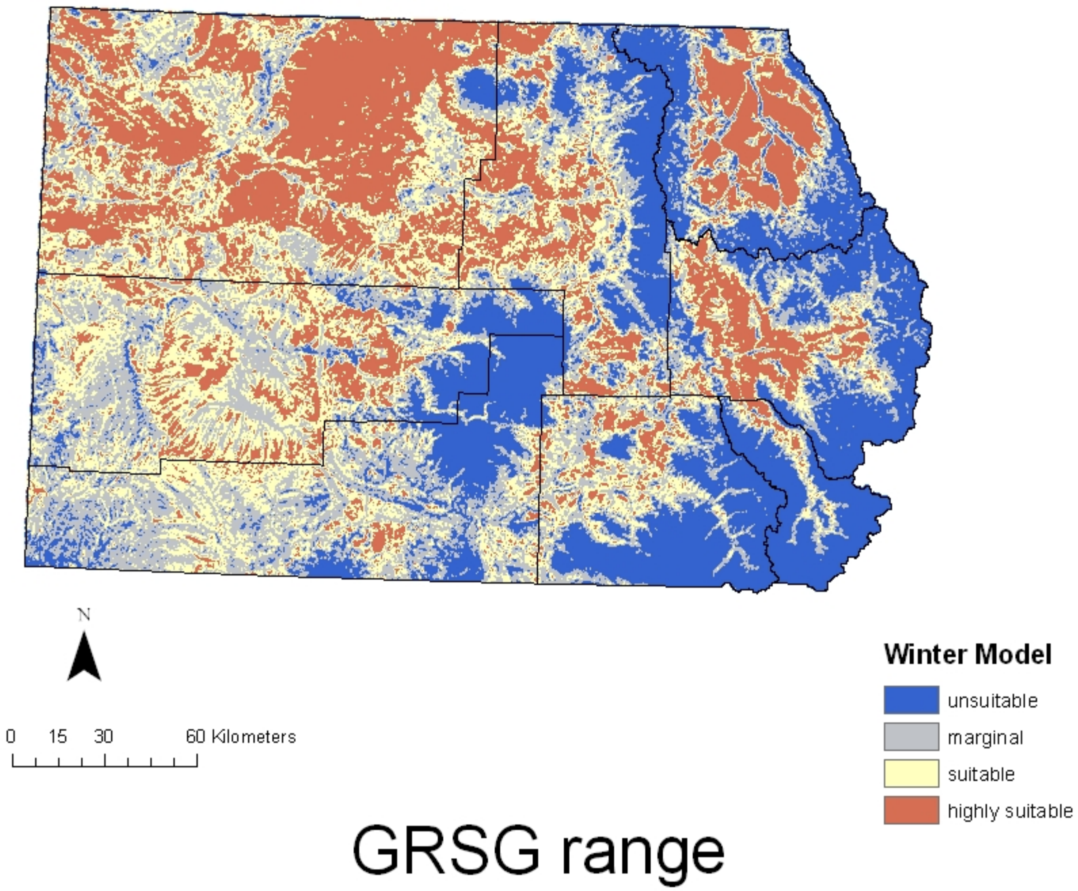
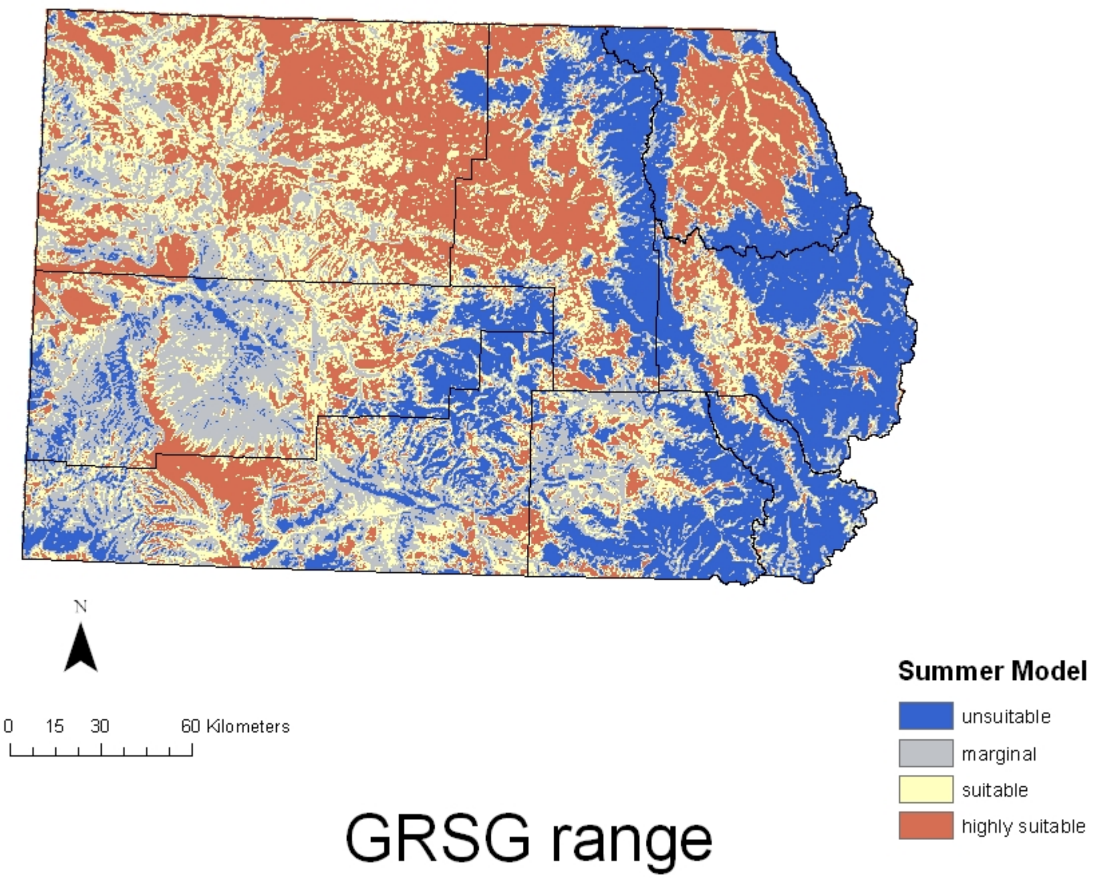
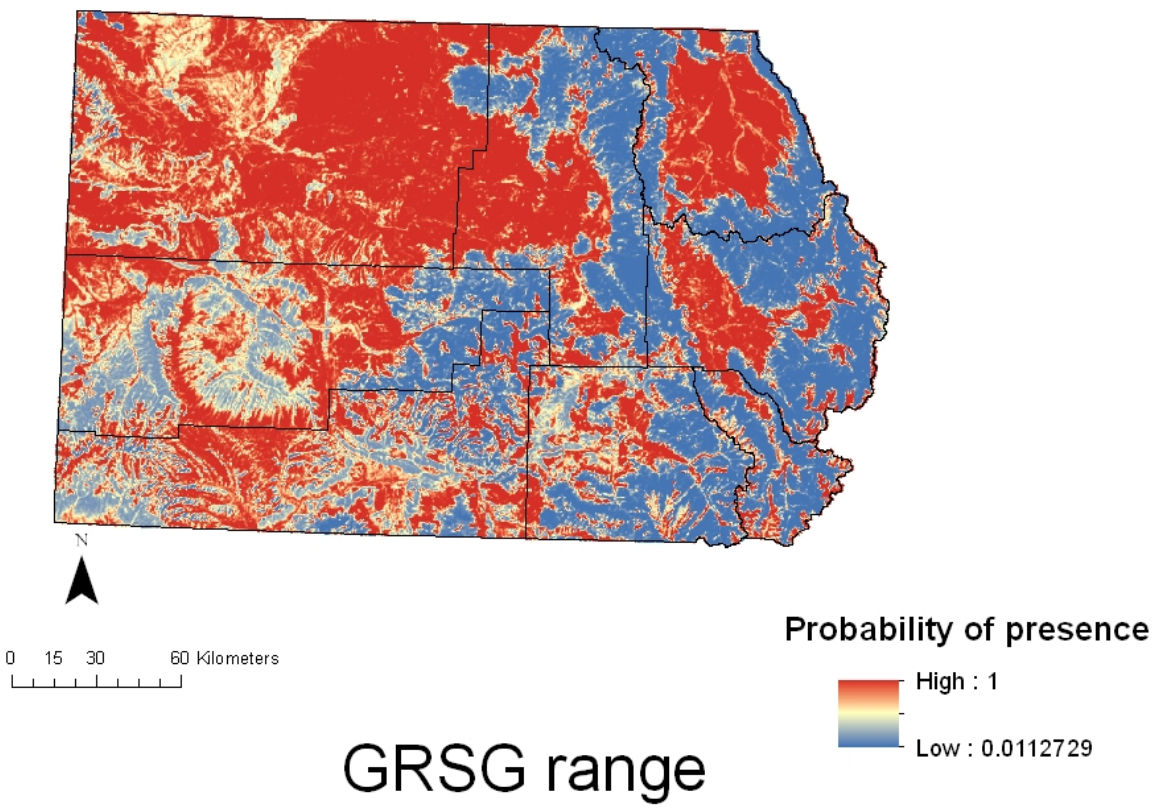


Figure 4. Probability of sage grouse presence in Northwest Colorado during the summer season.

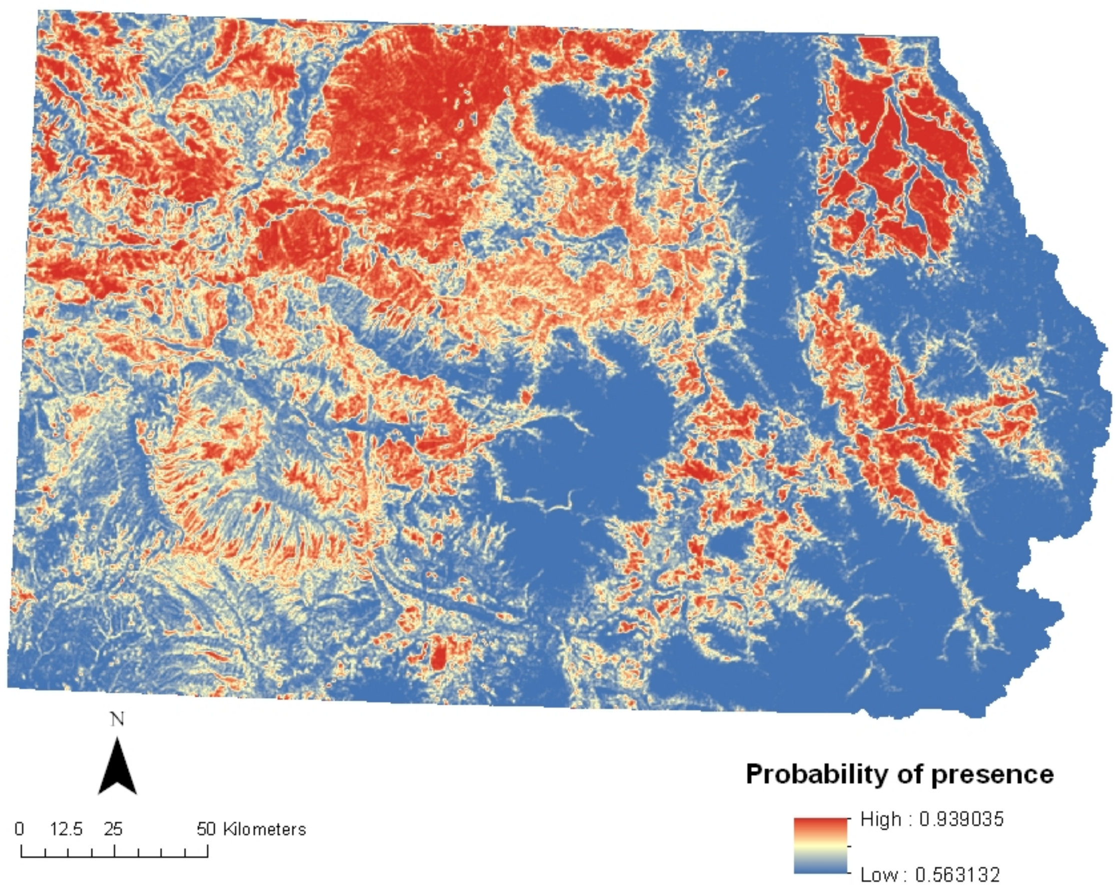


Appendix A. The original probability surfaces for (a) breeding, (b) winter, and (c) summer Greater Sage grouse habitat in northwest Colorado.

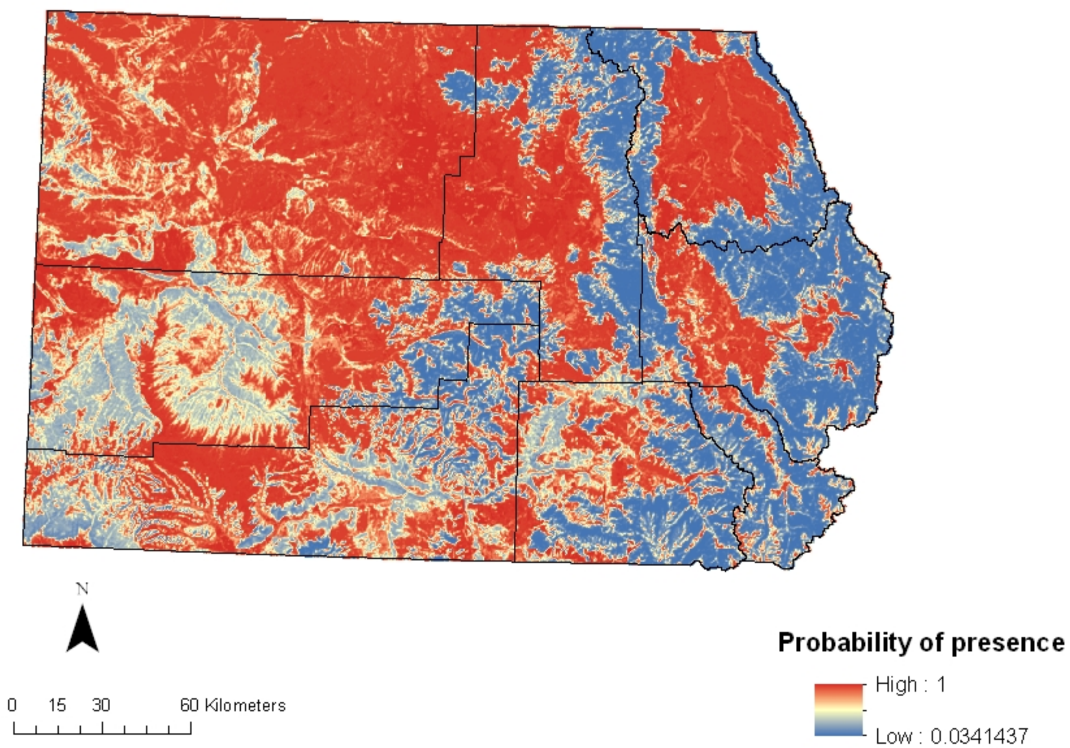
(a)



(b)


N
0 12.5 25 50 Kilometers
Probability of presence
High : 0.939035
Low : 0.563132

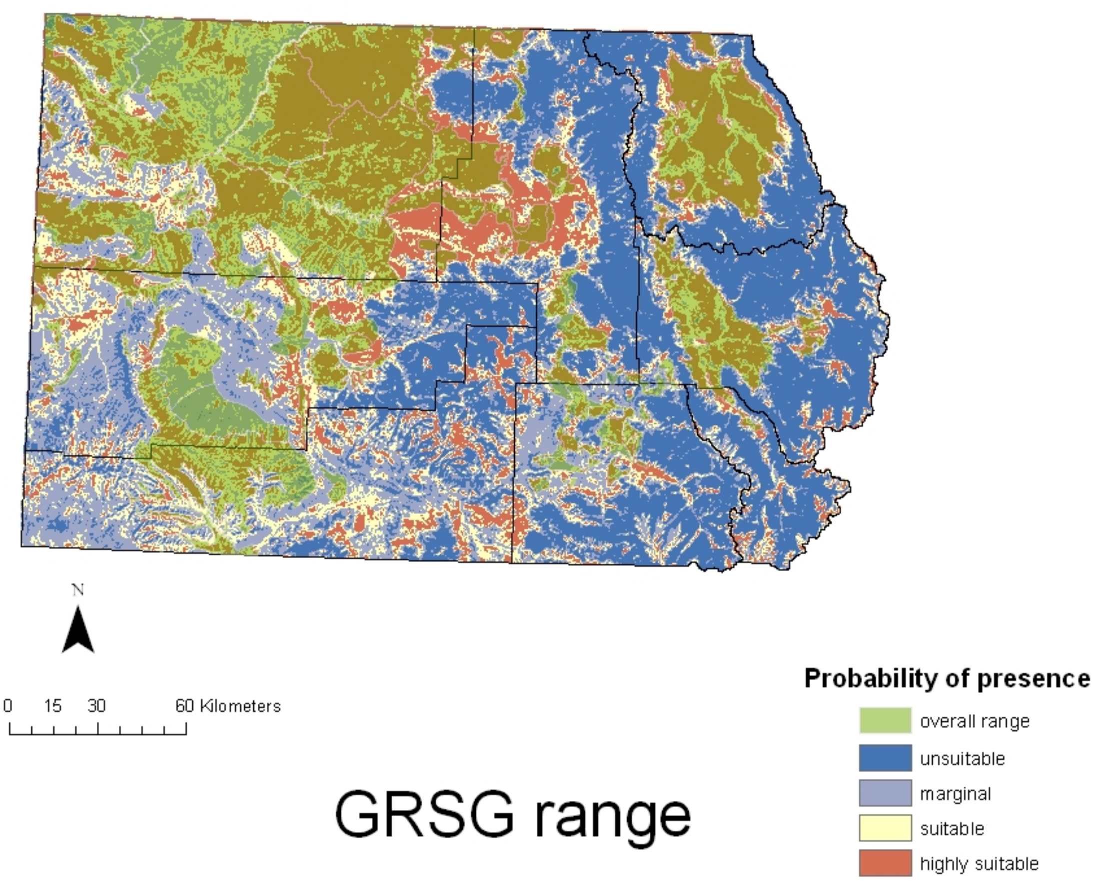
c)


N
0 15 30 60 Kilometers
Probability of presence
High : 1
Low : 0.0341437

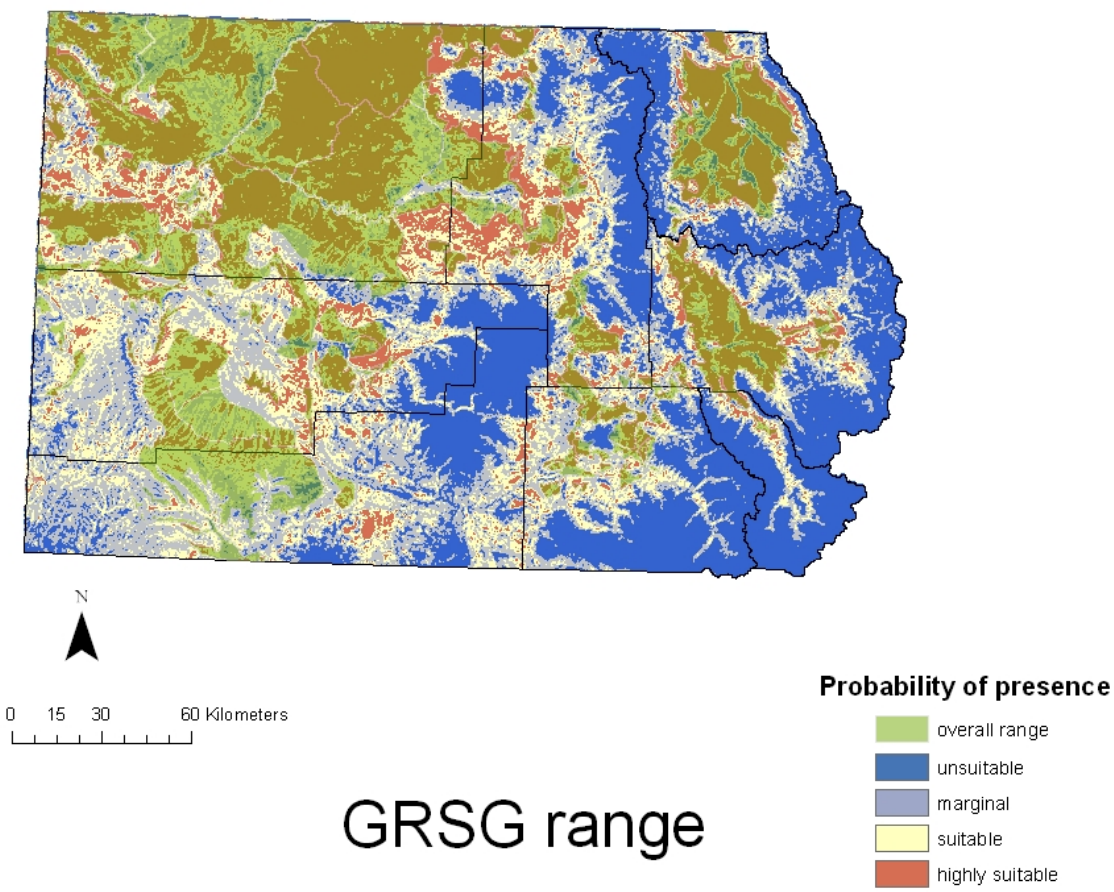
GRSG range

Appendix B. Greater sage-grouse models for the northwest Colorado population compared to the current and historical sage grouse range in Colorado for (a) breeding, (b) winter, and (c) summer habitat.

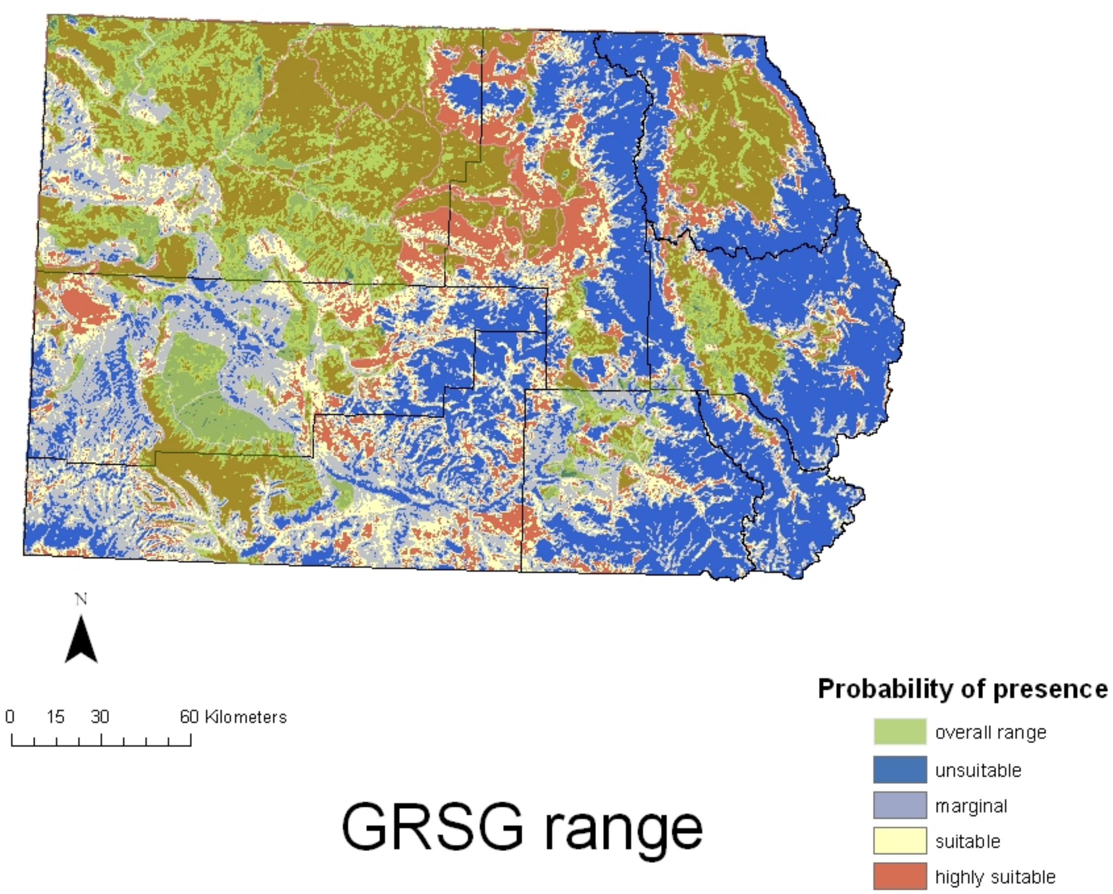
a) breeding



b) winter


N
0
15
30
60 Kilometers
Probability of presence
overall range
unsuitable
marginal
suitable
highly suitable
GRSG range

c) summer


N
0 15 30 60 Kilometers
GRSG range
Probability of presence
overall range
unsuitable
marginal
suitable
highly suitable

Appendix C. a) Testing a Generalized Linear Model with the Breeding season data and no random effects with the best model selected based on the highest AIC weight. (variables are abbreviated as follows: sb=sagebrush, ag=agriculture, gl=grassland, sd=salt desert shrub, sh=shrubland, pj=pinyon juniper, f= forest, fs=forested shrub, ms=mountain shrub, b= bare, a=alpine). b) coefficients for the top breeding model based on the generalized linear model

a).

Variable	# variables	AIC	AIC weight
sb, sd, ag, gl, sh, pj, f, fs, b, a, r	12	27983	0.2689
sb, sd, ag, gl, sh, pj, f, fs, b, r	11	27981	0.7311
sb, sd, ag, sh, pj, f, fs, b, r	10	28011	0.0000

*top model based on AIC weight

b).

Variable	Beta	SE	z-value
Int	2.2510	0.0085	265.181
sd	- 3.1766	0.1287	- 24.68
ag	- 4.1890	0.1511	- 27.73
gl	- 0.8696	0.1572	- 5.53
sh	- 1.7335	0.1475	- 11.75
pj	- 2.9913	0.1389	- 21.53
f	- 11.5183	0.6509	- 17.70
fs	- 5.2287	0.2352	- 22.24
b	- 5.3074	0.2324	- 22.84
sb	- 1.9813	0.0661	- 29.98
r	- 14.6905	2.1530	- 6.82

COLORADO PARKS AND WILDIFE – AVIAN RESEARCH PROGRAM
PROGRESS REPORT
September 2011

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

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

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

Period Covered: August 11, 2010 – August 31, 2011

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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. GRSG habitat use is known to be influenced by both landscape-scale factors 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 maps depicting seasonal habitat areas within larger landscapes across the range of GRSG in Colorado would be useful for agencies and industry to make informed decisions for conservation and mitigation. The proposed EOG Resources Energy Development (EOG RED) is within occupied range of GRSG and includes 7 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 digital maps showing GRSG seasonal habitat throughout North Park, including the proposed EOG RED oil field, 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 117 female GRSG in April 2010 and 2011. We will continue to radio-track these GRSG through the winter 2011-2012. We collected habitat measurements at used and unused locations for all seasonal habitats.

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

Progress Report, August 11, 2010 – August 31, 2011

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 and brood success.
2. Monitor used and unused sites for seasonal habitat model development.
3. Mark an additional sample of females and obtain a second season of demographic and movement data.

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 Parks and Wildlife (CPW) 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. 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. 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 was 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 EOG 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 4-wheel drive ATV. 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 1.0% or 1.2% of the body weight for adult and yearling females, respectively.

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-marked 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 corrected 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. A diagram of the nest location was drawn to assist with nest location after the cessation of nesting when the precise UTM location was collected. 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. Nest shrub species and height were measured. The height of the lowest live and dead nest bush branch above the nest bowl was measured from the edge of the nest bowl. Canopy cover (foliar intercept) of the shrub species overstory was determined using line intercept (Canfield 1941). 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 2.5 m, 5 m, and 10 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 were 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%. A single microplot was located at the nest bowl. Subsequent plots were placed systematically along 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 and unsuccessful females were located 1-2 times/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. Microhabitat variables were measured at brood and unsuccessful female sites. We estimated 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).

RESULTS AND DISCUSSION

A total of 95 female GRSG (Yearling = 22, Adult = 73) were radio-marked throughout the study area in April 2010. Of these, 51 females were still being tracked in March 2011, when an additional 22 females (Yearling = 18, Adult = 3, Unknown = 1) were radio-marked. In 2010 and 2011, 86 and 62 nests were documented, respectively. In 2010, apparent nest success was 47% (n = 40/86) and female success was 44% (n = 40/90). In 2011, apparent nest success was 64% (n = 40/62) and female success was 61% (40/65). Additionally, in 2010 and 2011 nest initiation rates were 88% (n = 80/91) and 85% (n = 55/65), respectively.

To date more than 4,200 use locations have been obtained. At the writing of this report 64 females are being actively monitored. Use locations suggest that habitats throughout North Park are extensively used during the breeding (Fig. 3), summer (Fig. 4) and winter (Fig. 5) seasons. Vegetation sampling was conducted on 82 nest, 115 non-use, 28 brood sites and 13 non-brood female, and 15 winter sites and these data are in the analyses phase. The vegetation data has been summarized and include the variables of total shrub cover (TOTSHRUBCC), grass height (GRASSHT), big sagebrush height (SAGEHT), total sagebrush cover (TOTSAGECC), forb cover (FORBCOV), perennial grass cover (PERGRASSCOV), bare ground (BAREGRD), litter cover (LITTERCOV), non-sagebrush cover (NONSAGECC), forb height (FORBHT), sagebrush nest bush height (SAGEHTNESTBUSH) (this variable represents sagebrush height at the 0 m pont for the 4 intersecting transects), forb species richness (FORBRICHNESS) and grass species richness (GRASSRICHNESS) for nest (Table 1), brood (Table 2), non-use (Table 3), and non-brood female (Table 4) sites.

Twenty-two yearling and 73 adult females were used to estimate annual survival from April 2010 through March 2011 (Fig. 6). Annual survival was 0.82 ± 0.02 (95% CI = 0.66 – 0.97) for yearling females and 0.49 ± 0.01 (95% CI = 0.37 – 0.60) for adult females. These estimates are generally consistent with a previous survival estimate for yearling (0.78 ± 0.03; 95% CI 0.72 – 0.75) and adult (0.59 ± 0.01; 95% CI 0.57 – 0.61) females for a 17-year banding study in North Park (Zablan *et al.* 2003). Yearling female survival was relatively consistent and steady through January followed by a small decline in February and March (Fig. 6). Adult female survival (females 2 years of age or older) declined consistently from capture through March 2011 (Fig. 6). The 2010-11 winter was considered severe and the annual survival rate for yearling females was higher than previously reported and was slightly lower than previously reported for adult females in North Park (Zablan *et al.* 2003). Additional data analyses are on-going with a final report planned for mid-2012.

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Table 1. Vegetation structure variable mean, SE, minimum and maximum values at greater sage-grouse female nest sites in North Park, Colorado, 2010.

	SITE			
	NEST		RANGE	
VARIABLE	***n***	**Mean ± SE**	**MIN**	**MAX**
TOTSHRUBCC	82	49.0 ± 1.4	23.4	81.8
GRASSHT	82	13.7 ± 0.5	7.0	32.2
SAGEHT	82	39.9 ± 2.2	12.3	177.4
TOTSAGECC	82	42.2.± 1.5	0.0	72.8
FORBCOV	82	10.0 ± 1.1	0.1	46.5
PERGRASSCOV	82	22.4 ± 1.1	4.9	51.7
BAREGRD	82	28.4 ± 1.9	0.4	70.0
LITTERCOV	82	60.0 ± 1.9	20.8	89.2
NONSAGECC	82	6.7 ± 1.1	0.0	63.4
FORBHT	81	7.7 ± 0.6	2.2	35.0
SAGEHTNESTBUSH	82	57.1 ± 1.6	32.0	124.0
FORBRICHNESS	81	5.4 ± 0.3	1.0	13.0
GRASSRICHNESS	81	4.5 ± 0.2	1.0	8.0

Table 2. Vegetation structure variable mean, SE, minimum and maximum values at greater sage-grouse female brood sites in North Park, Colorado, 2010.

	SITE			
	BROOD		RANGE	
VARIABLE	***n***	**Mean ± SE**	**MIN**	**MAX**
TOTSHRUBCC	28	19.0 ± 3.6	0.0	55.3
GRASSHT	28	13.5 ± 1.1	6.1	37.5
SAGEHT	28	33.1 ± 3.9	14.3	63.9
TOTSAGECC	28	13.5.± 3.1	0.0	47.0
FORBCOV	27	15.5 ± 2.3	1.2	44.2
PERGRASSCOV	28	43.3 ± 4.9	5.8	85.8
BAREGRD	28	19.3 ± 3.5	0.1	55.8
LITTERCOV	28	53.0 ± 4.0	21.1	91.1
NONSAGECC	28	5.5 ± 1.6	0.0	33.9
FORBHT	81	7.7 ± 0.6	2.2	35.0
SAGEHTNESTBUSH[1]	14	39.4 ± 5.8	10.0	89.0
FORBRICHNESS	28	5.5 ± 0.5	1.0	11.0
GRASSRICHNESS	28	4.9 ± 0.3	2.0	7.0

[1]A nest is not located at this site. This variable is representative of a sagebrush bush measured at the transect intersection for comparison to the same variable in Table 1.

Table 3. Vegetation structure variable mean, SE, minimum and maximum values at unsuccessful greater sage-grouse female use sites in North Park, Colorado, 2010.

	SITE			
	FEMALE SUMMER		RANGE	
VARIABLE	***n***	**Mean ± SE**	**MIN**	**MAX**
TOTSHRUBCC	13	17.8 ± 4.2	0.0	42.2
GRASSHT	13	13.2. ± 3.3	5.8	51.4
SAGEHT	10	23.3 ± 2.0	12.5	30.8
TOTSAGECC	13	15.2.± 3.7	0.0	40.2
FORBCOV	13	16.1 ± 5.7	0.8	76.5
PERGRASSCOV	13	32.6 ± 6.6	8.9	87.3
BAREGRD	13	23.8 ± 5.3	0.0	56.9
LITTERCOV	13	54.6 ± 5.8	26.5	91.1
NONSAGECC	13	2.6 ± 0.8	0.0	9.1
FORBHT	13	7.2 ± 1.9	2.3	29.5
SAGEHTNESTBUSH[1]	9	24.8 ± 4.5	3.0	46.0
FORBRICHNESS	13	4.8 ± 0.6	2.0	9.0
GRASSRICHNESS	13	4.4 ± 0.3	3.0	7.0

[1]A nest is not located at this site. This variable is representative of a sagebrush bush measured at the transect intersection for comparison to the same variable in Table 1.

Table 4. Vegetation structure variable mean, SE, minimum and maximum values at non-use sites in North Park, Colorado, 2010.

	SITE			
	NONUSE		RANGE	
VARIABLE	***n***	**Mean ± SE**	**MIN**	**MAX**
TOTSHRUBCC	115	24.5 ± 1.8	0.0	84.4
GRASSHT	113	15.4 ± 1.0	4.7	87.3
SAGEHT	78	30.6 ± 1.9	6.3	97.0
TOTSAGECC	115	15.5 ± 1.6	0.0	79.9
FORBCOV	109	14.7 ± 1.4	0.0	77.3
PERGRASSCOV	109	30.8 ± 2.3	0.4	94.2
BAREGRD	114	27.1 ± 2.0	0.0	85.8
LITTERCOV	114	54.6 ± 2.4	6.5	100.0
NONSAGECC	82	6.7 ± 1.1	0.0	63.4
FORBHT	108	8.5 ± 0.7	0.7	41.7
SAGEHTNESTBUSH[1]	71	28.2 ± 2.4	4.0	80.0
FORBRICHNESS	112	5.3 ± 0.3	0.0	14.0
GRASSRICHNESS	113	4.3 ± 0.2	1.0	11.0

[1]A nest is not located at this site. This variable is representative of a sagebrush bush measured at the transect intersection for comparison to the same variable in Table 1.

Figure 1. Study area depicting land ownership, core area designation, lek locations, and oil and gas well locations in North Park, Jackson County, Colorado, 2010.

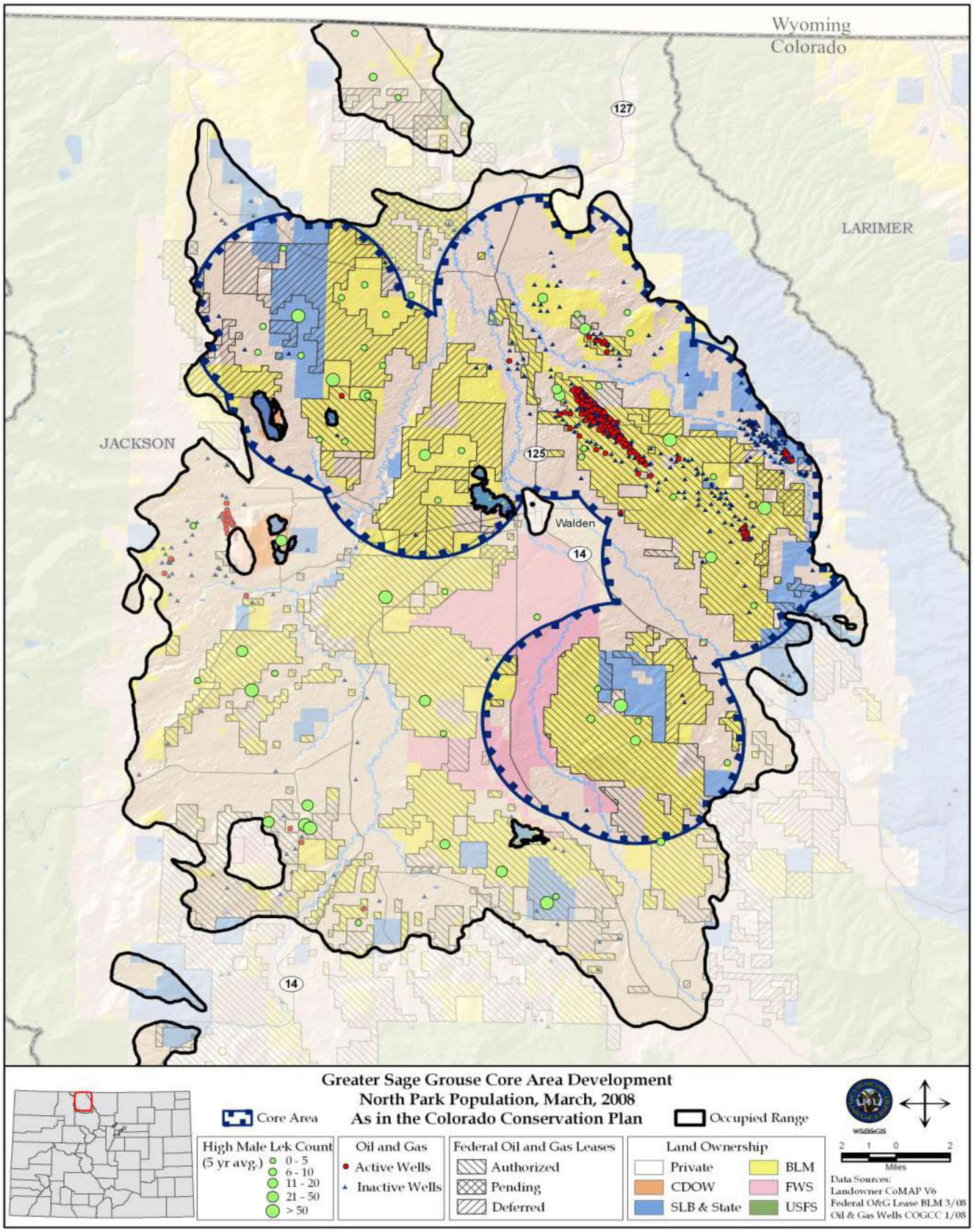


Figure 2. Study area depicting lek locations, core areas and varying status of EOG exploration activities in North park, Jackson County, Colorado, 2010.

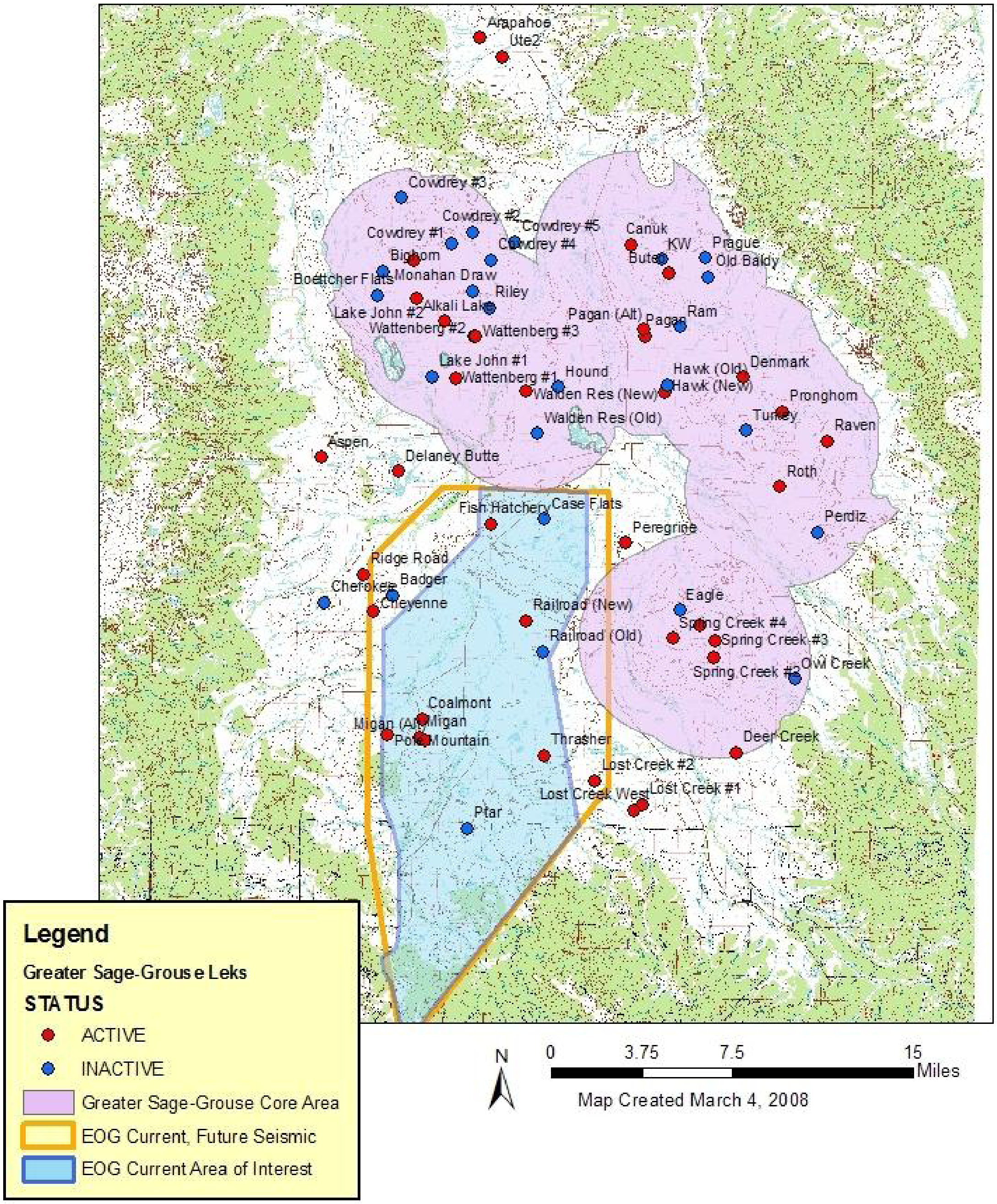
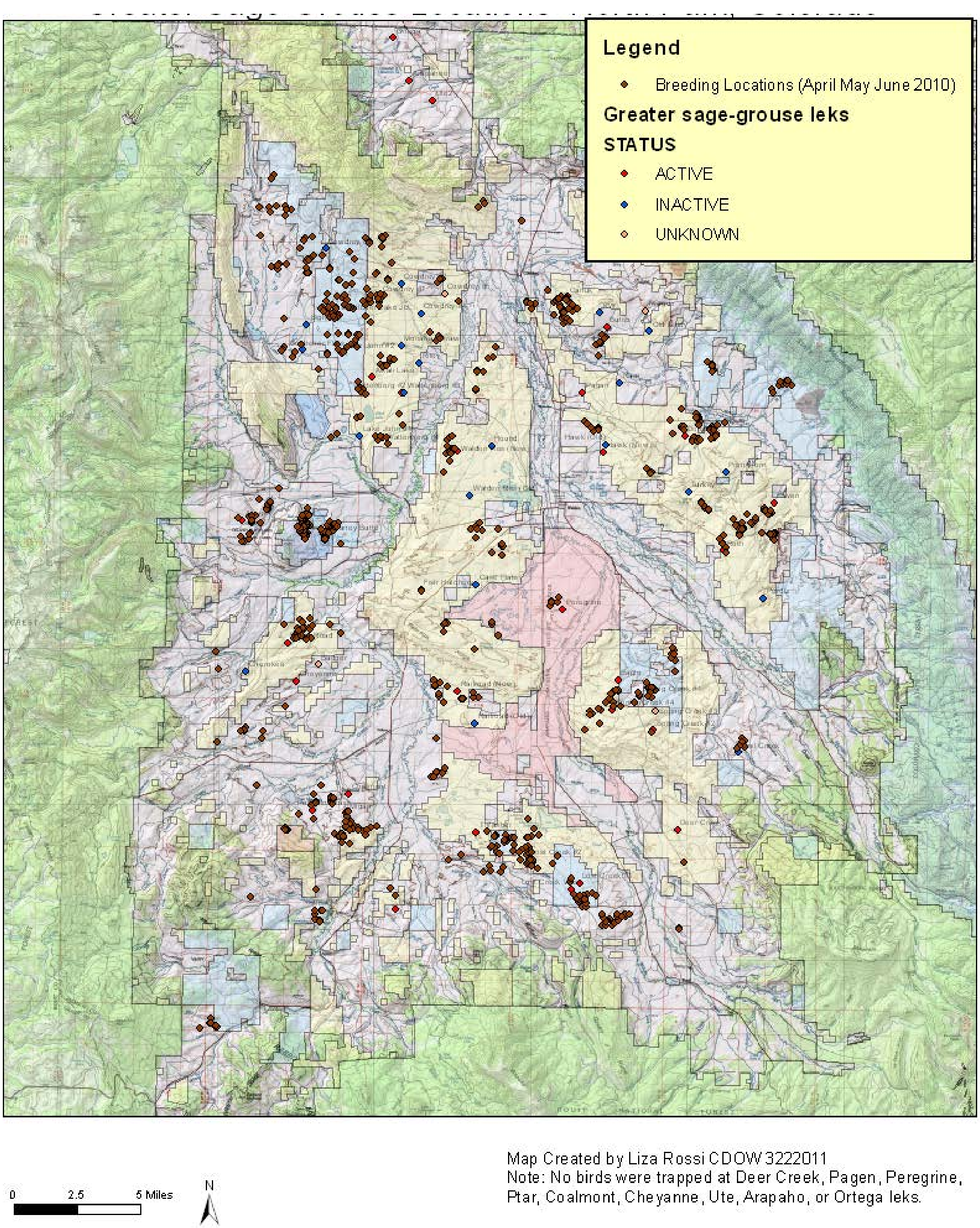


Figure 3. Female greater sage-grouse locations in North Park during April, May, and June, 2010.



Map Created by Liza Rossi CDOW 3222011
Note: No birds were trapped at Deer Creek, Pagen, Peregrine, Ptar, Coalmont, Cheyanne, Ute, Arapaho, or Ortega leks.

Figure 4. Female greater sage-grouse locations in North Park during August and September, 2010.

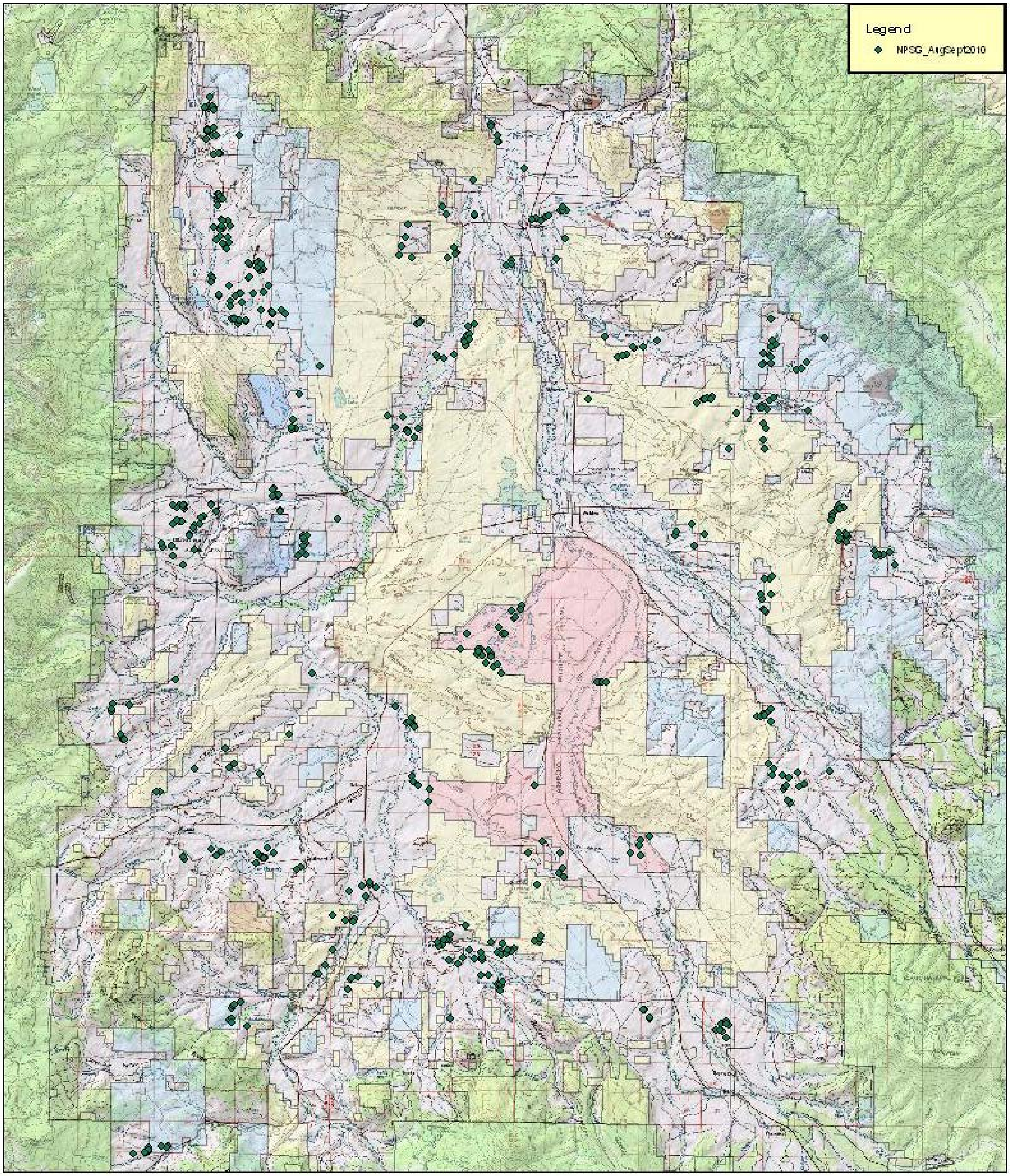


Figure 5. Female greater sage-grouse locations in North Park during January and February, 2011, in relation to previously mapped severe and non-severe winter range.

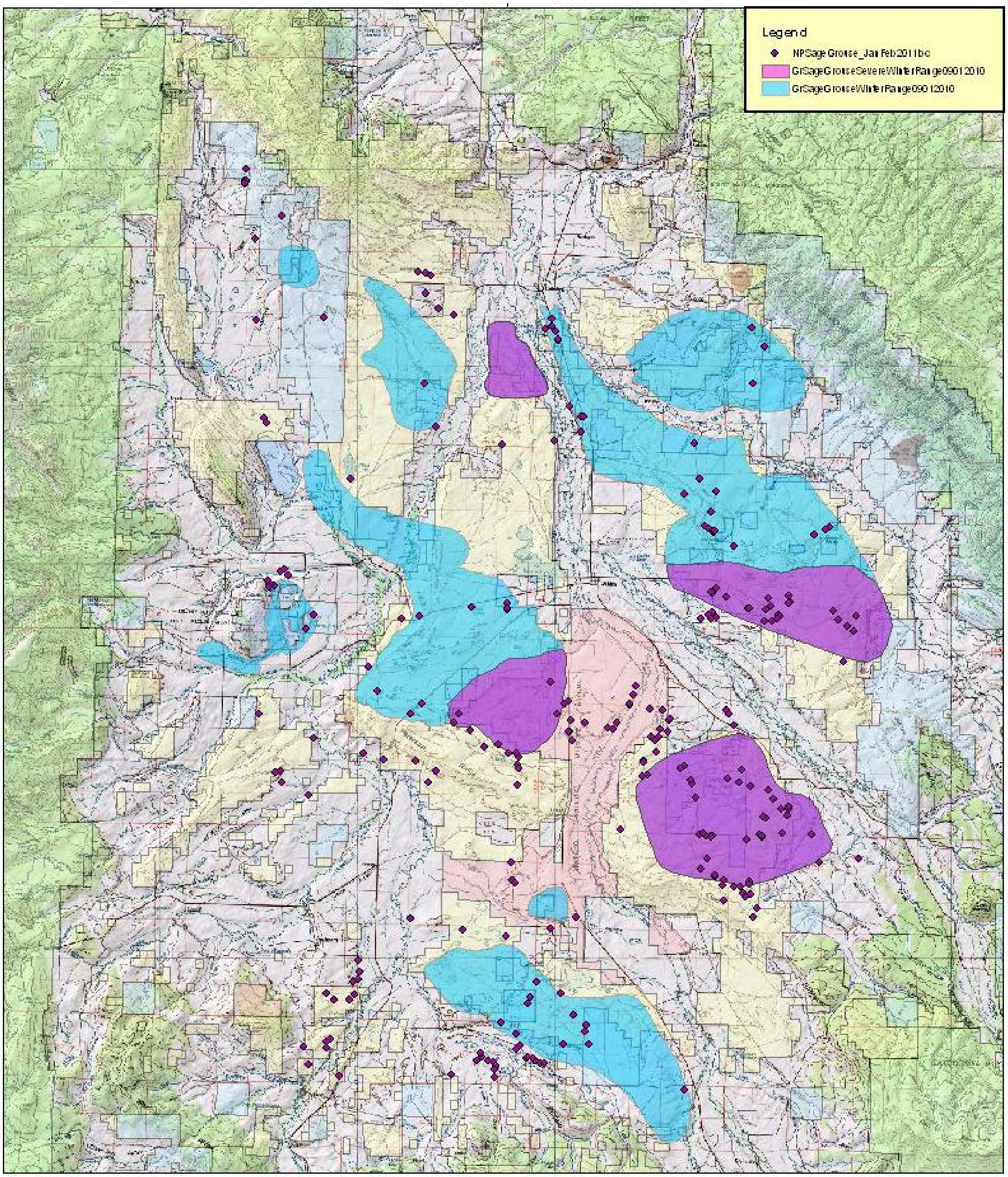
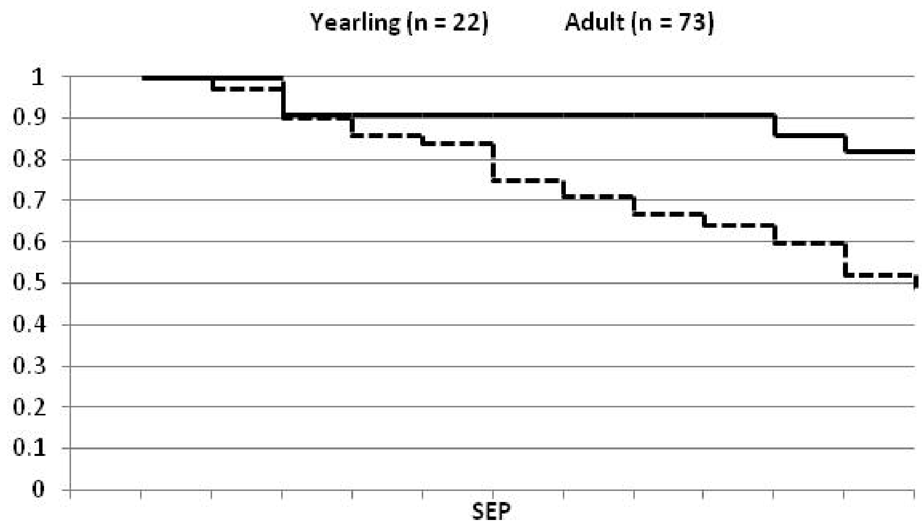


Figure 6. Annual product-limit survival curve for radio-marked adult and yearling female greater sage-grouse in North park, Colorado, April 2010-March 2011.



COLORADO DIVISION OF PARKS AND WILDLIFE - AVIAN RESEARCH PROGRAM
PROGRESS REPORT
September 2011

TITLE: Using GPS satellite transmitters to estimate survival, detectability on leks, lek attendance, inter-lek movements, and breeding season habitat use of male greater sage-grouse in northwestern Colorado

AUTHOR: B. L. Walker

PROJECT PERSONNEL: B. Holmes, Terrestrial Biologist (Meeker); B. Petch, Senior Terrestrial Biologist (Grand Junction); B. deVergie, Area Wildlife Manager (Meeker).

Period Covered: October 15, 2010 – June 10, 2011

ABSTRACT

Implementing effective monitoring and mitigation strategies is crucial for conserving populations of sensitive wildlife species. Concern over the status of greater sage-grouse (*Centrocercus urophasianus*) populations has increased both range-wide and in Colorado due to historical population declines, range contraction, continued loss and degradation of sagebrush habitat, and recent federal listing of the species as warranted but precluded under the Endangered Species Act in 2010. This concern is heightened in oil and gas fields due to recent studies that suggest negative impacts of development on sage-grouse abundance. Despite untested assumptions, lek-count data continue to be widely used as an index of abundance by state and federal agencies to monitor sage-grouse populations in oil and gas fields. Lek locations are also commonly used to help identify and protect important sage-grouse habitat in oil and gas fields by implementing buffers around known lek locations. However, the use of lek counts and lek locations to monitor and manage sage-grouse populations remains controversial. It is unclear how closely lek-count data track actual changes in male abundance from year to year. It is also unclear how effective lek buffers are at reducing disturbance to male sage-grouse and the habitats they use during the breeding season. These unresolved issues have the potential to cause disagreement, controversy, and conflict among agencies, industry, and other stakeholders where sage-grouse and oil and gas resources overlap. For this reason, there is a crucial need to collect empirical information to evaluate whether current lek-based monitoring methods provide reliable information about population trends in oil and gas fields and whether current lek-based management strategies are effective for conserving greater sage-grouse as energy development expands. Solar-powered GPS satellite transmitters have the potential to provide crucial data that can resolve these issues. However, GPS transmitters also need to be tested to ensure that any impacts of transmitters or the attachment method on males is minimal. The Colorado Division of Parks and Wildlife (CPW) is color-banding and deploying GPS transmitters on male greater sage-grouse and conducting double-observer counts and resighting at leks to obtain data on male survival, lek attendance, inter-lek movements, detectability, and diurnal and nocturnal habitat use around leks during the breeding season in and near the Hiawatha Regional Energy Development project area in northwestern Colorado.

USING GPS SATELLITE TRANSMITTERS TO ESTIMATE SURVIVAL, DETECTABILITY ON LEKS, LEK ATTENDANCE, INTER-LEK MOVEMENTS, AND BREEDING SEASON HABITAT USE OF MALE GREATER SAGE-GROUSE IN NORTHWESTERN COLORADO

Progress Report, October 15, 2010 – June 10, 2011

Brett L. Walker

PROJECT OBJECTIVES

(1) Test the effect of GPS transmitters on male greater sage-grouse:
   a. Estimate and compare seasonal and annual survival rates of yearling and adult male greater sage-grouse with GPS transmitters to published and empirical estimates for leg-banded males
   b. Compare fitted leg-loop size for adult vs. yearling males to assess whether yearling males will outgrow harnesses; if needed, recapture yearling males and refit harnesses in the field
   c. Compare strutting display rates between GPS males and color-banded or unmarked males
   d. Compare raw lek attendance rates between GPS males and color-banded males

(2) Use locations of GPS males to locate, verify, and count new leks in and around the study area

(3) Estimate the number of known and unknown leks in the study area

(4) Use unreconciled double-observer lek counts and time-to-detection models with lek-count and resighting data to estimate detectability of males attending leks

(5) Develop a modified sightability model approach to estimate daily, seasonal, and annual variation in male lek attendance

(6) Use movements of GPS males to determine presence near leks in the study area and to estimate the frequency, timing, and distance of breeding-season movement among leks

(7) Estimate daily and breeding-season survival rates of GPS males

(8) Use simulations to quantify how variation in age-specific male survival, presence, detectability, lek attendance, movement, and count frequency affect lek count indices and trend estimation

(9) If possible, use mark-resight data and counts of marked and unmarked males and females at leks to generate annual estimates of age- and sex-specific population size

(10) Quantify male habitat use and movement around leks to test the effectiveness of current oil and gas lease stipulations for lek buffers.

SEGMENT OBJECTIVES

(1) Capture and color-band 60 adult male and 60 yearling male greater sage-grouse in fall-winter within the Hiawatha Regional Energy Development boundary. Deploy GPS transmitters on half of the color-banded males (30 adult males, 30 yearling males).

(2) Locate, verify, and count new leks in and around the study area during the breeding season

(3) Resight color-banded males on leks attended by GPS males

(4) Compare fitted leg-loop size for adult vs. yearling males

(5) Collect data on display rates of GPS and non-GPS males attending leks attended by GPS males

(6) Conduct standard lek-counts and unreconciled double-observer at leks attended by GPS males

(7) Enter and proof field data.

INTRODUCTION

Greater sage-grouse (*Centrocercus urophasianus*) are a major conservation concern due to historical population declines, range contraction, and recent federal listing of the species as warranted but precluded under the Endangered Species Act (Connelly et al. 2004, Schroeder et al. 2004, USFWS 2010). The species continues to be threatened by ongoing anthropogenic and ecological changes to their habitat, including residential housing development, wildfire, invasive plants, pinyon-juniper encroachment, West Nile virus, agricultural conversion, and energy development (Connelly et al. 2004, CGSSC 2008, USFWS

2010). Accurately monitoring changes in sage-grouse abundance is crucial for assessing the current conservation status of populations, for quantifying responses of populations to potential stressors, and for documenting success or failure of conservation and mitigation efforts. Management strategies to protect sage-grouse habitat must also be validated to ensure they are effective at preventing unwanted impacts to populations.

Greater sage-grouse populations are typically monitored and managed using data collected at leks. Each spring, male sage-grouse congregate on traditional mating grounds, or leks, to display and mate with females (Schroeder et al. 1999). Males attending leks are then counted by observers on the ground or from aircraft following standardized protocols (Jenni and Hartzler 1978, Beck and Braun 1980, Autenrieth et al. 1982, Connelly et al. 2000). Lek counts are the primary index used by all state wildlife agencies in the western U.S., including the Colorado Division of Parks and Wildlife (CPW), to monitor sage-grouse population trends (Connelly et al. 2004, CGSSC 2008, WAFWA 2008). Changes in lek size and lek persistence derived from lek count data are also used to investigate how regional and range-wide populations respond to changes in habitat and to anthropogenic stressors such as oil and gas development (e.g., Braun et al. 2002, Walker et al. 2007, Aldridge et al. 2008, Doherty at el. 2010*b*, Harju et al. 2010, Tack 2010). Lek locations are also used to help identify and protect important habitat in land-use planning efforts because leks are typically centrally located within breeding areas (Gibson 1996, Doherty et al. 2010*c*). For example, federal oil and gas lease stipulations include timing and surface occupancy restrictions on oil and gas development within specific distance buffers around sage-grouse leks to minimize disturbance to males and their habitat during the breeding season. Many state and regional "core areas" have been delineated by placing buffers around known leks that meet male count and lek density criteria (e.g., CGSSC 2008, Doherty et al. 2010*a*, Hagen 2010, State of Wyoming 2010).

The importance of accurate and effective monitoring and management strategies is heightened in areas slated for energy development. A major threat factor in the listing decision was expanding energy development in the eastern portion of the range (USFWS 2010). Accumulated evidence suggests that sage-grouse populations show substantial declines following oil and gas development, even when standard mitigation measures are implemented (e.g., Holloran 2005, Walker et al. 2007, Doherty et al. 2008, Harju et al. 2010, Holloran et al. 2010). However, measured population responses to oil and gas development, while consistently negative, are not always of the same magnitude due to variation in: (a) the intensity of development; (b) the type of infrastructure required to develop the resource, which in turn affects the ecological processes by which impacts occur; (c) lag times between development and detection of impacts; (d) inherent differences in habitat quantity and configuration among populations subject to development; and (e) extent of overlap between development and important seasonal habitats (Harju et al. 2010). These same factors have also lead to the suggestion that it may not be appropriate to apply a one-size-fits-all protective buffer around leks based on range-wide data to local populations (Harju et al. 2010). Uncertainty about how quickly and how much sage-grouse populations will decline in response to development, and about the size of lek buffers required to minimize impacts on populations, creates potential for conflict among agencies, industry, and other stakeholders and underscores the need to test, validate, and implement scientifically defensible strategies for monitoring and managing populations in portions of greater sage-grouse range that overlap with planned energy development.

Lek-based monitoring and management strategies are also subject to empirical criticisms and require additional research to understand their uses and limitations (Applegate 2000). Using lek-count data as an index of population size has been called into question because the quantitative relationship between lek counts and actual population size has never been established (Beck and Braun 1980; Applegate 2000; Walsh 2002; Walsh et al. 2004, 2010). The probability of detecting a male during a lek count (p) is the product of: (1) the probability that a male is alive (*survival*, p_{alive}); (2) the probability of the male being present in the survey area, given that it is alive (*presence*, $p_{present}$); (3) the probability of the male attending the lek, given that it is alive and present (*availability*, p_{avail}); (4) the probability of detecting the male, given that it is alive, present, and attended the lek (*detectability*, p_{detect}); and (5) the probability that the lek is counted (*count probability*, p_{count}), such that: $p = p_{alive} * p_{present} * p_{avail} * p_{detect} * p_{count}$ (Walsh et al. 2004, Alldredge et al. 2007, Riddle et al. 2010). To understand the quantitative relationship between lek counts and male population size and to quantify how that relationship changes on an annual basis, I need daily and annual estimates of the proportion of males alive over the course of the breeding season, the proportion of those males present near leks in the study area (given that they are alive), the proportion of males attending leks (given that they are alive and present in the study area), the proportion of males detected on lek counts (given that they are alive, present in the study area, and attending a lek), and the probability that the lek is counted, which depends on count effort.

At present, too few quantitative data are available to estimate survival, presence, lek attendance, and detectability for male greater sage-grouse during the breeding season. No published studies have quantified how much annual variation occurs in the proportion of males detected or how much detectability varies among observers or with male age, weather, the observer's distance from lek, equipment used (binoculars vs. spotting scopes), or count method (e.g., ground vs. aerial counts) (Connelly et al. 2003, Walsh et al. 2004). Male lek attendance is known to vary with age, time of day relative to sunrise, date, weather, snow depth, renesting by females, predator activity, and human disturbance, but standardization of lek-count protocols only minimizes variation associated with some of these variables (Patterson 1952, Dalke et al. 1963, Rogers 1964, Hartzler 1972, Jenni and Hartzler 1978, Beck and Braun 1980, Autenrieth et al. 1982, Emmons and Braun 1984, Ellis 1984, Dunn and Braun 1985, Connelly et al. 2000, Connelly et al. 2003, Boyko et al. 2004, Walsh et al. 2004). Past studies that have addressed male lek attendance also did not collect or report data in a consistent fashion, making generalization across studies difficult (Walsh 2002, Walsh et al. 2004). In the most rigorous studies on lek attendance for greater sage-grouse to date, Walsh et al. (2004, 2010) emphasized the importance of individual heterogeneity, age, sex, time of day, and date, but because their data on lek attendance of greater sage-grouse came from only one year in one population, they concluded that additional research was needed to quantify annual variation in lek attendance. Age-specific inter-lek movements by males have been reported in several studies, with 4-50% of males known to have attended more than one known lek during a single breeding season (Dalke et al. 1963, Gill 1965, Wallestad and Schladweiler 1974, Emmons and Braun 1984, Dunn and Braun 1985, Bradbury et al. 1989, Walsh et al. 2004), but the effect of inter-lek movements on lek count data has not been quantified.

Several other factors that influence lek-count data have also never been addressed quantitatively including: disturbance by observers, predator activity (Ellis 1984), disturbance from activities associated with energy development (Braun et al. 2002), and annual variation in female attendance associated with renesting effort (Dalke et al. 1963, Eng 1963 *in* Walsh 2010). Methodological considerations may also affect counts. Non-random access to leks due to logistical constraints (e.g., road conditions, landowner permission) could bias population estimates derived from count data if access is correlated positively or negatively with attendance or abundance (e.g., if attendance is lower near roads). The number of counts conducted per breeding season can also influence lek-count data. Some states only record the maximum count of males at each lek in state-wide databases, and the maximum count is likely to be higher with more counts because any given count is more likely to coincide with peak attendance (Walsh et al. 2004).

Despite these shortfalls, lek-count data continue to be widely used. Large decreases in lek counts or disappearance of leks over large areas over time are thought to reliably indicate population decline or range contraction (Walker et al. 2007, Aldridge et al. 2008, Doherty et al. 2010*b*, Harju et al. 2010). The fact that core areas have been established based largely on counts of males on leks and lek density also suggest that state and federal agencies still consider higher lek counts, on average, to represent larger populations (CGSSC 2008, Doherty et al. 2010*a*, Hagen 2010). This raises an important, but unresolved question. How big of a change or difference in lek counts is required to confidently and reliably infer an actual change or difference in male population size? Investigating these questions and assessing the reliability of lek-count data collected using current, standard protocols for measuring changes in actual population size over time has been identified as a range-wide research priority (Naugle and Walker 2007).

There are two main options for resolving these issues. First, mark-recapture or mark-resight models using either marked birds or genetic data could be used to generate annual population estimates (Lukacs and Burnham 2005, Walsh et al. 2010), and over time, these estimates could be compared to maximum counts of males on leks to better understand the relationship between the two metrics. Using mark-resight approaches is probably the most rigorous way for generating defensible point population estimates (Clifton and Krementz 2006, Walsh et al. 2010), but they are generally too costly, and too time and resource-intensive to implement over large areas or on an annual basis (Walsh 2002, Walsh et al. 2004, Clifton and Krementz 2006, Walsh et al. 2010). A cheaper, easier method would be preferable for long-term monitoring.

Another alternative would be to estimate survival, presence, lek attendance, and detectability from field data in relation to measured ecological and methodological variables, then correct lek count data to obtain annual population estimates and measures of precision. Double-observer approaches, originally developed for use with songbird point counts (Nichols et al. 2000), have recently been modified to use raw count data from independent observers to estimate detectability of males on lek counts (Riddle et al. 2010). Time-to-detection models can also be used to estimate the effects of individual-, group-, survey- and time-specific covariates on detectability (Alldredge et al. 2007). In addition, sightability models have been widely used with other species to estimate the effects of covariates on detection probability and to generate corrected population estimates from annual count data (e.g., Samuel et al. 1987, Rice et al. 2008, Walsh et al. 2009). Such models can be modified for use with lekking species to estimate the probability that individual males attend leks as a function of ecological and methodological covariates that can be measured or recorded in the field (Walsh et al. 2004). Intensive monitoring of individuals with transmitters in the field can be used to calculate daily probability of survival, presence, and lek attendance during the breeding season.

Simulations would also be valuable for exploring the consequences of variation in survival, presence, lek attendance, detectability, and count probability on lek-count data. Most lek-count data are currently collected according to standardized protocols, but it may be that directing biologists to collect one or two more key covariates (e.g., distance from lek, type of optics used) would increase precision of population estimates without increasing cost. Even after following standard count protocols, it may still be beneficial, in terms of the precision of population and trend estimates, to collect and correct count data for weather, time of day, and count method using a modified sightability model. Moreover, not all variables known to influence detectability and lek attendance can be measured when collecting annual lek count data (e.g., inter-lek movement). It would be informative to use simulations based on empirical field data to quantify and illustrate how much lek-count data are likely to vary when I either do not correct for measurable covariates, cannot correct for unmeasured covariates, or both, even in the absence of actual population change. Simulations have been successfully used with other species to assess the effects of unmeasured sources of variation on count data, estimated abundance, and estimated population trends (e.g., Rice et al. 2008).

Lek-based management strategies are also subject to criticism. First, such strategies incorrectly assume that all lek locations are known. Several states, including Colorado, have used a combination of known lek locations, male counts at those leks, and vegetation layers to delineate priority areas for conservation of sage-grouse (e.g., "core areas"; CGSSC 2008, NRCS 2009, Doherty et al. 2010*a*, Hagen 2010). Each analysis used slightly different criteria and methodologies, but each assumed that all lek locations were known. This assumption is clearly violated. New leks are discovered annually, particularly in more remote portions of the species' range where surveying is more difficult. The number of known leks monitored range-wide increased 10-fold between 1965 and 2007 due to the discovery of new leks, and the majority of leks currently monitored were discovered after 1994 (WAFWA 2008). For that reason, current core areas are geographically biased toward areas with greater survey effort (which are typically areas closer to population centers and with easier access) and the extent of core areas is most likely underestimated. Moreover, lek-based oil and gas lease stipulations can only be applied to leks whose locations are known. In combination, the presence of unknown leks and underestimation of core areas could lead to inadequate levels of protection in oil and gas fields. Although monitoring data can be adjusted to account for unknown leks using area-based sampling designs (e.g., dual-frame sampling; WAFWA 2008) or estimators that incorporate correction factors (e.g., Huggins estimators; Walsh et al. 2004), lek-based management strategies. For this reason, one of the keys to appropriately managing sage-grouse in oil and gas fields is to locate all leks within and adjacent to the field prior to leasing and development. One way to do this would be to intensively track a representative sample of males to see where they go to display in the early morning hours during the breeding season.

Second, lek-based approaches for managing populations in areas with energy development have not been empirically validated. Oil and gas leases typically stipulate either no surface occupancy (NSO) or restricted surface occupancy (RSO) within certain buffer distances around leks. Historically, the Bureau of Land Management implemented a 0.25-mi. NSO or RSO buffer around leks to minimize disturbance to lekking males and to prevent degradation of the habitat males use during the breeding season, with the overall intention of minimizing long-term population declines and preventing extirpation in areas with development. However, the 0.25-mi. stipulation has no scientific basis (p. B-5, Appendix B, CGSSC 2008). More recently, a review of range-wide studies of male diurnal habitat use and movements during the lekking season suggested that a 0.6-mile buffer around leks may be more appropriate (p. B-6, Appendix B, CGSSC 2008), and this criterion is now recommended by state agencies in Colorado and Wyoming (CGSSC 2008, State of Wyoming 2010). However, the distribution of suitable habitat around leks often is not homogenous and no studies to date have empirically tested how large buffers need to be to protect habitat for males during the lekking season, so it is unclear whether a 0.6 mi. buffer is too large, adequate, or too small. Research is needed to quantify the buffer size needed by intensively tracking both day-time and night-time habitat use of individual males around leks during the breeding season without disturbing the males.

Recent technological advances have led to production of 22-30 g, solar-powered, global positioning system (GPS) satellite transmitters that may be well-suited for generating the data needed to resolve lek-based monitoring and management issues. Most research studies use very high frequency (VHF) transmitters attached to a neck collar to radio-track individual sage-grouse. VHF necklace collars are widely accepted as the current standard method for radio-marking (Connelly et al. 2003), and necklace collars have been widely used on males (Ellis et al. 1987, Walsh et al. 2004, Knerr 2007, Robinson 2007, Wisinski 2007, Holloran et al. 2010, Walsh et al. 2010). However, no studies to date have tested the impact of VHF collars on male (or female) survival, and field observations have generated concern whether males can safely be fitted with necklace-style VHF collars. Necklace collars may interfere with male displays by bouncing up and striking the male’s beak during strutting; they may restrict breathing or foraging when neck and breast tissue swells during the breeding season; they may prevent yearling males from swallowing as their necks grow over time, leading to suffocation or starvation; and males may become distressed and repeatedly attempt to remove the collar, thereby increasing their detectability to predators (B. Walker, pers. obs.). Lek attendance of females with necklace-mounted VHF collars did not appear to be affected (Walsh et al. 2004), but females do not display, so whether necklace collars reduce male lek attendance remains unclear.

GPS transmitters have several advantages over VHF necklace collars. GPS transmitters record multiple locations per day at specific, pre-programmed times; logistical problems that prevent crews from locating birds on the ground are eliminated (e.g., weather, road conditions, truck breakdowns, technicians oversleeping, denied access, etc.); data are gathered without disturbing the bird or its flock mates; and they provide high-resolution data on survival, movement, lek attendance, and diurnal and nocturnal habitat use around leks. Collecting data of comparable resolution and accuracy using VHF collars would result in excessive disturbance to birds and be logistically impossible. However, solar cells require that transmitters be mounted dorsally so they are exposed to the sun. Because of their similarity to backpack-style transmitters (Brander 1968, Amstrup 1980), there is concern that rump-mounted transmitters may directly or indirectly reduce survival of sage-grouse. Moreover, as with any new technology, data are also needed to assess the proportion and accuracy of GPS locations acquired, transmitter durability and longevity under field conditions, and cost effectiveness in comparison with VHF collars.

Current studies with female greater sage-grouse indicate that rump-mounted leg-loop harnesses may be a viable option for attaching GPS transmitters to males as well. Satellite GPS transmitters cannot be used with necklace collars because solar cells under the neck receive insufficient sunlight to charge the battery (B. Henke, Northstar Science and Technology; C. Bykowsky, Microwave Telemetry, pers. comm.). Five separate studies are now using GPS transmitters with a rump-mounted leg-loop harness design to track female sage-grouse. Survival of females with VHF transmitters ($n = 42$) and GPS transmitters ($n = 50$) was tracked in northwestern Colorado from spring 2009 to spring 2010. VHF and GPS females had similar survival rates through October 2009, but survival of GPS females was lower from October 2009 - March 2010, resulting in lower estimates of annual survival (0.556 ± 0.073 SE for VHF vs. 0.406 ± 0.068 SE for GPS). Despite limited sample sizes, these results suggest that the ratio of transmitter size to body size reduced, the harness design should be made more flexible, transmitters should be fit less snugly, or all three. Because males are larger than females, 30-g transmitters (38 g including harness and crimps) would be proportionally less of male body mass, approximately 1.1-1.9%, depending on male age (~2000-2400 g for yearlings, ~2800-3300 g for adults; Beck and Braun 1978). Leg-loop harnesses may still cause skin irritation under the legs, particularly during males' vigorous strutting displays. Moreover, if harnesses are fitted too tightly around the legs, or if swelling occurs around the legs prior to the breeding season (as it does around the neck and breast), this may also restrict the ability of males to display in spring. Having a GPS transmitter with a highly reflective solar cell attached dorsally may also increase detectability of males to predators or alter their distribution of body weight such that it impedes flight and makes them more susceptible to predation or targeted by visual predators. If yearling males grow during the course of the study, they may also outgrow a less flexible or snugly-fitting harness. If leg-loop harnesses impact survival of males, I would predict lower survival rates for GPS males than those published for leg-banded males. Band-recapture data suggest that survival rates of male sage-grouse vary annually and by age (0.635 ± 0.034 SE for yearlings vs. 0.368 ± 0.007 SE for adults; Zablan et al. 2003). Males with VHF collars in southwestern Montana averaged 0.34 ± 0.067 SE annual survival, but the author did not distinguish between yearling and adult males (Wisinski 2007). If harnesses hinder movement or displays of males, I would also predict reduced display rates for GPS males compared to either color-banded or unmarked males of the same age under the same conditions.

This study is intended to be a three-year investigation of greater sage-grouse lek monitoring and management strategies using males deployed with GPS transmitters in the Hiawatha Regional Energy Development Project area in NW Colorado and SW Wyoming.

STUDY AREA

The study area covers the Hiawatha Regional Energy Development project boundary in northwestern Colorado and southwestern Wyoming and includes birds from both Colorado (Zone 1; "Cold Spring Mountain/Hiawatha") and Wyoming ("Salt Wells") core breeding populations (Fig. 1). This area holds a large, robust population that is contiguous with the rest of greater sage-grouse range in northwestern Colorado and south-central Wyoming. The maximum count of males on known leks in Colorado's Zone 1 varies annually (in part due to variation in effort), but it is considered a stable population (CGSSC 2008, p. 259). Previous data from VHF- and GPS-marked females in this region indicate that sage-grouse typically winter in or near the Hiawatha project area and attend leks both within the project area and at higher elevations surrounding the project area. There are currently nine known leks within the study area plus six more immediately adjacent to the study area. Of these 15 leks, seven were discovered in 2007 or later. It is unclear what proportion of males in the population our sample will represent because not all leks are known and it is unclear how the number of males counted on known leks relates to actual population size. Research is being conducted with the support of the Wyoming Game and Fish Department and the Rock Springs (WY) and Little Snake (CO) field offices of the Bureau of Land Management.

METHODS

Capture and Handling

All males will be captured in fall and winter habitat prior to the onset of the breeding season to prevent biasing data on lek attendance the following spring (Walsh et al. 2004). Trapping effort and GPS unit deployment will follow a probability-based sampling scheme based on winter habitat identified in seasonal habitat models (Walker 2010) to ensure that males from all potential wintering areas and therefore all leks in the project area are represented in the sample. I plan to capture and attach 30-g, rump-mounted solar-powered GPS PTT satellite transmitters (Northstar Science and Technology, King George, VA) on 30 adult male sage-grouse in November-December 2010 and on 30 yearling male sage-grouse in February 2011. I selected 30-g transmitters because they have larger battery capacity than 22-g models, which decreases risk of transmitter failure (or temporary failure to transmit data) under low-light conditions. GPS males will also receive individually numbered aluminum leg bands (size 16) and distinctive combinations of colored leg bands. I also plan to capture and individually color-band 30 adult males in November-December 2010 and 30 yearling male sage-grouse in February 2011. I will alternate marking methods during captures to maintain equal proportions of GPS males versus color-banded males in each portion of the study area. Trapping yearling males in February rather than in the fall will allow them to reach larger body mass prior to deploying the transmitter, thereby reducing the chance that they will outgrow the harness during the breeding season. Transmitters from birds that die may be recovered, cleaned, refurbished, and redeployed to maintain or increase sample sizes for survival analyses and or collecting mark-resight data.

Capture and handling methods will follow standard operating procedures established for sage-grouse (Appendix A), with the exception that the decision whether injured birds will either be released or euthanized will be made by the PI in the field rather than transporting birds back to Fort Collins. This is because no known rehabilitators in Colorado currently have the facilities to care for wild sage-grouse. I will use night-time spotlighting and hoop-netting for all captures (Wakkinen 1992). I selected a sample size of 30 individuals per age class (yearling vs. adult). It is crucial to estimate parameters for each age class separately because they have different survival rates (Zablan et al. 2003) and different rates of lek attendance (Walsh et al. 2004). Sample size must also be balanced with the potential for impacts on the population should GPS transmitters have highly detrimental effects on male survival. With a sample size of 30 males in each age class, statistical power will be > 0.80 if survival of adult males is < 0.14 or > 0.62 or if survival of yearling males is < 0.39 or > 0.86. This sample size will only allow detection of relatively large differences in survival with statistical power > 0.80. However, deploying more GPS transmitters would be unethical without data regarding whether the transmitters have catastrophic effects on survival. The loss of > 30 males in any given age class in any given year in this population would likely pose an unacceptable risk to stakeholders and cooperators. A sample size of 30 should inform us whether GPS transmitters have catastrophic effects on survival.

GPS Transmitter Attachment

I will use a rump-mount attachment for GPS transmitters based on the method B design described in Bedrosian and Craighead (2007) modified for sage-grouse (Figs. 2-3). Transmitters will be manufactured with a medium-brown, sand-textured finish to reduce reflected light. A thin layer of neoprene is glued to the bottom side of the transmitter to ensure that contact between the transmitter material and the bird's lower back is padded and insulated. The harness material is 0.55-cm (0.25-inch) wide, brown Teflon ribbon (Bally Ribbon Mills, Bally, PA). A 12 cm length of 0.55-cm wide elastic cord is sewn into the center of a 75-cm (36-inch) length of Teflon ribbon such that 4-6 cm of stretchy Teflon ribbon extends out from the attachment points on either side (Fig. 2). The elastic gives the harness flexibility when the bird extends its legs during take-off and when males are displaying. Yearling harnesses will be sewn with more elastic (16 cm) to accommodate possible increases in body size over time. The transmitter side, front, and back are painted camouflage to decrease visibility to predators (Fig. 3). Harnesses are fit with the bird held in a standing position. The transmitter is mounted on the bird's lower back centered between the legs (as seen from behind and as seen from the side of the bird) with the antenna extending toward the rear above the tail (Fig. 3). The Teflon ribbon is fitted down, around, and underneath the legs and attached to the loops using a small section of 0.55-cm (0.25-inch) diameter copper tubing as a crimp (Fig. 2). Copper crimps typically quickly become tarnished with exposure to the elements, but as a precaution, crimps are marked with black ink before release to be sure they don't reflect light. I trim the Teflon ribbon at an angle and leave just enough excess ribbon on each side (~3 cm) to allow us to refit or enlarge the harness should it become necessary during fitting. The end of the excess ribbon is dabbed with Superglue® (Super Glue Corporation, Rancho Cucamonga, CA) to prevent fraying. The life span of the exposed Teflon ribbon has not been tested, but it has been used successfully with rump-mount transmitters on female sage-grouse for >16 months already without showing signs of fraying, wear, or deterioration. The life of the elastic cord is unknown. Transmitters will be fitted just snugly enough to prevent birds from dropping transmitters.

The units are solar-powered and may last for 3-5 years, which is longer than the life span of almost all male sage-grouse (Zablan et al. 2003). All GPS units will be pre-programmed to collect 8 locations per day from March-May so as to get data on early morning lek attendance (6 am, 7 am, 8 am), mid-day feeding/loafing areas (12 pm), evening feeding areas (6 pm), and night roost locations (12 am). Units will be programmed to collect two locations per day at 12 pm and 12 am from June-Feb to capture basic patterns of seasonal habitat use and movements while reducing demand on the battery during low-light conditions encountered in fall and winter. I anticipate studying males for multiple seasons (if possible), so I do not plan to remove GPS transmitters unless leg-loop data suggest refitting of yearlings will be required. If preliminary survival data indicate little or no impact of GPS-transmitters on male survival, I will clean and re-deploy GPS transmitters recovered from mortalities on additional males to maximize sample sizes for survival analyses. Brett Walker was trained in the attachment technique in the field in March 2009 by Bryan Bedrosian, who has used GPS transmitters with raptors, corvids, and sage-grouse (Craighead and Bedrosian 2009).

The ARGOS system sends GPS transmitter data as a text file by email every three days. I then parse the raw text files using the "DSDCODE" software provided by Northstar Science and Technology. This software automatically parses the data and amends new locations from GPS birds to an ArcGIS shapefile for each individual. I amend the parsed data (in .dbf format) to an existing Microsoft Excel® spreadsheet of GPS bird locations and manipulate the spreadsheet to remove duplicate records, flag date and location errors, and to identify records signifying important events (e.g., mortality).

Lek and Lek Attendance Definitions

I define a lek as any area within which ≥ 2 males have displayed in ≥ 2 years, which is consistent with previous state-wide and range-wide definitions (Connelly et al. 2000, CGSSC 2008). I use this definition to ensure that small leks and "satellite" leks are included, but that locations where males do not consistently display are excluded (i.e., one-time use locations). The status of a lek may be active or inactive in any given year. Leks used by displaying males at least once within the past 5 years are considered active (CGSSC 2008). Newly-discovered leks > 500 m from all other known leks will be designated as potential leks. If those locations have displaying males in ≥ 2 years, they will be classified as new leks and assigned a name based on local geography. I will delineate a "count boundary" for each known lek prior to the first count and for each new lek immediately following its discovery. The count boundary represents the specific perimeter within which males would be visible and available for counting by observers during any given count. The purpose of establishing a count boundary is to ensure that the geographic area of observation for each lek is consistent over time. This prevents the characteristics of specific leks (e.g., their area, location, topography, etc.) from changing over time. This count boundary will necessarily be larger than the outer perimeter around displaying males on any given date because: (a) observers can typically see and count males over an area larger than just the area where displaying males are found, (b) males may shift the location where they strut slightly from day to day (WAFWA 2008), and (c) observers typically adjust the location from which they count males from day to day to maximize their ability to obtain complete counts of males.

It is also important to unambiguously define lek "attendance" because some males use habitat near leks, but they may or may not be within the area that can be counted by observers. I define lek "attendance" for each male as a binomial variable. Lek attendance is classified as 1 if the male is inside the count boundary (i.e., visible and available for counting by observers) at any time during the standard count period (0.5 hrs before sunrise to 1.5 hrs after sunrise) and as 0 if the male is either: (a) outside the count boundary (i.e., not visible and unavailable for counting) during the standard count period, or (b) inside the count boundary at a time other than during the standard count period. Lek attendance of GPS males should be straightforward to assess when resighters are present, but there may be some ambiguity about lek attendance for GPS males that are not directly observed (those that attend leks at which no observers are present). The accuracy of high-quality locations derived from GPS transmitters is typically ≤ 26 m. Only GPS males with early morning locations within 26 m of the count boundary will be considered to have attended a lek.

Lek Counts and Resighting

CPW lek-count protocol instructs observers to obtain a maximum count of males by conducting repeated counts 5-10 minutes apart over a 30-minute period between 0.5 hr before and 1.0 hr after sunrise (Appendix B). Although no specific guidelines are given for exactly how far away to be, biologists and wildlife managers typically count leks from 50-400 m away, depending on topography, access, and how far away they need to stay to keep from disturbing birds at the lek. They use whichever optics are required to obtain a reliable count (binoculars or spotting scope) and whichever mode of transportation (truck, ATV, on foot) gets them close enough to the lek to count it. A truck is preferred because it reduces disturbance to birds and is logistically easier and more comfortable for conducting repeated scans.

Field crews will focus on collecting count data and resighting data at only those leks attended by GPS males, most of which are likely to be within or adjacent to the study area. Observers will visit each of these leks once a week. The field crew will be divided into three groups: resighters, counters, and surveyors. Surveyors will check locations of potential new leks as needed, and if males are present, will conduct a standard 30-minute lek count. Resighters will each go to a different lek and collect resighting data on GPS and color-banded males during each 30-minute interval from 0.5 hr before local sunrise to either 1.0 hrs after sunrise or to when all birds depart the lek, whichever is later. Resighters will use a spotting scope from a portable blind placed ~50 m from the lek (Walsh et al. 2004). The goal of each resighter is to collect accurate data on the identity of all GPS and color-banded males present on the lek during each 30-minute interval. Portable blinds will be placed near leks either the night before or >1 hr before to sunrise to prevent disturbance to birds on the lek (Walsh et al. 2004). Blinds will have raptor perch deterrents installed on top to prevent aerial predators from using blinds as perches. Counters will work in pairs, and each pair will conduct a 30-minute lek count during the standard count period at two leks per day (the same leks being observed by resighters). For counters, each 30-minute visit to a lek will be divided into six 5-minute scan intervals. Counters will follow CPW count protocols and record the maximum number of yearling and adult males and females counted during each 5-minute interval. The goal of each counter is to get an accurate count of yearling and adult males and females during each scan interval and to determine the number (and eventually, the identity) of all GPS males present on the lek. Counters will also record any birds that arrive or leave the lek during each interval. Counters will alternate between using a spotting scope and binoculars during each scan interval. Each observer will be allowed to scan the lek multiple times within each 5-minute interval because that is typically how lek counts are conducted by CPW biologists and wildlife managers. At the end of each count, the counters will consult with the resighter by two-way radio to reconcile and confirm the identity of any GPS males observed on the lek.

Observers will be systematically rotated such that each observer conducts an equal number of lek counts and resighting days with each other observer. I will only hire observers with experience conducting lek counts. All observers will be trained in standard lek-count protocols, will practice resighting prior to collecting field data, and will collect data on standardized forms. All counts will be conducted from within a realistic distance from leks, depending on topography and optics (50-400 m), and all counters will record the distance (m) to the approximate lek center using a laser rangefinder. All observers will conduct counts using the same standard make and model of 10x binoculars and 20-60x zoom spotting scopes.

Aerial lek counts will be conducted using two observers flying in fixed-wing aircraft (the pilot and an independent observer). Aerial observers will record the number of males observed, but cannot distinguish between marked and unmarked males or between adult and yearling males.

Objective 1a: Survival Comparison

I will use location and mortality data from males with GPS transmitters to estimate seasonal and annual survival rates of yearlings and adults. The null hypothesis is that male greater sage-grouse with GPS transmitters in each age class have survival rates indistinguishable from those reported for leg-banded males in the published literature. If location data from a GPS male indicate a stationary transmitter, field crews will visit all subsequent locations to determine whether it was a mortality or a dropped transmitter and to recover the transmitter using a metal detector. Transmitters deployed so far have typically been recovered within 20 m of their last set of stationary location(s) (B. Walker, unpub. data). I do not anticipate estimating cause-specific mortality rates because the delay between when birds are killed, the acquisition and processing of satellite data, and when locations can be checked by field crews is typically 4-7 days.

I will use an information-theoretic approach (Burnham and Anderson 2002) to evaluate sets of *a priori* candidate models describing variation in daily and seasonal survival rates of males during breeding, summer, fall, and winter. Survival analyses of GPS male data will use a continuous-time approach such as a Cox proportional hazards model (Murray 2006). Age will be a fixed effect in all seasons (adult vs. yearling), and landscape-scale habitat variables known to influence habitat selection in each season (e.g., terrain ruggedness, proportion sagebrush habitat within 1 km; Walker 2010) will be included as additional explanatory variables. During the breeding-season, daily lek attendance status will be included as an explanatory variable to quantify risk due to lek attendance.

As a separate test of the effects of GPS transmitters on breeding-season and annual survival, I will use a Barker model to jointly estimate survival of GPS and color-banded only males (Barker 1997) in MARK. I will use GPS location data, mark-resight data from each spring's resighting effort, and recoveries from harvested birds to generate capture histories. Age and mark (GPS vs. color-banded) will be fixed effects.

Objective 1b: Leg-loop Size Comparison

Leg loops will be marked at various distances from the front attachment point using colored iridescent, permanent markers. The exact length of the leg loop from the front to the rear attachment point will be recorded in the field on each leg on each bird after fitting. Means and variances of harness lengths will be compared between yearlings and adults using a standard one-sided, two-sample t-test because of the *a priori* expectation that yearlings will have smaller leg-loop lengths than adults. If needed, yearlings may have to be recaptured after the breeding season to refit them with adult-sized harnesses. Recapture of yearlings may be difficult because the transmitters cannot be tracked in real time. If needed, I will use location data to identify recent night roost locations of yearling males and attempt to find and capture those males by trapping in those areas.

Objective 1c: Comparison of GPS and Color-banded Male Display Rates

During lek counts at which marked males are present, the resighter will record the display rate (no. struts/minute) of the GPS male nearest the observer and of the color-banded male in the same age class that is nearest the observed GPS male. The resighter will conduct three 1-minute observations per individual spaced 1 minute apart. Data from the three 1-minute observation periods will be summed. Observation periods will alternate between GPS and color-banded males, and the first bird to be observed will be randomly determined. If no color-banded males are present on the lek, the resighter will observe the nearest color-banded only or unmarked male in the same age class. The observation period will occur during at some time during the first 1.0 hr after local sunrise to ensure that light is sufficient to record behavioral data, but after resighting data have been collected. When more than one GPS male and more than one color-banded male are present, the resighter will collect on the next pair of marked males at the next earliest opportunity. Time spent fighting with other males or copulating with females will be excluded when calculating display rates. The null statistical hypothesis is that GPS males and color-banded males will show no difference in mean display rate. Comparisons will be made using a paired-sample, repeated-measures design because the dataset will include repeated observations from the same individuals over time.

Objective 1d: Comparison of GPS and Color-banded Male Lek Attendance Rates

The null statistical hypothesis is that GPS males and color-banded males will show no difference raw rates of season-long lek attendance. Raw lek attendance for each individual will be calculated as the proportion of the total number of 30-minute intervals during the breeding season during which each marked bird was resighted on a lek. I will then compare raw lek attendance among GPS and color-banded males separately for each age class because the two age classes will be marked at different times of year.

Objective 2: Using GPS Males to Find New Leks

Early morning locations of GPS males will be compared against locations of known leks every three days as satellite data arrive and are processed to identify potential new lek locations in and near the study area. Males that make ≥ 2 early morning visits to the same location on consecutive mornings during the breeding season will be considered to have visited a potential lek location. The surveyor will then visit those locations or they will be checked from the air at least once during the next 7 days to document whether displaying males or their sign (e.g., pellets, tracks, feathers) are present or absent, and if so, how many. If displaying males or sign are present at a newly discovered lek, then that lek will be added to the list of regularly counted leks following standard protocols, and the count boundary determined prior to the next visit. A GPS male that uses a location within the count boundary during the count period that is subsequently discovered to be a lek will be considered to have attended that lek on that date.

Objective 3: Estimate Number of Leks in the Study Area

Data from GPS males will be used in a mark-recapture framework to estimate the number of leks in the study area. Visits by marked GPS males can be used to “capture” leks and subsequent visits by marked birds to that lek constitute “recaptures” of that lek. Recapture histories for individual leks can then be derived and analyzed using an appropriate mark-resight model (Bartmann et al. 1987, Bowden and Kufeld 1995, McClintock et al. 2008).

Objective 4: Estimating Detectability of Males on Leks

I will compare three methods for estimating detectability of males on leks. Two of the methods have only recently been published and require validation for use with lekking species (Alldredge et al. 2007, Riddle et al. 2010). The third method is included as a way to double-check an assumption of the first two methods.

First, I will use an unreconciled, independent, double-observer approach to estimate detectability from lek-count data (Riddle et al. 2010). Standard double-observer and removal models require that observers match or reconcile specific individual animals that were or were not detected by each observer (Nichols et al. 2000). Because there may be as many as 80 or more males on any given lek and most of these males will be unmarked, this would be impossible to do on most lek counts. Unreconciled double-observer models use raw maximum counts of the number of individuals detected (in each age class) from each of two independent observers to generate a site history for each observer on each count (e.g., 13, 15) (Riddle et al. 2010). Site histories are then analyzed using the repeated-counts hierarchical model of Royle (2004) in program PRESENCE, with the difference being that, in the unreconciled double-observer model, each observer is considered an independent "visit" (Riddle et al. 2010). One of the benefits of this approach is that leks do not actually have to be visited twice, and the closed population assumption is met (Riddle et al. 2010). The method may require using a negative binomial or zero-inflated Poisson distribution in place of a Poisson distribution if data are overdispersed (Riddle et al. 2010). This estimator may become unstable when detectability is low (P. Lukacs, pers. comm.). However, I anticipate relatively high detectability because observers typically position themselves to maximize their ability to detect males attending the lek.

The counting protocol outlined above (under *Lek counts and resighting*) results in dataset with six repeated counts from the same lek on each date for each counter for each age class of males and for females, with three of the six counts by each counter done with a spotting scope and three with binoculars. Counters will record distance to approximate lek center and presence or absence of snow cover on the count as well as predator activity and weather (temperature, wind speed, precipitation, visibility, illumination) at the end of each 5-minute interval. Predator activity will be broken into three classes (no predator detected, predator visible near lek, predator on, over, or attacking males) based on observations of potential predators of adults (eagles, hawks, falcons, owls, coyote, red fox, bobcat, mountain lion, feral dog) that, in the opinion of the counter or resighter, should have been visible to males attending the lek. Covariates in the analysis of site histories will include a random effect of lek and fixed effects of lek size (i.e., max no. of males counted), distance from lek, optics used (binoculars vs. spotting scope), predator activity, weather, and an interaction between optics and distance from the lek. Because the data consist of repeated counts from the same lek within and among days, this dependence will have to be addressed using a repeated-measures approach.

Second, I will use a time-to-detection approach with resighting data from GPS males collected by counters to estimate detectability. Time-to-detection approaches use resighting data to generate capture histories for individual males detected during the count, and at least four intervals are required for modeling (Alldredge et al. 2007). In the field, counters will record the number of GPS males they detect on the lek during each of the six 5-minute scan intervals. GPS transmitters should be visible at distances at which counts are typically conducted using binoculars. Counters will then double-check with resighters by two-way radio to confirm the identity of GPS males observed on the lek. Resightings will also be checked against early morning locations of GPS males to ensure correct identification of males. I use data from counters instead of from resighters to ensure that detectability measured is representative of how counts are typically conducted. Detections by resighters are not used in detectability calculations because lek counts generally are conducted at distances > 50 m from leks. Resighting data from counters will result in a dataset of capture histories for each marked individual observed during each scan interval for each count period on each date on each lek (e.g., 101011). Capture histories will then be linked with individual-, group-, count-, and interval-specific covariates. This method assumes that males do not arrive, leave, or leave then return to the lek between intervals within each 30-minute count period (i.e., it assumes a closed population). The method has fewer assumptions and more flexibility for modeling than either traditional double-observer (Nichols et al. 2000) or removal methods (Farnsworth et al. 2002). Covariates will include a random effect of either lek or observer (but not both at the same time) and fixed effects of distance from lek, optics used (binoculars vs. spotting scope), predator activity, weather, and an interaction between optics and distance from lek. Time-to-detection models for estimating detectability will be run in program MARK, version 6.0 (Alldredge et al. 2007, White 2010).

I will also estimate detectability by calculating the proportion of GPS males known to have attended a lek that were also detected by either resighting or counting observers during lek counts on that same date. This is to test the implicit assumption that all males that attend a lek are available for counting. It is possible that not all males attending a lek are necessarily visible to both observers (e.g., some may be hidden by topography). Although time-to-detection and unreconciled double-observer approaches should both theoretically account for males attending that are hidden from view, it would be good to directly test this assumption. To do this, I will compare early morning locations of males with GPS transmitters against records of individual marked GPS males observed by resighters during lek counts at approximately the same times that GPS transmitters are scheduled to record early morning locations (6 am, 7 am, and 8 am). The resighting observer will estimate individual marked bird locations by correcting observer UTM locations for direction (θ, in degrees) and distance (m) using the formulas: $northing_{male} = northing_{observer} + \cos(\theta) * distance$ and $easting_{male} = easting_{observer} + \sin(\theta) * distance$. Resighters will record their locations in Universal Transverse Mercator (UTM) coordinates in the North American Datum 1983 using a high-sensitivity GPS unit (Garmin eTrex Vista HCx), they will estimate direction to males from true north with a declinated compass (Silva Ranger CL), and they will estimate distance to those males using a laser rangefinder (Nikon Prostaff 550).

To estimate the effect of counting males from the air on detectability, I use the maximum raw count of all males combined from counters on the ground versus the maximum raw count from a counter in a fixed-wing aircraft (either the pilot or an observer) using the same unreconciled double-observer approach as above. In this case, the difference in detection probability among observers represents the difference in detectability of counting on the ground versus from the air. The comparison will be made between data recorded on the flight and data recorded over the entire 30-minute count period on the ground. This comparison is appropriate because ground counts based on data from a 30-minute count period and flight counts based on data from 3-5 minute count periods are recorded with equal weight in statewide count databases. I will attempt to conduct 40 paired lek counts per year on the ground and from fixed-wing aircraft on the same dates and at the same times. Detectability from the air may be lower because data are derived from only 2-3 passes during a brief window of time (3-5 minutes) rather than counted for an extended period of time during the morning (30 minutes) as is typical for ground counts. However, it is possible that ground-based counts could result in lower counts if topography prevents observers on the ground from detecting all males.

Objective 5: Estimate Age-specific Lek Attendance of Males

I will analyze lek attendance data in two ways. First, as recommended by Walsh et al. (2004), I will develop a modified "sightability" approach to estimate lek attendance for adult and yearling males using data from GPS males. I will use early morning locations of GPS males to determine which leks (or potential leks) GPS males are attending or likely to attend. Field crews will make every effort to count and resight GPS and color-banded males on each of those leks at least once in random order during each week-long resighting occasion throughout the season. Resighting observations will be lumped into 30-

minute resighting periods starting at 0.5 hr before local sunrise for lek attendance analyses. Resighters will also collect data on covariates likely to influence lek attendance for each 30-minute interval. Covariates collected by observers at the lek will also be applied to non-attending GPS males because the focus of this analysis is on testing factors that influence presence on the lek rather than factors influencing presence at locations away from leks. Because GPS males sometimes move between leks, they may not always be present on leks they previously attended that get counted. For this reason, data for the modified "sightability" model will necessarily come from a subset of our sample of GPS males. Data from males that attend non-counted leks will be excluded from this analysis. The dependent variable is lek attendance (1 = attended lek, 0 = did not attend lek). Covariates will include a random effect of lek, fixed effects of time of day, date, snow depth, the previous day's weather, presence or absence of females on the lek, probability of female attendance, lek size (i.e., maximum count of males), and marking type (GPS vs. color-banded), as well as fixed effects of weather variables, predator activity, and frequency of anthropogenic disturbance during the previous 30-minute interval. Logistic regression will be conducted in program R (version 2.11.0, R Development Core Team 2010). Although misidentification of color-bands combinations is a concern for resighting, comparison of color-band combinations recorded against early-morning locations should allow us to correct any misidentification of GPS males by resighters. If misidentification is a problem, new mark-recapture approaches may be available to address that issue (e.g., Link et al. 2010).

Second, I will use the entire GPS male dataset to estimate lek attendance as a function of variables that can be measured without observing attending males directly. I will compare early morning locations of males with GPS transmitters against the count boundary for all known active lek locations to determine whether or not GPS males attended leks (see definition of "attending a lek" in *Objective 4*, above). I can then estimate daily rates of lek attendance for each male using logistic regression. Field crews will document all major weather events that could influence male attendance throughout the field season (e.g., storms, high winds). Daily lek attendance will be modeled as a function of date, current weather (temperature, wind speed, precipitation), the previous day's weather, resighter presence, counter presence, average lek size, previous lek attendance (as a measure of reproductive effort), and probability of female attendance (estimated from counts of females at leks over the course of the season). I include observer presence because having observers count leks may cause males or females to move to another lek or to forgo lek attendance that day, yet this has never been tested. Overall lek attendance for each individual over the season will be calculated by summing the total number of days that each bird attended a lek and dividing that value by the total number of days for which each individual was alive and its early morning location was known.

Detection probability (the joint probability of detectability and lek attendance), may also be estimated as part of estimating male population size (see *Objective 9*, below) and can be compared against the product of detectability and lek attendance estimated separately.

Objective 6: Estimating Probability of Age-specific Presence Using Movements of Males

As outlined above, probability of presence is one of five key components of detection probability for sage-grouse males on leks that need to be estimated for running simulations. I will use location data to estimate the daily probability of presence for each GPS male for each lek within the survey area on each day of the breeding season. Data will be stored as an N x L x D matrix, where N = the number of GPS males in the sample, L = the number of leks attended by GPS males, and D = the number of days during the breeding season. Each cell in the matrix is assigned a 1 or a 0 based on the presence (1) or absence (0) of each GPS male within a certain distance of each lek on each day. A value of 1 does not denote lek attendance because males have the option of either attending or not attending the nearest lek to them on each day. From this matrix, I can calculate the raw proportion of the males in our population that were present at or near each lek we're studying on each day. This is the daily probability of presence that will be used in simulations. Because I will be tracking the location and movement of each male and identifying all leks used by males, where GPS males move and where field crews can determine lek status will define the survey area. However, if a male moves so far outside of the study area that field crews cannot survey any leks he might be attending and it is impossible to determine whether or not he attended a lek, then he will be excluded from the dataset (all values for that male for those days will remain blank). I will also use location data from GPS males overlaid with locations of all known active leks to document the frequency, timing, and distance of inter-lek movements by yearling and adult males.

Objective 7: Estimating Age-specific Survival During the Breeding Season

The purpose of estimating daily survival is to determine the proportion of males in each age class that remain alive on each date over the course of the breeding season in each year for simulations. Age will be used as the only predictor variable in this analysis (adult vs. yearling). Survival analysis will use a continuous-time Cox proportional hazards model (Murray 2006).

Objective 8: Simulate Lek-count Data

I will use empirical data on variation in male survival, presence, lek attendance, detectability, and lek-count effort in conjunction with important covariates (e.g., time of day, date, weather, etc.) to simulate how much lek counts are likely to vary in the absence of population change when conducted according to standardized protocols. I will simulate data for the same sample of leks for which I have data on the number of males counted, as well as data on survival, presence, lek attendance, and detectability. The number of males in the simulated population will be set at a value equal to the maximum count of yearling or adult males at each lek during the period of peak attendance for each age group divided by age-specific detectability estimated during that period. I can use these data to simulate what proportion of the simulated population of adult and yearling males would actually be alive, present, and attending each lek during each time period of the morning on each day of the breeding season in each year. I would then run scenarios using this simulated dataset with realistic combinations of measured and unmeasured variables that influence detectability (e.g., time of day, optics, distance from lek, weather, and number of counts per season). Scenarios would include counts conducted: (a) under more restrictive (0.5 hrs before to 0.5 hrs after sunrise) or less restrictive (0.5 hrs before to 1.0 hrs after sunrise) time of day requirements; (b) with binoculars versus spotting scope; (c) close to leks, farther away from leks, or at various distances from leks; (d) in good versus marginal weather conditions; (e) using a varying number of counts per season from 1 to 6 on randomly selected dates at least a week apart (to mimic data contained in state databases); (f) with varying proportions of leks counted to mimic access problems encountered in the field. Simulations will be set up in program R (version 2.11.0, R Development Core Team 2010).

Objective 9: Estimate Age-specific Population Size

If sufficient data from repeated counts are available at leks within the study area, I will use mark-resight and lek count data to estimate detection probabilities and population size for yearling males, adult males, and females. Because this is an open population (many leks surround the study area), I will analyze the data using an immigration-emigration mixed logit-normal mark-resight model (Bartmann et al. 1987, Neal et al. 1993, Clifton and Krementz 2006) in program MARK (version 6.0, White 2010). Population estimates will be generated in each year of the study. Although previous authors concluded that the joint hypergeometric estimator was unsuitable for greater sage-grouse because it does not allow for individual heterogeneity in lek attendance, violation of the closed-population assumption could lead to even greater bias in population estimates.

Objective 10: Test 0.6-mile Lek Buffer

Portions of the study area have had oil and gas development since the 1920's (Walker 2010). However, most leks within the study area are far enough away from areas with oil and gas development that I should have sufficient data to measure how male sage-grouse use habitat around leks in the absence of disturbance related to oil and gas development. If the hypothesis that males avoid disturbance is true, I would predict a pattern of constrained habitat use around leks within or near development compared to those outside development after accounting for habitat features. This can be tested by comparing buffer distances required to protect the same proportion of the male population at leks inside and outside development after controlling for habitat and topography.

I will measure distances of three off-lek locations per day (at noon, 6 pm, and midnight) for each male to the center of the lek attended that day, the lek most recently attended, the nearest active lek (as recorded in CPW databases or by field crews), and the lek attended on the next visit. I will then calculate the proportion of off-lek locations (for each portion of the day) that fall within specific distances of dissolved buffers around the centers of known active leks to test the effectiveness of the current 0.6-mi. NSO/RSO stipulation for lek buffers and to make recommendations on the most efficient buffer size to use to protect specific proportions of the population. It may also be possible to use a kernel or bivariate normal mixture model to estimate the probability of males using the area around leks (D. Walsh, pers. comm.). I will also compare the effectiveness of conserving areas that fall within different circular buffer sizes to areas of high priority habitat of similar size already identified using VHF locations of females (Walker 2010).

RESULTS AND DISCUSSION

Field crews captured and color-banded a total of 75 adult male greater sage-grouse in October 2010-March 2011 and 25 yearling males in February-March 2011 within or immediately adjacent to the Hiawatha Regional Energy Development boundary. Of those, one adult had a pre-existing injury that I aggravated during capture and one yearling's leg was dislocated during capture; both were released with metal bands only and were excluded from the study. Of the remaining 98 males (74 adults, 24 yearlings), I deployed GPS transmitters on 37 adults and 22 yearlings. Capturing yearling males in late winter proved more difficult than I anticipated, so I opted to deploy GPS transmitters on as many yearlings as possible rather than just color-banding and to increase our sample size of adult males (by 7 GPS males and 7 color-banded only males). Eight males with GPS transmitters (5 adults, 3 yearlings) slipped their transmitters, which resulted in those eight individuals being reclassified as color-banded only. This resulted in a final sample size of 32 adult and 19 yearling GPS males and 42 adult and 5 yearling color-banded only males.

I monitored the locations of all GPS males every 3 days (as new data became available) throughout the spring breeding season (20 March – 10 June) in 2011 to determine: (a) locations of potential new leks for crews to check, (b) which males were alive, (c) which males were within the study area, (d) which males were attending leks, (e) inter-lek movements, and (f) nocturnal and diurnal habitat use around leks.

Field crews checked numerous potential lek locations and located, verified, and counted 3 previously unknown leks: North Kinney Rim (WY), Owl Bench 2 (WY), and Central Sand Wash (CO) (Fig. 1). Field crews conducted standard lek counts, unreconciled double-observer counts, resighting, and display rate observations at leks within the study area from 17 March - 10 June 2011. This effort resulted in 34 standard lek counts at 7 different lek locations (5 active) in Colorado, 49 standard lek counts at 15 lek locations (14 active) in Wyoming, 92 lek-days of resighting at 20 different leks, 58 unreconciled double-observer counts, and 43 paired display rate observations. I was unable to conduct paired aerial and ground counts for logistical reasons. Field crews entered and proofed all field data by the end of June 2011. Data are now being checked for consistency and accuracy prior to analyses.

Preliminary analysis indicate that a lower proportion of GPS males (0.594 of 32 adult GPS males; 0.444 of 18 yearling GPS males; 0.54 of 50 total GPS males) were resighted at least once on leks in spring 2011 than were color-banded only males (0.762 of 42 color-banded only adults; 0.600 of 5 color-banded only yearlings; 0.745 of 47 total color-banded only males). Breeding-season survival of GPS males has not yet been analyzed. Estimates of annual survival of GPS males versus color-banded only males will be available after resighting data are collected in spring 2012.

Yearling males had fitted leg-loop lengths that averaged 0.38 in. smaller than adults (10.44 in. vs. 10.82 in.; $n = 37, 21$; $t < 0.001$). This difference may be offset by the longer elastic built into yearling transmitter harnesses. Nonetheless, this fall I will attempt to recapture any yearlings that are still alive and in or near the Hiawatha project area to check and, if necessary, re-fit their harnesses.

Observers at leks in Hiawatha in spring 2011 noted that transmitter antennas are pushed to the side by the upright tail during strutting and do not appear to interfere with the display. Preliminary data from a paired comparison of strutting behavior on leks detected no difference in mean display rate between males with GPS transmitters (4.06 displays/min ± 0.45 SE) and adjacent, unmarked males in the same age class (3.61 displays/min ± 0.36 SE) (paired t-test; $t = 0.254$, $n = 43$).

Three yearling males and one adult made long-distance movements (30-70 km) well away from the Hiawatha project area during spring 2011; one of these yearlings then returned ~35 km to summer on Cold Springs Mountain (Fig. 4). Diurnal and nocturnal location data will be useful for empirically assessing the effectiveness of lek buffers of different sizes for protecting habitat used by males during each season (Fig. 5).

SUMMARY

Experience with the data from spring 2011 suggests that GPS transmitters are useful for obtaining data on daily lek attendance, diurnal and nocturnal habitat use, and inter-lek movements. It remains unclear whether GPS transmitters affect male survival. I am still analyzing data on male survival, lek attendance, inter-lek movements, habitat use around leks during the breeding season, and on the accuracy and completeness of location data obtained from GPS transmitters. Those results will be summarized in a subsequent progress report.

GPS transmitters appear promising for discovering new leks and for documenting male movements into and out of the study area, lek attendance, inter-lek movements, and nocturnal and diurnal habitat use. I will use resighting data in spring 2012 to assess whether they affect annual male survival.

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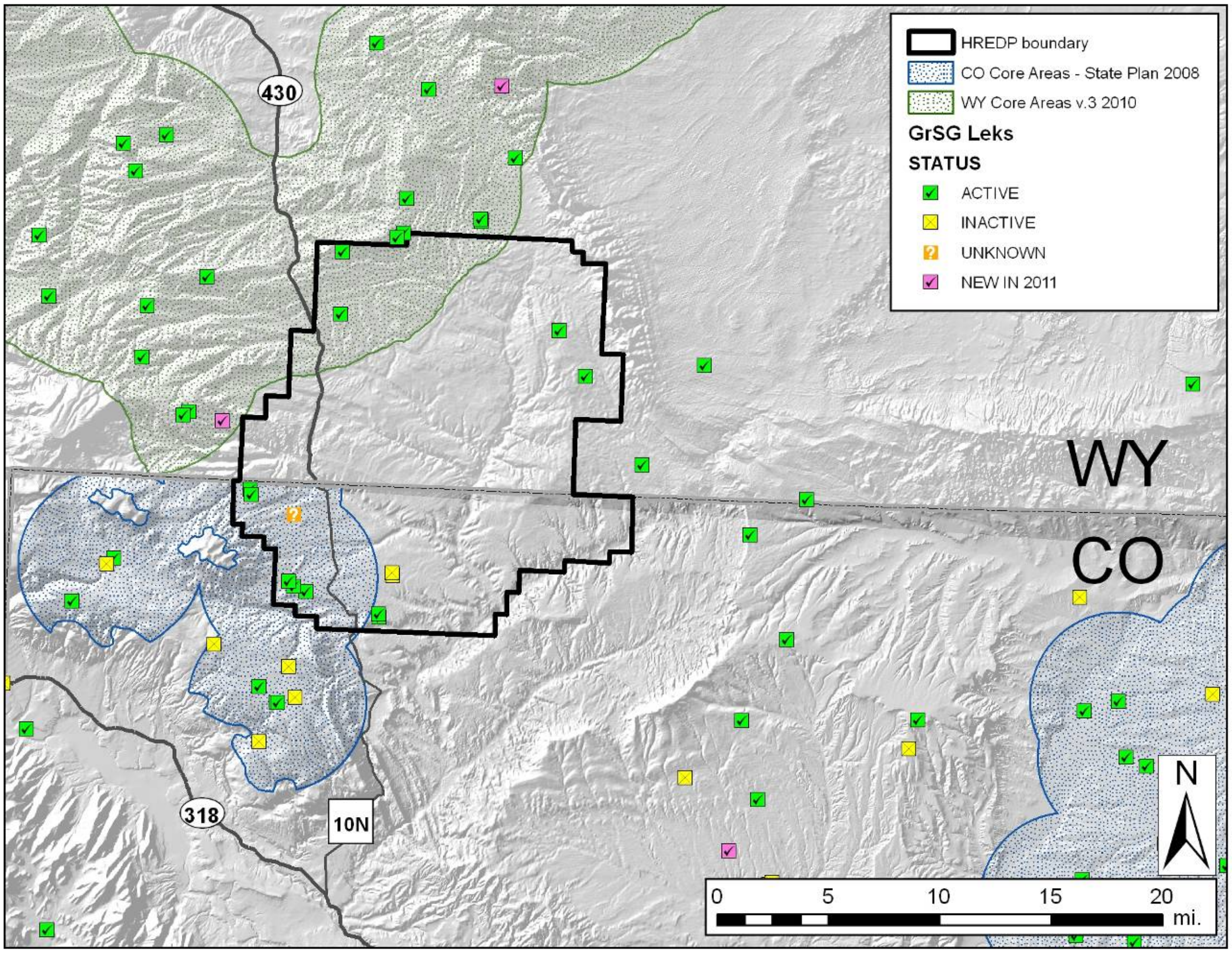

Figure 1. Hiawatha Regional Energy Development project area and surrounding areas showing known active, inactive, and unknown status greater sage-grouse leks as of 2010, plus new leks that were discovered by monitoring and checking early-morning locations of GPS males in 2011.

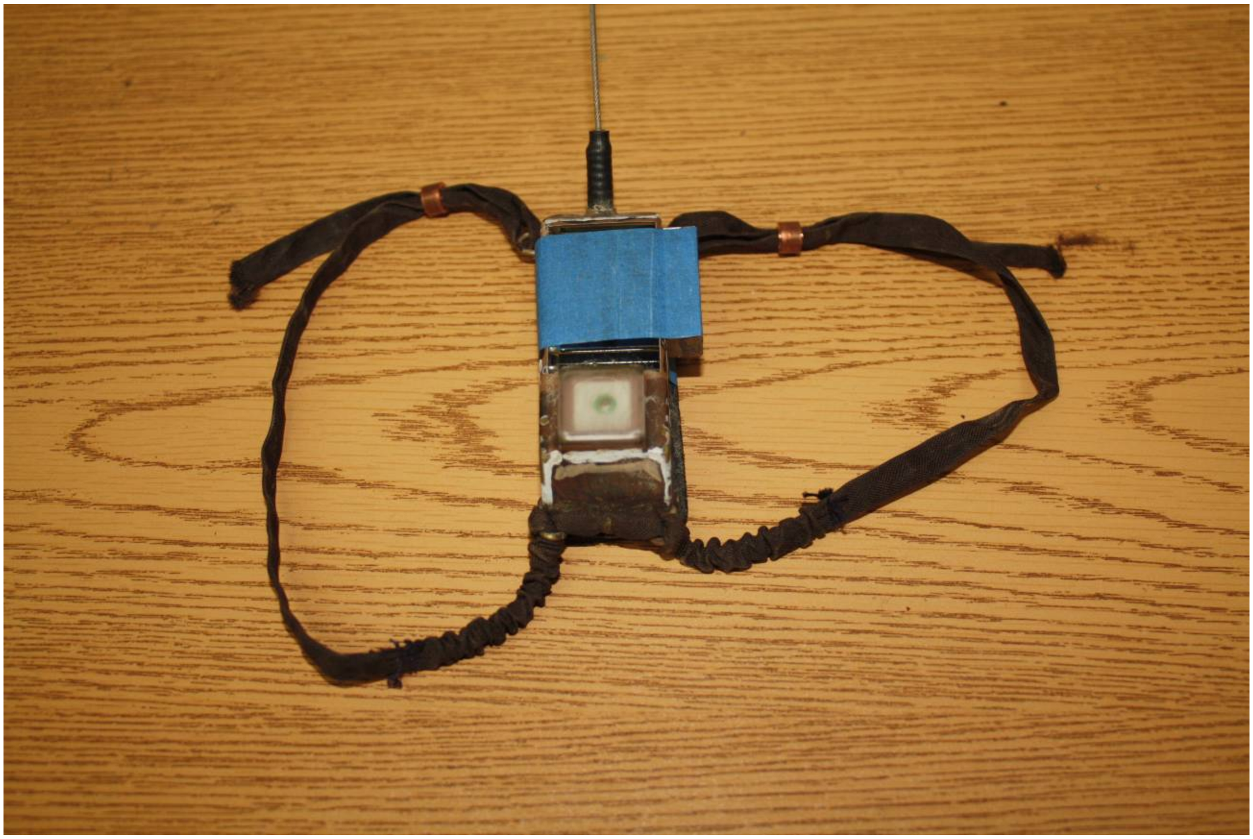

Figure 2. Harness design for rump-mounted leg-loop attachment of solar-powered GPS satellite PTT transmitters to male greater sage-grouse.

Figure 3. Attachment, placement, and camouflage of rump-mounted, solar-powered, GPS satellite PTT transmitters for male greater sage-grouse.

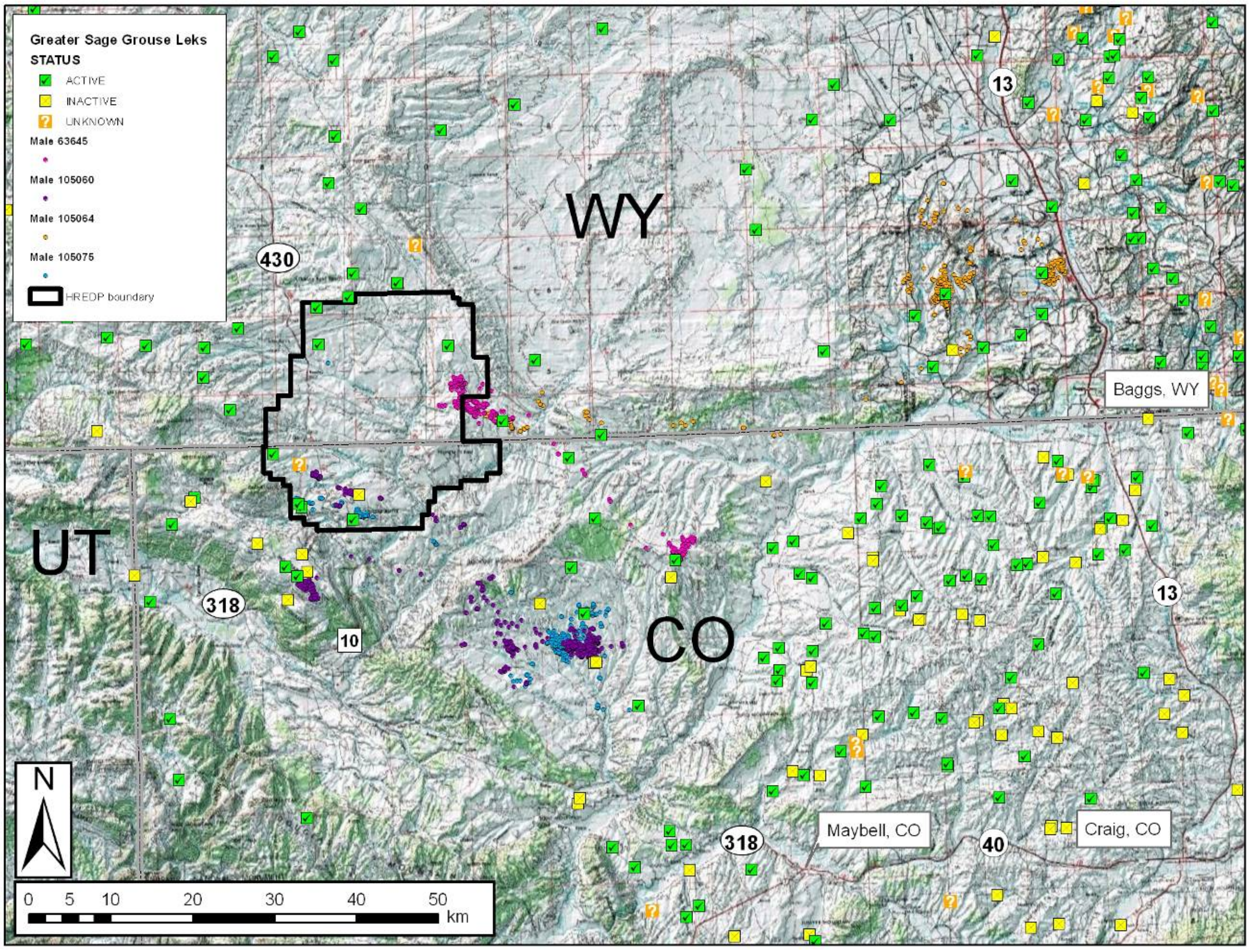

Figure 4. Long-distance movements by selected GPS males in spring-summer 2011 in relation to the Hiawatha Regional Energy Development project area and known lek locations (excluding satellite leks) in Sweetwater and Carbon counties, WY and Moffat Co., CO.

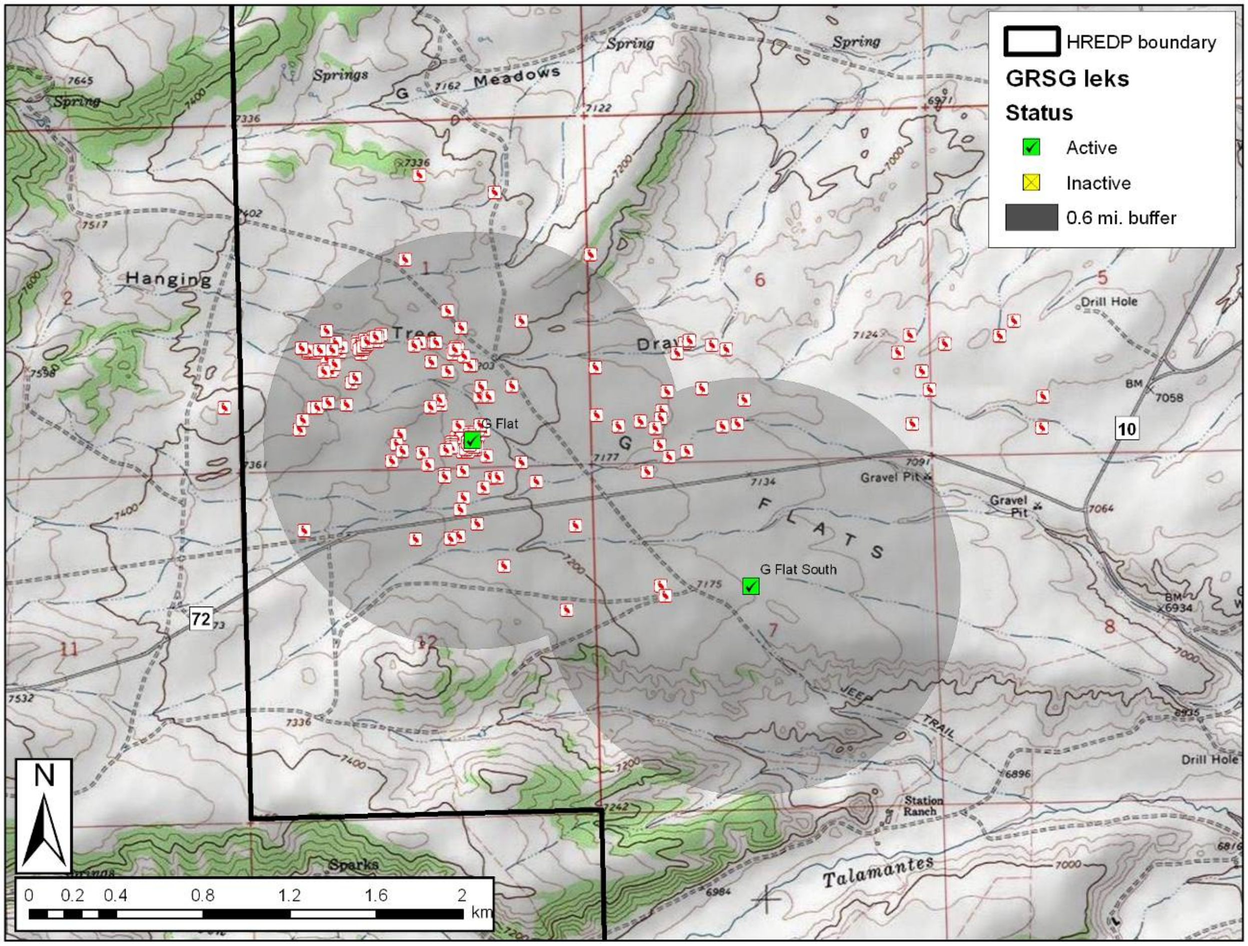

Figure 5. Example of non-strutting locations (12 pm, 6 pm, 12 am) of an adult male greater sage-grouse outfitted with a GPS transmitter around the G Flat and G Flat South lek locations from 14 March - 23 May 2011 in the southwest portion of the Hiawatha Regional Energy Development project area in Moffat Co., CO. Locations shown are those with estimated accuracy < 26 m. The male only attended G Flat lek.

COLORADO DIVISION OF PARKS AND WILDLIFE - AVIAN RESEARCH PROGRAM
PROGRESS REPORT
September 2011

TITLE: **Assessment of greater sage-grouse response to pinyon-juniper removal in the Parachute-Piceance-Roan Population of northwestern Colorado**

AUTHOR: **B. L. Walker**

PROJECT PERSONNEL: **B. Holmes, Terrestrial Biologist (CDOW - Meeker); B. Petch, Senior Terrestrial Biologist (CDOW - Grand Junction); T. Knowles, DWM (CDOW - Meeker); B. deVergie, AWM (CDOW - Meeker)**

Period covered: **December 2008 - August 2011**

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

Loss and degradation of sagebrush habitat throughout western North America has led to growing concern for conservation of greater sage-grouse (*Centrocercus urophasianus*) and recent listing of the species as warranted but precluded under the Endangered Species Act. Greater sage-grouse in the Parachute-Piceance-Roan (PPR) region of western Colorado face two major potential stressors: projected habitat loss from energy development and a long-term decline in habitat suitability associated with pinyon-juniper (PJ) encroachment. Although PJ removal is widely used as a mitigation tool to increase habitat for sage-grouse throughout the species' range, including Colorado, no studies have quantified the timing or magnitude of sage-grouse responses to treatment. Since 2008, the Colorado Division of Parks and Wildlife (CPW) and industry and landowner partners have been cooperating to investigate the effectiveness of removing PJ to offset other potential habitat losses in the PPR. In fall 2008, I established nine study plots, arranged in three groups of three, with each group consisting of a sagebrush control plot, an untreated PJ control plot, and a PJ treatment plot. Treatments were completed on the first PJ-treatment plot in June 2010, on the second plot in November 2010, and on the third plot in August 2011. Pre-treatment surveys over three winters from 2008-2011 indicated that mean track occupancy, as expected, was higher on sagebrush control plots (range 0.006-0.076) than on plots with encroaching PJ (0.00). Surveys over three summers (2009-2011) indicated that mean pellet occupancy was higher on sagebrush control plots (range 0.397-0.449) than on plots with encroaching PJ (range 0.048-0.076). There was no detectable increase in occupancy within one year after PJ removal on two plots treated in 2010. Twelve additional transect-based plots were added in fall 2010 and surveyed for tracks in winter 2010-2011. Preliminary transect data from winter 2010-2011 detected no sage-grouse tracks on eight transect plots with PJ encroachment, tracks on only one of three sagebrush control transect plots, and no tracks on a transect plot 3 years post-treatment (Lower Barnes). Two more transect plots were added and surveyed for pellets in summer 2011. I surveyed all 14 transect plots for pellets in summer 2011. Preliminary pellet data indicated low mean pellet densities (0.00-0.03 pellet piles detected per km of transect) on three PJ – treatment transect plots prior to treatment and two PJ – treatment transect plots within 6 months after treatment. Pellet density was substantially higher (11.10 piles/km) on four sagebrush-control transect plots and on one transect plot 3 years after treatment (Lower Barnes; 13.78 piles/km). Detectability of pellets on survey test plots was low (mean = 0.118) and variable among observers (range 0.00-0.22) in 2009, but higher and less variable among observers in 2010 (mean 0.375; range 0.344-0.406) and in 2011 (mean 0.297-

0.323; range 0.281-0.375). Variation in observer ability to detect pellets will need to be considered when interpreting treatment responses with pellet data.

ASSESSMENT OF GREATER SAGE-GROUSE RESPONSE TO PINYON-JUNIPER REMOVAL IN THE PARACHUTE-PICEANCE-ROAN POPULATION OF NORTHWESTERN COLORADO

Progress Report, December 2008 – August 2011

Brett L. Walker

PROJECT OBJECTIVES

The main objective of this study is to measure short-term (2-5 years) responses of greater sage-grouse to experimental PJ removal using changes in winter track and pellet occupancy in a before-after control-treatment framework.

SEGMENT OBJECTIVES

Objectives of this study in 2010-2011 were to:

1) Complete winter track surveys and pellet surveys on the 9 original plots established in 2008
2) Establish and survey 14 additional transect-based plots
3) Complete PJ removal on treatment plots
4) Summarize winter track survey and pellet survey from 2008-2011.

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 contributed to the recent listing of the species as warranted but precluded under the Endangered Species Act (DOI 2010). The Parachute-Piceance-Roan (PPR) region holds one of seven distinct geographic populations of greater sage-grouse in northwestern Colorado. Greater sage-grouse in the PPR are of conservation concern due to declining population indices, long-term reduction in habitat suitability caused by encroachment of pinyon pine (*Pinus monophylla*) and juniper (*Juniperus* spp.) into sagebrush, and potential impacts from rapidly increasing energy development.

Removal of pinyon-juniper (PJ) from areas with an existing sagebrush understory may help restore sage-grouse habitat in the PPR and offset future potential habitat losses from energy development. Pinyon-juniper encroachment into sagebrush has been identified as a threat to the species' habitat in Colorado and range-wide (CGSSC 2008; Chapter IV; Fig. 30). 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). Pinyon-juniper removal has been widely implemented in Colorado and range-wide (CGSSC 2008). However, sage-grouse responses to PJ removal remain poorly studied (Commons et al. 1999), and the timing and magnitude of greater sage-grouse responses following treatment is unknown. For this reason, it is difficult to judge whether PJ removal can effectively offset impacts from energy development within this population by increasing available habitat.

Since 2008, the Colorado Division of Parks and Wildlife (CPW) and industry and landowner partners have been cooperating on research to assess the value of removing encroaching PJ as mitigation in the PPR. The main objective of this study is to measure short-term (2-5 years) responses of greater sage-grouse to experimental PJ removal using changes in winter track and pellet occupancy in a before-after control-treatment framework. This progress report summarizes preliminary results from winter track and summer pellet surveys for the period December 2008 - August 2011.

STUDY AREA

Study plots are within or immediately adjacent to the current occupied range of greater sage-grouse in the PPR (Fig. 1). Birds in the PPR population inhabit the tops of ridges and plateaus dominated by mountain big sagebrush (*Artemisia tridentata vaseyana*) and a mixture of sagebrush and "mountain shrubs" (e.g., serviceberry, *Amelanchier* spp.; Gambel oak, *Quercus gambelii*, snowberry, *Symphoricarpus* sp.; antelope bitterbrush, *Purshia tridentata*, mountain mahogany, *Cercocarpus* sp., etc.). These areas are typically interspersed with patches of aspen (*Populus tremuloides*) and Douglas-fir (*Pseudotsuga menziesii*). Sagebrush and mixed sagebrush-mountain shrub habitats at higher elevation give way to PJ woodland on lower-elevation ridges that appears to preclude use by sage-grouse. Our study plots are situated along the ecotone where PJ is encroaching upslope into sagebrush and sagebrush-mountain shrub habitat.

METHODS

Plot Selection and Assignment

I used vegetation, topography, marked bird locations, and aerial photography as well as on-site visits to identify nine study plots in 2008 (Fig. 2) and 14 additional study plots in 2010 and 2011 (Figs. 2-4). Two of the plots added in 2010 (Upper and Lower Bar D) were treated by the Bureau of Land Management and included opportunistically in our study (Fig. 2). Study plots were selected based on: (1) density of PJ; (2) existing shrub composition, density, and height; (3) topography; (4) proximity to areas of current known use by greater sage-grouse; and (5) proximity to, and likelihood of, energy development within 5 years. All plots had a sagebrush-dominated shrub layer (typically intermixed with mountain shrubs) and topography similar to habitats used by sage-grouse in the PPR from 2006-2010 (Apa 2010, Walker 2010). The southeast portion of the PPR population is experiencing intensive energy development, but there is currently no development within the study plots and only limited development near plots.

I am using a before-after, control-treatment design to compare changes in sage-grouse winter track occupancy and pellet occupancy among control and removal plots before and after encroaching PJ is removed. Caution must be exercised in interpreting results because estimates of track and pellet occupancy only give an index of frequency of use during a defined survey period, rather than a measure of abundance, density, habitat quality, or habitat selection (*contra* Dahlgren et al. 2006).

I have three levels of treatment: (1) "PJ-Treatment" plots where encroaching PJ is removed, (2) "PJ-Control" plots where encroaching PJ is not removed, and (3) "Sagebrush-Control" plots with no PJ. Data from PJ-Treatment plots are used to measure changes in track and pellet occupancy before and after PJ removal. PJ-Control plots allow us to measure background changes in track and pellet occupancy over time in areas with encroaching PJ in the absence of treatment. Sagebrush-Control plots allow us to estimate trends and background variation in track and pellet occupancy in habitats already suitable for sage-grouse. Most plots were surveyed for 1-3 years prior to PJ removal and will be surveyed for 2-5 years following removal, depending on the timing of treatment and the timing and magnitude of observed sage-grouse responses. I established 3 study plots per treatment in fall 2008 for a total of nine original study plots (Fig. 2). I established 12 additional transect-based study plots in fall 2010 and two more transect-based plots in summer 2011 (Figs. 2-4), for a total of 23 study plots (9 survey, 14 transect).

Pinyon-juniper Removal

All treatments were done by contractors using either a Bobcat with a Fecon head or a Hydro-axe. Contractors were instructed to remove only pinyon-juniper and to avoid removing sagebrush or mountain shrubs. A partial treatment was done on the Black Sulphur plot in August 2009 and completed in July

2010, the Upper Galloway plot was treated in November 2010, and the Ryan Gulch plot was treated in August 2011. Among transect plots, two (Upper and Lower Bar D) were treated by BLM in January 2011 following one round of winter surveys, and three (Cottonwood, Magnolia South, and Lower Wagonroad) will be treated in summer-fall 2011.

Winter Track Surveys and Transects

I originally planned to estimate frequency of winter use using occupancy and density of tracks measured on snowshoe surveys (McKenzie et al. 2006). I hypothesize that, after controlling for local- and landscape-scale habitat conditions, winter track occupancy and density will increase following removal of encroaching PJ, but with a time lag due to fidelity of adults to wintering areas. I am using two different sampling methods. The first method is based on a sample unit probability estimator (SUPE; Becker et al. 1994, 1998) and provides an estimate of occupancy, or the proportion of the plot used by sage-grouse during a 24-36 hr survey period following winter storms. Field work involves searching for sage-grouse tracks in the snow within a systematic-random sample of 30 x 30 m square sample units within each study plot. I selected 30 x 30 m sample units so that they would be large enough to have a reasonable probability of containing sage-grouse tracks but small enough to ensure that all tracks within the sample unit would be detected by observers. This method was used on the original nine study plots established in 2008. I refer to these nine plots as "survey" plots. The second method is based on a transect-intercept probability estimator (Becker 1991, Becker et al. 1994). Field work involves surveying a systematic-random sample of parallel, variable-length transects and documenting the number and path of sage-grouse tracks that intersect transect lines. I used transect sampling on the 12 plots established in fall 2010 and on the two plots established in summer 2011. I refer to these 14 plots as "transect" plots.

Winter track surveys and transects have the following assumptions: (1) all sage-grouse move and leave tracks during the survey period (i.e., between when snowfall stops and when the survey is conducted); (2) all sage-grouse tracks deposited in sampled units or along transects during the survey period can be seen and correctly identified to species; (3) surveying does not influence whether or not tracks are present in sampled units or along transects; (4) pre-storm tracks can be distinguished from post-storm tracks; and (5) all sample units or transects 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 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 (but not always) followed by 1-2 days of relatively calm, sunny, cold weather. To ensure that I meet Assumption 1, I only conducted surveys when weather conditions during the survey period (24-36 hr for survey plots, 36-72 hr for transect plots) were suitable for tracks to persist. Assumption 2 is met because observers can distinguish sage-grouse tracks from other birds by size, behavior, and pellet characteristics. Sage-grouse typically travel from one sagebrush plant to another, sometimes dropping leaves on the snow as they forage, whereas dusky grouse (*Dendragapus obscurus*) forage on and travel between conifers in winter. Common ravens (*Corvus corax*) typically double-hop on snow rather than walking and do not eat sagebrush. Sage-grouse also deposit distinctive pellets that smell like sagebrush; sage-grouse consume >99% sagebrush in winter (Wallestad et al. 1975). Sagebrush has never been documented in the diet of dusky grouse in any season (Zwickel 1992). Dusky grouse pellets smell like defecated plant material. Assumption 3 may be violated if surveyors flush birds that then land within another sample unit or walk across a transect line surveyed later. To minimize this potential bias, I recorded whether birds flushed from a sample unit or transect, how many, and whether they flew toward or away from the unsurveyed portion of the plot. Assumption 4 is met because surveys are specifically designed to be conducted after snowstorms or wind events bury old tracks. Fresh, post-storm tracks are easily distinguished from older, pre-storm tracks, even when old tracks aren't completely covered. To meet assumption 5, I conducted surveys on all 3 plots within each group on the same day. However, I sampled different groups of plots on different days because the number of observers available on any given day was limited.

For survey plots, I recorded presence or absence of sage-grouse tracks and estimated the number of individuals that left tracks within each sample unit surveyed. I also collected basic data on habitat covariates within each sample unit that might influence use: (1) pinyon-juniper height and density; (2) snow depth at center; (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. Once field data collection is complete, I will also measure, and incorporate into analyses, any landscape-scale covariates identified as important predictors of seasonal habitat use (Walker 2010). This will allow us to control for the influence of landscape-scale habitat variables on sage-grouse responses to PJ removal. Because it may take longer for sage-grouse to colonize areas farther away, I will also include a covariate with 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, I will incorporate a time-trend variable, with the prediction that use will increase either linearly or quadratically over time. I will use a logit-link in the analysis to constrain occupancy estimates to a (0, 1) interval.

Winter Pellet Collection for Genetic Analysis

No previous studies have estimated winter track occupancy for sage-grouse, and the quantitative relationship between track occupancy and actual abundance remains unknown, so the method requires validation. I plan to test whether occupancy reflects actual abundance by comparing occupancy estimates to abundance estimated from genetic mark-recapture results. I plan to use mark-recapture methods using non-invasive genetic samples based on winter pellet sampling to estimate the number of individuals using each plot over the course of the winter. I attempted to collect ≥1 fecal pellets per individual track encountered during winter track 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. Details of genetic methods are described in Oyler-McCance and St. John (2008). 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., so it is likely that pellets can be obtained for most if not all birds whose tracks cross a surveyed sample unit or transect line. Because surveys of each plot are usually repeated, I can also use pellets collected during the second or third sampling visit to estimate detectability of individuals using mark-recapture analyses. 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 and Transects

I obtained an index of frequency of sage-grouse use of plots by surveying for pellets during the summer and estimating pellet occupancy. As with the winter work, I used two different sampling techniques (sample unit-based surveys and transect surveys). On survey plots, I used a subset of the same systematic-random sample of 30 m x 30 m sample units used for winter track surveys for conducting pellet surveys in summer. On transect plots, I used the same transects for both track sampling in winter and pellet sampling in summer.

With both sampling methods, I searched for, counted, and removed pellets from each sample unit (or transect line) within the plot once per year in July-August. For all pellets, I recorded their condition and appearance (crumbly-bleached vs. hard-dry, vs. fresh-wet) to estimate age and used composition to estimate when during the year they were deposited. I identified those containing intact insect parts and flower heads as “summer” pellets (April-Oct) and those containing only digested sagebrush leaves as “winter” pellets (Nov-Mar) (Wallestad et al. 1975). I recorded single pellets, pellet piles (i.e., day or night roost piles), and cecal droppings separately. Observers record pellets or groups of pellets within 10 cm of each other as one pile, with the constraint that pellets or groups of pellets > 10 cm apart could not be counted as the same pile.

I initially planned to sample each study plot twice per summer – at the start and end of each 3-mo. summer period. However, surveys took too long to complete, so I opted to sample each plot only once per year in July-August and to change the "survey period" (i.e., the period during which birds can deposit pellets) from 3 mo. to 12 mo. instead. I marked all sample unit centers and transect lines with aluminum tags, high-visibility flagging, or both to ensure consistency in sampling across years. On survey plots, each observer carefully and thoroughly surveys sample units by slowly walking 10 parallel 30-m lines spaced 3 m apart. On transect plots, observers survey for pellets by walking flagged transect lines, trying to stay on the line as much as possible, and searching within 1.5 m on either side. Observers also recorded anecdotal evidence of occupancy encountered while surveying (e.g., clocker droppings, nests and eggs, feathers, birds, etc.).

These two survey methods for pellets have the following assumptions: (1) all pellets can be correctly identified to species; (2) all pellets can be correctly distinguished as either a chick or adult pellet by size; (3) all pellets deposited during the survey period (during the previous year) can be correctly distinguished from pellets deposited prior to the survey period by condition and appearance; (4) all pellets can be correctly distinguished by season ("winter" vs. "summer") by pellet composition; (5) surveying does not influence whether or not pellets are present in sampled units (or along transects). To address assumption 1, I trained observers to distinguish dusky grouse from sage-grouse pellets prior to surveys. Adult pellets of the two species can be distinguished by composition and smell in any season. Adult-sized sage-grouse typically consume 13-39% sagebrush throughout the spring and summer and >99% sagebrush in winter (Wallestad et al. 1975, Schroeder et al. 1999). For this reason, pellets of adult sage-grouse contain sagebrush year-round, and unlike dusky grouse, consistently smell like sage, even after a year in the field. To address assumption 2, I trained crews to distinguish adult from chick pellets by length and diameter. Quantitative analyses will only include data on adult-size pellets because it may not be possible to distinguish pellets of dusky grouse vs. sage-grouse chicks due to overlap in chick diets (both species consume primarily insects and forbs as chicks; Zwickel 1992, Drut et al. 1994). To address assumption 3, crews differentiated pellets in the field based on condition (bleached and crumbly vs. hard and dry vs. fresh and green/moist). I are also testing how pellet condition changes with age by placing piles of fresh test pellets within representative sagebrush habitat in the field and photographing changes in condition over time. I will test assumption 4 by testing how often observers correctly assess composition and season for pellets collected from marked birds in different seasons. Assumption 5 may be violated if surveyors flushed birds that then landed within another sample unit or along a transect line later surveyed. However, violation of this assumption is unlikely to meaningfully influence analyses because the number of pellets birds could deposit before the unit or transect gets surveyed (on the order of minutes or hours) is miniscule compared to the survey period (12 mo.).

Pellet Detectability

Detectability of sage-grouse pellets is typically low and may vary among observers (Dahlgren et al. 2006) and with pellet condition and appearance. In summer 2009, I determined that crews were unable to sample each plot more than once per summer due to logistical constraints, so I instead estimated variation in detectability of pellets among observers by having each observer survey eight test sample units in which I placed clusters of fresh pellets of various sizes at random directions and distances within the sample unit from the sample unit center. Pellet clusters of different sizes and different condition and appearance classes (bleached-crumbly vs. hard-dry and fresh-green/moist) were also placed at random distances within 1.5 m along two 400-m long test transects. Test clusters were placed at the nearest point on the ground (i.e., not on top of vegetation) to the randomly selected location. Sample units and transects used for testing detectability and observer bias were exhaustively grid-searched for pellets and pellets were removed prior to testing to ensure that no other pellets were present during the test. Testing of observers was blind; observers did not know which sample units or transects contained pellets, how many, or their condition and appearance.

Vegetation Sampling

I sampled vegetation at locations used by marked sage-grouse in winter and within a systematic-random subset of sample units and transect points in July-August to determine whether local-scale habitat on study plots would be suitable as winter habitat for sage-grouse once PJ treatments were done. At each veg sampling point, I laid out two 30-m perpendicular tapes running N-S and E-W and measured: (1) shrub canopy cover by species using the line-intercept method (Canfield et al. 1941) and (2) species and height of the nearest shrub (excluding inflorescences) within 2.5 m every 5 m along each tape.

RESULTS AND DISCUSSION

I completed 1-3 rounds of winter track surveys per winter on the original nine survey plots in each winter 2008-2009, 2009-2010, and 2010-2011 and 1-3 rounds of surveys on 12 transect plots in winter 2010-2011. The number of rounds of surveys completed each winter depended on the number of storms that deposited fresh snow and on weather conditions following each storm. Mean winter track occupancy was consistently higher on sagebrush control survey plots than on survey plots with encroaching PJ in all three years (Table 1). Sagebrush control plots had winter track occupancy estimates of 0.006-0.076, whereas plots with encroaching PJ showed zero occupancy (Table 1). I counted a mean of 8.39 tracks per plot (range 0-45) on sagebrush control plots during the survey period, whereas I found zero tracks on plots with encroaching PJ (Table 1). Field crews reported that estimating the number of individuals using a sample unit based on tracks was difficult for large flock sizes (i.e., > 10). Mean winter track density was higher on one sagebrush control transect plot than on transect plots with encroaching PJ, but no tracks were found on two of the three sagebrush-control transect plots (Table 2).

I collected 90 pellet samples in winter 2008-2009, 24 samples in winter 2009-2010, and 19 samples in winter 2010-2011 on survey plots. I collected 68 pellet samples in winter 2010-2011 from transect plots. Genetic analyses are underway in Dr. Oyler McCance's laboratory at USGS in Fort Collins, Colorado. Results of genetic analyses will be included in a subsequent progress report when they become available.

I conducted one round of pellet surveys on each of the 9 original plots in August 2009, July-August 2010, and July-August 2011 and one round of pellet surveys on each of 14 transect plots in July-August 2011. Pellet survey data from 2009-2011 indicated substantially higher mean summer, winter, and year-round occupancy on sagebrush control survey plots than on survey plots with encroaching PJ in all three years (Tables 3-5). I observed no increase in year-round pellet occupancy on Black Sulphur and Upper Galloway plots within 1 year following treatments (Fig. 5, Tables 3-5). Pellet occupancy on sagebrush-control plots generally declined from 2009-2011 (Fig. 5). A similar pattern was found on transect plots, with much higher pellet densities on sagebrush control transect plots than on transect plots that had encroaching PJ (Table 6). The two plots from which PJ had been recently removed (Upper and Lower Bar D) showed no evidence of pellets, whereas pellet density on the plot treated by BLM in 2007-2008 (Lower Barnes) was comparable to those on sagebrush-control plots.

Observers conducted pellet surveys on eight 30 x 30 m test sample units on the Upper Galloway plot in 2009, on eight test sample units on the Stake Springs plot in 2010, and on all 16 sample units on both plots in 2011. Each test sample unit contained piles of fresh sage-grouse pellets of different sizes. I were forced to use test units on Stake Springs in 2010 because the Upper Galloway plot was inaccessible when testing was conducted. Mean detectability of test pellets on Upper Galloway in 2009 was low overall (0.125) and variable among the five observers (range 0.06-0.22). Mean detectability on Stake

Springs was higher in 2010 (0.375) and less variable among the three observers (range 0.344-0.406). Detectability on Upper Galloway was higher in 2011 (0.323) than in 2009 (0.125) but lower on Stake Springs in 2011 (0.297) than in 2010 (0.375). Detectability among the six observers in 2011 was less variable than in 2009 but similar to values in 2010 (range 0.281-0.375 on Upper Galloway, range 0.281-0.375 on Stake Springs). I found no indication of any substantive difference in average pellet detectability between plots in 2011 (0.323 ± 0.027 SE on Upper Galloway; 0.297 ± 0.021 SE on Stake Springs).

Observers conducted test pellet surveys along two 400 m long transects on Bar D ridge in August 2011. The first test transect had shorter shrubs and less shrub cover but more grass cover than the second test transect. Mean detectability of pellets on test transects was similar to that on test survey plots (Transect 1: 0.220 ± 0.040 SE; Transect 2: 0.390 ± 0.020 SE), but detectability was higher on the plot with taller, denser shrubs and less grass cover. Variation in detectability among observers ranged from 0.100-0.350 on the first transect and 0.350-0.450 on the second transect.

Vegetation sampling data were collected on the nine original survey plots in 2010, but have not yet been analyzed. Vegetation sampling data on transect plots are currently being collected. Visual assessment suggests that mountain shrub density and height are denser on the easternmost Cottonwood and Sprague plots than on the other 21 plots. A summary of vegetation sampling data will be presented in a subsequent progress report.

Overall, preliminary data from winter track surveys and summer pellet surveys during the pre-treatment phase of the project were largely as expected, with greater use of sagebrush control plots than plots with encroaching PJ (either PJ-control plots or PJ-treatment plots prior to treatment). However, the amount of time it takes to conduct pellet surveys prevented us from repeating them. This in turn, prevented us from estimating detectability in an occupancy framework and forced us to estimate detectability experimentally using test plots instead. Variation in pellet detectability among observers may be an issue for interpretation of data from pellet surveys if the effect size of PJ treatment is small compared to variation in detectability of pellets among observers. The reason for substantially lower detectability on the Upper Galloway plot in 2009 than on Stake Springs in 2010 or on both plots in 2011 is unknown.

Annual variation in snow conditions and weather made winter track surveys logistically challenging for field crews, made it difficult to maintain consistency in survey effort (i.e., the number of sampling visits per winter) across years (Tables 1 and 2), and forced us to abandon our original goal of sampling each plot three times per winter. Low snowpack in 2008-2009 left large stretches of road barren, making it difficult for crews to access plots and causing substantial wear and tear on snowmobiles. In 2009-2010, snow pack was adequate for travel and winter storms passed through regularly, and there were enough calm, clear days following each storm in which to conduct surveys. Winter 2010-2011 saw numerous storms come through back-to-back, often within a few days of each other, and conditions that prevented repeat surveys on some transect plots (Table 2).

It is unclear why there is an apparent decline in track occupancy and pellet occupancy on sagebrush control plots between 2009 and 2011. It may reflect a decline in population size or density. Lek-count data from 2009-2011 suggest that the PPR population declined to an all-time population low in 2010 and remained low in 2011 (Neubaum 2011). Alternatively, this decline may simply reflect natural variation in occupancy estimates due to methodology (i.e., insufficient sampling effort relative to the density of birds). I have some evidence for the latter. First, sage-grouse may not always be detected even when they are known to be present within a study plot. On the Dry Gulch plot on 23 February 2010, observers did not find any tracks inside sample units, resulting in an occupancy estimate of zero on that date, but they found fresh sage-grouse tracks between sample units, indicating that the study plot was indeed occupied. Crews have also detected old, pre-storm tracks within sample units, but no post-storm tracks, indicating occupancy immediately prior to, but not during, the survey period. I detected no tracks on 2 of 3 sagebrush control transect plots in winter 2011 even though these plots were known to have been used by marked individuals in previous winters. This complication is inherent in surveying any population in which animals occur at low density – detecting occupancy requires greater effort as density decreases. However, again, it is unclear if this is a function of declining overall population size or an artifact of sampling methodology. I are seeing a similar decline in pellet occupancy between 2009-2011. Again, it is unclear whether fewer birds are using our sagebrush-control study plots over time or whether occupancy estimates vary over time due to sampling methodology.

Current post-treatment data are insufficient to draw conclusions about short-term (2-5 years) responses of greater sage-grouse to PJ removal. Post-treatment data on the Black Sulphur and Upper Galloway plots (Table 3) indicated no significant increase in use in any season within 1 year following treatment. This result is not unexpected, considering that adult sage-grouse typically show high site fidelity, and dispersing yearlings are more likely to colonize newly-created adjacent habitat. Detecting a response to PJ treatment may also take longer than expected if small or declining population size results in fewer yearlings available in the population.

Because of delays in completing PJ removals, I plan to continue documenting sage-grouse responses to PJ treatment using winter track and summer pellet surveys through summer 2014 (Table 7).

SUMMARY

- Pre-treatment results were largely as expected, with greater use of sagebrush-control plots than either PJ-control plots or PJ-treatment plots (prior to treatment).
- Variation in pellet detectability among observers may be an issue for interpretation of data from pellet surveys if the effect size of PJ treatment is small compared to variation in detectability of pellets among observers.
- Annual variation in snow conditions and weather make winter track surveys logistically challenging and sometimes prevented crews from achieving sampling objectives.
- All PJ treatments are scheduled to be complete by fall 2011.
- An apparent decline in track occupancy and pellet occupancy on sagebrush control plots between 2009 and 2011 may reflect a decline in population size or density or simply natural variation in occupancy estimates due to our methodology. This complication is inherent in surveying any population in which animals occur at low density.
- Current data are insufficient to draw conclusions about short-term (2-5 years) responses of greater sage-grouse to PJ removal. Detecting a response to PJ treatment may take longer than expected if small or declining population size results in fewer yearlings available in the population.
- Analyses to compare shrub composition, cover, and height on PJ-treatment plots versus sage-grouse winter use locations will be completed this winter.
- Post-treatment monitoring of sage-grouse responses will continue through summer 2014.

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Table 1. Preliminary winter track occupancy estimates (Ψ ± SE) and number of tracks detected for greater sage-grouse in the Parachute-Piceance-Roan region of western Colorado, USA, during the winters 2008-2009, 2009-2010, and 2010-2011. Crews attempted to survey all 30 x 30 m sample units within each plot on each sampling visit, but it was not always possible, so sample size of units per plot (n) varies. The Upper Galloway, Ryan Gulch, Eureka, and Stake Springs plots were reduced in size between winter 2008-2009 and winter 2009-2010 to better match treatment areas (Upper Galloway and Ryan Gulch) or to ensure that each plot within each group could be sampled within a single day (Eureka and Stake Springs). Detectability of sage-grouse winter tracks in snow within 30 m x 30 m sample units is assumed to be 1.0.

	PJ - Treatment Plots			**PJ - Control (No Treatment) Plots**			**Sagebrush - Control Plots**		
	1-Upper Galloway	2-Black Sulphur	3-Ryan Gulch	1-Dry Ryan	2-Eureka	3-Stake Springs	1-Dry Gulch	2-Canyon Creek	3-Black Cabin
					Winter 2008-2009				
Ψ[a]	0.000[b] ± 0.000	0.000[b] ± 0.000	0.000[b] ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.076 ± 0.006	0.012 ± 0.012	0.036 ± 0.020
T[c]	0, 0	0	0	0, 0	0	0	45, 21	17	18
N[d]	2	1	1	2	1	1	2	1	1
n[e]	109, 109	74	76[d]	65, 65	93[d]	76 [d]	84[d], 87	82	83[d]
					Winter 2009-2010				
Ψ[a]	0.000[b] ± 0.000	0.000[f] ± 0.000	0.000[b] ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.015 ± 0.010	0.012 ± 0.012	0.006 ± 0.006
T[c]	0, 0, 0	0, 0, 0	0, 0	0, 0, 0	0, 0, 0	0, 0	10, 12, 0	10, 0, 0	2, 0
N[d]	3	3	2	3	3	2	3	3	2
n[e]	82, 84, 84	74	71[d], 72	65, 65, 65	86, 86, 81	63, 63	87, 87, 87	82, 81, 82	85, 84
					Winter 2010-2011				
Ψ[a]	0.000[g] ± 0.000	0.000[h] ± 0.000	0.000[b] ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.017 ± 0.006	0.006 ± 0.006	0.006 ± 0.006
T[c]	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	7, 2	0, 5	0, 2
N[d]	2	2	2	2	2	2	2	2	2
n[e]	84, 84	74, 74	72, 72	65, 65	86, 86	63, 63	87, 87	84, 84	84, 84

[a] Ψ = estimated winter track occupancy. Values for plots surveyed on multiple visits are means averaged across visits.
[b] Pre-treatment data
[c] T = total no. of individual tracks detected per sampling visit.
[d] N = no. of sampling visits per winter.
[e] n = no. of 30 x 30 m sample units surveyed per plot per sampling visit.
[f] The Black Sulphur plot was partially treated in fall 2009. Values represent data collected 3-5 mo. following partial PJ removal.
[g] The Upper Galloway plot was completed in summer 2010. Values represent data collected 6-8 mo. following complete PJ removal.
[h] Treatment on the Black Sulphur plot was completed in summer 2010. Values represent data collected 6-8 mo. following complete PJ removal.

Table 2. Preliminary estimates of track density for greater sage-grouse on transect plots in the Parachute-Piceance-Roan region of western Colorado, USA, in winter 2010-2011. Detectability of sage-grouse winter tracks in snow that cross transect lines is assumed to be 1.0.

	PJ – Treatment Transect Plots						**PJ – Control (No Treatment) Transect Plots**				**Sagebrush – Control Transect Plots**			
	Pre-treatment					**Post-treatment**								
	Lower Bar D	Upper Bar D	Magnolia South	Cotton-wood	Lower Wagon-road	Lower Barnes[a]	Bar D Split	Magnolia North	Sprague	Upper Wagon road	Bar D Control	Magnolia Control	Upper Barnes Control	Wagon-road Control
x[b]	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00	0.00[a]	-	0.00 ± 0.00	0.00	0.00	0.00 ± 0.00	7.21 ± 0.29	- -	0.00
T[c]	0, 0, 0	0, 0, 0	0, 0	0	0	0, 0[a]	-	0, 0	0	0	0, 0	51, 47	-	0
I[d]	0, 0, 0	0, 0, 0	0, 0	0	0	0, 0[a]	-	0, 0	0	0	0, 0	51, 47	-	0
N[e]	3	3	2	1	1	1	-	2	1	1	2	2	-	1
km[f]	9.58	6.36	9.80	7.70	7.64	5.88	-	6.44	13.40	9.80	5.88	6.80	-	5.88

[a] Data on Lower Barnes were collected opportunistically and are presented for comparison only. Data represent 3 years post-treatment. Treatments on Lower Barnes were started in summer 2007 and completed in summer 2008 by the Bureau of Land Management. No pre-treatment data are available.
[b] x = no. of individual tracks encountered per km of transect. Estimates for plots surveyed on multiple sampling visits are means averaged across visits ± SE.
[c] T = total no. of individual tracks detected per sampling visit.
[d] I = total no. of tracks detected intersecting transects per sampling visit.
[e] N = no. of sampling visits per winter.
[f] Total kilometers of transect line surveyed per plot per sampling visit.

Table 3. Preliminary estimates of proportion occupied sample units (p ± SE) for greater sage-grouse pellets on survey plots in the Parachute-Piceance-Roan population of western Colorado, USA in 2009. Values presented do not account for variation in pellet detectability.

	PJ - Treatment Plots: Pre-treatment				PJ - Control (No Treatment) Plots				Sagebrush - Control Plots			
	1-Upper Galloway[a]	2-Black Sulphur[a]	3-Ryan Gulch[a]	Mean ± SE	1-Dry Ryan	2-Eureka	3-Stake Springs	Mean ± SE	1-Dry Gulch	2-Canyon Creek	3-Black Cabin	Mean ± SE
	n = 49[b]	n = 38[b]	n = 48[b]	N = 3[c]	n = 35	n = 50	n = 38	N = 3	n = 54	n = 41	n = 42	N = 3
p_S[d]	0.061	0.000	0.042	0.034	0.000	0.040	0.026	0.022	0.111	0.049	0.119	0.093
	± 0.034	± 0.000	± 0.029	± 0.018	± 0.000	± 0.033	± 0.026	± 0.012	± 0.043	± 0.034	± 0.05	± 0.022
p_W[d]	0.061	0.000	0.104	0.055	0.000	0.000	0.079	0.026	0.389	0.268	0.381	0.346
	± 0.034	± 0.000	± 0.044	± 0.03	± 0.000	± 0.000	± 0.044	± 0.026	± 0.066	± 0.069	± 0.075	± 0.039
p_{YR}[d]	0.082	0.000	0.146	0.076	0.000	0.040	0.105	0.048	0.444	0.293	0.452	0.397
	± 0.039	± 0.000	± 0.051	± 0.042	± 0.000	± 0.033	± 0.05	± 0.031	± 0.068	± 0.071	± 0.077	± 0.052

[a] Data represent pre-treatment values. Numbers preceding plot names refer to which set the plot is in (e.g., Set 1 = Upper Galloway, Dry Ryan, Dry Gulch; Fig. 2).

[b] n refers to no. of 30 x 30 m units sampled within the study plot.

[c] N refers to no. of study plots.

[d] p = proportion of sample units per plots in which greater sage-grouse pellets were detected. Subscripts refer to season (S = summer; W = winter; YR = year-round).

Table 4. Preliminary estimates of proportion occupied sample units (p ± SE) for greater sage-grouse pellets on survey plots in the Parachute-Piceance-Roan population of western Colorado, USA in 2010. Values presented do not account for variation in pellet detectability.

	PJ - Treatment Plots				**PJ - Control (No Treatment) Plots**				**Sagebrush - Control Plots**			
	Pre-treatment			**Post-treatment**								
	1-Upper Galloway[a]	3-Ryan Gulch[a]	Mean ± SE	2-Black Sulphur[a,b]	1-Dry Ryan	2-Eureka	3-Stake Springs	Mean ± SE	1-Dry Gulch	2-Canyon Creek	3-Black Cabin	Mean ± SE
	n = 49[c]	n = 48[c]	N = 2[d]	n = 38[c]	n = 35	n = 50	n = 38	N = 3	n = 43	n = 41	n = 42	N = 3
p_S[e]	0.000	0.042	0.021	0.000	0.000	0.020	0.000	0.007	0.326	0.024	0.095	0.148
	± 0.000	± 0.029	0.021	± 0.000	± 0.000	± 0.02	± 0.000	± 0.007	± 0.071	± 0.024	± 0.045	± 0.091
p_W[e]	0.000	0.063	0.031	0.026	0.029	0.020	0.026	0.025	0.558	0.293	0.333	0.395
	± 0.000	± 0.035	0.031	± 0.026	± 0.028	± 0.02	± 0.026	± 0.003	± 0.076	± 0.071	± 0.073	± 0.083
p_{YR}[e]	0.000	0.104	0.052	0.026	0.029	0.040	0.026	0.032	0.721	0.293	0.333	0.449
	± 0.000	± 0.044	± 0.052	± 0.026	± 0.028	± 0.028	± 0.026	± 0.004	± 0.068	± 0.071	± 0.073	± 0.136

[a] Data represent pre-treatment values. Numbers preceding plot names refer to set (e.g., Set 1 = Upper Galloway, Dry Ryan, Dry Gulch, etc.; Fig. 2).

[b] The Black Sulphur plot was partially treated in fall 2009. PJ removal was completed in June 2010 prior to pellet surveys in July-August 2010 .

[c] n refers to the no. of 30 x 30 m units sampled within the study plot.

[d] N refers to the no. of study plots.

[e] p = proportion of sample units per plots in which greater sage-grouse pellets were detected. Subscripts refer to season (S = summer; W = winter; YR = year-round).

Table 5. Preliminary estimates of proportion occupied sample units (p ± SE) for greater sage-grouse pellets on survey plots in the Parachute-Piceance-Roan population of western Colorado, USA in 2011. Values presented do not account for variation in pellet detectability.

	PJ - Treatment Plots				**PJ - Control (No Treatment) Plots**				**Sagebrush - Control Plots**			
	Pre-treatment	**Post-treatment**										
	3-Ryan Gulch[a]	1-Upper Galloway[b]	2-Black Sulphur[b]	Mean ± SE	1-Dry Ryan	2-Eureka	3-Stake Springs	Mean ± SE	1-Dry Gulch	2-Canyon Creek	3-Black Cabin	Mean ± SE
	n = 48[c]	n = 49[c]	n = 38[c]	N = 2[d]	n = 35	n = 50	n = 38	N = 3	n = 43	n = 41	n = 42	N = 3
p_S[e]	0.000[a] ± 0.000	0.020[b] ± 0.020	0.000[b] ± 0.000	0.010 ± 0.010	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.093 ± 0.044	0.000 ± 0.000	0.000 ± 0.000	0.031 ± 0.031
p_W[e]	0.063[a] ± 0.035	0.061[b] ± 0.034	0.000[b] ± 0.000	0.031 ± 0.031	0.000 ± 0.000	0.020 ± 0.020	0.000 ± 0.000	0.007 ± 0.007	0.349 ± 0.073	0.171 ± 0.059	0.071 ± 0.040	0.197 ± 0.081
p_{YR}[e]	0.063[a] ± 0.035	0.082[b] ± 0.039	0.000[b] ± 0.000	0.041 ± 0.041	0.000 ± 0.000	0.020 ± 0.020	0.000 ± 0.000	0.007 ± 0.007	0.349 ± 0.073	0.171 ± 0.059	0.071 ± 0.040	0.197 ± 0.081

[a] Data represent pre-treatment values.

[b] Data represent 1 yr post-treatment. Treatments on Black Sulphur and Upper Galloway were completed in summer 2010. Numbers preceding plots names refer to which set the plot is in (e.g., Set 1 = Upper Galloway, Dry Ryan, Dry Gulch, etc.; Fig. 2).

[c] n refers to the no. of 30 x 30 m units sampled within the study plot.

[d] N refers to the no. of study plots.

[e] p = proportion of sample units per plots in which greater sage-grouse pellets were detected. Subscripts refer to season (S = summer; W = winter; YR = year-round).

Table 6. Preliminary estimates of the density of greater sage-grouse pellets encountered on transect plots in the Parachute-Piceance-Roan population of western Colorado, USA in 2011. Values presented do not account for variation in pellet detectability.

	PJ - Treatment Plots						**PJ - Control (No Treatment) Plots**				**Sagebrush - Control Plots**			
	Pre-treatment			**Post-treatment**										
	Magnolia South	Cotton-wood	Lower Wagon-road	Lower Bar D[a]	Upper Bar D[a]	Lower Barnes[b]	Bar D Split	Magnolia North	Sprague	Upper Wagon-road	Bar D Control	Magnolia Control	Upper Barnes Control	Wagon-road Control
x_S[c]	0.00	0.00	0.00	0.00	0.00	2.38[b]	0.00	0.00	0.00	0.00	2.38	0.59	0.00	1.70
X_S[d]		0.00 ± 0.00		0.00 ± 0.00[e]				0.00 ± 0.00				1.17 ± 0.72		
x_W[c]	0.10	0.00	0.00	0.00	0.00	11.39[b]	0.00	0.00	0.00	0.00	3.23	18.24	13.51	4.76
X_W[d]		0.03 ± 0.03		0.00 ± 0.00[e]				0.00 ± 0.00				9.94 ± 4.43		
x_{YR}[c]	0.10	0.00	0.00	0.00	0.00	13.78[b]	0.00	0.00	0.00	0.00	5.61	18.82	13.51	6.46
X_{YR}[d]		0.03 ± 0.03		0.00 ± 0.00[e]				0.00 ± 0.00				11.10 ± 3.84		
km[f]	9.80	7.70	7.64	9.58	6.36	5.88	4.68	6.44	13.40	9.80	5.88	6.80	5.92	5.88

[a] Treatments on Lower Bar D and Upper Bar D were completed in January 2011. Data represent 6 mo. post-treatment.

[b] Data on Lower Barnes were collected opportunistically and are presented for comparison only. Data represent 3 years post-treatment. Treatments on Lower Barnes were started in summer 2007 and completed in summer 2008 by the Bureau of Land Management. No pre-treatment data are available.

[c] x = no. pellet piles detected per km of transect. Subscripts refer to season (S = summer; W = winter; YR = year-round).

[d] X = mean no. pellet piles detected per km of transect across study plots in each treatment. Subscripts refer to season (S = summer; W = winter; YR = year-round).

[e] Post-treatment mean values for PJ – Treatment plots include data from the Lower and Upper Bar D plots and exclude data from Lower Barnes.

[f] Total kilometers of transect line surveyed per plot.

Table 7. Timeline for research on greater sage-grouse response to pinyon-juniper removal in the Parachute-Piceance-Roan population, western Colorado, 2008-2014.

Task	Initiation	Completion
Identification of plots for PJ removal	COMPLETE	COMPLETE
Remove encroaching PJ on survey plots (2009-2011)	COMPLETE	COMPLETE
Remove encroaching PJ on transect plots (in progress)	1 Aug 2011	30 Nov 2011
Winter track surveys, pellet collection (annually)	1 Dec	10 Mar
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 2014	1 Oct 2014

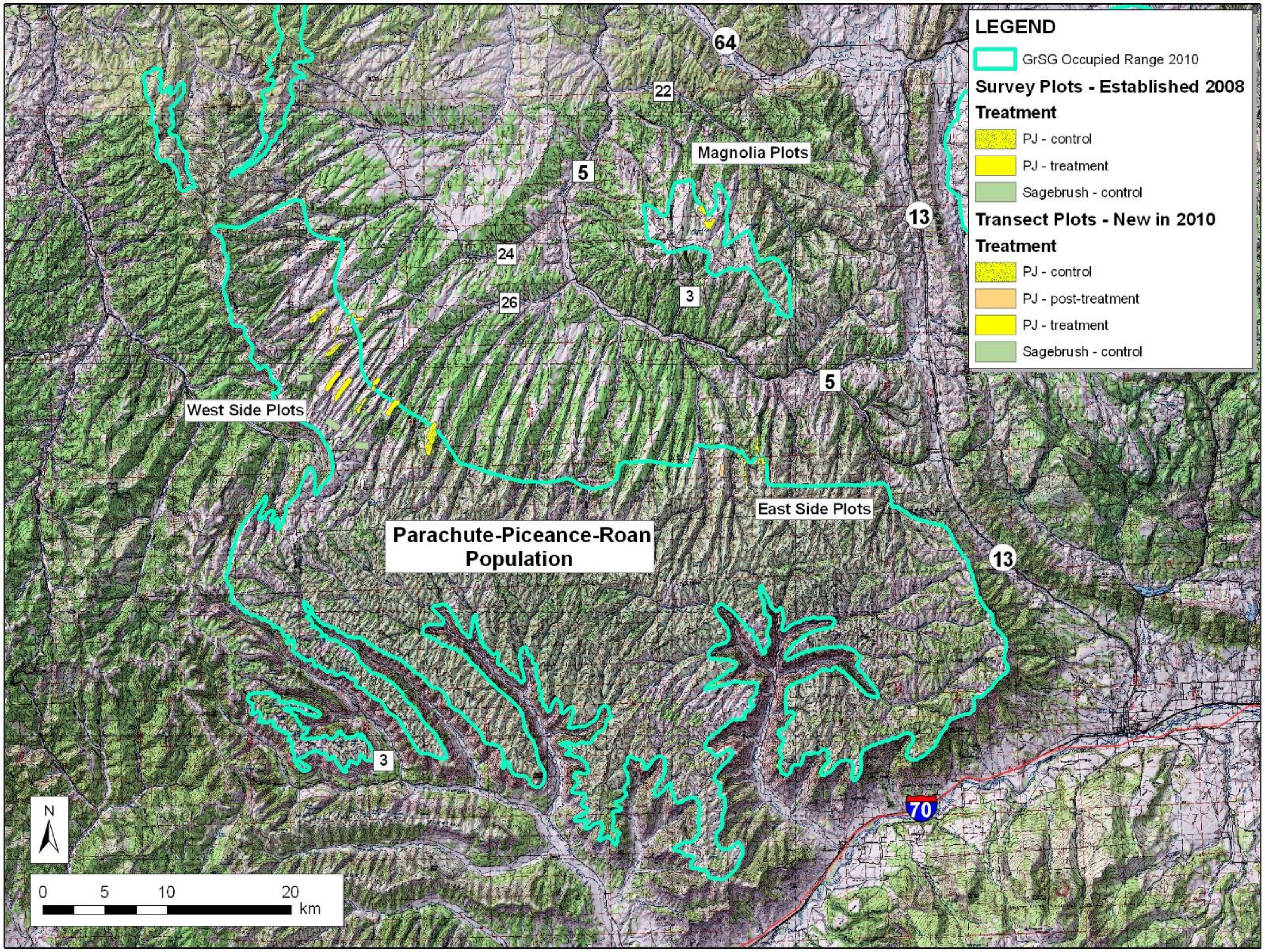

Fig. 1. Map of greater sage-grouse occupied range (as of 2010) showing study plot locations for the pinyon-juniper removal experiment in the Parachute-Piceance-Roan population of western Colorado, USA.

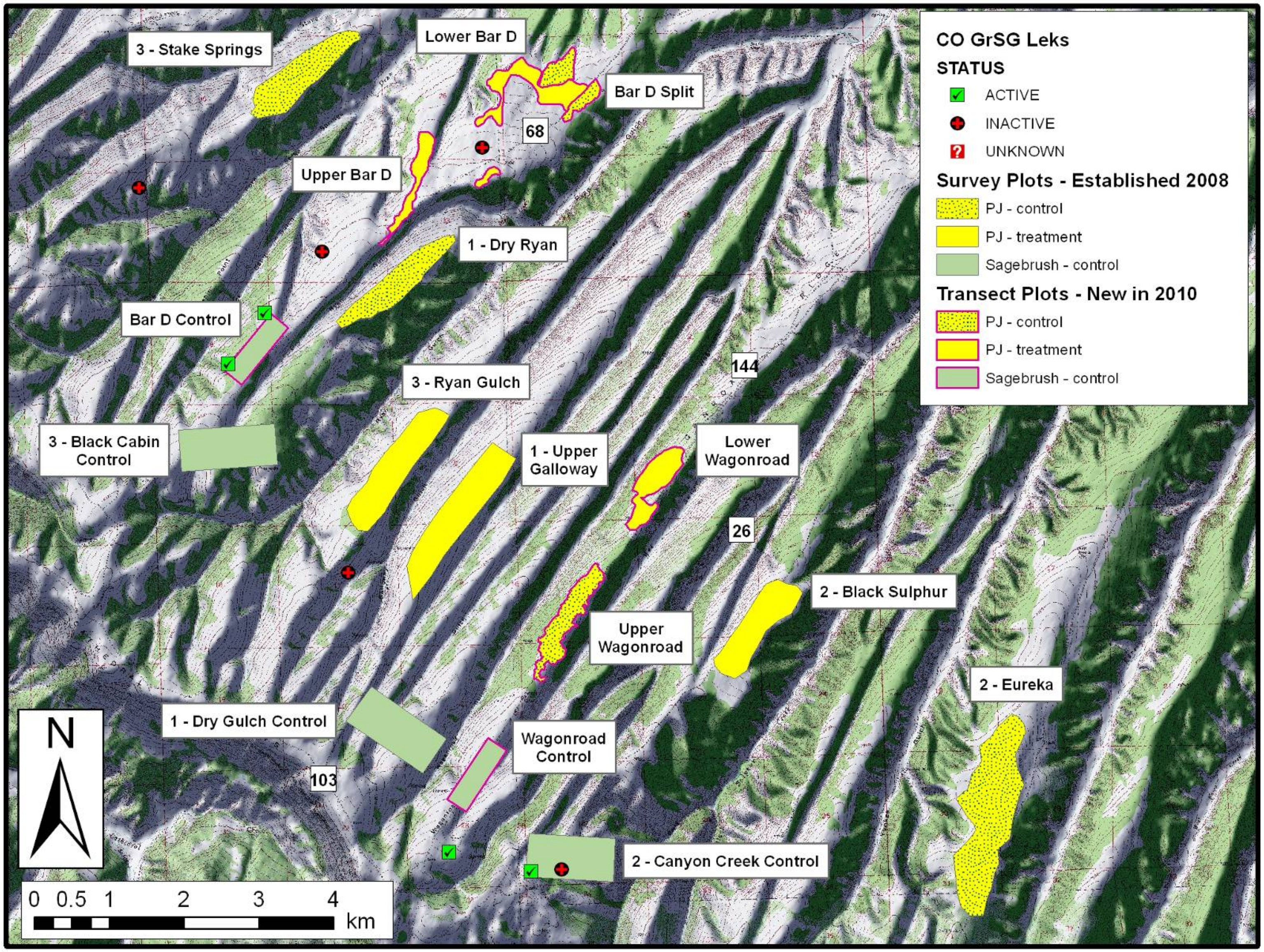

Fig. 2. Map of the west side plots, showing the original nine survey plots established in 2008 and seven new transect plots established either in fall 2010 or summer 2011 (Bar D Split) for the pinyon-juniper removal experiment in the Parachute-Piceance-Roan greater sage-grouse population.

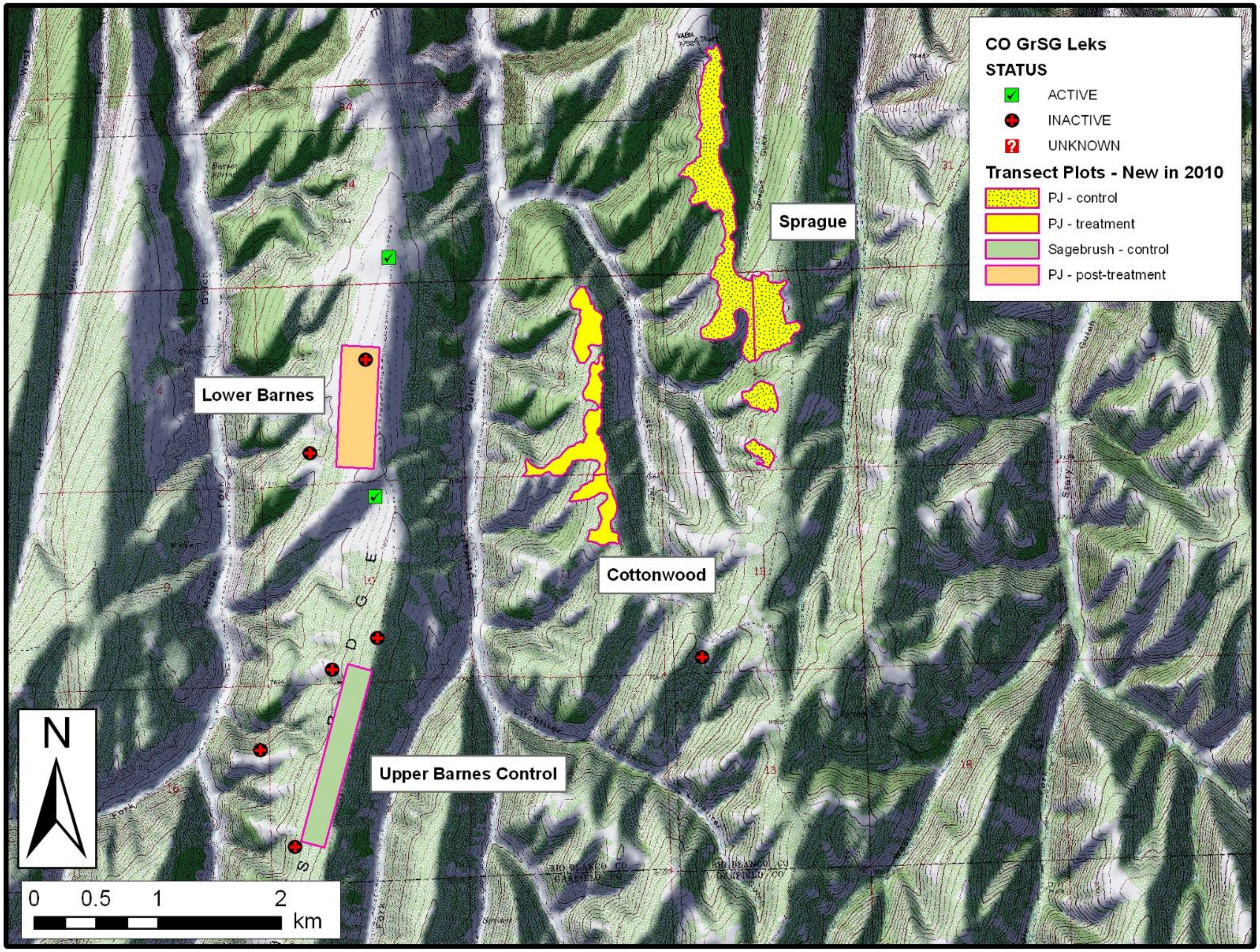

Fig. 3. Map of the east side plots, showing the four new transect study plots for the pinyon-juniper removal experiment in the Parachute-Piceance-Roan greater sage-grouse population. All plots shown were established in fall 2010 except Upper Barnes, which was established in summer 2011.

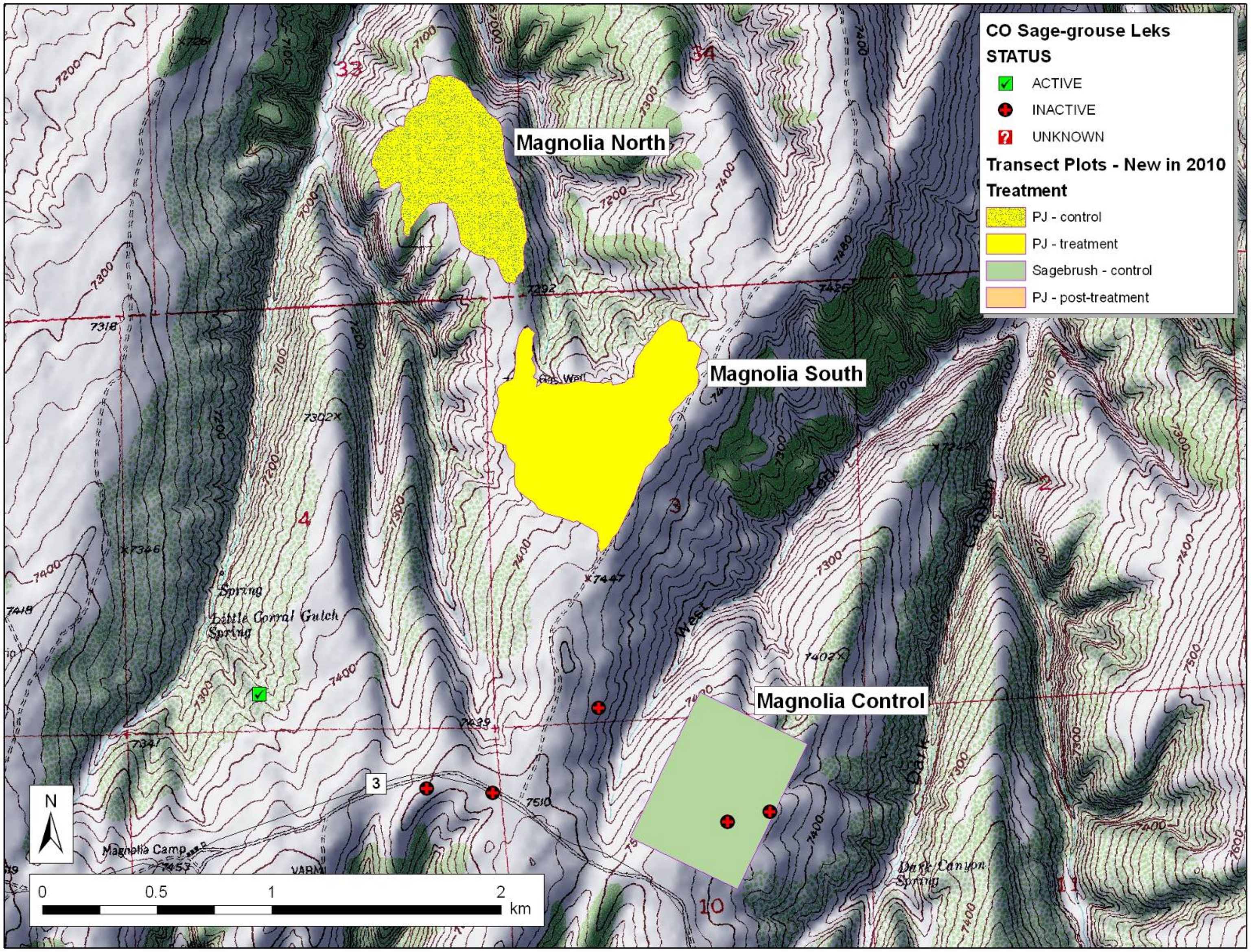

Fig. 4. Map of the Magnolia plots, showing the three new transect study plots established in fall 2010 for the pinyon-juniper removal experiment in the Parachute-Piceance-Roan greater sage-grouse population.

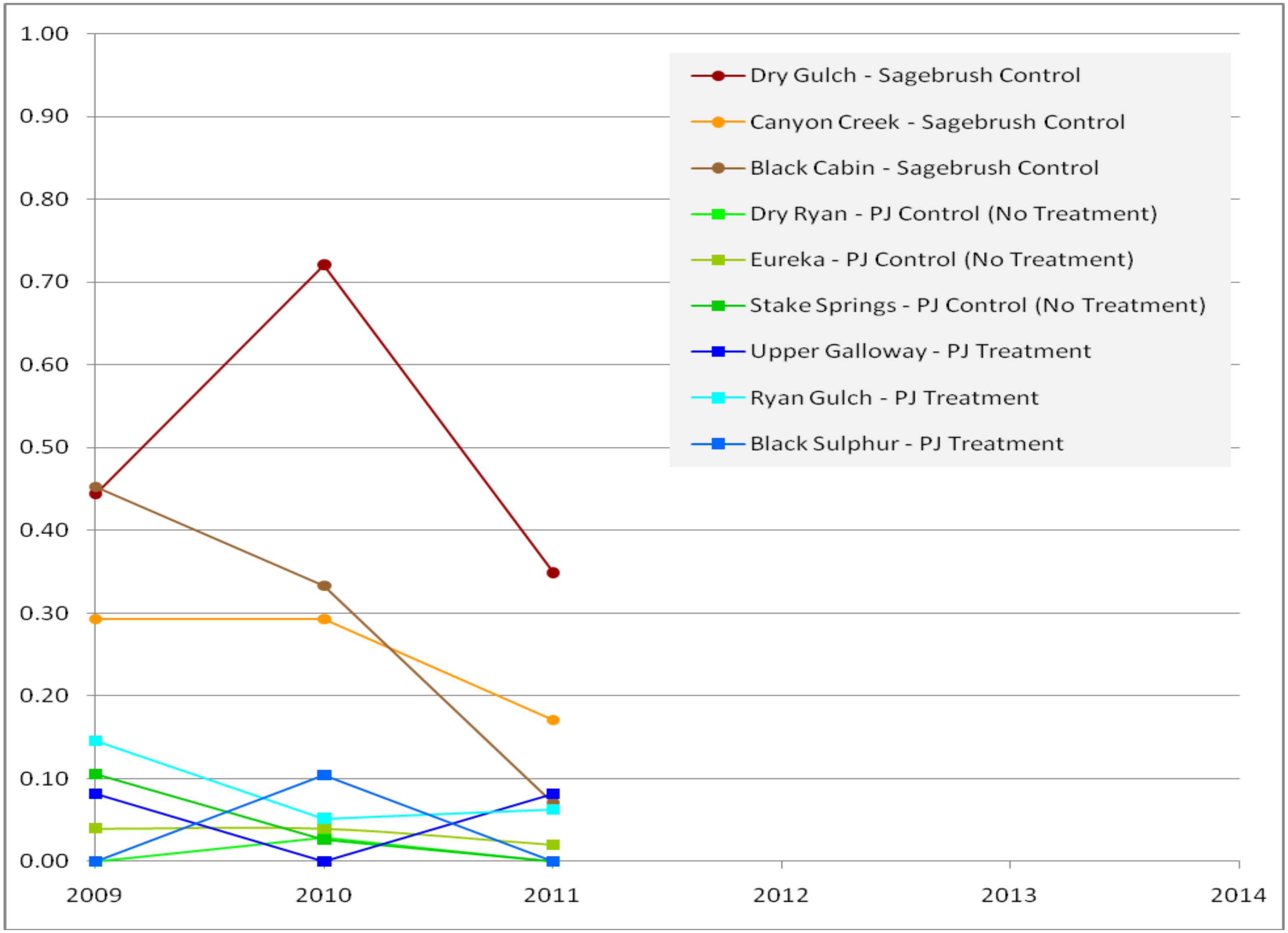

Fig. 5. Trends in the proportion of sample units detected with greater sage-grouse pellets by study plot (and treatment) in the Parachute-Piceance-Roan population of western Colorado, USA. Values presented do not account for variation in pellet detectability.

COLORADO DIVISION OF PARKS AND WILDLIFE – AVIAN RESEARCH PROGRAM
PROGRESS REPORT
September 2011

TITLE: Restoring energy fields for wildlife

AUTHOR: D. B. Johnston

PROJECT PERSONNEL: R. Velarde, Regional Manager; B. DeVergie, Area Wildlife Manager; JT Romatzke, Area Wildlife Manager; JC Rivale, Property Technician

Period Covered: January 16, 2010 – January 15, 2011

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ABSTRACT

Restoring disturbed areas as wildlife habitat requires re-establishing a diverse mixture of perennial grasses, forbs, and shrubs. Achieving this goal in Colorado oil and gas fields is often difficult because of the variety of impacted ecological zones and the threat of weed invasion. An area of particular concern is the Piceance Basin gas field because of its value to mule deer, sage-grouse, and other wildlife. At lower elevations in the Piceance Basin, cheatgrass (*Bromus tectorum*) presents a major obstacle to reclamation. At higher elevations, reclamation is easier to achieve, but we lack reliable methods for restoring broadleaf forbs and shrubs. At middle elevations, the choice between minimizing the threat of weed invasion and maximizing the potential for plant community diversity can be difficult to make. In order to test techniques over their full range of potential usefulness, a series of 5 experiments was implemented in 2008 and 2009 on simulated well pads and pipelines covering the wide range of precipitation, soil development, and plant community types represented in the Piceance Basin gas field.

The Pipeline experiment began in 2008 on simulated pipeline disturbances at 6 lower elevation locations. It compares 2 approaches to controlling cheatgrass and promoting native plants: applying Plateau™ herbicide (ammonium salt of imazapic, BASF corporation, *hereafter* Plateau) at 105 g ai/ha (6 oz/ac) just prior to seeding, and using soil tillage. The tillage treatments examined were disking (D), rolling (R), disking+rolling (DR), and vibratory drum rolling (V). The tillage treatments were of interest because cheatgrass has been shown to be sensitive to seed burial and soil compaction. In 2010, vegetation response was quantified by assessing percent cover. Plateau increased perennial grass cover by 60%, reduced annual cover by 58%, and had no discernable effect on perennial forbs. The effect of Plateau on cheatgrass and other annual species differed by site. The tillage treatments were ineffective. These results differed from those in 2009 seeding density estimates, which showed a reduction in cheatgrass density and increase in perennial density with disking.

The Competition experiment began in 2009 on simulated well pad disturbances at 2 middle elevation sites. The goal of the Competition experiment is to examine novel factors which may affect the competitive ability of native wheatgrasses versus cheatgrass. The density of both wheatgrass and cheatgrass seed was controlled. The treatments were: addition of a super-absorbant polymer called Luquasorb® (BASF Corporation), addition of a soil binding agent called DirtGlue® (DirtGlue® Enterprises), and rolling with a heavy lawn roller. In 2010, vegetation response was quantified by seeding density. At an application rate of 30 g/m^2, super-absorbent polymer addition increased perennial grass density by 34%. Where soils had been compacted by a static roller, super-absorbent polymer had a

greater effect. There was no effect of super-absorbent polymer on cheatgrass density. At 1 of 2 sites, binding agent addition increased cheatgrass density slightly. Rolling without other treatments had no significant main effects.

The Gulley experiment began in 2009 on simulated well pad disturbances at 4 low elevation locations with very weedy surrounding landscapes. The Gulley experiment focuses on identifying which potential sources of weeds are important to control: those which originate from within the soil seed bank of the reclamation area, those which enter from the surrounding landscape, or both. The treatments were application of Plateau herbicide at 140 g ai/ha (8 oz/ac) just prior to seeding, fallowing for one year with the broad-spectrum pre-emergent herbicide Pendulum™ (pendamethilin, BASF Corporation, *hereafter* Pendulum), and surrounding plots with seed dispersal barriers composed of aluminum window screen secured to oak stakes. In 2009, unfallowed plots were treated with Plateau and seeded, and fallowed plots were treated with Pendulum. In 2010, the experiment was completed by applying Plateau and seed to the fallowed plots.

The Mountain Top experiment began in 2009 at 4 high elevation sites surrounded by desirable mixtures of grasses, forbs, and shrubs. In such situations, the best reclamation outcome would be to re-create the surrounding plant community. The Mountain Top experiment examines the relative importance of creating soil heterogeneity and facilitating seed entrapment versus seeding. The treatments were: creating a rough soil surface of mounds and holes, spreading brush mulch, and seeding with native grasses, forbs, and shrubs in quantities typically used in reclamation areas in the Piceance Basin. Vegetation response was quantified in 2010 by measuring seedling density. The rough soil surface reduced the density of annuals by 18%, and, when combined with seeding, increased the density of perennial grasses by 18% and increased the density of perennial forbs by 160%. Seeding brought about a 10-fold increase in perennial grasses and a 4-fold increase in perennial forbs, but had no effect on the density of annuals. There was no effect of the brush mulch on the density of any plant functional group.

The Strategy Choice experiment was implemented in 2009 on simulated well pad disturbances at 4 middle elevation sites with surrounding plant communities which contained both desirable and undesirable species. At sites such as these, the degree of threat from invasive weeds is often unclear. The Strategy Choice experiment combines some elements of the experiments conducted at lower and higher elevations in order to improve our understanding of the optimal reclamation strategies. The treatments were: Plateau herbicide applied just prior to seeding at 140 g ai/ha (8 oz/ac), a rough soil surface with holes and brush mulch versus a flat soil surface with straw mulch, and a high competition versus a low competition seed mix. In 2010, vegetation response was assessed by seedling density. The Plateau treatment dramatically reduced density of all plant functional groups. The seed mix treatment affected the composition of plants: plots with the low competition seed mix had 58% higher perennial forb density and 49% lower perennial grass density than plots with the high competition seed mix. The soil surface/mulch treatment affected many plant groups. Plots with the rough soil surface/brush mulch treatment had 41% lower density of annual forbs, 48% lower density of perennial forbs, and 21% lower density of perennial grasses than plots with the flat soil surface/straw mulch treatment.

One to 2 years after the initiation of experiments, initial results indicate that the outcome of reclamation for wildlife in certain situations may be improved by applying Plateau herbicide, applying super absorbent polymer, seeding a low competition seed mix, and creating a rough soil surface. Plateau herbicide appears to initially hinder growth of both desirable and undesirable species, but the benefit of reduced competition with annuals allows higher perennial grass cover through time. Application of super absorbent polymer appears to improve the competitive ability of perennial grasses when in competition with cheatgrass. Use of a low competition seed mix resulted in a more favorable composition of forbs versus grasses than did a high competition seed mix, and did not incur a cost in terms of increased density of annuals. Creating a rough soil surface greatly increased the density of perennial forbs at high elevations sites, but at middle elevation sites, where the rough soil surface was compared to a flat surface plus straw mulch, the trend was reversed. At both high and middle elevation sites, the rough soil surface reduced the density of annuals, which is a beneficial result as the majority of annuals in the study area are non-native.

All 5 experiments will continue to be monitored in 2011 and 2012.

RESTORING ENERGY FIELDS FOR WILDLIFE
Progress Report, January 16, 2010- January 15, 2011
Danielle B. Johnston

PROJECT OBJECTIVES

- Develop reclamation techniques for big sagebrush (*Artemisia tridentata* L.) habitats impacted by oil and gas development in northwestern Colorado. Maximize wildlife habitat quality by promoting native, perennial plant communities containing a mixture of grasses, forbs, and shrubs.
- Determine which weed control techniques are effective in reclamation. Test techniques such as application of a selective herbicide, fallowing with a broad-spectrum herbicide, manipulation of soil density, and creation of barriers to weed seed dispersal. Determine where and how these weed control techniques should be applied.
- Determine which techniques are effective at promoting plant community diversity in reclamation. Test techniques such as use of a low competition/high diversity seed mix, creation of a rough soil surface, and use of brush mulch. Determine where and how these techniques should be applied.

SEGMENT OBJECTIVES

This project consists of 5 separate experiments with different objectives for this reporting year:

- *Pipeline Experiment (formerly called Experiment 1):* Assess vegetation response 2 years following herbicide and tillage treatments by measuring plant cover in 10 plots at each of 6 research sites.
- *Competition Experiment:* Assess vegetation one year following soil additive and compaction treatments by measuring seedling density in 60 plots at each of 2 research sites. Assess soil moisture twice in all plots.
- *Gulley Experiment:* Complete implementation of the experiment by seeding 12 plots at each of 4 sites which had received a chemical fallow treatment in 2009.
- *Mountain Top Experiment:* Assess vegetation one year following seeding, soil surface roughening, and brush mulch treatments by measuring seedling density in 24 plots at each of 4 research sites.
- *Strategy Choice Experiment:* Assess vegetation one year following herbicide, soil surface roughening, and seed mix treatments by measuring seedling density in 12-24 plots at each of 4 research sites.
- *All experiments:* Continue to monitor reference conditions at study sites by:
    - Quantifying propagule pressure of cheatgrass (*Bromus tectorum* L.) seed using 8 seed traps placed in undisturbed vegetation near 8 research sites.
    - Collecting rain and temperature data at research sites.

INTRODUCTION

Preserving wildlife habitat quality in oil and gas fields requires effective restoration of impacted areas. Successful restoration entails preventing soil loss, overcoming the threat of weed invasion, and promoting natural plant successional processes so that a diverse mixture of perennial grasses, forbs, and shrubs are established. A detailed knowledge of soils, climate, topography, land use history, and plant competition is needed to accomplish this goal, and optimal choices of reclamation techniques are site-specific. The need for site-specific knowledge often prompts local reclamation trials by organizations cause large-scale disturbances, such as coal mining companies. In oil and gas fields, however, local reclamation trials are difficult to implement due to the spatial pattern of disturbance.

In contrast to coal mines, which typically result in a small number of large disturbances, oil and gas fields result in a large number of smaller disturbances, each connected by a web of pipelines and access roads which may extend across hundreds of thousands of acres. The complexities of gathering knowledge at the appropriate scales, administering recommendations for the multitude of sites involved, and enforcing appropriate 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 area than that directly occupied by development activities. For instance, greater sage-grouse (*Centrocercus urophasianus*) populations (Walker et al. 2007) and mule deer (*Odocoileus hemionus*) habitat use (Sawyer et al. 2006) may decline within large buffer areas surrounding development. Furthermore, non-native species establishment due to development (Bergquist et al. 2007) could reduce wildlife habitat quality over large areas if disturbances are allowed to provide vectors for weed invasion into otherwise undisturbed habitat (Trammell and Butler 1995). Because of this threat, preventing weed invasion through successful restoration of all impacted areas is a top management priority for wildlife. The goal of this study is to promote such restoration by replicating tests of promising techniques at the scale of an oil field.

The Piceance Basin in northwestern Colorado provides an ideal laboratory for conducting a large-scale study of restoration 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 at the edge of the eastern expansion of cheatgrass (*Bromus tectorum* L.), allowing an opportunity to assess control measures for this weed in an area where such measures may have the most effect.

Because elevation is an important driver of precipitation, plant community composition, and weed prevalence in the area, experiments were assigned according to elevation zone. Twelve study sites, ranging in elevation from 1561to 2676 m, house 5 experiments, each repeated at 2-6 sites. Each experiment tests 3-6 treatments, some of which are tested in multiple experiments. This 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.

The 3 experiments conducted at lower elevations emphasize weed control, particularly that of cheatgrass, which presents a serious obstacle to effective reclamation in the study area (Pilkington and Redente 2006). The 3 lower elevation experiments are the Pipeline experiment (implemented at 6 sites ranging from 1561 to 2216 m in elevation), the Competition experiment (implemented at 2 sites of elevations 2004 and 2216 m), and the Gulley experiment (implemented at 4 sites ranging from 1561 to 2084 m in elevation). The remaining 2 experiments, conducted at high or middle elevations, emphasized maximizing plant community diversity. The Mountain Top experiment was implemented at the 4 highest elevation sites, ranging from 2342 to 2676 m. The Strategy Choice experiment was implemented at 4 moderate elevation sites ranging from 1662 to 2216 m.

The Pipeline experiment evaluates the effectiveness of tillage treatments versus an herbicide treatment at controlling cheatgrass and promoting establishment of a diverse, predominately perennial, native plant community. 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, rolling with a static roller, rolling with a vibratory drum roller, or disking plus compaction with a static roller. The herbicide investigated is Plateau ™ (ammonium salt of imazapic, BASF Corporation, Research Triangle Park, NC, *hereafter* Plateau), as it has been shown to reduce cheatgrass with little effect on some perennial grasses (Kyser et al. 2007). However, it also reduces the vigor and density of established forbs (Baker et al. 2007), and little is known about its effect on germination of desirable species.

The Competition experiment also examines compaction by rolling, but does so in conjunction with soil additives, in an environment where the density of cheatgrass seeds is controlled. Earlier work has shown that the density of weed seeds, or propagule pressure, has a large influence on the likelihood that a weed will become dominant when an ecosystem is disturbed (Thomsen et al. 2006). Therefore, variation in propagule pressure can confound attempts to study which reclamation techniques promote desirable species, particularly if the effects are subtle. Cheatgrass propagule pressure was controlled in the Competition experiment by adding a known quantity of cheatgrass seeds to areas that were previously free of cheatgrass, (and then surrounding the research area by physical and chemical barriers to prevent cheatgrass from leaving the area). The first soil additive examined is a super-absorbent polymer called Luquasorb® (cross-linked copolymer of Potassium acrylate and acrylic acid in granulated form, BASF Corporation, Ludwigshafen, Germany). When added to degraded soils, super-absorbent polymers absorb and then gradually release water, reducing the effects of water stress (Huttermann et al. 2009). This may hinder cheatgrass, as cheatgrass has been shown to be a more effective invader when soil moisture is more variable (Chambers et al. 2007). The second soil additive examined is a soil binding agent called DirtGlue® (DirtGlue® Enterprises, Amesbury, MA). Soil binding agents are commonly used to stabilize soil and facilitate binding of seed to the soil surface, but their effect on competitive interactions is unknown. DirtGlue® is used in this study because of its claimed ability to bind soil particles while increasing water infiltration. The combination of soil binding agent with rolling was of interest because of the potential for creating a crust which might hinder cheatgrass emergence.

The Gulley experiment focuses on identifying which potential sources of weeds are important to control: those which originate from within the soil seed bank of the reclamation area, those which enter from the surrounding landscape, or both. Like the Pipeline experiment, the Gulley experiment includes a test of Plateau herbicide as a strategy to control certain species in the soil seed bank. A second herbicide is also tested: 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 a drastic measure designed to eliminate as much of the existing seed bank as possible. To control seeds originating from areas surrounding the reclamation area, seed dispersal barriers were constructed of aluminum window screen, using a design that had been effective in a Utah seed bank study (Smith et al. 2008). This is of interest because a recent DOW study demonstrated that a sufficient number of cheatgrass seeds may disperse from the surrounding plant community to compromise reclamation efforts (Johnston 2011).

The Mountain Top experiment sites were surrounded by perennial, predominately native plant communities (Table 1); therefore weed control was not a great concern. At sites such as these, the goal of reclamation should be to re-create the desirable mixture of grasses, forbs, and shrubs found in the undisturbed habitat. However, prior studies have shown that even after decades of recovery, reclamation areas may remain dominated by grasses (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). Creating treatments which re-establish resource heterogeneity, encourage native seed dispersal, and avoid undue competition from seeded grasses may result in a plant community which better serves the needs of wildlife. In this study, we examine 3 such treatments: creating a rough soil surface of mounds and holes, spreading brush mulch, and foregoing seeding. A rough soil surface may be helpful because it creates variability in soil depth, contains microsites of higher moisture availability, and traps 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 2 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 soil heterogeneity and encouraging natural seed dispersal in establishing a diverse plant community?

At sites similar to those used for the Strategy Choice experiment, the degree of threat from invasive weeds is ambiguous. In such situations, should one take a conservative strategy by seeding a highly competitive seed mix, using aggressive weed control measures, and avoiding contaminating the site with seed from the surrounding area? Such measures often come at a price of reduced plant diversity and forb establishment (Marlette and Anderson 1986, Chambers 2000, Krzic et al. 2000, Baker et al. 2007). Therefore, one might wish to adopt an optimistic strategy by seeding a low competition/high diversity seed mix with a minimal fraction of rhizomatous grasses, avoiding using herbicide, and entrapping seeds via brush mulch, holes, or other mechanisms. 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 2 strategies in situations where the risk of weed invasion is moderate, and the surrounding plant community contains both desirable and undesirable species. The treatments examined include use of Plateau, creation of a rough soil surface with holes and brush mulch, and comparison of a high competition versus low competition/high diversity seed mix. The goal of the study is to shed light on the question: What conditions mandate a conservative approach to reclamation?

In all experiments, establishment of native, perennial plants was emphasized. Perennial plants are critical for wildlife because they provide nutritious forage for a longer portion of the growing season, their overall productivity is higher, and their productivity is less variable from year to year than that of annual plants (DiTomaso 2000). The experiments focus 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.

STUDY AREA

The Piceance Basin study area is in Rio Blanco and Garfield Counties, Colorado, USA (Figure 1). Elevation increases gradually from north to south as one travels from Piceance Creek (~1,800 m) to the top of the Roan Plateau (~2,500 m), then drops off sharply at the Book Cliffs to the Colorado River Valley (~1,500 m). Precipitation and temperature vary across the region with both elevation and latitude; more northerly sites are colder and receive less precipitation than southerly sites of similar elevation. Northernmost sites receive approximately 280 mm per year, 40% as snow. The southerly Colorado River Valley sites receive approximately 340 mm of precipitation per year, 25% as snow. The wettest, highest elevation sites are at the southern edge of the Roan Plateau, and receive approximately 500 mm per year, 60% as snow. Low elevations are characterized by Wyoming big sagebrush, cheatgrass, Indian ricegrass (*Oryzopsis hymenoides*), western wheatgrass (*Agropyron smithii*), prairie junegrass (*Koeleria cristata*), and globemallow (*Sphaeralcea coccinea*) in flatter areas with a mixture of pinyon pine (*Pinus* sp.) and Utah juniper (*Juniperous utahensis*) on steeper slopes and greasewood (*Sarcobatus vermiculatus*) in floodplains. High elevations are characterized by mountain big sagebrush, mountain brome (*Bromus marginatus*) and diverse forbs in flatter areas, serviceberry (*Amelanchier alnifolia*), snowberry

(*Symphoricarpos albus*), and Gambel's oak (*Quercus gambelii*) on slopes, and aspen (*Populus tremuloides*) mixed with Engleman spruce (*Picea engelmanii*) in the highest elevation, north-facing slopes.

Twelve research locations were chosen within the Piceance Basin in sagebrush habitats (Figure 1, Table 1). These 12 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 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.

METHODS: DISTURBANCE CREATION

Two types of disturbances, simulated pipelines and simulated well pads, were created to provide templates for the experiments. Pipeline disturbances measured 11 m X 52 m 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 1 m wide X 1 m 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.The Pipeline experiment was immediately implemented on these disturbances.

Well pads differ from pipelines in the length of time topsoil is stockpiled and in the degree of subsoil disturbance which occurs. Well pad disturbances measured 31 m X 52 m and were simulated using a bulldozer. Vegetation was cleared, the top 20 cm of topsoil was scraped and stockpiled in windrows less than 2 m in height, 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. The Gulley, Strategy Choice, Competition, and Mountain Top experiments were implemented on the well pad disturbances in 2009 and 2010.

All sites were fenced with 2.4 m (8 ft) fencing after experiments were implemented.

PIPELINE EXPERIMENT

Overview

- Goal: Compare effectiveness of Plateau herbicide and tillage treatments for controlling cheatgrass.
- Conducted at 6 sites: YC1, YC2, RYG, WRR, GVM and SKH (Figure 1, Table 1).
- Treatments:
    - Herbicide (2 levels): Plateau applied (Plateau) or no Plateau applied (No Plateau)
    - Tillage (5 levels): disking (D), compaction with a static roller (R), compaction with a vibratory drum roller (V), disking plus compaction with a static roller (DR), or control (C)
- Design: Factorial split-plot. Herbicide treatments were randomly assigned to whole plots, and tillage treatments were randomly assigned to subplots (Figure 2).
- Plot size: 11 m X 10 m

Methods

Tillage treatments were implemented shortly after pipeline disturbances were created in the fall of 2008. In C plots, bulldozer and backhoe tracks were left in place. The soil surface varied from smooth to very rough. D plots were disked to 4 inches. R plots were rolled once with a static roller supplying a linear load of 20.8 lbs/in (36.5 N/cm). V plots received 4 passes with a vibratory drum roller (Wacker DH-12). DR plots were disked to 4 inches, then wetted to 1 cm using an ATV tow sprayer, then rolled 5 times with a non-vibratory roller. The DR treatment was an effort to create slight soil compaction at the surface, while avoiding heavy compaction of the rooting zone, which can restrict root growth and compromise establishment of deeply-rooted perennial plants (Thompson et al. 1987). At the Yellow Creek sites, the V treatment was not implemented.

Herbicide was applied in October 2008. At the time of application, cheatgrass was at the 1-leaf stage (~5 cm tall) at WRR and RYG, had just begun emerging at the Yellow Creek sites, and had not emerged at SKH or GVM. Plateau was applied at 105 g ai/ha (420 g/ac or 6 oz/ac) with glyphosate at 210 g ai/ha (8 oz *Roundup Pro* /ac) and methylated seed oil (2% v/v) using an ATV tow sprayer (Agri-Fab 45-0424). The rate of Plateau application was a compromise between the 700 g/ac rate, which has been shown to provide good brome control at the expense of strong negative effects on native forbs (Baker et al. 2007) and the 280 g/ac rate, which has been shown to avoid serious negative effects on most desirable species but provides only moderate brome control (Bekedam 2004). Glyphosate was added because cheatgrass had emerged at some sites at the time of application, and methylated seed soil was added to facilitate bonding of the herbicide to leaf surfaces.

Following herbicide application, sites were drill seeded using a Tye Pasture Pleaser rangeland drill, calibrated to plant seed approximately 1 cm deep in tilled soil. Drill rows were about 25 cm apart, and the drill produced a minimal amount of soil disturbance. All sites received the same seed mixture (Table 2). Grasses and shadscale species were mixed together, as were all forb species. Grass/shadscale and forb mixtures were seeded in separate rows by taping poster board dividers in the seed box, and placing seed mixes in alternating divisions. Rice hulls were added at 50% v/v in order to keep seeds of different sizes suspended evenly in the mixtures (St. John et al. 2005). Wyoming big sagebrush seed collected from Dry Creek Basin, Colorado, an area with similar temperature and moisture characteristics to the study area, was broadcast seeded onto snow in mid-January. Plots were seeded at a rate of 8.6 pounds pure live seed per acre. This low seeding rate was chosen because lower seeding rates facilitate establishment of mixed stands (Redente et al. 1984).

Vegetation response was quantified in 2010 by assessing percent cover by species between 24 June and 19 July. Nine $1m^2$ subplots were arrayed systematically per plot, with one subplot in the center of the plot, and the remaining subplots equidistant from the center subplot and either a plot corner or the midpoint of a plot edge. Thirty-six point-intercept hits were measured per subplot, and all layers of vegetation as well as ground cover were identified at each hit. Because of overlapping canopy layers, it is possible for cover to exceed 100%.

Percent cover of functional groups of interest (perennial grasses, perennial forbs, total annuals, annual forbs, annual grasses, total shrubs, big sagebrush, and cheatgrass) was determined. Diversity was calculated from cover data using the Shannon Index, with each hit for a given species considered as an occurrence of that species. When calculated this way, the index reflects the number of species hit and the evenness of cover among those species.

Responses of cover groups and diversity to Plateau treatment, the tillage treatments (D, R, and V), and 2-way interactions among them were analyzed as fixed effects using ANOVA in SAS PROC MIXED. Site and a site*Plateau Treatment term (to account for the split-plot design) were included as random effects. Biennial forbs were lumped with annual forbs. Models including all possible different combinations of fixed effects and 2-way interactions among fixed effects were compared using Akaike's Information Criterion, adjusted for small sample size (AIC_c). A null model with no fixed effects was also tested. A total of 19 models were tested for each functional group or species-specific response. The magnitude of treatment effects were evaluated using ESTIMATE statements in the model with the lowest AIC_c value. Effect sizes are presented ± 95% confidence intervals.

Results

The Plateau treatment increased cover of perennial grasses, with Plateau plots having 11.3 ± 9.0% higher cover of perennial grasses than plots without Plateau (Figure 3, Table A1). The Plateau treatment exerted a strong effect on the cover of total annuals, with Plateau plots having 39.8 ± 21.5% lower cover of annuals than No Plateau plots (Figure 3, Table A2). The lowest AIC_c model for cheatgrass cover contained the Plateau treatment (Table A3), but the effect of 25.6 ± 33.2% lower cheatgrass in No Plateau plots was only borderline significant ($p = 0.10$).

The lowest AIC_c models for perennial forb cover, annual forb cover, annual grass cover, shrub cover, big sagebrush cover, and species diversity did not contain the Plateau parameter, indicating that our data show little consistent effect of Plateau on these responses (Tables A4- A9).

The tillage treatments had no main effects significant at the 0.05 level, and were rarely represented in the models with the lowest AIC_c value (Appendix 1). The lowest AIC_c models for total shrub cover and Big Sagebrush cover contained a parameter for the rolling treatment, but the effect of the rolling treatment in both cases was only borderline significant and very slight, with Rolled plots having 1.0 ± 1.9 % lower total shrub cover and 0.08 ± 0.10 % lower big sagebrush cover than Not rolled plots ($p < 0.12$; Tables A7- A8). The lowest AIC_c models for perennial grass cover, total annual cover, cheatgrass cover, perennial forb cover, annual forb cover, annual grass cover, and species diversity did not contain any of the tillage treatments (Tables A1- A6, A9).

Discussion

Plateau herbicide increased perennial grass cover in reclamation areas 2 years after herbicide application and seeding. There was no discernable effect of Plateau on species diversity or on native forb cover. This is in contrast to in an earlier study which found forb cover to be greatly reduced one year after applying Plateau to mature plants (Baker et al. 2009). The difference may be due to the longer period of time between herbicide application and sampling which occurred in this study, or it may have been due to the rate or timing of application.

Plateau dramatically reduced cover of annuals. This was beneficial in this study, as 98.5% of annual cover was non-native. Reduced competition with annuals is a likely explanation for the increase in perennial grass cover. In this study, 85.1% of perennial cover was native. Plateau therefore improved the outcome of reclamation by promoting perennial, primarily native grasses, at the expense of non-native annuals.

While Plateau was effective on annuals when considered as a whole, there was no significant effect of Plateau on annual grasses, annual forbs, or cheatgrass when considered separately. This may be due to the fact that different species of annuals were dominant at different sites; the particular suite of species present may influence how Plateau affects a given species. For instance, cheatgrass cover was lower in Plateau plots at most sites, but was higher in Plateau plots at GVM. At GVM, Russian thistle (*Salsola tragus* L.), a non-native annual forb, heavily dominated No Plateau plots. In Plateau plots, reduced competition with Russian thistle could have allowed cheatgrass to grow more effectively in spite of the presence of the herbicide.

The Plateau treatment effects were more pronounced in the 2010 measurements of plant cover than they were in the 2009 assessment of seedling density. In 2009, there was no effect of Plateau on the density of native seedlings, and effects on cheatgrass seedlings were only evident at 2 of 6 sites. Plateau herbicide remains effective in the soil for 2 years post-application. It appears that the herbicide benefits maturing native plants through time as annuals continue to be suppressed.

The tillage treatments were ineffective except for a slight negative effect of rolling on shrub cover and big sagebrush cover. The rolling treatment in this study increased soil bulk density throughout the rooting zone. This likely made root penetration difficult. The lack of beneficial effect of rolling at controlling cheatgrass may mean that slight soil compaction is not a useful tool to control cheatgrass, or it may mean that a different method of implementation is needed in order to compact upper soil layers without influencing deeper parts of the rooting zone.

Disking did not affect annuals, perennials, or any of the functional groups studied. These results are in contrast to the seedling counts from 2009, which showed increased native seedling density and decreased cheatgrass seedling density with disking. It is likely that under the conditions studied, the effect of disking was too slight to persist through time.

COMPETITION EXPERIMENT

Overview:

- Goal: Test novel techniques for minimizing the competitive advantage of cheatgrass under a condition of controlled cheatgrass propagule pressure.
- Conducted at 2 sites: WRR and SGE (Figure 1, Table 1)
- Treatments:
  - Binding agent (3 levels): a low level of binding agent applied (Low BA), a high level of binding agent applied (High BA), or no binding agent applied (No BA)
  - Super-absorbent polymer (2 levels): super-absorbent polymer applied (SAP) or no polymer applied (No SAP)
  - Rolling (2 levels): rolled with a static heavy roller (Rolled) or not rolled (Not rolled)
- Design: Factorial split-split plot, with completely randomized whole plots. The subplot factor was binding agent, the split plot factor was super-absorbent polymer, and the whole plot factor was rolling (Figure 4).
- Plot size: 2.4 m X 2.4 m
- 5 replicates per site

Methods

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, 2009, 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 5 g 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 collection were mixed together, and then a volume of seed sufficient to supply 300 seeds/m^2 was prepared for each 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 seed density for a Piceance Basin site in the initial phases of invasion.

A mixture of native wheatgrasses (Table 3) was drill-seeded using a Plotmaster™ 400 (Tecomate Wildlife Systems, San Antonio, TX) in mid-October, 2009. Seed was mixed 1:1 by volume with rice hulls to maintain suspension of the seed mixture. For SAP plots, granulated super-absorbent polymer was added to the seed/rice hull mixture. At SGE, 6.7 g/m^2 of polymer was added, and at WRR, 30.8 g/m^2 was added. These rates 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 10 times with a static roller supplying a linear load of 20.8 lbs/in (36.5 N/cm). Binding agent subplots were then treated by sprinkling plots using hand watering cans. High BA plots received 4100 li/ha (440 gal/ac) of binding agent, diluted 6:1 with water. Low BA plots received 1600 li/ha (175 gal/ac) of binding agent, 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 0.6 m-high aluminum window screen supported by oak stakes was constructed adjacent to the plots. Outside of this, we applied a chemical barrier of Pendulum, a broad spectrum pre-emergent herbicide, at 3200 g ai/ha (0.75 gal/ac) to a 1m wide strip of bare ground.

To assess vegetation response, seedlings were counted by species in late July and early August, 2010 in a 1 m X 1 m area centered within each plot. Three soil moisture readings were made in random locations within each plot on 21 May and 7 June, 2010 to evaluate treatment effects on soil moisture. Readings were taken to 12 cm using a Hydro Sense® Soil Water Measurement System (Campbell Scientific, Inc, Logan, Utah) and were averaged for each plot.

The density of perennial grasses, density of cheatgrass, and volumetric soil moisture in response to rolling, super-absorbent polymer, and binding agent treatments was analyzed in SAS PROC MIXED for a split-split plot structure, with main effects and 2-way interactions among them included as fixed effects. A backwards model selection process ($\alpha = 0.05$) was used to determine the final model. Sites were analyzed separately because the amount of super-absorbent polymer applied differed between sites. The magnitude of significant treatments was determined using ESTIMATE statements. Effect sizes are given ± 95% confidence intervals.

Results

The super-absorbent polymer treatment was effective at WRR, where perennial grass density was 17.3 ± 11.8 plants/m^2 higher in SAP plots than in No SAP plots ($p = 0.012$). The effect was more pronounced (30.4 ± 15.9 perennial grasses /m^2) in No SAP plots also receiving the rolling treatment (treatment interaction $p = 0.036$; Figure 5). Cheatgrass density did not discernibly differ between SAP and No SAP plots at WRR ($p = 0.29$). At SGE, neither perennial grass nor cheatgrass density differed between SAP and No SAP plots ($p > 0.21$), although the pattern of the averages for perennial grasses was similar to that at WRR (Figure 5). We did not detect a difference in soil moisture between SAP and No SAP plots on either measurement date at WRR ($p > 0.46$) or at SGE ($p > 0.69$).

The binding agent treatment increased soil moisture on 5/21/10 at both SGE and WRR ($p < 0.006$). At SGE, soil moisture was 3.6 ± 2.2 % higher in Low BA or High BA plots versus the No BA plots (Figure 6). At WRR this difference was 4.0 ± 2.0 %. There was no significant difference at either site on 6/7/10 ($p > 0.09$). At WRR, neither perennial grass nor cheatgrass density differed among the binding agent treatments ($p > 0.67$). At SGE, cheatgrass density differed by binding agent treatment, with 5.0 ± 3.4 plants/m^2 higher cheatgrass density in Low BA plots than in No BA plots ($p = 0.004$; Figure 7). Perennial grass density did not differ by binding agent treatment at SGE ($p = 0.49$).

Aside from the aforementioned interaction between the rolling and super-absorbent polymer treatment at WRR, there were no differences in perennial grass density, cheatgrass density, or soil moisture between Rolled and Not rolled plots at WRR or at SGE ($p > 0.11$).

Discussion

The treatment increased the density of perennial grasses at WRR, where it was applied at 30.8 g/m^2, but not at the SGE site, where it was applied at 6.7 g/m^2. The effect of super-absorbent polymer was more pronounced when applied with the rolling treatment. If these trends continue, then addition of super-absorbent polymer at 30 g/m^2 may be a useful tool for promoting perennial grasses under competition from cheatgrass, especially in compacted soils. Although we did not detect an effect of the super-absorbent polymer treatment on soil moisture, this may have been a result of the pattern of application. Polymer was applied only in drill seeded rows, where growing plants may have removed any extra moisture that was made available. Also, the soil moisture readings were taken from throughout the plot, where the action of the polymer may not have been detectable.

The binding agent treatment increased soil moisture in late May, supporting the manufacturer's claim that the product studied, DirtGlue, increases water infiltration. In contrast to super-absorbent polymer, binding agent was applied throughout each plot, where it might impact cheatgrass seed as well as the drill-seeded grasses. Cheatgrass density was higher when binding agent was applied at the moderate rate than when no binding agent was applied at the SGE site. This may mean that under certain conditions, the increased early season soil moisture resulting from binding agent application may promote cheatgrass establishment.

The rolling treatment had little or no effect on perennial grass density, cheatgrass density, or soil moisture. The combination of rolling with other treatments used in this experiment was an effort to improve the effectiveness of surface compaction as compared to the way rolling was applied in the Pipeline experiment. In the Pipeline experiment, rolling was not applied in concert with a soil binding agent, and it was hypothesized that using rolling with a binding agent might create a surface crust useful in preventing cheatgrass germination. If the trends seen in 2010 persist, then it will seem as though rolling is not a useful tool for controlling cheatgrass, whether used alone or with the particular binding agent tested here.

Perennial grasses and cheatgrass have different water use patterns through the growing season. Cheatgrass performs well in ecosystems where soil moisture is plentiful only in the early season, while perennial grasses perform best when soil moisture is available throughout the growing season. The soil additives used in the study manipulate the amount and timing of soil moisture availability by either improving the depth to which rainfall penetrates, or by slowly releasing rainfall at times when soils would otherwise be dry. In either case, the action of the additives depends on rainfall. Therefore, the usefulness of the additives will depend on rainfall patterns in a particular location. In 2010, late growing season rain was higher than the prior year, resulting in favorable conditions for perennial seedling survival (Appendix 3). If either additive improves the competitive advantage of perennial grasses in this study, then a broader scale study, encompassing areas with different rainfall patterns, would be warranted.

In 2011 and 2012, vegetation responses will be assessed using percent cover of perennial grasses and cheatgrass. Soil moisture will continue to be monitored in May and June. Costs and recommended application procedures will be discussed for any treatments promoting dominance of desirable vegetation under competition from cheatgrass.

GULLEY EXPERIMENT

Overview

- Goal*:* identify which potential sources of weeds are important to control: those which originate from within the soil seed bank of the reclamation area, those which enter from the surrounding landscape, or both.
- Conducted at 4 sites: RYG, SKH, YC1, and YC2 (Figure 1, Table 1)
- Treatments:
    - Fallowing (2 levels): fallowed with Pendulum herbicide for one year prior to seeding (Fallowed) or seeded immediately (Unfallowed)
    - Plateau application (2 levels): Plateau applied (Plateau) or no Plateau applied (No Plateau)
    - Seed Barriers (2 levels): surrounded by a seed dispersal barrier (Barrier) or not surrounded (No Barrier)
- Design: Factorial split-split plot, with completely randomized whole plots. The subplot factor was Plateau, the split plot factor was seed barriers, and the whole plot factor was fallowing (Figure 8).
- Plot size: 9 m X 6 m
- 3 replicates per site

Methods

In late August and early September, 2009, Fallowed 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. 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. Next, the mixture of native grasses, forbs, and shrubs in Table 4 (except big sagebrush) was hand-broadcast. 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. The same day as seeding, Plateau was applied at 140 g ai/ha (8 oz/ac) with 655 li/ha (70 gal/ac) of water using a backpack sprayer to Unfallowed, Plateau plots. Dye indicator was used to ensure even application.

To prevent wind and water erosion, soil binding agent (DirtGlue®, DirtGlue® Enterprises, Amesbury, MA) was applied to all plots in September 2009. Soil binding agent 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 window screen seed dispersal barriers. Barriers were 0.6 m high and were secured to oak stakes with staples. One meter wide buffer strips separated Barrier subplots (Figure 8). Finally, locally collected big sagebrush seed was hand-broadcast on top of snow in Unfallowed plots in December of 2009.

During the 2010 growing season, Fallowed plots were maintained in a nearly unvegetated condition by applying glyphosate at 560 g/ac (8 oz./ac) in early June, and hand-pulling any plants nearing seed production in late June. In early September, 2010, soil compaction was relieved in Fallowed plots by ripping to 30 cm with a Plotmaster™ 400 (Tecomate Wildlife Systems, San Antonio, TX). This necessitated removing and then rebuilding the seed dispersal barriers in Fallowed plots. Following ripping, Fallowed, Plateau plots were treated with Plateau at 140 g ai/ha (8 oz/ac) applied with 655 li/ha (70 gal/ac) of water with a backpack sprayer. Fallowed plots were seeded in late September using the same seed mixture and techniques as had been used in 2009 for Unfallowed plots. Locally collected big sagebrush seed was hand-broadcast on top of snow in Fallowed plots in December of 2010.

Some cheatgrass seed which had been caught in the dispersal barriers the prior year germinated and grew through the barrier (Figure 9). To fortify the barriers, we applied Plateau at 140 g ai/ha (8 oz/ac) in a 0.1 m strip between 9/14/10 and 9/28/10 at the base of the barrier.

A difficulty with constructing a fair test of the barriers is that subplots on the edge of the experiment area are likely to be subject to more seed blowing in from the surrounding landscape than are subplots in the interior. We moderated this effect by hand-broadcasting cheatgrass seed within the buffer strips separating subplots in 2009 and again in 2010. To determine how much seed to scatter, we used annual data on ambient cheatgrass seed rain known from our Tanglefoot seed rain traps (Appendix 2). 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). The scattered cheatgrass seed had been collected from near-monocultures within 100 m of each site in June and July, 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 five 5g subsamples, and then counting and weighing all of the fully developed, hard-coated cheatgrass seeds for each subsample.

A photo of Unfallowed plots in the 2010 season is included as Figure 10.

At 2 of the sites, RYG and SKH, barriers were badly damaged by cow trampling after the cheatgrass seed had been broadcast in 2009. 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 further damage.

Vegetation assessments in the Gulley experiment will begin in 2011, and will continue for at least 3 growing seasons. The performance of the treatments will be assessed by quantifying cover and diversity of vegetation in the study plots. 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 costs and benefits of the 3 weed control measures tested will be compared and discussed.

MOUNTAIN TOP EXPERIMENT

Overview

- Goal: Identify techniques to maximize plant diversity, shrub establishment, and forb establishment in areas where the threat of weed invasion is low.
- Conducted at 4 sites: SCD, SPG, TGC and SQS (Figure 1, Table 1)
- Locations had predominately native and desirable surrounding plant communities, and varied in elevation from 2342 m (7681 ft) to 2676m (8777 ft; Table 1).
- Treatments:
    - Seeding (2 levels): Seeded or Unseeded
    - Soil surface (2 levels): roughened with holes and mounds (Rough) or left flat (Flat)
    - Brush mulch (2 levels): mulched with brush (Brush) or not mulched with brush (No Brush)
- Design: Completely randomized factorial (Figure 11)
- Plot size: 9 m X 6 m
- 3 replications per site

Methods

Treatments were implemented in August and September of 2009. The rough surface treatment was created using a mini excavator to dig holes approximately 100 cm X 60 cm X 50 cm deep. 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.

Seed (Table 5) was mixed 1:1 by volume with rice hulls to help ensure even distribution of species in Seeded plots. In Flat plots, seed was drilled approximately 1 cm deep using a Plotmaster™ 400 with a hunter grain drill attachment. In Rough plots, seed was broadcast and then lightly raked to incorporate the seed into the soil. Seeding rates were the same for both seeding methods.

The brush mulch treatment was achieved by distributing approximately 1.2 m^3 of stockpiled woody debris to each plot receiving the brush treatment. 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. Approximately 4 liters of topsoil from brush stockpiles was scattered over each Brush plot.

Sagebrush seed was collected within 10 miles of each study site in November 2009 and broadcast seeded in November and December of 2009 in Seeded plots.

Vegetation response was quantified in 2010 by assessing density of seedlings by species. Where species identification could not be made, the functional group (shrub, forb, or grass) and lifespan (annual or perennial) of the seedling was noted. Counts were made for five 0.5 m X 1 m subplots arrayed systematically within each plot. One subplot was placed in the center of each plot, and the remaining 4 subplots were placed equidistant from this plot and the plot corners. Subplot density values were averaged to determine plot-level density.

The density of annuals, perennial forbs, perennial grasses, and shrubs in response to the seeding treatment, the soil surface treatment, and the brush treatment were analyzed in SAS PROC MIXED with main effects and 2-way interactions among them included as fixed effects, and site as a random effect. Biennial forbs were lumped with annual forbs. Backwards model selection with $\alpha = 0.05$ was used to determine the final model. The magnitude of significant treatments was determined using ESTIMATE statements in this model. Effect sizes are given ± 95% confidence intervals. Annual forbs and annual grasses were not analyzed separately in this experiment because 99% of annuals were forbs.

Results

The density of annuals was 12.7 ± 4.6 plants/m^2 lower in Rough plots than in the Flat plots (Figure 12). For perennial grass and perennial forbs, the effect of the soil surface treatment depended upon the seeding treatment (treatment interaction $p < 0.005$). Without seeding, there was no difference between Rough and Flat plots, but with seeding, perennial grass density was 6.4 ± 3.5 plants/m^2 higher in Rough plots than in Flat plots (Figure 13). For perennial forbs, this difference was 12.8 ± 6.7 plants/m^2 (Figure 14). There was no significant effect of the soil surface treatment on shrubs ($p = 0.07$).

The seeding treatment had no significant effect on the density of annuals ($p = 0.08$). Averaged across the surface treatments, seeding increased the density of perennial grasses by 22.2 ± 2.5 plants/m^2 and the density of perennial forbs by 12.4 ± 4.7 plants/m^2. Seeding had no significant effect on the density of shrubs ($p = 0.25$). There was no significant difference in annual, perennial grass, perennial forb, or shrub density in Brush versus No Brush plots.

Discussion

In the first year post-treatment, the rough surface treatment promoted several responses which may result in a more diverse, perennial plant community. The density of annuals was lower, the density of perennial grasses was slightly higher, and the density of perennial forbs, when combined with seeding, was more than twice as high as that in Flat surface plots. The reduction in annuals is a beneficial response because approximately 85% of annuals in this experiment were non-native. The overall increase in perennial plant density is beneficial, and the more dramatic response of forbs versus that of grasses is also likely beneficial to the long-term goal of promoting a mixed plant community.

The effect of the rough surface treatment on perennials was constrained to plots that were seeded. This implies that the action of the treatment was due to increased germination and/or survival of seeds, rather than to capture of dispersing seed. The rough surface treatment was applied in the fall of 2009, after most plants had finished dispersing seed for that year. It is possible that that an effect of the rough surface treatment may be realized in unseeded plots once natural dispersal has had more time to take place.

Perennial grass and forb density was much higher in plots that were seeded. This is unsurprising, as all of the seeded species were perennials. There was no effect of seeding on the density of annuals. Annual plant density and cover may increase in unseeded plots if natural dispersal provides insufficient seed to compete with annuals. Alternately, the naturally recruited plants in unseeded plots may provide sufficient competition to control annuals.

The brush treatment did not affect any of the response variables. The effect of brush at creating microsites and capturing seed may be negligible under the conditions studied, or an effect may become evident through time.

The Mountain Top experiment will be monitored for at least 3 additional growing seasons. In future years the performance of the treatments will be assessed by quantifying cover of desirable vegetation in the study plots. 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.

STRATEGY CHOICE EXPERIMENT

Overview

- Goal: compare two mutually exclusive reclamation strategies (one which maximizes plant diversity and one which minimizes weed invasion) in situations where the threat of weed invasion is ambiguous.
- Conducted at 4 sites: WRR, SGE, GVM, MTN (Figure 1, Table 1)
- Treatments include:
    - Seed mix (2 levels): seeded with a high competition seed mix (HC) or a low competition mix (LC)
    - Soil surface/mulch type (2 levels): flat with straw mulch (Flat/Straw) or rough surface with brush mulch (Rough/Brush; Figure 15).
    - Herbicide (2 levels): Plateau applied (Plateau) or no Plateau applied (No Plateau)
- Completely randomized factorial (Figure 16)
- Plot size: 9 m X 6 m
- 3 replications per site
- The 4 locations had 0-15% non-native cover prior to the start of the experiment

Methods

At GVM and MTN, the full experiment with all 3 treatments was implemented. At WRR and SGE, space constraints mandated implementing an abbreviated form of the experiment, and the herbicide treatment was omitted. Treatments were implemented in October of 2009.

Seed mixes for the HC and LC plots are shown in Table 6. A key difference between the mixes is in the number and type of grass seeds used. In the high competition mix, 344 grass seeds/m^2 (32 seeds/ft^2) were used, and these were mostly rhizomatous wheatgrasses. In the low competition mix, 156 grass seeds/m^2 (15 seeds/ft^2) were used, and 90% of these were less competitive bunchgrass species.

In Rough/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 remainder 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 Flat/Straw plots. Straw was crimped in place using a custom-built mini crimper pulled behind an ATV. Rough/Brush plots were treated 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.

Plateau plots were sprayed with 140 g ai/ha of Plateau (8 oz /ac) applied with 655 li/ha of water (70 gal /ac) with a backpack sprayer. To hit the target rate, a quantity of liquid sufficient to treat 2 plots was mixed, and then that quantity was applied to the 2 plots with a dye indicator to ensure even application. In Plateau, Flat/Straw plots, the amount of water used in herbicide application was tripled to aid the Plateau in penetrating the straw mulch.

After Plateau application, brush which had been cleared and stockpiled next to each site was applied to Rough/Brush plots. Approximately 5 m^3 of brush was applied evenly to each plot. Big sagebrush was hand-broadcast on top of snow in all plots in December of 2009.

Vegetation response was quantified in 2010 by assessing density of seedlings by species. Counts were made for five 0.5 m X 1 m subplots arrayed systematically within each plot. One subplot was placed in the center of each plot, and the remaining 4 subplots were placed equidistant from this plot and the plot corners. Subplot density values were averaged to determine plot-level density.

The density of perennial grasses, perennial forbs, shrubs, annual grasses, and annual forbs in response to the seeding treatment, the soil surface/mulch type treatment, and the Plateau treatment were analyzed in SAS PROC MIXED with main effects and 2-way interactions among them included as fixed effects, and site as a random effect. Biennial forbs were lumped with annual forbs. Because the Plateau treatment was only conducted at 2 of the 4 sites, separate backwards model selection processes (α = 0.05) were conducted for models with the Plateau treatment versus those without. Plots receiving Plateau were excluded from models not containing the Plateau treatment parameter, and sites where Plateau was not applied were excluded from models containing the Plateau treatment parameter. The magnitude of significant treatments was determined using ESTIMATE statements in final models. Effect sizes are given ± 95% confidence intervals.

Results

The Plateau treatment affected the density of perennial grasses, perennial forbs, shrubs, annual grasses, and annual forbs ($p < 0.01$). In Plateau plots, perennial grass density was 13.1 ± 7.8 plants/m^2

lower, perennial forb density was 21.4 ± 4.7 plants/m^2 lower, shrub density was 5.6 ± 1.5 plants/m^2 lower, annual grass density was 3.7 ± 2.8 plants/m^2 lower, and annual forb density was 4.2 ± 1.5 plants/m^2 lower than No Plateau plots (Figure 17).

In No Plateau plots, the seed mix treatment affected the density of perennial grasses and perennial forbs ($p < 0.0001$), but did not detectably affect shrubs, annual grasses, or annual forbs ($p > 0.13$; Figure 19). Perennial grasses were 19.2 ± 7.2 plants/m^2 less dense in LC plots than in HC plots. Perennial forbs were 14.8 ± 6.4 plants/m^2 more dense in LC plots than in HC plots. The seed mix and Plateau treatments interacted for perennial forbs ($p = 0.04$); where Plateau was applied, the density of perennial forbs did not differ between LC plots and HC plots ($p=0.44$). There was no evident interaction between seed mix and Plateau application for perennial grasses, shrubs, annual forbs, or annual grasses ($p > 0.60$). There was no interaction between the seed mix treatment and the soil surface/mulch treatment for any functional group ($p > 0.36$).

In the absence of Plateau, the soil surface/mulch treatment affected the density of perennial grasses, perennial forbs, shrubs, and annual forbs ($p < 0.04$), but did not detectably affect the density of annual grasses ($p = 0.73$; Figure 20). In Rough/Brush plots, perennial grass density was 7.6 ± 7.2 plants/m^2 lower, perennial forb density was 19.6 ± 6.4 plants/m^2 lower, shrub density was 6.2 ± 3.8 plants/m^2 lower, and annual forb density was 5.5 ± 2.6 plants/m^2 lower than in Flat/Straw plots. At sites where Plateau was applied, the Plateau treatment interacted with the surface treatment for annual forbs, perennial forbs, and shrubs ($p < 0.03$) but did not interact with the surface treatment for annual grasses or perennial grasses ($p > 0.48$). For annual forbs, perennial forbs, and shrubs, there was no effect of the soil surface treatment in plots treated with Plateau ($p > 0.36$), but plots without Plateau had soil surface effects similar to those quoted above. An unexpected result in Flat/Straw plots was germination of wheat from seed included in the straw mulch. Wheat plants were present at 14.7 ± 7.5 plants/m^2 in Flat/Straw plots.

A photo indicating some of the treatment differences is included as Figure 18.

Discussion

The 2 seed mixes differed in the relative densities of perennial grasses versus perennial forbs one year post-treatment: the low competition mix resulted in a higher density of perennial forbs, while the high competition mix resulted in a higher density of perennial grasses. There was no difference in the density of annual forbs or annual grasses due to the seed mix treatment. If these trends continue, the higher proportion of forbs produced by the low competition mix may result in a more favorable mixture of plant types. Also, one may conclude that the composition of plants in the low competition mix, while less competitive than that in the high competition mix, is sufficient to suppress annuals. This is a benefit because 94.5% of annual cover was non-native in this study.

The Rough/Brush plots had lower densities of most plant groups than the Flat/Straw plots. Because both desirable and undesirable plant density was lessened in the Rough/Brush plots, it is difficult to determine which treatment will ultimately result in a more desirable plant community. The Rough/Brush plots averaged 41.0 ± 7.7 perennial plants/m^2. Values as low as 5 perennial plants/m^2 have been used as the lower limit of success for rangeland seedings (Vallentine 1989). Therefore survival rates as low as 12% in the Rough/Brush plots may still result in a desirable plant community, if that plant community is diverse and palatable to wildlife.

The Plateau treatment lessened the density of all plant groups. Plots with Plateau averaged 20.3 ± 9.0 perennial plants/m^2, while plots without Plateau averaged 60.4 ± 9.8 perennial plants/m^2. Perennial forbs were especially reduced in Plateau plots; perennial forb density was 79% lower in plots with Plateau than in plots without Plateau, while perennial grass density was 48% lower in plots with Plateau. Like the soil surface/mulch treatments, it is difficult to determine which herbicide treatment will ultimately result in a more desirable plant community. If survival of desirable plants in plots with Plateau is high, and the herbicide continues to suppress undesirable plants, then a more favorable plant community could result from the Plateau treatment. If survival is poor in plots treated with Plateau, or the relatively higher grass density reduces forb productivity, then plots without Plateau may result in a more favorable community.

The Strategy Choice experiment will be monitored for at least 3 additional growing seasons. In future years the performance of the treatments will be assessed by quantifying cover and diversity of vegetation in the study plots. If the effectiveness of treatments differs across study sites, a site-by-site analysis will be done. The cost and value of highly competitive versus less competitive seed mixes, flat versus rough soil surface preparation, and Plateau herbicide will be discussed in the context of weed prevalence in the surrounding plant community.

SUMMARY

Two years after the initiation of this suite of experiments, several treatments appear promising in improving the quality of reclaimed wildlife habitat by promoting mixed, perennial plant communities in reclamation areas: applying Plateau herbicide, creating a rough soil surface composed of mounds and holes, using a seed mix with a small fraction of rhizomotous grasses, and including granulated super-absorbent polymer when drill seeding.

This report contains results of 2 experiments in which Plateau herbicide was applied. In both cases, the herbicide was applied in the fall just prior to seeding. In the Pipeline experiment, Plateau was applied with a boom sprayer at 105 g ai/ha (6 oz/ac), while in the Strategy Choice experiment, Plateau was applied with a backpack sprayer at 140 g ai/ha (8 oz/ac). Results of percent cover assessments 2 years following treatment in the Pipeline experiment are favorable: annuals are reduced, perennial grasses are increased, and perennial forbs are unaffected by treatment with Plateau. Results of plant density assessments one year following treatment in the Strategy Choice experiment are not apparently favorable: the density of perennial grasses, shrubs, and perennial forbs, as well as that of annuals, are reduced by treatment with Plateau. The length of time since treatment is probably the largest factor in the differences between the 2 experiments. In the Pipeline experiment, the apparent vigor of all plants was lower one year post-treatment in plots treated with Plateau, but that result had changed by 2 years post-treatment. It appears that while Plateau herbicide does incur a cost in terms of reduced density and vigor of desirable plants, the reduced competition with annuals allows those perennials which do survive to eventually outperform (in the case of perennial grasses) or at least perform comparably (in the case of perennial forbs) to those which were never treated with herbicide. While this is a beneficial result, the potential of Plateau to favor grasses over forbs should be carefully weighed against the benefits. When applying Plateau, the 105 g ai/ha (6 oz/ac) seems sufficient for areas where the ground has been disturbed, and may reduce the effect on forbs to an acceptable level. In undisturbed areas, where the density of viable weed seeds is likely to be higher, a higher rate of herbicide might be needed. In those cases, a cost-effective seed mix might be limited to those few forbs which appear more resistant to the herbicide. One such forb which established well in Plateau plots in this study is Utah sweetvetch (*Hedysarum boreale*).

There were 2 experiments where a roughed soil surface of mounds and holes, coupled with broadcast seeding, was compared to a flat soil surface coupled with drill seeding. In the Mountain Top experiment, the rough soil surface treatment was crossed with a brush mulch treatment, while in the Strategy Choice experiment, the rough soil surface treatment was always applied with brush mulch, and the flat soil surface treatment was always applied with straw mulch. In the Mountain Top experiment, the rough soil surface performed well: the density of annuals was lower, the density of perennial grasses was higher, and the density of perennial forbs was higher as compared to the Flat plots. In the Strategy Choice experiment, the results were different: perennial grasses, perennial forbs, shrubs, and annuals all had lower density in the Rough plots than in the Flat plots. The difference is likely to be due to the

addition of straw mulch in the Strategy Choice experiment Flat plots, which probably improved water infiltration and retention. Even so, Strategy Choice Rough plot perennial grass and forb densities were still quite high; the treatment producing the most desirable outcome will depend on the survival rates of plants of different types. In the Mountain Top experiment, the higher perennial grass and forb density in Rough plots was surprising because Rough plots were broadcast seeded at the same rate as drill-seeded Flat plots. In both experiments, a benefit of the rough soil surface was a reduction in annuals. If these trends continue, the rough soil surface may be a cost effective alternative, because the lack of need for a drill seeder, mulch, and mulch crimper would offset the cost of creating the holes and mounds. This result confirms and extends those of Eldridge et al. (2011), who found that a rough soil surface treatment improved the cover of native plants at low elevation sites in the Colorado River Valley.

One year after treatment implementation, the low competition seed mix tested in the Strategy Choice experiment seems to perform well. There was no difference in the density of annuals between the low competition mix and the high competition mix, and the low competition mix resulted in a higher proportion of perennial forbs. The idea that seed mixes should limit the proportion of competitive rhizomatous grasses in order to promote a mixed plant stand was proposed nearly 30 years ago (Redente et al. 1984). However, most seed mixes continue to be dominated by grasses, probably out of a fear of weed invasion, a lack of availability of appropriate forb seeds, and/or a need for an inexpensive seed mix. Also, the degree to which rhizomatous grass seed should be reduced had not been determined. This study made use of several forb species provided by the Uncompagre Partnership (http://www.upartnership.org/) which are either not yet commercially available or have no Colorado-specific variety available. Several of these species established well, including local cultivars of many-lobed groundsel (*Packera multilobata*), hairy golden aster (*Heterotheca villosa*), sulfur flower buckwheat (*Eriogonum umbellatum*), bluestem penstemon (*Penstemon cyanocaulis*), and western yarrow (*Achillia millefolium*). The amount of rhizomatous grass seed (western wheatgrass and slender wheatgrass) included in the mix was only 16 seeds/m^2 (1.5 seeds/ft^2 or 0.5 PLS pounds/ac), and the cost of the mix, aside from the species which have no commercially available variety, was $384/ha ($159/ac). If the trends shown in 2010 continue, then a seed mix similar to the low competition mix (perhaps more appropriately called a high diversity mix) may successfully and cost-effectively prevent weed invasion and promote mixed plant communities.

One year post-implementation, the use of granulated super-absorbent polymer, tested in the Competition experiment, shows some promise. Where applied at 30 g/m^2 to compacted soils, super-absorbent polymer increased the density of seeded perennial grasses, but did not increase the density of cheatgrass. The cost of this treatment is approximately $210/ha ($85/ac). If these trends continue, then the addition of super-absorbent polymer to soils in reclamation areas should be studied in additional soil types and with more complex seed mixes. A limitation of super-absorbent polymer is that it must be incorporated into soil to avoid breakdown due to ultraviolet light. It could be added when redistributing topsoil or when drill seeding, but would be difficult to use with broadcast seeding.

Treatments which do not appear beneficial at this time include surface compaction and addition of a soil binding agent to the soil. Slight soil surface compaction was attempted in 2 studies: the Pipeline experiment and the Competition experiment. The goal of this treatment in these experiments was to determine if creating a crust of compacted soil would benefit reclamation by preventing the emergence of cheatgrass. In the Pipeline experiment, compaction with both a static and vibratory roller was tested, and in the Competition experiment, the combination of a static roller with a soil binding agent was tested. An ideal treatment would have created a denser surface crust without affecting the rooting zone, but this was not achieved. Where a surface crust was created, cheatgrass was noted emerging through inevitable cracks in the crust. In none of the cases was cheatgrass emergence affected, and a slight negative effect on shrubs was found in the Pipeline experiment, probably due to restricted root development. Although cheatgrass has been shown to have reduced emergence in slightly compacted soil in the laboratory (Thill et al. 1979), it remains to be shown that compacting soil is a practical approach for discouraging cheatgrass growth in a field setting. The soil binding agent tested, DirtGlue, was promoted by the manufacturer as increasing water infiltration, and we found that it was successful at increasing soil moisture in late May, but not later in the growing season. A slight effect of increased cheatgrass density with DirtGlue addition was found at one of 2 study sites, and no effect was found on perennial grass density. If these trends continue, then use of this soil binding agent is not likely to positively affect the competitive ability of perennial plants under competition from cheatgrass.

Re-creating wildlife habitat in areas disturbed by oil and gas development implies challenges greater than those typically met in reclamation. Not only must soil be stabilized and weeds controlled, but plant diversity and plant functional group diversity must be maintained or improved. While perfection in reaching this goal will always be elusive, opportunities exist to maximize the outcome of reclaimed areas as wildlife habitat. Capitalizing on these opportunities requires assessing reclamation difficulties in particular locations and then making judicious use of herbicides, seed mixes, and soil preparations. In the Piceance Basin, much of the variability in reclamation difficulty is associated with elevation and aspect. As additional time allows the outcome of these experiments become more finalized, specific information about which treatments are recommended in which elevation zones will be compiled and disseminated.

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Table 1. Basic information about study locations. Relative cover is for undisturbed ground near each study location in the growing season of 2009.

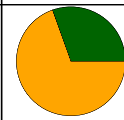
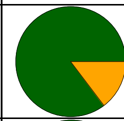
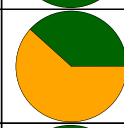
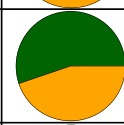
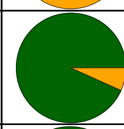
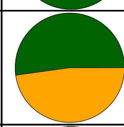
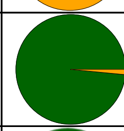
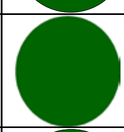
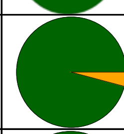
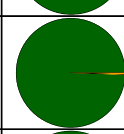
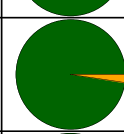
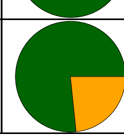
Code	Name	Landowner	Elev. m (ft)	Experiment(s) Conducted	RelativeCover Native NonNative
SKH	SK Holdings	Williams	1561 (5120)	Pipeline Gulley	
GVM	Grand Valley Mesa	Williams	1662 (5451)	Pipeline Strategy Choice	
YC2	Yellow Creek 2	DOW	1829 (5999)	Pipeline Gulley	
YC1	Yellow Creek 1	DOW	1905 (6248)	Pipeline Gulley	
SGE	Sagebrush	BLM	2004 (6573)	Strategy Choice Competition	
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	
SCD	Scandard	BLM	2342 (7681)	Mountain Top	
SPG	Sprague	Conoco	2445 (8019)	Mountain Top	
TGC	The Girls' Claims	Encana	2527 (8288)	Mountain Top	
SQS	Square S	DOW	2676 (8777)	Mountain Top	

Table 2. Seed mix used in the Pipeline experiment.

Scientific Name	Common Name	PLS (lbs/ ac)	Live seeds/m^2
forbs			
Achillea lanulosa	western yarrow	0.10	67
Erigonum umbellatum	sulfur flower buckwheat	1.03	53
Hedsarum boreale	Utah sweetvetch	0.44	11
Heterotheca villose	hairy golden aster	1.11	137
Linum lewisii	Lewis flax	0.38	28
Packera multilobata	lobeleaf groundsel	0.10	67
Penstemon strictus	Rocky Mountain penstemon	0.33	23
grasses			
Achnatherum lymenoides	Indian ricegrass (Nezpar)	0.83	33
Agropyron smithii	western wheatgrass	0.40	11
Agropyron spicatum	bearded bluebunch wheatgrass P-7	0.38	11
Agropyron spicatum	bearded bluebunch wheatgrass Secar	0.36	10
Agropyron trachycaulum	slender wheatgrass	0.24	10
Elymus elymoides	bottlebrush squirreltail	0.45	21
Koeleria macrantha	prarie junegrass	0.18	105
Poa secunda	sandberg bluegrass	0.26	68
Stipa viridula	green needlegrass	0.68	22
shrubs			
Artemesia tridentata ssp. *Wyomingensis*	Wyoming big sagebrush	0.33	246
Atriplex canescens	fourwing saltbush	0.54	7
Atriplex confertifolia	shadscale saltbush	0.47	7
	TOTAL	**8.60**	

Table 3. Seed mix of grasses used in the Competition experiment. Cheatgrass (*Bromus tectorum*) was also seeded at 300 seeds/m2.

Scientific Name	**Common Name**	**Variety**	**Seeds/ m2**	**PLS (kg/ha)**	**Seeds/ ft2**	**PLS (lbs/ac)**
Elymus lanceolatus spp. lanceolatus	thickspike wheatgrass	Critana	150.7	4.5	14	4.0
Elymus trachycaulus spp. trachycaulus	slender wheatgrass	San Luis	150.7	5.1	14	4.5
Pascopyrum smithii	western wheatgrass	Rosana	150.7	5.8	14	5.2
		TOTAL	**452.1**	**15.3**	**42**	**13.7**

Table 4. Seed mix used in the Gulley experiment.

Scientific name	Common Name	Variety	Seeds/ m2	PLS (kg/ha)	Seeds/ ft2	PLS (lbs/ac)
forbs						
Achillia millefolium	western yarrow	VNS	183	0.3	17	0.3
Hedysarum boreale	Utah sweetvetch	Timp	22	2.1	2	1.9
Linum lewisii	lewis flax	Maple Gr.	54	0.8	5	0.7
grasses						
Achnatherum hymenoides	Indian ricegrass	Rimrock	108	3.0	10	2.7
Elymus elymoides	squirreltail	Toe Jam Ck.	108	2.5	10	2.3
Elymus lanceolatus spp. lanceolatus	thickspike wheatgrass	Critana	65	1.9	6	1.7
Elymus trachycaulus spp. trachycaulus	slender wheatgrass	San Luis	65	2.2	6	1.9
Leymus cinereus	basin wild rye	Trailhead	43	1.3	4	1.2
Pascopyrum smithii	western wheatgrass	Rosana	65	2.5	6	2.2
Pleuraphis jamesii	galleta grass	Viva	54	1.6	5	1.4
Poa fendleriana	muttongrass	VNS	323	0.7	30	0.7
Pseudoroegneria spicata spp. spicata	bluebunch wheatgrass	Anatone	108	3.9	10	3.5
shrubs						
Artemesia tridentat spp. Wyomingensis	Wyo. big sagebrush	VNS	250	0.6	23	0.5
Atriplex canescens	fourwing saltbush	VNS	32	3.3	3	3.0
Ericameria nauseosa	rubber rabbitbrush	VNS	22	0.2	2	0.2
Kraschenninnikovia lanata	winterfat	VNS	16	0.6	1.5	0.5
		TOTAL	**1514**	**28**	**141**	**25**

Table 5. Seed mix used in the Mountain Top experiment.

Scientific Name	Common Name	Variety	Seeds/ m^2	PLS (kg/ha)	Seeds/ ft^2	PLS (lbs/ac)
forbs						
Achillia millefolium	western yarrow	Eagle Mtn.	161	0.3	15	0.2
Hedysarum boreale	Utah sweetvetch	Timp	15	1.5	1	1.3
Penstemon palmeri	palmer penstemon	Cedar	215	1.7	20	1.5
Penstemon strictus	Rocky Mtn. penstemon	Bandera	108	1.7	10	1.5
grasses						
Bromus marginatus	mountain brome	Garnet	54	3.8	5	3.4
Elymus lanceolatus spp. lanceolatus	thickspike wheatgrass	Critana	22	0.6	2	0.6
Elymus trachycaulus spp. trachycaulus	slender wheatgrass	San Luis	65	2.2	6	1.9
Nassella viridula	green needlegrass	Lowdorm	43	1.2	4	1.0
Poa fendleriana	muttongrass	VNS	215	0.5	20	0.4
Pseudoroegneria spicata spp. spicata	bluebunch wheatgrass	Anatone	65	2.3	6	2.1
shrubs						
Artemisia cana	silver sage	VNS	323	1.3	30	1.2
*Artemisia tridentata spp. vaseyana**	mtn. big sagebrush	VNS	250	0.6	23	0.5
Ericameria nauseosa	rubber rabbitbrush	VNS	22	0.2	2	0.2
		TOTAL	**1556**	**17.8**	**145**	**15.9**

Table 6. Seed mixes used in the Strategy Choice experiment. Species noted as "drill seeded" were drill seeded in plots with a flat surface. In plots with a rough surface, all seed was broadcast.

	Scientific Name	Common Name	Variety	high competition mix seeds/ m^2	high competition mix PLS (kg/ha)	low competition mix seeds/ m^2	low competition mix PLS (kg/ha)
drill seeded	***forbs***						
	Hedysarum boreale	Utah sweetvetch	Timp	22	2.1	22	2.1
	grasses						
	Achnatherum hymenoides	Indian ricegrass	Rimrock	65	1.8	11	0.3
	Elymus lanceolatus spp. lanceolatus	thickspike wheatgrass	Critana	65	1.9		
	Elymus trachycaulus spp. trachycaulus	slender wheatgrass	San Luis	75	2.5	11	0.4
	Pascopyrum smithii	western wheatgrass	Rosana	65	2.5	5	0.2
	Pleuraphis jamesii	galleta grass	Viva	75	2.2		
	Poa fendleriana	muttongrass	VNS			54	0.1
	Pseudoroegneria spicata spp. spicata	bluebunch wheatgrass	Anatone			22	0.8
	shrubs						
	Atriplex canescens	fourwing saltbush	VNS CO	11	1.1	11	1.1
broadcast seeded	***forbs***						
	Achillia millefolium	western yarrow	VNS	129	0.2	129	0.2
	Erigeron speciosis	oregon daisy	VNS			323	0.9
	Eriogonum umbellatum	sulphur flower buckwheat	VNS	108	2.3	108	2.3
	Heterotheca villosa	hairy golden aster	VNS			215	1.3
	Linum lewisii	lewis flax	Maple Gr.	54	0.8	54	0.8
	Packera multilobata	many-lobed grounsel	VNS			215	1.3
	Penstemon cyanocaulis	bluestem penstemon	VNS	108	0.7	108	0.7
	grasses						
	Koeleria macrantha	prairie junegrass	VNS			54	0.1
	shrubs						
	Krascheninnikovia lanata	winterfat	VNS	22	0.8	22	0.8
	Artemesia tridentat spp. Wyomingensis	Wyoming big sagebrush	VNS	253	0.6	253	0.6
			GRASS TOTAL	***344***	***9.8***	***156***	***1.7***
			FORB TOTAL	420	5.6	1173	8.7
			SHRUB TOTAL	285	2.2	285	2.2
			OVERALL TOTAL	**1049**	**17.6**	**1614**	**12.6**

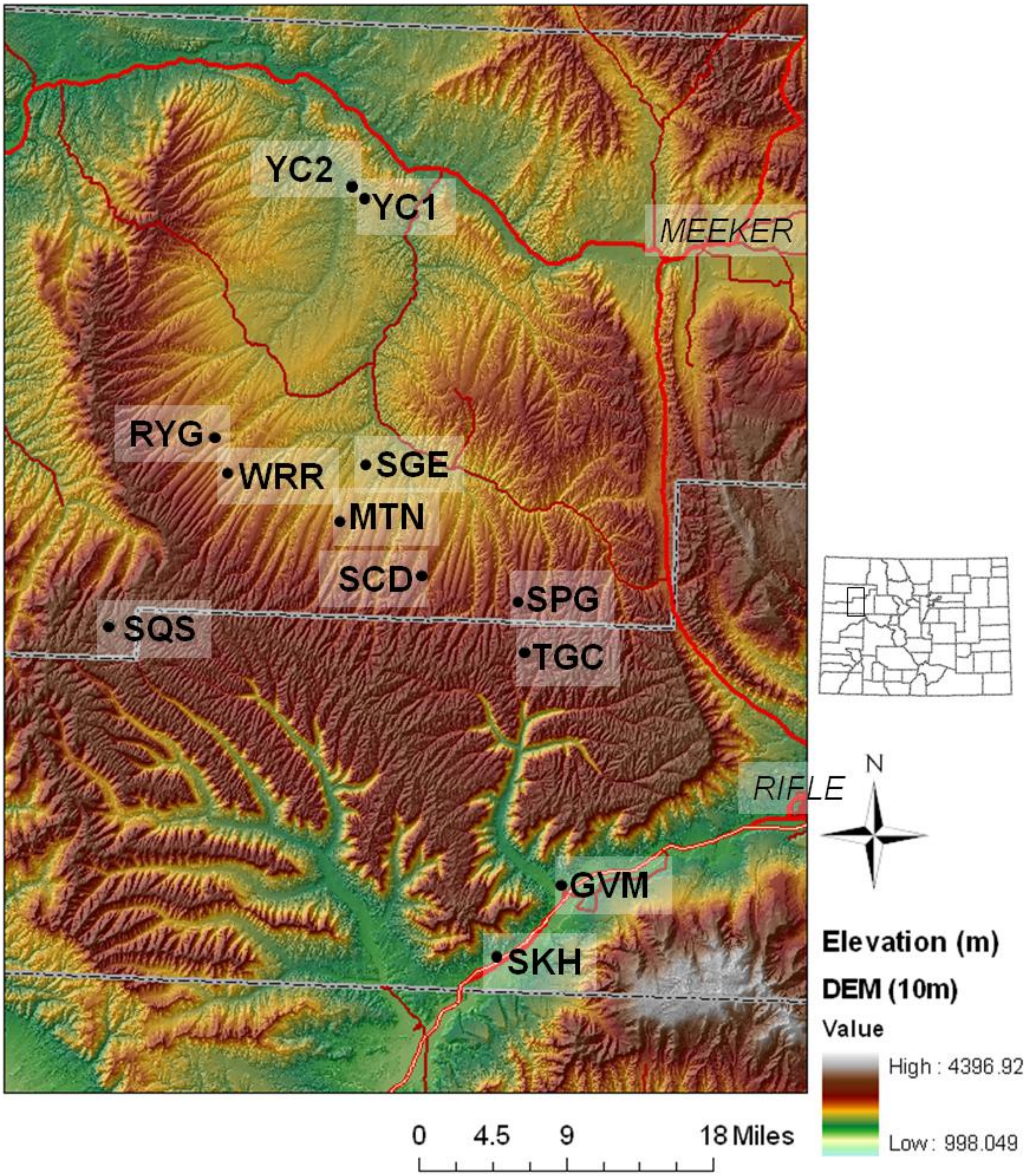


Figure 1. Locations of the 12 research sites in Rio Blanco and Garfield counties, Colorado.

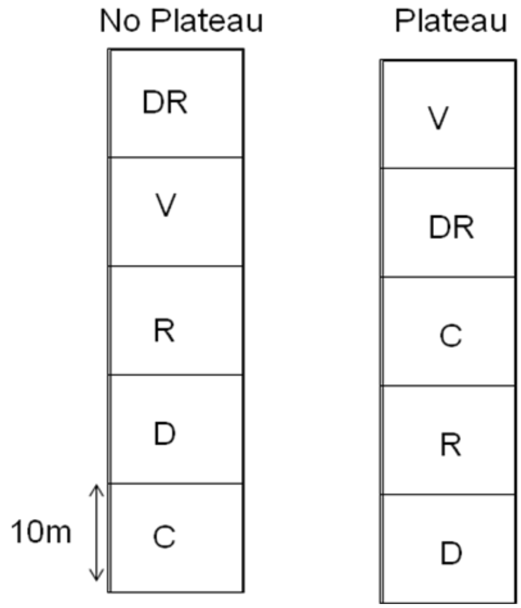


Figure 2. Layout of the Pipeline experiment at one of 6 sites. D = disked, R = rolled, DR = disked and rolled, V = rolled with a vibratory drum compactor, C = control.

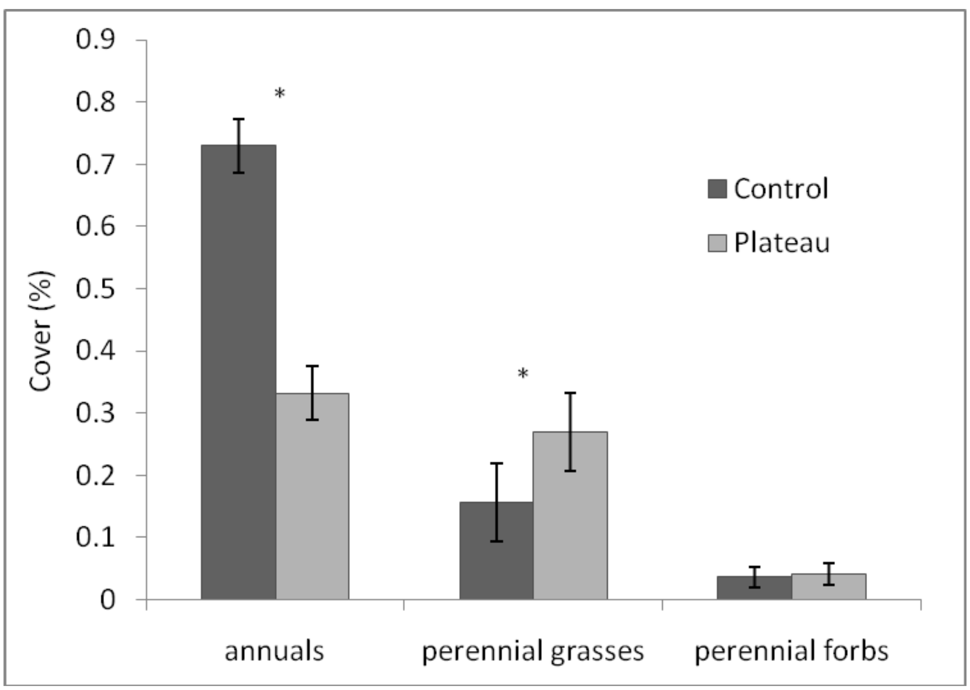


Figure 3. Cover of annuals, perennial grasses, and perennial forbs in plots with versus without Plateau herbicide 2 years after herbicide application and seeding in the Pipeline experiment. Stars denote significant differences at $\alpha = 0.05$. Error bars = SE. SE's include random site effects which cancel when means are compared.

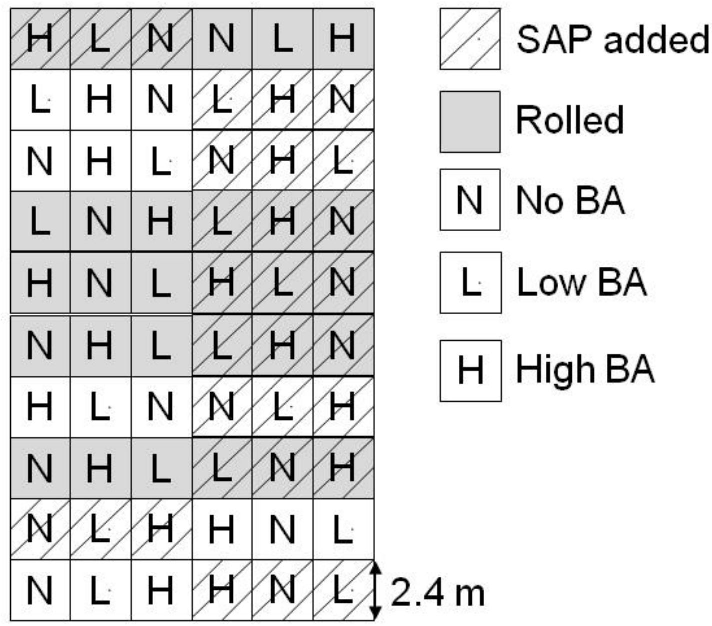


Figure 4. Layout of the Competition experiment at one of 2 research sites. SAP = super- absorbent polymer. BA = soil binding agent.

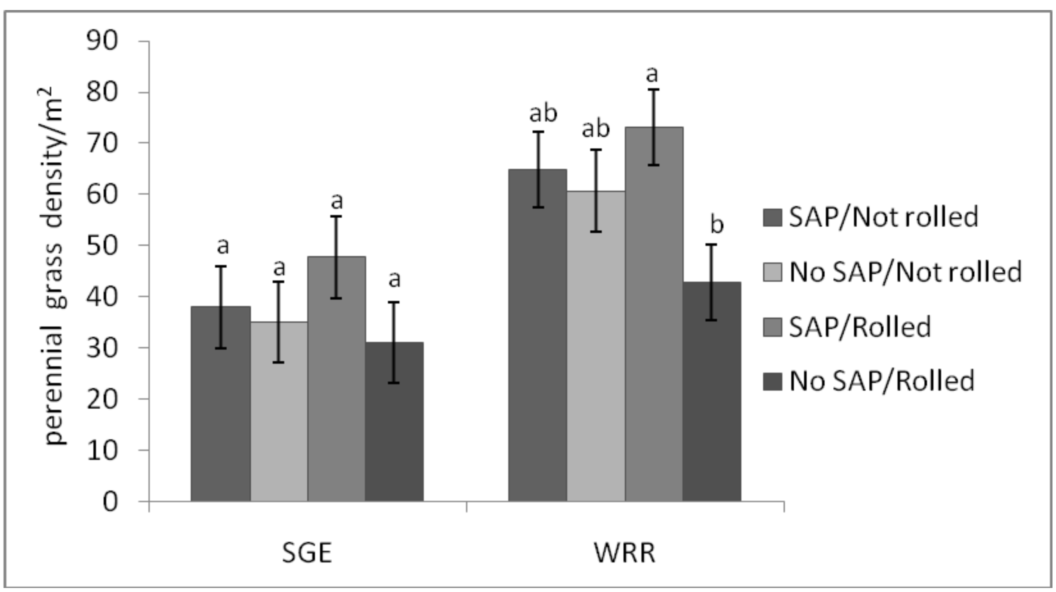


Figure 5. Effect of super-absorbent polymer (SAP) and compaction by a static roller on density of perennial grasses at 2 study sites, SGE and WRR. Bars not sharing a letter denote significant differences within a site at $\alpha = 0.05$. Error bars = SE. SE's include random site effects which cancel when means are compared.

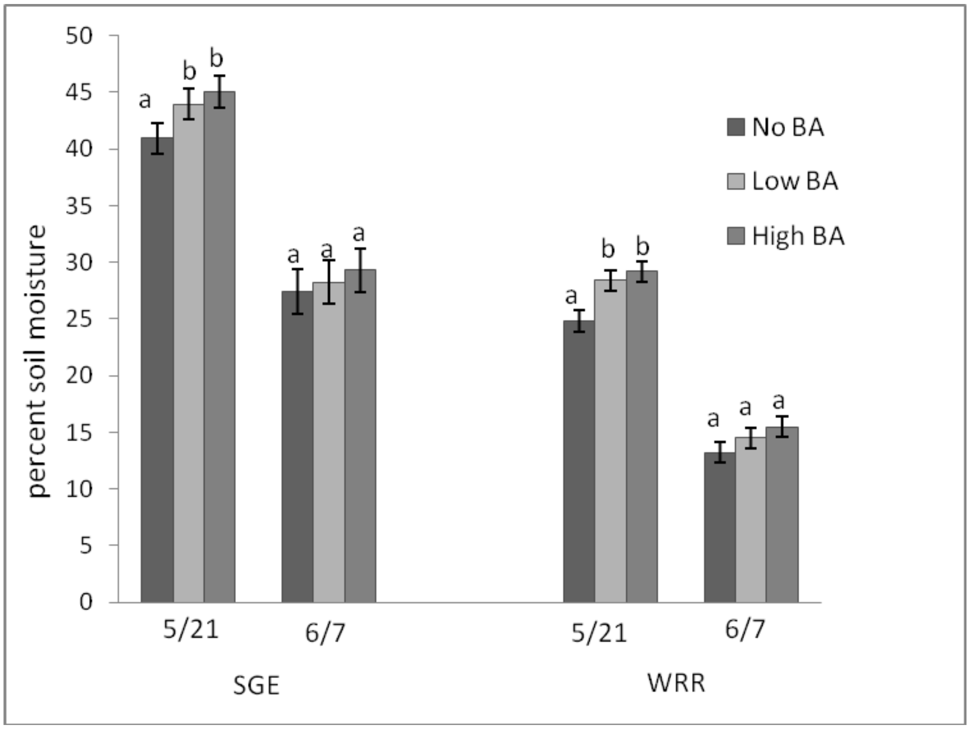


Figure 6. Effect of 3 levels of soil binding agent (BA) on percent soil moisture at 2 study sites, SGE and WRR, on May 21 and June 7, 2010. Bars not sharing a letter denote significant differences within a site and measurement date at α = 0.05. Error bars = SE. SE's include random site effects which cancel when means are compared.

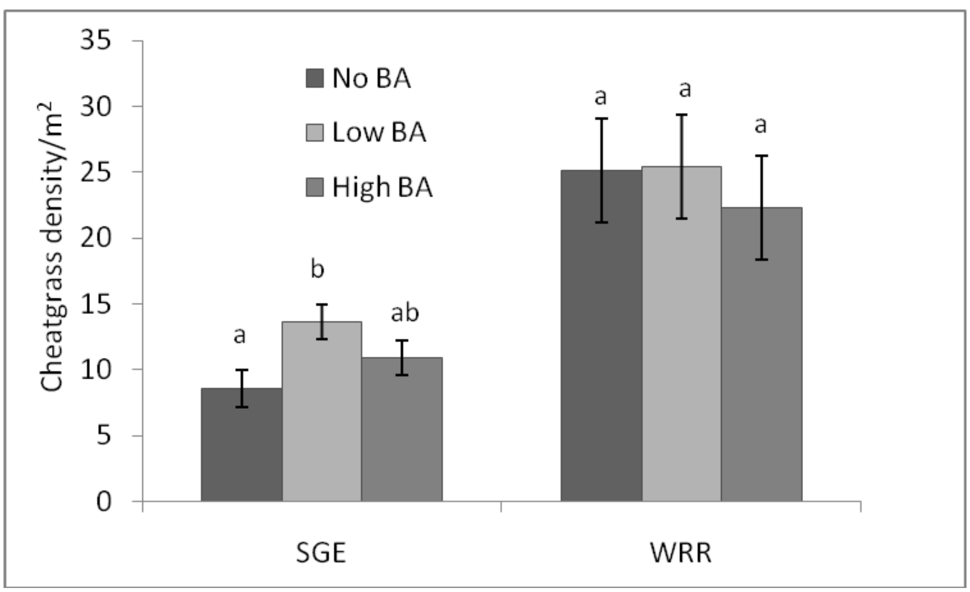


Figure 7. Effect of 3 levels of soil binding agent (none, low, high) on density of cheatgrass at the SGE and WRR study sites. Bars not sharing a letter denote significant differences within a site at α = 0.05. Error bars = SE. SE's include random site effects which cancel when means are compared.

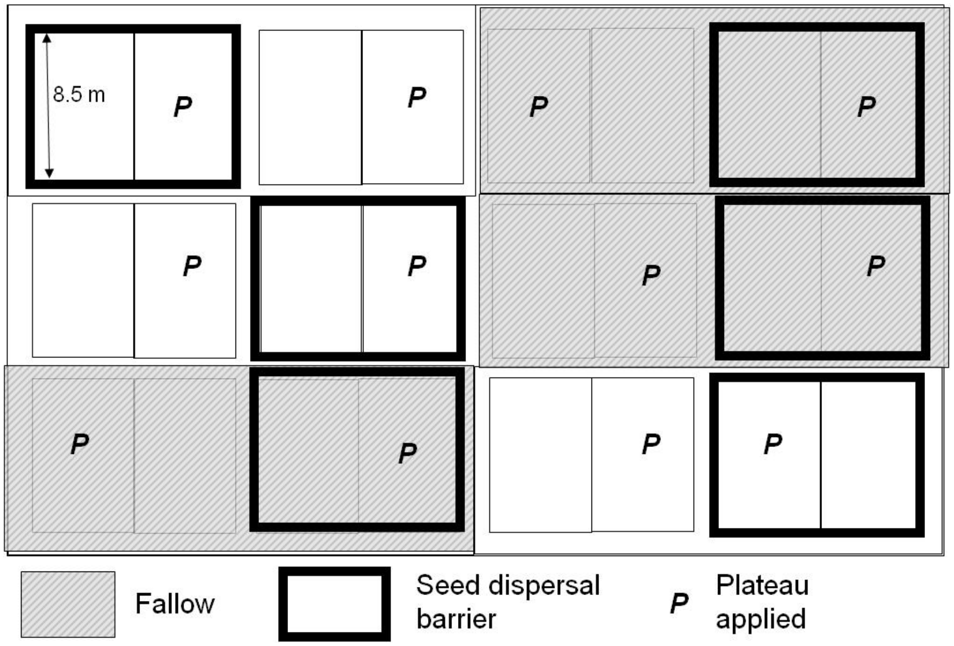


Figure 8. Layout of the Gulley experiment at one of 4 research sites.

Figure 9. Cheatgrass seed caught in barrier in 2009 (left) and cheatgrass seedlings growing through barrier in 2010 (right).

Figure 10.   Gulley experiment Unfallowed plots at RYG in 2010. In foreground, plot treated with Plateau is on the left, untreated plot is on the right. The majority of plants on the right are the non-native annual Blue Mustard (*Chorospora tenella*).

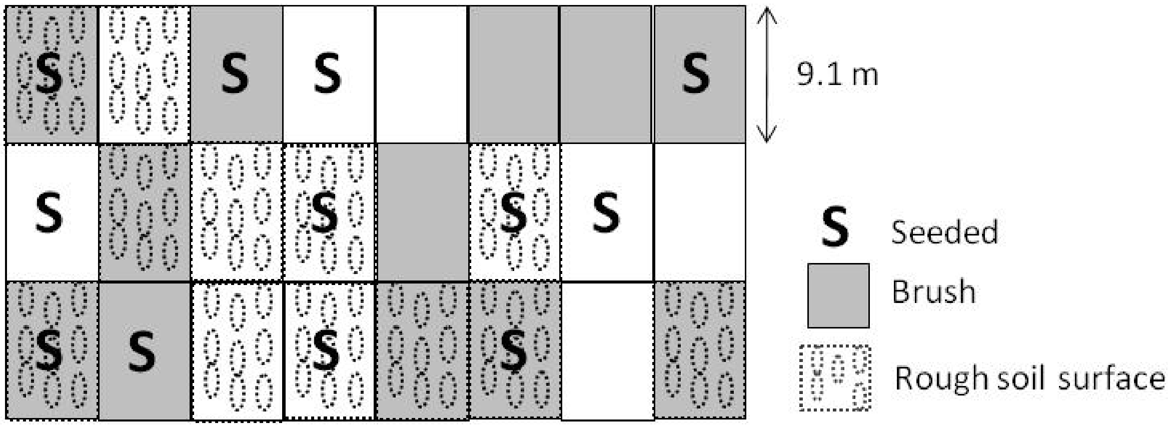


Figure 11. Layout of the Mountain Top experiment at one of 4 research sites.

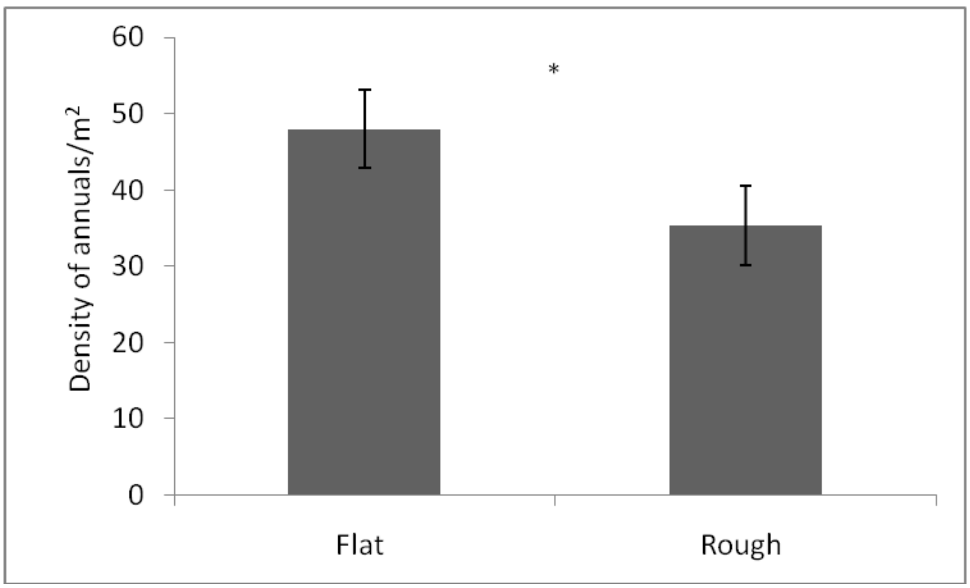


Figure 12. Density of annuals in the Mountain Top experiment in plots with a flat surface versus plots with a rough surface of mounds and holes. Star denotes a significant difference at $\alpha = 0.05$. Error bars = SE. SE's include random site effects which cancel when means are compared.

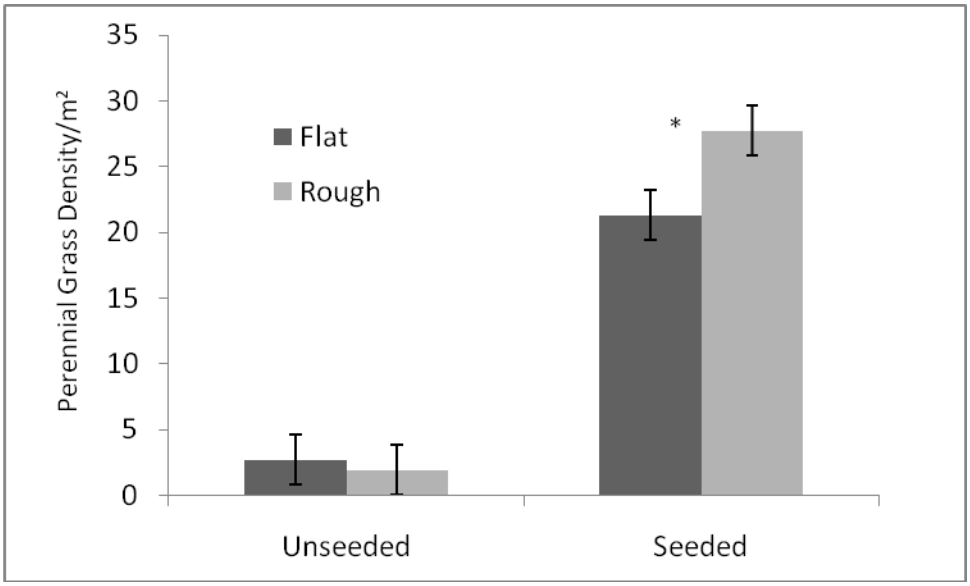


Figure 13. Density of perennial grasses in response to the seeding and soil surface treatments in the Mountain Top experiment. Star denotes a significant difference at $\alpha = 0.05$. Error bars = SE. SE's include random site effects which cancel when means are compared.

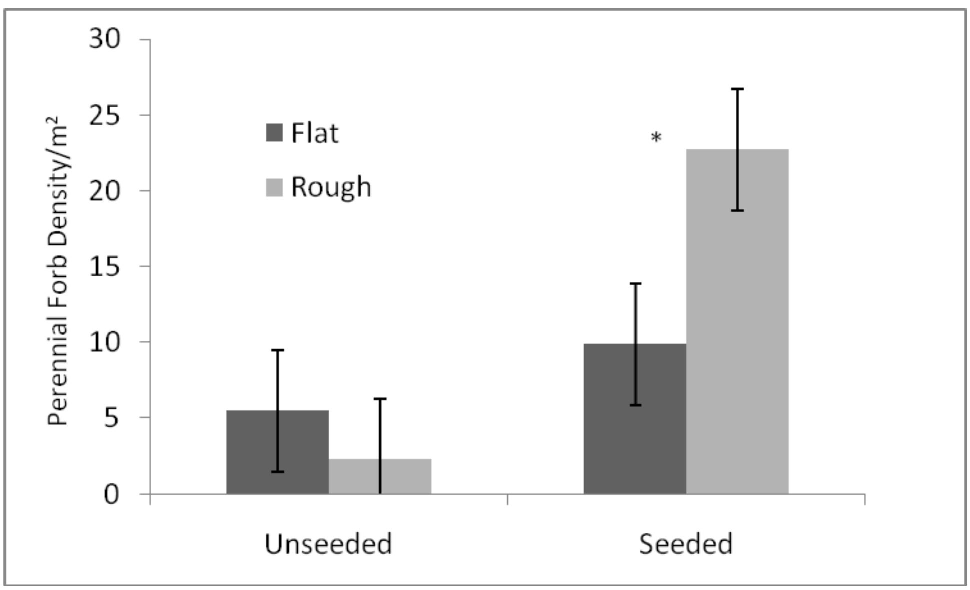


Figure 14. Density of perennial forbs in response to the seeding and soil surface treatments in the Mountain Top experiment. Star denotes a significant difference at $\alpha = 0.05$. Error bars = SE. SE's include random site effects which cancel when means are compared.

Figure 15. The rough soil surface/brush treatment in the Strategy Choice experiment.

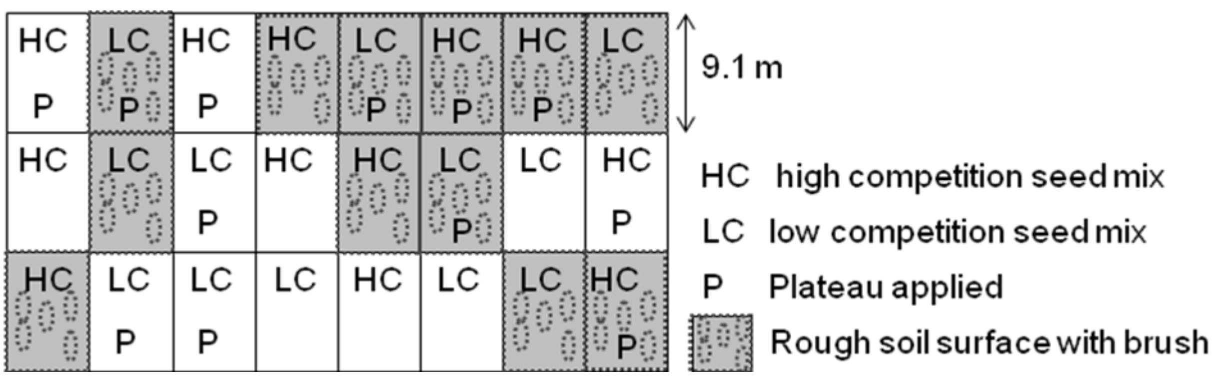


Figure 16. Layout of the Strategy Choice experiments at one of 2 sites where the full experiment was implemented. At 2 additional sites, a reduced form of the experiment lacking the Plateau treatment was implemented.

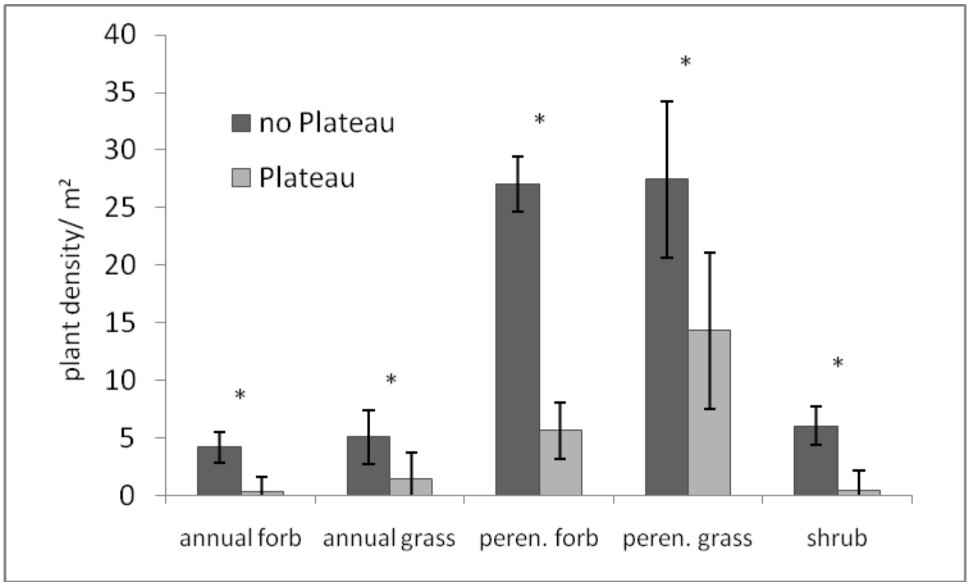


Figure 17. Effect of Plateau herbicide in the Strategy Choice experiment one year after herbicide application and seeding. Stars denote significant differences at $\alpha = 0.05$. Error bars = SE. SE's include random site effects which cancel when means are compared.

Figure 18. The Strategy Choice experiment at the MTN site on 10/19/2010. In the foreground, the plot on the left received the high competition seed mix, the flat surface with straw mulch treatment, and no Plateau. The plot on the right received the low competition seed mix, the rough soil surface with brush mulch treatment, and Plateau.

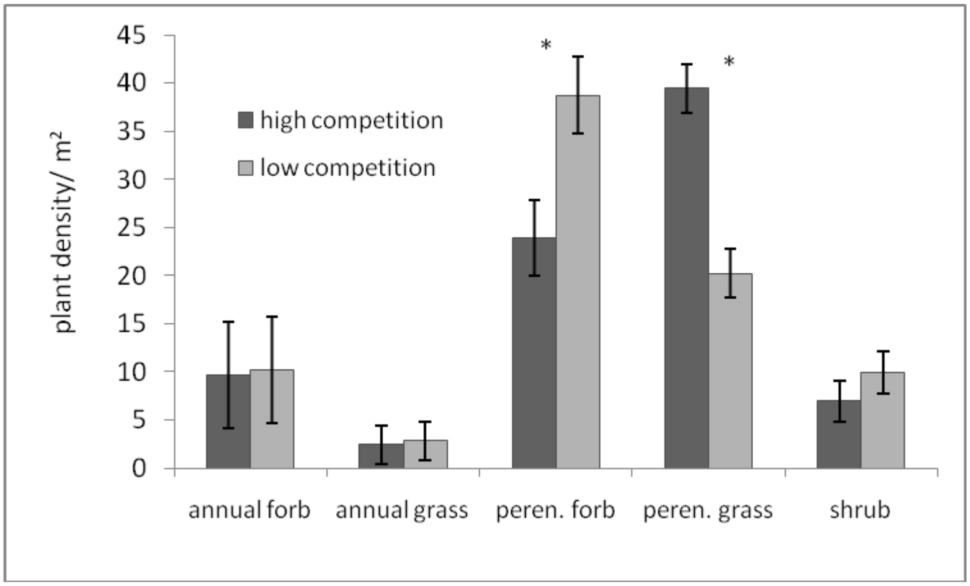


Figure 19. Effect of the seed mix treatment in the Stategy Choice experiment one year after seeding. The high competition mix contained a higher concentration of rhizomatous grasses than the low competition mix. Stars denote significant differences at $\alpha = 0.05$. Error bars = SE. SE's include random site effects which cancel when means are compared.

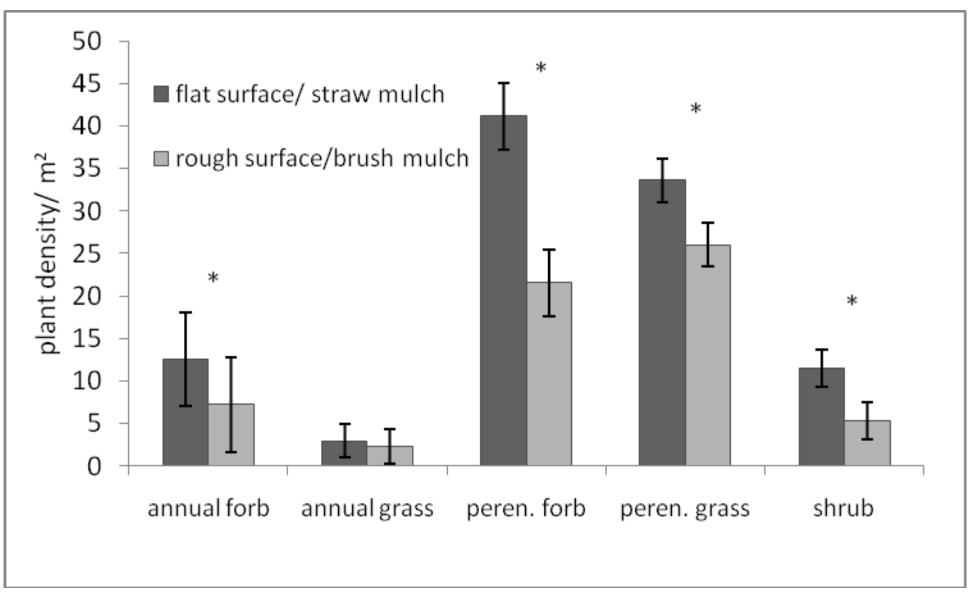


Figure 20. Effect of the soil surface/mulch type treatment in the Strategy Choice experiment one year after implementation. Stars denote significant differences at $\alpha = 0.05$. Error bars = SE. SE's include random site effects which cancel when means are compared.

APPENDIX 1: MODEL SELECTION RESULTS FOR PIPELINE EXPERIMENT

Table A1. Models of percent cover of perennial grasses. P = Plateau treatment, D = disking treatment, R = rolling treatment, V = vibratory drum roller treatment.

Parameter(s) in Model	AIC_c	ΔR	Likelihood	W_r
P	-107.7	0.00	1.00	0.295
P, D	-106.8	0.89	0.64	0.188
P, D, R	-105.4	2.34	0.31	0.091
P, R, P*R	-104.4	3.31	0.19	0.056
P, D, P*D	-104.3	3.46	0.18	0.052
P, V, P*V	-104.1	3.63	0.16	0.048
null	-104.0	3.72	0.16	0.046
D	-103.2	4.50	0.11	0.031
R	-103.2	4.54	0.10	0.030
V	-103.0	4.71	0.09	0.028
P, D, R, V	-103.0	4.74	0.09	0.027
P, D, R,P*R	-102.9	4.80	0.09	0.027
P, D, R, P*D	-102.7	5.01	0.08	0.024
P, D, V, P*V	-102.3	5.43	0.07	0.020
D, R	-101.9	5.85	0.05	0.016
P, D, R, P*R, R*D	-100.2	7.50	0.02	0.007
P, D, R, P*D, R*D	-100.0	7.71	0.02	0.006
D, R, D*R	-99.4	8.34	0.02	0.005
P, D, R, P*V, R*D	-97.4	10.33	0.01	0.002

Table A2. Models of percent cover of total annuals. P = Plateau treatment, D = disking treatment, R = rolling treatment, V = vibratory drum roller treatment.

Parameter(s) in Model	AIC_c	ΔR	Likelihood	W_r
P	-56.7	0.00	1.00	0.45
P, D	-54.5	2.13	0.35	0.16
P, D, P*D	-54.0	2.61	0.27	0.12
P, R, P*R	-52.7	3.92	0.14	0.06
P, V, P*V	-52.4	4.24	0.12	0.05
P, D, R	-52.1	4.52	0.10	0.05
P, D, R, P*D	-51.6	5.10	0.08	0.04
P, D, R,P*R	-50.5	6.18	0.05	0.02
P, D, V, P*V	-50.0	6.61	0.04	0.02
P, D, R, V	-49.6	7.06	0.03	0.01
P, D, R, P*D, R*D	-49.2	7.41	0.02	0.01
P, D, R, P*R, R*D	-48.2	8.50	0.01	0.01
null	-46.2	10.45	0.01	0.00
P, D, R, P*V, R*D	-45.0	11.63	0.00	0.00
D	-44.2	12.49	0.00	0.00
V	-44.0	12.70	0.00	0.00
R	-43.9	12.72	0.00	0.00
D, R	-41.9	14.80	0.00	0.00
D, R, D*R	-39.7	16.93	0.00	0.00

Table A3. Models of percent cover of cheatgrass. P = Plateau treatment, D = disking treatment, R = rolling treatment, V = vibratory drum roller treatment.

Parameter(s) in Model	AIC_c	ΔR	Likelihood	W_r
P	-39.58	0.00	1.00	0.23
V	-38.74	0.85	0.65	0.15
R	-38.65	0.93	0.63	0.15
D	-38.64	0.94	0.62	0.15
P, D	-37.11	2.47	0.29	0.07
P, R, P*R	-37.05	2.53	0.28	0.07
D, R	-36.27	3.31	0.19	0.04
P, V, P*V	-35.82	3.77	0.15	0.04
P, D, P*D	-35.41	4.17	0.12	0.03
P, D, R	-34.56	5.02	0.08	0.02
P, D, R,P*R	-34.39	5.20	0.07	0.02
D, R, D*R	-33.97	5.61	0.06	0.01
P, D, V, P*V	-33.15	6.43	0.04	0.01
P, D, R, P*D	-32.75	6.83	0.03	0.01
P, D, R, V	-31.98	7.60	0.02	0.01
P, D, R, P*R, R*D	-31.80	7.79	0.02	0.00
P, D, R, P*D, R*D	-30.16	9.42	0.01	0.00
P, D, R, P*V, R*D	-27.77	11.82	0.00	0.00
			4.29	

Table A4. Models of percent cover of perennial forbs. P = Plateau treatment, D = disking treatment, R = rolling treatment, V = vibratory drum roller treatment.

Parameter(s) in Model	AIC_c	ΔR	Likelihood	W_r
null	-206.7	0.00	1.00	0.355
D	-204.7	2.01	0.37	0.130
P	-204.5	2.22	0.33	0.117
V	-204.4	2.27	0.32	0.114
R	-204.3	2.37	0.31	0.109
P, D	-202.4	4.34	0.11	0.040
D, R	-202.2	4.47	0.11	0.038
D, R, D*R	-201.8	4.94	0.08	0.030
P, D, P*D	-200.4	6.31	0.04	0.015
P, R, P*R	-199.9	6.85	0.03	0.012
P, D, R	-199.8	6.90	0.03	0.011
P, V, P*V	-199.5	7.17	0.03	0.010
P, D, R, P*D	-197.7	8.97	0.01	0.004
P, D, R,P*R	-197.6	9.14	0.01	0.004
P, D, R, V	-197.2	9.54	0.01	0.003
P, D, V, P*V	-197.1	9.56	0.01	0.003
P, D, R, P*D, R*D	-197.1	9.62	0.01	0.003
P, D, R, P*R, R*D	-196.9	9.81	0.01	0.003
P, D, R, P*V, R*D	-193.9	12.79	0.00	0.001

Table A5. Models of percent cover of annual forbs. P = Plateau treatment, D = disking treatment, R = rolling treatment, V = vibratory drum roller treatment.

Parameter(s) in Model	AIC_c	ΔR	Likelihood	W_r
null	-84.0	0.00	1.00	0.248
P	-83.3	0.73	0.69	0.172
D	-82.2	1.75	0.42	0.103
R	-82.1	1.85	0.40	0.098
V	-81.7	2.34	0.31	0.077
P, D	-81.4	2.62	0.27	0.067
P, D, P*D	-80.7	3.29	0.19	0.048
D, R	-80.6	3.43	0.18	0.045
D, R, D*R	-79.5	4.47	0.11	0.027
P, D, R	-79.5	4.47	0.11	0.026
P, R, P*R	-79.0	4.96	0.08	0.021
P, D, R, P*D	-78.8	5.22	0.07	0.018
P, V, P*V	-78.4	5.57	0.06	0.015
P, D, R, P*D, R*D	-77.5	6.51	0.04	0.010
P, D, R,P*R	-77.2	6.81	0.03	0.008
P, D, R, V	-76.9	7.14	0.03	0.007
P, D, V, P*V	-76.4	7.60	0.02	0.006
P, D, R, P*R, R*D	-75.9	8.15	0.02	0.004
P, D, R, P*V, R*D	-72.9	11.07	0.00	0.001

Table A6. Models of percent cover of annual grasses. P = Plateau treatment, D = disking treatment, R = rolling treatment, V = vibratory drum roller treatment.

Parameter(s) in Model	AIC_c	ΔR	Likelihood	W_r
null	-41.5	0.00	1.00	0.317
P	-40.1	1.38	0.50	0.159
V	-39.3	2.24	0.33	0.104
R	-39.2	2.33	0.31	0.099
D	-39.2	2.34	0.31	0.098
P, D	-37.7	3.85	0.15	0.046
P, R, P*R	-37.6	3.86	0.15	0.046
D, R	-36.8	4.71	0.09	0.030
P, V, P*V	-36.4	5.14	0.08	0.024
P, D, P*D	-36.0	5.50	0.06	0.020
P, D, R	-35.1	6.40	0.04	0.013
P, D, R,P*R	-35.0	6.52	0.04	0.012
D, R, D*R	-34.5	7.00	0.03	0.010
P, D, V, P*V	-33.7	7.81	0.02	0.006
P, D, R, P*D	-33.3	8.16	0.02	0.005
P, D, R, V	-32.5	8.97	0.01	0.004
P, D, R, P*R, R*D	-32.4	9.10	0.01	0.003
P, D, R, P*D, R*D	-30.8	10.74	0.00	0.001
P, D, R, P*V, R*D	-28.3	13.17	0.00	0.000

Table A7. Models of percent cover of shrubs. P = Plateau treatment, D = disking treatment, R = rolling treatment, V = vibratory drum roller treatment.

Parameter(s) in Model	AIC_c	ΔR	Likelihood	W_r
R	-264.08	0.00	1.00	0.23
null	-264.00	0.08	0.96	0.22
P, R, P*R	-263.21	0.86	0.65	0.15
D, R	-261.75	2.32	0.31	0.07
V	-261.73	2.35	0.31	0.07
D	-261.73	2.35	0.31	0.07
P	-261.18	2.90	0.23	0.05
P, D, R,P*R	-260.61	3.47	0.18	0.04
D, R, D*R	-260.30	3.78	0.15	0.03
P, D, R, P*R, R*D	-258.96	5.11	0.08	0.02
P, D	-258.70	5.38	0.07	0.02
P, D, R	-258.55	5.53	0.06	0.01
P, V, P*V	-257.37	6.70	0.04	0.01
P, D, P*D	-256.15	7.93	0.02	0.00
P, D, R, V	-256.05	8.03	0.02	0.00
P, D, R, P*D	-255.89	8.19	0.02	0.00
P, D, V, P*V	-254.70	9.37	0.01	0.00
P, D, R, P*D, R*D	-254.13	9.94	0.01	0.00
P, D, R, P*V, R*D	-252.60	11.48	0.00	0.00

Table A8. Models of percent cover of big sagebrush (*Artimesia tridentata*). P = Plateau treatment, D = disking treatment, R = rolling treatment, V = vibratory drum roller treatment.

Parameter(s) in Model	AIC_c	ΔR	Likelihood	W_r
R	-272.5	0.00	1.00	0.271
null	-272.2	0.24	0.89	0.240
D, R	-270.3	2.16	0.34	0.092
V	-270.1	2.33	0.31	0.084
D	-270.0	2.50	0.29	0.078
P, R, P*R	-269.5	2.96	0.23	0.062
P	-269.4	3.02	0.22	0.060
D, R, D*R	-267.9	4.53	0.10	0.028
P, D, R	-267.2	5.30	0.07	0.019
P, D, R,P*R	-267.1	5.39	0.07	0.018
P, D	-267.0	5.46	0.07	0.018
P, V, P*V	-264.7	7.73	0.02	0.006
P, D, R, P*D	-264.6	7.87	0.02	0.005
P, D, P*D	-264.5	7.93	0.02	0.005
P, D, R, V	-264.5	7.97	0.02	0.005
P, D, R, P*R, R*D	-264.4	8.06	0.02	0.005
P, D, V, P*V	-262.2	10.27	0.01	0.002
P, D, R, P*D, R*D	-261.9	10.55	0.01	0.001
P, D, R, P*V, R*D	-259.1	13.36	0.00	0.000

Table A9. Models of Diversity (Shannon Index). P = Plateau treatment, D = disking treatment, R = rolling treatment, V = vibratory drum roller treatment.

Parameter(s) in Model	AIC_c	ΔR	Likelihood	W_r
null	35.1	0.00	1.00	0.301
V	36.3	1.16	0.56	0.169
P	36.8	1.64	0.44	0.133
R	37.2	2.04	0.36	0.108
D	37.4	2.30	0.32	0.095
P, D	39.2	4.11	0.13	0.039
D, R	39.5	4.42	0.11	0.033
P, D, P*D	40.1	4.95	0.08	0.025
D, R, D*R	40.3	5.21	0.07	0.022
P, V, P*V	40.6	5.52	0.06	0.019
P, R, P*R	41.5	6.34	0.04	0.013
P, D, R	41.5	6.42	0.04	0.012
P, D, R, P*D	42.5	7.34	0.03	0.008
P, D, R, V	43.2	8.03	0.02	0.005
P, D, V, P*V	43.2	8.05	0.02	0.005
P, D, R, P*D, R*D	43.5	8.38	0.02	0.005
P, D, R,P*R	44.1	9.00	0.01	0.003
P, D, R, P*R, R*D	45.2	10.09	0.01	0.002
P, D, R, P*V, R*D	46.0	10.91	0.00	0.001

APPENDIX 2: CHEATGRASS PROPAGULE PRESSURE

Background

The study sites chosen for these experiments 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). Therefore, cheatgrass propagule pressure is an important covariate for the experiments. We quantified cheatgrass propagule pressure at the 8 sites where cheatgrass was present: SKH, GVM, RYG, YC1, YC2, WRR, SGE, and MTN.

Methods

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 (Figure A2-1). Eight traps were set in systematically chosen locations in undisturbed vegetation surrounding each site. Cheatgrass seeds were counted and removed from traps biweekly from 5/11/2010 until 9/28/2010. Tanglefoot was reapplied as necessary to ensure a sticky surface. Total growing season cheatgrass propagule pressure (seeds/m^2) was calculated by summing the seeds on each trap, and then taking an average for the site.

Figure A2-1. A seed trap.

Results

Cheatgrass propagule pressure varied widely by site (Figure A2-2).

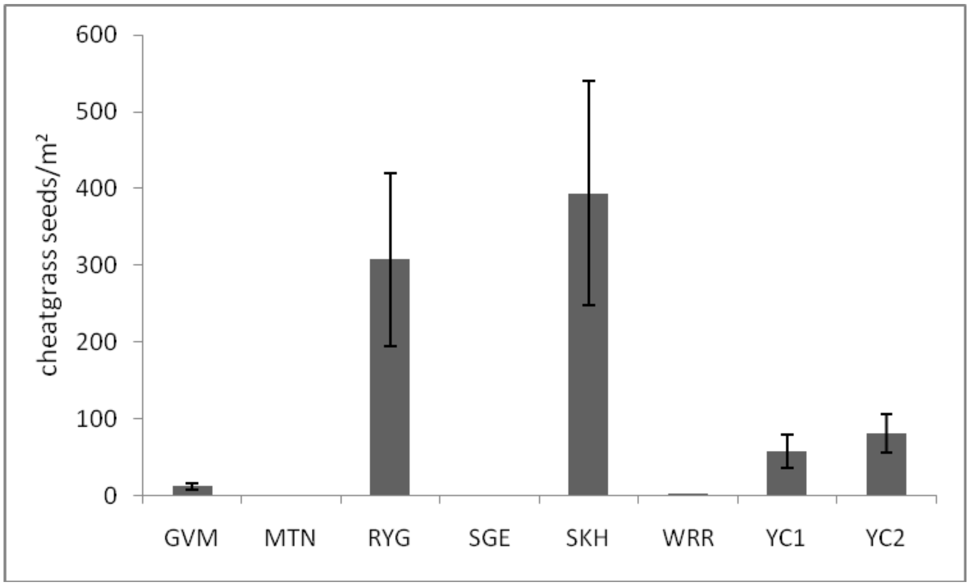


Figure A2-2. Cheatgrass propagule pressure in undisturbed areas surrounding each of 8 study sites, GVM, MTN, RYG, SGE, SKH, WRR, YC1, and YC2. Error bars = SE for 8 traps at each site.

APPENDIX 3: RAIN DATA

Precipitation data were collected at each study site using RG3 datalogging rain gauges (Onset® Computer Corporation) mounted 1.2 m from the ground surface. Rain events were recorded in 0.2mm increments, and then summed over seasons of interest. Gauges at GVM, RYG, SKH, WRR, YC1, and YC2 were installed about May 20, 2009. Gauges at MTN, SGE, SPG, SQS, TGC, and SCD were installed about May 20, 2010. Logger failure resulted in lost data at TGC (all data), SCD (all data), and WRR (winter 09-10 data). Results are shown in Table A3-1.

Table A3-1. Precipitation totals for the study sites. "early growing season" is May 20- July 15; "late growing season" is July 16- September 30"; "prior winter" is the remainder of the year.

	2009		2010		
SITE	early growing season (mm)	late growing season (mm)	prior winter (mm)	early growing season (mm)	late growing season (mm)
GVM	99	28	169	31	61
MTN				28	75
RYG	111	63	215	29	94
SGE				36	86
SKH	107	33	148	23	55
SPG				54	100
SQS				8	92
WRR	94	45		27	90
YC1	94	41	156	36	112
YC2	82	42	178	41	155

COLORADO DIVISION OF PARKS AND WILDLIFE- AVIAN RESEARCH PROGRAM
PROGRESS REPORT
September 2011

TITLE: Using rangewide information on chick survival on mountain plovers (*Charadrius montanus*) to inform management strategies

AUTHORS: V. J. Dreitz and M. Riordan

PROJECT PERSONNEL: S. Dinsmore, Iowa State University; K. Huyvaert, Colorado State University; T. Dallas, J. Green, A. Harrington, K. Hosek, P. Kelly, and L. Messinger, Avian Research technicians.

Period Covered: October 1, 2009 – December 31, 2010

ABSTRACT

The mountain plover (*Charadrius montanus*) is an upland precocial shorebird that breeds throughout the prairie ecosystems of the North American Great Plains. Steep, constant declines in population size have been reported for mountain plovers across their range since 1966. 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). Information on survival rates and causes of mortality for birds transitioning through the post-hatching stage (i.e., the period from hatching to fledging) are lacking. From a conservation perspective, information on the post-hatching stage is imperative because population dynamics often show great sensitivity to survival of young (Anders et al. 1997, Colwell et al. 2007).

A stage-specific matrix model based on data obtained in Colorado and Montana suggested that increasing chick survival should be a priority for conservation efforts that are restricted to breeding grounds (Dinsmore et al. 2010). Multiple factors may influence the survival of young birds. Young individuals lack experience with selective pressures such as predation, foraging efficiency, parasites, migration patterns, and extremes in environmental conditions which are correlated with habitat quality. Further, these selective pressures can differ spatially and temporally across the range of a species. 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 North American Great Plains may be critical to the reproductive output of mountain plovers.

The objective of this study is to investigate the factors influencing the survival of mountain plover chicks over the species range to provide insight into the relative role two local breeding areas have on overall reproductive output. Specifically, the study will: (1) investigate natural and anthropogenic factors influencing mountain plover chick survival across the species' range; (2) identify landscape characteristics across the species' breeding range that are correlated with the highest levels of chick survival, and (3) provide information to further develop conservation, restoration, and management efforts for mountain plovers on public and private lands. Specifically, we planned to examine to what degree various factors (e.g., habitat types, predation, parasites, starvation) impact chick survival in eastern Colorado and Montana. The eastern Colorado study area is considered 'highly fragmented' with plovers

breeding on grassland with and without prairie dogs and agricultural fields. The Montana study area is less fragmented with plovers breeding predominately on grassland with prairie dogs.

In spring 2009, we completed pilot studies in Colorado and Montana to determine appropriate field methods for a range-wide comparative study. Below, we describe our progress in Colorado providing descriptive statistics for the 2010 field season. In 2010 the breeding season in Colorado was prolonged, ending in mid August versus mid- to late-July. Our main hypothesis for this occurrence is a colder and wetter spring than the past 5-10 years in our study area; however, we have not yet closely examined weather data obtained from portable weather stations in the study area. Our preliminary findings suggest that causes of chick mortality differ among habitat types. Avian depredations occurred most often on prairie dog habitats, mammalian depredations most frequently on native grassland without prairie dogs, and weather was found to be the main cause of death on agricultural fields. Confirming or refuting this one year's findings will require additional years of field data collection.

USING RANGEWIDE INFORMATION ON CHICK SURVIVAL ON MOUNTAIN PLOVERS (*Charadrius montanus*) TO INFORM MANAGEMENT STRATEGIES

Progress Report, October 1, 2009 – December 31, 2010

Victoria J. Dreitz and Maggie Riordan

PROJECT OBJECTIVES

The objective of this study is to investigate the factors influencing the survival of mountain plover chicks over the species range to provide insight into the relative role local breeding areas have on overall reproductive output. The study will 1) investigate natural and anthropogenic factors influencing mountain plover chick mortality across the species' range, 2) identify the spatial areas across the species' breeding range that are positively correlated with the lowest levels of chick mortality, and 3) provide information to assist in developing management actions for mountain plovers on public and private lands. This is a comparative, range-wide study on mountain plovers including breeding locales in eastern Colorado (Dreitz) and Montana (Dinsmore). The eastern Colorado breeding locale is considered 'highly fragmented' with plovers breeding on grassland with and without prairie dogs and agricultural fields. The Montana study area is less fragmented with plovers breeding predominately on grassland with prairie dogs in Montana. The Colorado Division of Parks and Wildlife (CPW) will be overseeing all field data collection in eastern Colorado.

SEGMENT OBJECTIVES

1. Investigate differences in mortality of mountain plover chicks between different habitat types – grassland with prairie dogs, grassland without prairie dogs, and agricultural fields.
2. Identify causes of mountain plover chick mortality on the three different habitats.
3. Summarize and analyze data, publish information as a Progress Report.

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 U.S. Fish and Wildlife Service petitioned for 'threatened' status of the mountain plover, the listing decision was found not warranted in 2003 (USFWS 2003), reconsidered for listing in 2010, and a decision to withdraw the proposed listing as threatened May 12, 2011 (USFWS 2011). 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.

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. 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 of chick mortality to be predation by swift fox (*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, migration patterns, and extremes in environmental conditions which may be correlated with habitat quality. 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 eastern Colorado 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 (~10g at hatching). Radios placed on the chicks (≤ 0.35 g) 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, Dreitz et al. 2011). Additionally this attachment technique was tested in the field and proved to be a plausible method to track mountain plover chicks and evaluate cause specific mortality (Dreitz and Riordan 2009).

METHODS

Study Area

The study area was located exclusively on privately owned lands in Lincoln County, CO. Private landowners in this area have collaborated on previous studies on mountain plovers in Colorado (Dreitz and Knopf 2007, Dreitz unpubl. data) allowing continued access to >3000 km^2. In eastern Colorado mountain plovers primarily use the following habitats for breeding activity: grasslands occupied by black-tailed prairie dogs (*Cynomys ludovicianus*, hereafter simply 'prairie dog'); native grassland without prairie dogs; and agricultural fields, predominantly dryland agriculture.

Placement of Transmitters on Chicks

This field study was conducted by monitoring radio transmittered mountain plover chicks from 1 d post-hatch to ≥30 d post-hatch. We identified ~1d old plover chicks by monitoring nests. We used egg flotation (Westerskov 1950) to age eggs and to estimate days until hatching. Mountain plover chicks are precocial and leave the nest shortly after hatching (Knopf and Wunder 2006). If hatching date is missed, locating the adult and its brood is difficult. In efforts to avoid missing placement of transmitters on ~1 day old chicks, we attached a 1.8 g radio transmitter to the nest tending adult ≤5 d prior to hatching. Transmitters were affixed by applying a light coating of waterproof epoxy and sliding it under the upper back feathers. Care was taken to avoid exposing epoxy to the skin of the bird. This procedure enables the transmitters to drop off during molting (Dreitz et al. 2005; Dreitz 2009, 2010).

After hatching and when chicks were completely dry, we captured them by hand. Chicks were weighed and examined for ectoparasites and a small blood sample (<50 µL) was obtained by jugular or brachial venipuncture at this initial and subsequent captures (~16 d old, see below). Within a brood we randomly selected the number of chicks to receive a transmitter such that 0, 1, 2, or 3 chicks within a brood received a transmitter. This process assists with further evaluation of transmitter impacts on chick survival in a field setting.

Average mass of mountain plover chicks at hatch is 7-11 g (Graul 1975, Miller and Knopf 1993). A 0.35 g transmitter was placed on <1 d to ~16 d old chicks that were assigned a transmitter. The 0.35 g transmitter falls within the suggested guidelines of transmitters not exceeding 5% of body mass for small birds (<50 g; Caccamise and Hedin 1985, Gaunt et al. 1999). Battery life of the 0.35 g transmitters was ~20 d. To monitor radio transmittered plover chicks to fledging age, ≥30 d, we recaptured transmittered chicks at ≤16 d by catching them by hand. We replaced the 0.35 g radio transmitter with a 0.65 g radio transmitter. Data on body mass of mountain plover chicks is limited, but suggests 16 d old chicks are >20 g (Dreitz unpubl. data). At transmitter replacement we placed plastic colored bands on chicks, obtained morphometric measurements, collected blood and feather (if present) samples, and noted ectoparasite loads as done at the initial capture. Additionally, we captured all plover chicks we observed (i.e., chicks who's sibling had a transmitter or from unknown nests) and processed them in a similar manner.

Captive studies have tested different transmitter attachment methods (e.g., glue, sutures) on a surrogate species, killdeer (*Charadrius vociferous*), and mountain plovers. A leg harness technique modified from one described by Rappole and Tipton (1991) has minimal to no impact on captive killdeer and mountain plover chicks from 1-42 d post-hatch (Dreitz 2007, 2008). The leg harness technique used in this study consists of a 100% polyurethane clear, flat elastic material (Stretchrite®) cut to ~1.5mm in width. The material is assembled in a figure-8 design with two leg loops that expand to accommodate chick growth; the transmitter sits in the middle of the chick's back (Dreitz 2007, 2008, Dreitz et al. 2011). This transmitter attachment was assembled in advance so transmitter placement took <15 sec.

Monitoring Chicks from Hatch to Fledging

Once transmitters were deployed on chicks, they were monitored at ≤ 24 hr intervals depending on weather conditions. We recorded information including status (live/dead), number of chicks observed within the brood, habitat type, UTM coordinates, time of day, and observer for each location datum collected. Chicks without a transmitter were monitored indirectly by the transmittered adult and/or sibling(s). Initially the transmitters were located via vehicle or all-terrain vehicle, then by foot. We attempted to locate transmitters via air if we could not locate them for 5-7 d on the ground.

Suspected mortalities were located on foot and the area was thorough inspected for evidence of the cause of morality. We classified chick mortality as one of the following: avian predation, mammalian predation, unknown predation, weather-induced (e.g., hail or rain), or unknown mortality cause. We determined avian predation based on evidence such as finding the transmitter near avian plucking post, nest site, or in avian pellets. We identified mammalian predation when we found transmitters that were in mammalian dens, cached, scat was found near the transmitter or carcass, and/or other physical signs (e.g., teeth marks) were present on the carcass or transmitter. We defined an unknown predation when the transmitter was found with or without remnants of a chick or the transmittered chick was not with the adult but its sibling(s) were still present. Mortalities were classified as weather-induced when the whole carcass of a chick was found with the transmitter and known extreme weather events (e.g., hail) had occurred 24 hrs prior. These chicks were collected and evaluated by necropsy to confirm a weather-induced mortality event. Mortalities were defined as unknown when there was not enough evidence to suggest one of the other 4 mortality categories but remains of the chick were found.

Cases in which we located carcasses of chicks that had not substantially decomposed were collected. Dissections were performed <8 hours after collection and the liver and brain were removed. The remainder of the body was placed in formalin for preservation and later evaluation to confirm cause of death through necropsy.

RESULTS

We located and monitored 129 nests in three habitat types; native grassland (n = 52), grassland with prairie dogs (n = 53), and agricultural lands (n = 24). A total of 43 out of the 129 nests successfully hatched (e.g. ≥1 egg hatched).

We placed 0.35 g radio transmitters on 93 1-5 day old mountain plover chicks on 3 different habitat types in eastern Colorado: 36 chicks that hatched on prairie dog, 28 chicks that hatched on native grassland, and 24 chicks that hatched on agricultural fields (Table1). A total of 30 transmittered chicks survived to 16 d: 11 chicks were located on prairie dog at time of transmitter replacement, 9 chicks on native grassland, and 10 chicks on agricultural fields (Table 1). We confirmed fledging (survival to ≥30 d) of 9 transmittered chicks: 1 chick was primarily located on prairie dog, 3 chicks were primarily located on native grassland, and 5 chicks were primarily located on agricultural fields (Table 1). Additionally, we confirmed fledging in 8 chicks without radio transmitters (some chicks within a brood did not receive a radio transmitter): 2 chicks primarily located on prairie dog, 2 chicks primarily located on native grassland, and 4 chicks primarily located on agricultural fields.

We confirmed mortalities of 38 transmittered chicks. Most mortalities (n = 13, 34%) occurred due to avian predation, mainly by burrowing owls (*Athene cunicularia*) and prior to chicks reaching 16 d. Mammalian predation was confirmed for 8 of the 38 known mortalities. The mammalian predators occurred more often on older chicks, > 16 d, and included Swift Fox (*Vulpes velox*) and American Badger (*Taxidea taxus*). Unknown predation occurred for 3 of the transmittered chicks. Weather is suspected in the deaths of 5 transmittered chicks; necropsy results support this conclusion. Unknown mortality occurred in 9 transmittered chicks.

Avian predation was confirmed more often on prairie dog habitat (n=7) than grassland (n=4) or agricultural fields (n=1), while mammalian predation was confirmed more often on grassland (n=7) than prairie dog (n=0) and agricultural fields (n=1). Weather-induced mortality occurred most often on agricultural fields (n=4) than prairie dog (n=0) or grassland (n=1). Agricultural fields also had the most unknown mortalities (n=5) compared to grassland (n=3) or prairie dog (n=1). Diagnostic laboratory results for 6 of the 9 unknown mortalities suggested no definitive conclusion on the cause of mortality. Protozoal organisms within Kupffer cells were found in one chick suggesting infection with avian malaria. Another chick was found with cestoda parasites (i.e., tapeworms) in the intestine. The final chick had glycogen depletion as well as signs of dehydration. Additionally, preliminary molecular analyses of a subset of blood samples collected from chicks suggest that a small number of chicks were exposed to blood parasites and morality from blood parasitism was not observed. These preliminary results suggest that the causes of mountain plover chick mortality do differ among habitats in Colorado.

We confirmed survival to fledging for 10% (9 transmittered chicks out of 93 initially transmittered). This result excludes two transmittered chicks who were brood mates and reached our fledging criteria of ≥30 d old that were found died at 32 d old on an agricultural field. In addition, we confirmed fledging of 8 chicks that did not have a transmitter but their brood mate(s) and/or parent did have a transmitter. We were unable to determine survival or mortality in 45% of the transmittered chicks (44 of 93 initially transmittered chicks) due to sampling procedures (e.g., inability to access property), equipment malfunction (e.g., premature failure of radio transmitter battery life), potential predator taking remains out of study area, and other potential issues.

DISCUSSION

We confirmed survival to fledging for 10 (9 chicks in Colorado, 1 chick in Montana) out of 132 radio-transmittered mountain plover chicks (93 chicks in Colorado, 39 chicks in Montana). On prairie dog habitat in both study areas, avian predation was the main cause of mortality, with Burrowing Owls the main confirmed avian predator, especially on younger chicks, those <16 d. This result may be an artifact of a higher density of Burrowing Owls compared to other avian predators in the study or the ease of locating transmitters near Burrowing Owl nest sites or roosting areas compared to those of other avian predators. However, our data are the first to provide information that Burrowing Owls do prey on mountain plover chicks.

The preliminary results of this field study suggest that the causes of mountain plover chick mortality do differ among habitats but may be consistent within particular habitat types across the species' range. Conservation and management efforts will be difficult and controversial given that the main avian and mammalian predators on mountain plover chicks, a species of conservation concern, are other species of conservation concern, Burrowing Owl and Swift Fox. Additional years of study are warranted to confirm or refute this one year finding. We caution any interpretation or manipulation of these data beyond that contained in this report. The information in this report is preliminary and subject to further evaluation including more in-depth laboratory and statistical analyses.

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Table 1. Summary of mountain plover (*Charadrius montanus*) chicks with and without transmitters monitored from hatch until fledging in the spring and summer of 2010.

	Prairie Dog Colonies	Native Grassland	Agricultural Fields	Total
1-5 Day Chicks				
Transmitter	36	28	24	93
No Transmitter	17	12	9	38
16-20 Day Chicks				
Transmitter	11	9	10	30
No Transmitter	7	9	2	18
≥30 Day Chicks				
Transmitter	1	3	5	9
No Transmitter	2	2	4	8

COLORADO DIVISION OF PARKS AND WILDLIFE - AVIAN RESEARCH PROGRAM
PROGRESS REPORT
September 2011

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: February 1, 2010– August 31, 2011

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 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 2010-2011 regular duck season was the third field season of the project. 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 waterfowl and small game 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 2010-2011 duck season, we obtained information from 1314 hunting parties on study SWAs, of which 894 were duck hunting parties. Activity varied from a high of 429 duck hunting parties and 774 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). From interview data, season-long harvest success, measured as ducks bagged per hunter per day, was lowest on Overland Trail SWA (restricted) at 0 ducks per hunter per day, better on Atwood SWA (unrestricted 0.3), slightly better at Jean K. Tool/Brush SWAs (unrestricted, 0.4), 0.6 on Bravo SWA (restricted), and 1.6 on both Red Lion (unrestricted) and Jackson Lake SWAs (restricted). 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 slightly satisfied with duck numbers on off-channel properties. Numbers of migrating/wintering ducks in the SPR were low, except in December when high concentrations were seen on large, ice-free reservoirs. This study is expected to continue for 3 additional years, with a cross-over of regulation assignments to study SWAs occurring in the 2011-12 season.

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

Progress Report, February 1, 2010 – August 31, 2011

Jon Runge and Jim 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 2010-2011 regular duck hunting season.

2. Conduct periodic aerial surveys of waterfowl numbers and distribution along the SPR corridor throughout the 2010-2011 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 hunters hunt exclusively or regularly on public lands (Colorado Division of Wildlife 2006). There are 26 State Wildlife Areas (SWAs) 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 Parks and Wildlife (CPW) 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 CPW 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), 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. The possibility exists that detection probability decreased over those years, but it is unlikely that it decreased by 50%; thus winter 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 day), 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 channels, 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 CPW, 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 summarize methods and results from the first 3 years 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). 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. Note that the crossover will begin with the 2011-12 duck season.

		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 and 2009, significant ice buildup was noted on the ponds at Jackson Lake and Red Lion SWAs during the third week in November. For comparative purposes, data from before November 23 and on or after November 23 are summarized separately for these 2 SWAs. After December 5, 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 12 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 claim 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 SWAs on the same day were consolidated into 1 hunting party for the day.

Aerial surveys of the SPR corridor from Greeley to the state line were conducted monthly during the regular duck hunting season (October 4, November 4, December 9, and January 5) 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 all 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. Additionally, wildlife count software was used to establish VCFs through post-flight testing of observers. 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 2010-11 waterfowl hunting season, we obtained harvest and satisfaction measures from 1314 hunting parties. Of these, 894 (68%) were duck hunting parties. We interviewed 799 duck hunting parties, and 95 additional duck hunting parties left checkout cards at unmanned check stations. Jean K. Tool and Brush SWAs had the highest use, with 429 duck hunting parties and 774 duck hunter-days, and Overland Trail SWA had the lowest use, with 11 duck hunting parties and 21 duck hunter-days (Table 1).

Overall, 32% of duck hunters at the 7 study SWAs were in their first year of hunting the lower SPR corridor (vs. 35% in 2009-2010 and 32% in 2008-09), 15% had hunted the area for 2 years (15% in 2009-2010, 11% in 2008-09), 10% for 3 years (9% in 2009-2010, 10% in 2008-09), 6% for 4 years (4% in 20009-2010, 6% in 2008-09), and 37% for 5 years or more (37% in 2009-2010, 41% in 2008-09). Most (81%) of the duck hunters surveyed hunted mainly public lands, 5% hunted mainly private lands, and 14% said they hunted both equally. The average duck hunting party size ranged from 1.8 on Jean K. Tool/Brush SWAs to 2.4 on Jackson Lake SWA (Table 1). Across all 7 SWAs, 73% of all parties used standard decoys and 39% used spinning wing decoys, both similar to 2009-2010. Dogs were used by 35% of hunting parties, and 76% of hunting parties reported using duck calls, again similar to 2009-2010 results.

A total of 1368 ducks was reported harvested on the 7 study SWAs, compared to 1499 in 2009-2010. Season-long harvest success was measured as ducks bagged per hunter per party per day over the 2010-2011 regular duck season. From interview data, hunters at restricted areas experienced greater success than unrestricted areas except at Overland Trail SWA where no interviewees reported bagging ducks, whereas Atwood SWA experienced some success (0.3 ducks per hunter per day). Bravo SWA experienced greater success than Jean K. Tool/Brush SWAs (0.6 vs. 0.4), and Jackson Lake SWA slightly greater than Red Lion SWA until freeze-up (1.60 vs. 1.56) as well as after freeze-up (0.8 vs. 0.3).

As with 2009-2010, 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 (Figure 2). Hunters experienced proportionally fewer 0 bag days on the large on-channel properties (Jean K. Tool, Brush, and Bravo SWA) and proportionally more days with >2 ducks bagged (Figure 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 (Figure 4). Averaged across all study areas, daily bag per hunter was in the area of 1-2 birds per hunter per day during opening weekend, peaked at 2.5 the following Wednesday, then experienced a steady decline until colder weather in January appeared to boost success (Figure 5).

Satisfaction with number of other hunters (i.e., 'crowding') was high at all areas, ranging from an average of 4.2 (on a scale of 1-5) at Red Lion SWA to an average of 4.8 at Atwood SWA (Table 2), almost identical to 2009-2010. Satisfaction with bird numbers was lower than previous years ranging from 1.8 at Overland Trail SWA to 3.1 at Jackson Lake SWA. Average satisfaction with habitat conditions ranged from 3.4 at Overland Trail to 4.4 at Red Lion SWA. Satisfaction with property-specific hunting regulations ranged from 4.1 at Red Lion SWA to 4.6 at Atwood SWA. Overall satisfaction levels ranged from 2.9 at Overland Trail SWA to 3.8 at Jackson Lake and Red Lion SWAs, a decrease from previous years.

We estimated correlation coefficients between satisfaction measures of crowding, hunting regulations, duck numbers seen, 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 suggests no correlation between two factors. Overland Trail SWA had low sample size with many outlying correlation estimates, therefore we did not consider it in this analysis. On average the two factors most correlated with overall satisfaction were bird numbers seen (range of 0.27-0.60, Table 3) and hunting success (range of 0.30-0.60). As in 2009-2010, crowding issues did not exhibit high degrees of correlation with overall satisfaction (range: 0.00 – 0.20), and opinions on current hunting regulations on a given SWA exhibited a slightly higher correlation (0.05-0.37).

Estimates of ducks in the count area during aerial surveys of the South Platte corridor increased from 4874 in October to 19,384 in November, peaked at 95,489 in December, and declined to 59,600 in January (Figure 6). December 2010 saw many ducks in the middle of large reservoirs, particularly Jumbo Reservoir, as they were not yet completely frozen. VCFs were estimated at 1.3, for the October flight, 1.5 for the November flight, 1.2 for the December flight, and 1.0 for the January flight.

Other game harvested and recorded as part of the study included 148 quail, 84 Canada goose, 35 pheasant, 30 squirrel, 23 coot, 19 rabbit, 6 light goose, and 4 dove (Table 4). Three parties specifically targeted coyotes, but none were harvested. Species-specific harvest of duck included 390 mallard (30%), 228 green-winged teal (17%), 208 blue-winged teal (16%), 112 northern shoveler (9%), 106 American widgeon (8%), 81 wood duck (6%), 67 gadwall (5%), 41 northern pintail (3%), 35 redhead (3%), 15 ring-necked duck (1%), 8 bufflehead (1%), 6 scaup (<1%), 6 merganser (<1%), 4 goldeneye (<1%), 2 canvasback (<1%), 2 ruddy duck (<1%), and 57 ducks for which species was not indicated (Table 4).

Compliance with the study was lower than in 2009-2010, with the lowest checkout rates at Brush SWA (82%) and Overland Trail SWA (83%). Red Lion SWA had 88% compliance rates, Bravo SWA 92%, Jean K. Tool SWA 94%, Atwood SWA 95%, and Jackson Lake SWA 95% (Table 5).

This study is expected to continue for 3 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 2011. An appendix with hunter comments is included with this report (Appendix B).

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Table 1. Statistics associated with duck hunting parties on selected State Wildlife Areas (SWAs) along the South Platte River corridor during 2010-2011. Percent statistics are the percent of parties that used decoys, spinning wing decoys, dogs, or duck calls.

SWA	Total parties	Total hunter days	Avg. hunters in party	Avg. total duck harvest	Avg. ducks /hunter /day	% Parties using decoys	% Using spinning wing	% Using dogs	% Using duck calls
Interviews									
Atwood (U)	67	128	1.9	0.4	0.3	71	26	33	74
Overland Trail (R)	8	17	2.1	0.0	0.0	100	57	71	86
Jean K Tool /Brush (U)	402	733	1.8	0.7	0.4	65	30	34	68
Bravo (R)	54	105	2.0	1.1	0.6	81	43	43	81
Red Lion (U)	136	285	2.1	3.5	1.6	84	62	36	83
Jackson Lake (R)	105	250	2.4	3.9	1.6	98	61	44	93
Cards									
Atwood (U)	6	10	1.7	0.3	0.3	60	0	60	67
Overland Trail (R)	3	4	1.3	1.3	1.3	100	100	0	100
Jean K Tool /Brush (U)	27	41	1.5	0.4	0.3	50	30	16	76
Bravo (R)	7	14	2.0	0.3	0.1	80	83	40	100
Red Lion (U)	3	6	2.0	1.0	0.5	100	67	100	100
Jackson Lake (R)	4	8	2.0	0.8	0.4	100	75	67	50
Total: Interviews & Cards									
Atwood (U)	73	138	1.9	0.4	0.3	70	24	35	74
Overland Trail (R)	11	21	1.9	0.4	0.4	100	63	63	88
Jean K Tool /Brush (U)	429	774	1.8	0.7	0.4	64	30	32	68
Bravo (R)	61	119	2.0	1.0	0.5	81	47	43	82
Red Lion (U)	139	291	2.1	3.4	1.5	85	62	37	84
Jackson Lake (R)	109	258	2.4	3.7	1.6	98	61	45	92
After ice-up									
Red Lion (U)	35	70	1.9	0.5	0.3	38	19	32	68
Jackson Lake (R)	36	72	2.1	1.6	0.8	83	33	21	85

Table 2. Average satisfaction measures of duck hunting parties on selected State Wildlife Areas (SWAs) along the South Platte River corridor during 2010-2011. 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 regulations.

SWA	Total parties	Crowding	Bird numbers	Habitat conditions	Hunting regulations	Overall
Interviews						
Atwood (U)	67	4.8	2.4	4.3	4.6	3.7
Overland Trail (R)	8	4.5	1.7	3.3	4.1	2.7
Jean K Tool /Brush (U)	402	4.4	2.5	4.1	4.3	3.4
Bravo (R)	54	4.5	2.5	3.7	4.2	3.2
Red Lion (U)	136	4.3	3.0	4.4	4.1	3.8
Jackson Lake (R)	105	4.5	3.2	4.3	4.4	3.7
Cards						
Atwood (U)	6	5.0	2.6	3.6	5.0	3.0
Overland Trail (R)	3	3.7	2.0	4.0	5.0	4.0
Jean K Tool /Brush (U)	27	4.3	2.4	3.7	3.8	3.3
Bravo (R)	7	3.7	2.8	3.5	4.0	2.7
Red Lion (U)	3	1.7	1.7	3.7	3.3	3.0
Jackson Lake (R)	4	5.0	2.3	4.5	5.0	4.8
Total: Interviews & Cards						
Atwood (U)	73	4.8	2.4	4.2	4.6	3.6
Overland Trail (R)	11	4.3	1.8	3.4	4.3	2.9
Jean K Tool /Brush (U)	422	4.4	2.5	4.1	4.2	3.4
Bravo (R)	61	4.4	2.5	3.7	4.2	3.2
Red Lion (U)	139	4.2	2.9	4.4	4.1	3.8
Jackson Lake (R)	109	4.5	3.1	4.3	4.4	3.8
After ice-up						
Red Lion (U)	31	4.7	3.4	4.2	3.5	3.6
Jackson Lake (R)	34	4.5	3.5	4.3	4.1	3.5

Table 3. Correlation coefficients between some of the factors measured from duck hunting parties at selected State Wildlife Areas (SWAs) along the South Platte River corridor during the 2010-2011 regular duck season.

SWA	Factor	Crowding	Bird numbers	Hunting regulations	Avg. ducks /hunter /day
Atwood (U)	Bird numbers	-0.07			
	Hunting regulations	0.05	-0.16		
	Avg. ducks /hunter /day	0.11	0.24	0.04	
	Overall	0.00	0.39	0.05	0.32
Overland Trail (R)	Bird numbers	-0.40			
	Hunting regulations	-0.35	-0.35		
	Avg. ducks /hunter /day				
	Overall	0.30	-0.40	0.64	
Jean K Tool / Brush (U)	Bird numbers	-0.02			
	Hunting regulations	0.10	0.07		
	Avg. ducks /hunter /day	-0.02	0.26	0.03	
	Overall	0.11	0.27	0.28	0.30
Bravo (R)	Bird numbers	0.24			
	Hunting regulations	0.10	-0.12		
	Avg. ducks /hunter /day	0.17	0.32	0.11	
	Overall	0.20	0.44	0.10	0.42
Red Lion (U)	Bird numbers	-0.26			
	Hunting regulations	0.14	0.16		
	Avg. ducks /hunter /day	-0.15	0.44	-0.04	
	Overall	0.05	0.47	0.06	0.44
Jackson Lake (R)	Bird numbers	-0.09			
	Hunting regulations	0.26	0.20		
	Avg. ducks /hunter /day	0.06	0.60	0.25	
	Overall	0.14	0.60	0.37	0.60

Table 4. 2010-2011 harvest totals for all small game and duck species reported at the 7 study SWAs during the regular duck season.

Species	Atwood	Overland	JKT	Brush	Bravo	Red Lion	Jackson	**Total**
Ducks								
Mallard	28	1	119	14	18	142	68	**390**
Green-winged teal	0	0	25	1	14	85	103	**228**
Blue-winged teal	0	1	14	0	6	62	125	**208**
Shoveler	0	0	21	1	1	45	44	**112**
Wigeon	0	0	32	2	8	43	21	**106**
Wood duck	2	2	38	11	7	15	6	**81**
Gadwall	0	0	6	1	4	41	15	**67**
Pintail	0	0	2	0	0	18	21	**41**
Redhead	0	0	0	0	1	16	18	**35**
Ring-necked duck	0	0	0	1	0	12	2	**15**
Bufflehead	0	0	1	2	0	2	3	**8**
Scaup	0	0	0	1	0	2	3	**6**
Merganser	0	0	1	0	1	2	2	**6**
Goldeneye	0	0	2	1	1	0	0	**4**
Canvasback	0	0	0	0	0	2	0	**2**
Ruddy duck	0	0	1	0	0	0	1	**2**
Unspecified duck	2	0	8	3	2	10	32	**57**
Total Ducks	**32**	**4**	**270**	**38**	**63**	**497**	**464**	**1368**
Geese								
Canada Goose	14	0	26	9	10	25	0	**84**
Snow Goose	0	0	0	0	0	6	0	**6**
Other small game								
Quail	16	12	5	20	95	0	0	**148**
Pheasant	13	0	0	3	3	14	2	**35**
Squirrel	0	0	7	16	7	0	0	**30**
Coot	0	0	0	0	0	3	20	**23**
Rabbit	2	0	4	1	8	4	0	**19**
Dove	0	2	0	1	1	0	0	**4**

Table 5. Statistics for vehicles using study SWA parking lots during 2010-2011 regular duck season.

				Uses other than waterfowl and small game hunting				
Check station	**Checked out**	**No check-out**	**Compliance**	**Recreation**	**Parking only**	**Scouting**	**Deer hunting**	**Fishing**
Atwood	144	7	95%	6	1	8	15	0
Overland	15	3	83%	0	0	0	14	0
Brush	206	46	82%	110	26	33	26	106
Jean K Tool	305	21	94%	95	23	32	21	10
Bravo	87	8	92%	1	1	2	23	0
Red Lion	205	27	88%	3	5	19	0	11
Jackson Lake	145	8	95%	0	0	1	0	0

Figure 1. South Platte River corridor from Greeley to the state line, showing State Wildlife Areas included in the study.

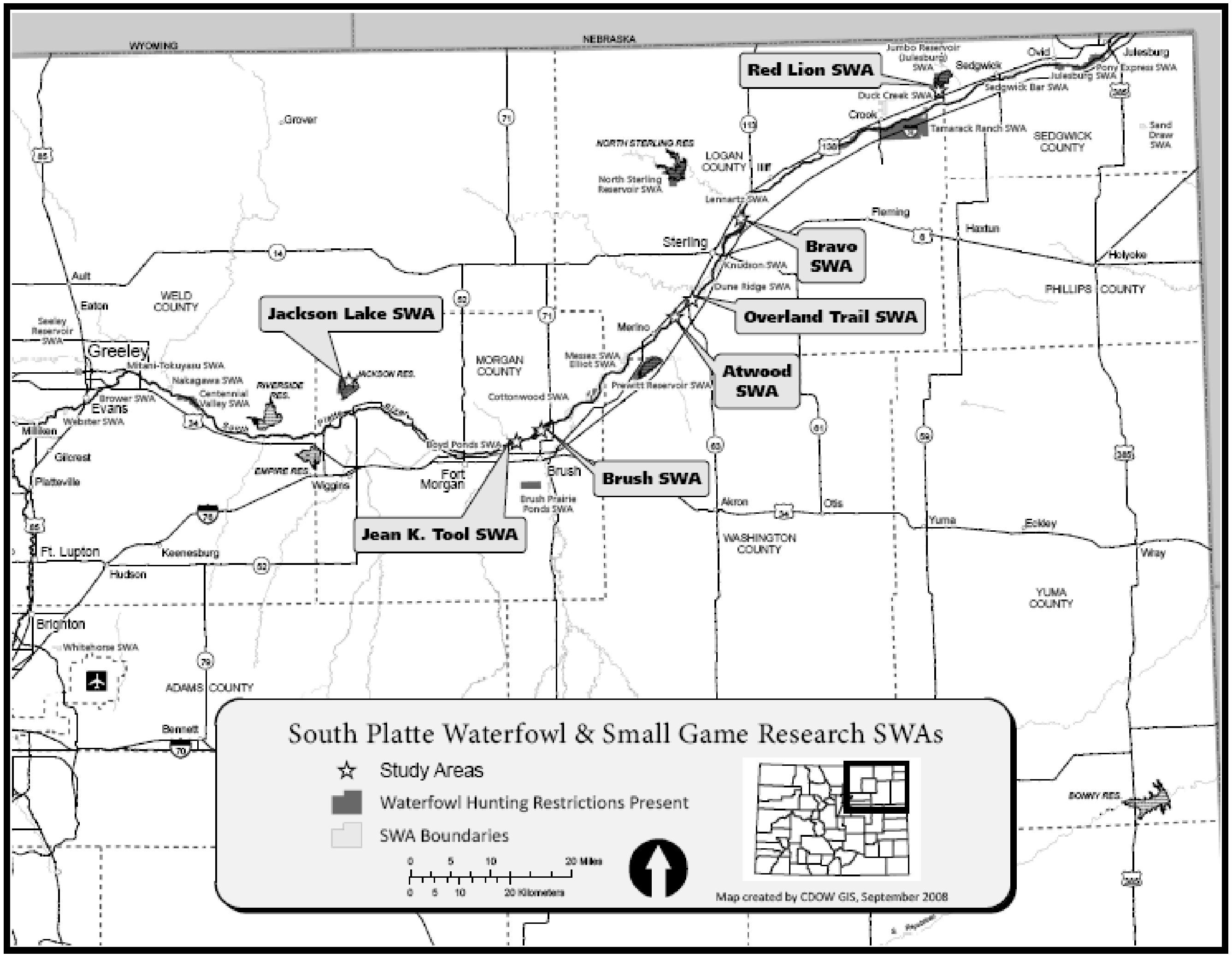


Figure 2. Distribution of average ducks harvested per hunter per day for parties hunting Atwood (Unrestricted) and Overland Trail (Restricted) SWAs during the 2010-2011 regular duck season.

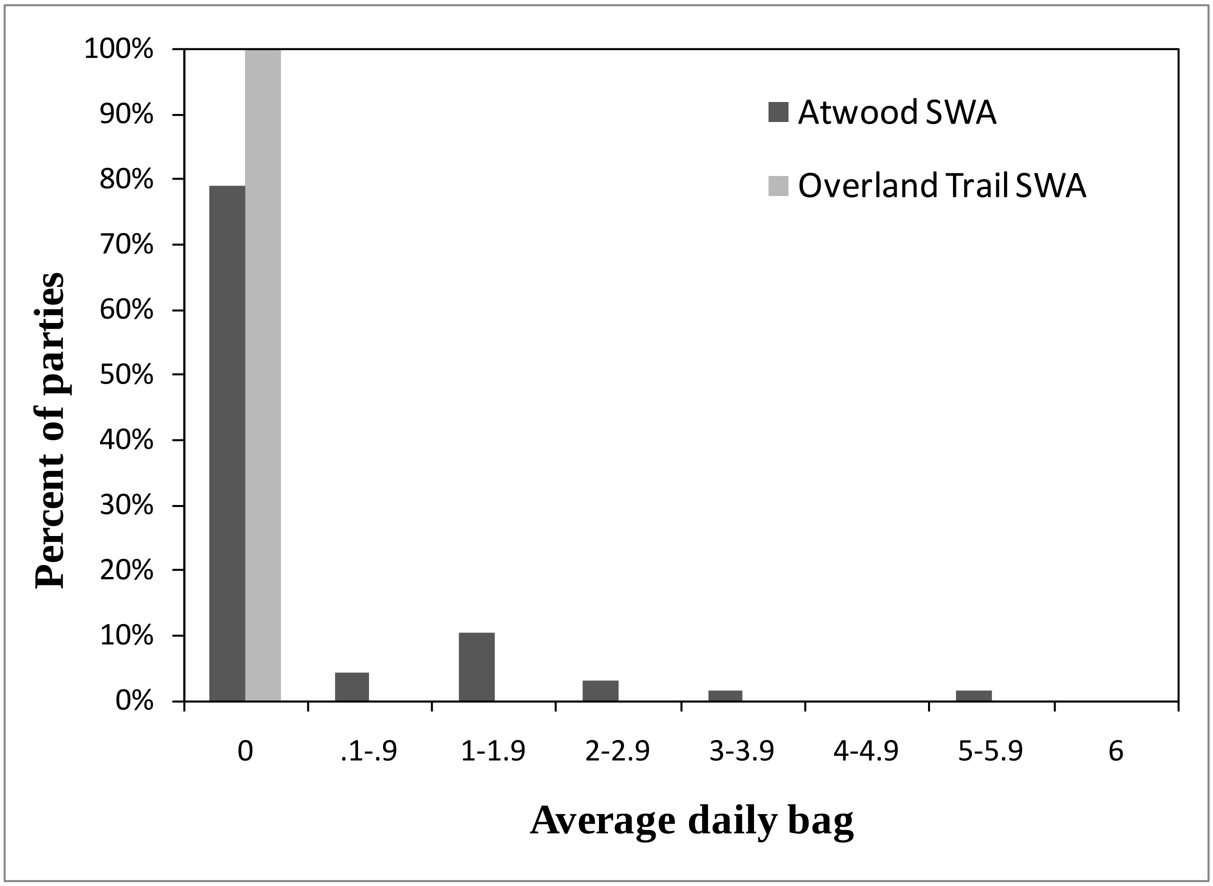


Figure 3. Distribution of average ducks harvested per hunter per day for parties hunting Jean K. Tool/Brush (Unrestricted) and Bravo (Restricted) SWAs during the 2010-2011 regular duck season.

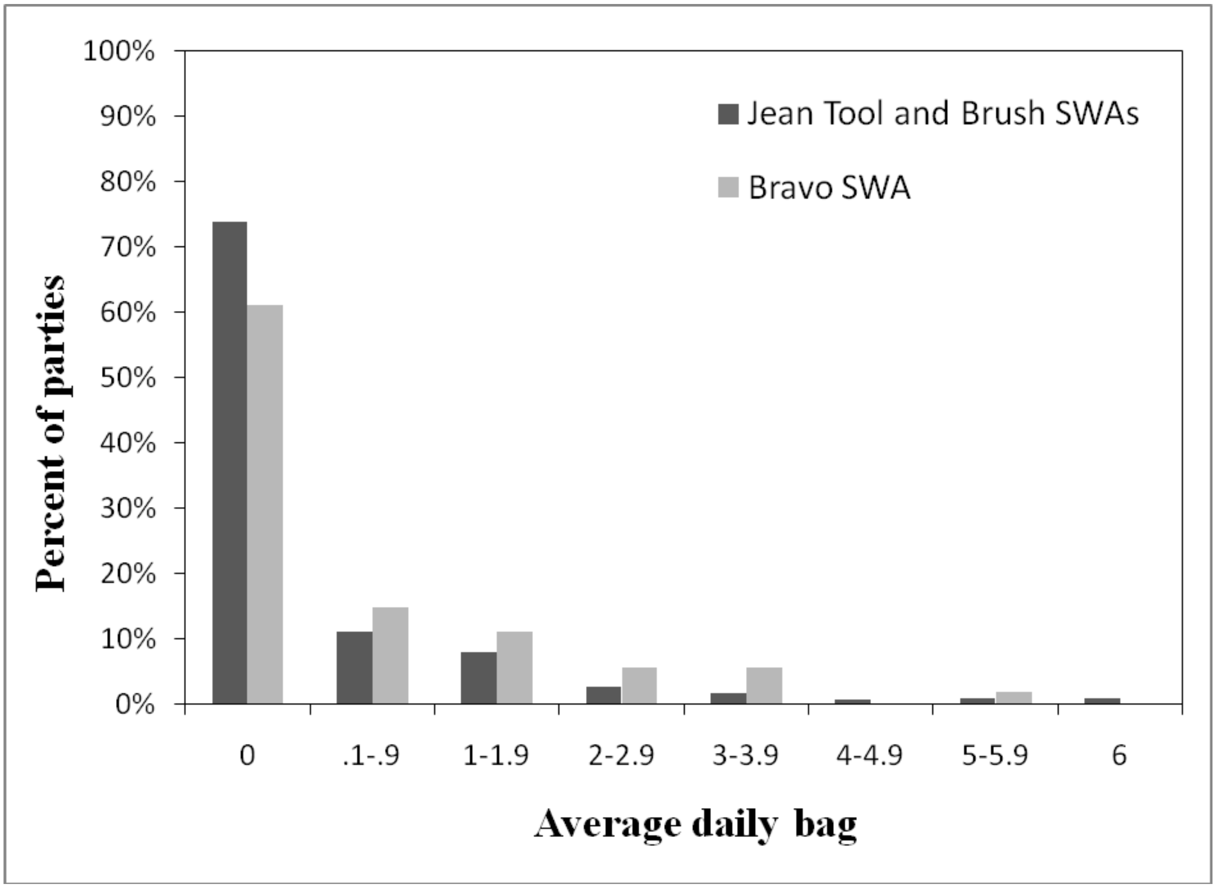


Figure 4. Distribution of average ducks harvested per hunter per day for parties hunting Red Lion (Unrestricted) and Jackson Lake (Restricted) SWAs during the 2010-2011 regular duck season.

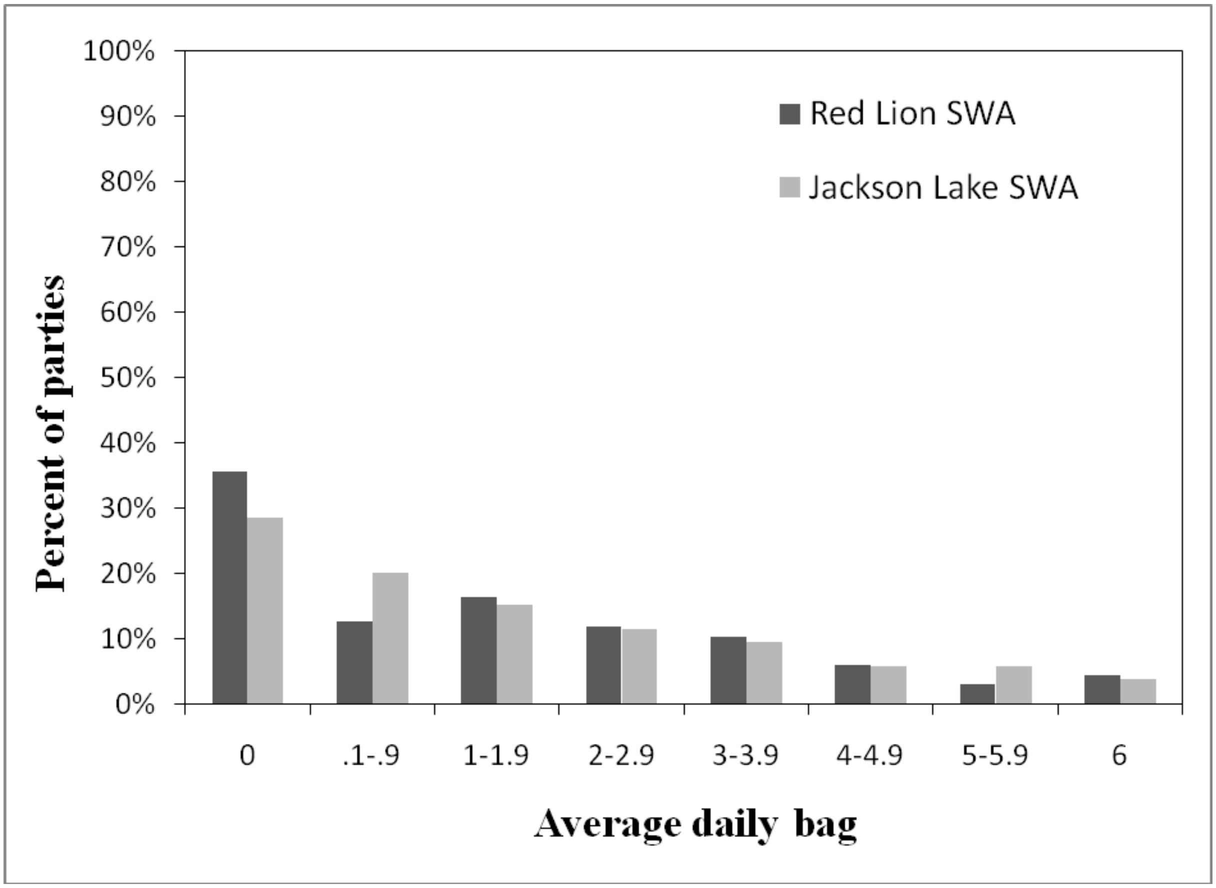


Figure 5. Chronology of duck hunting success on 7 SWAs along the South Platte River corridor during the 2010-2011 regular duck season.

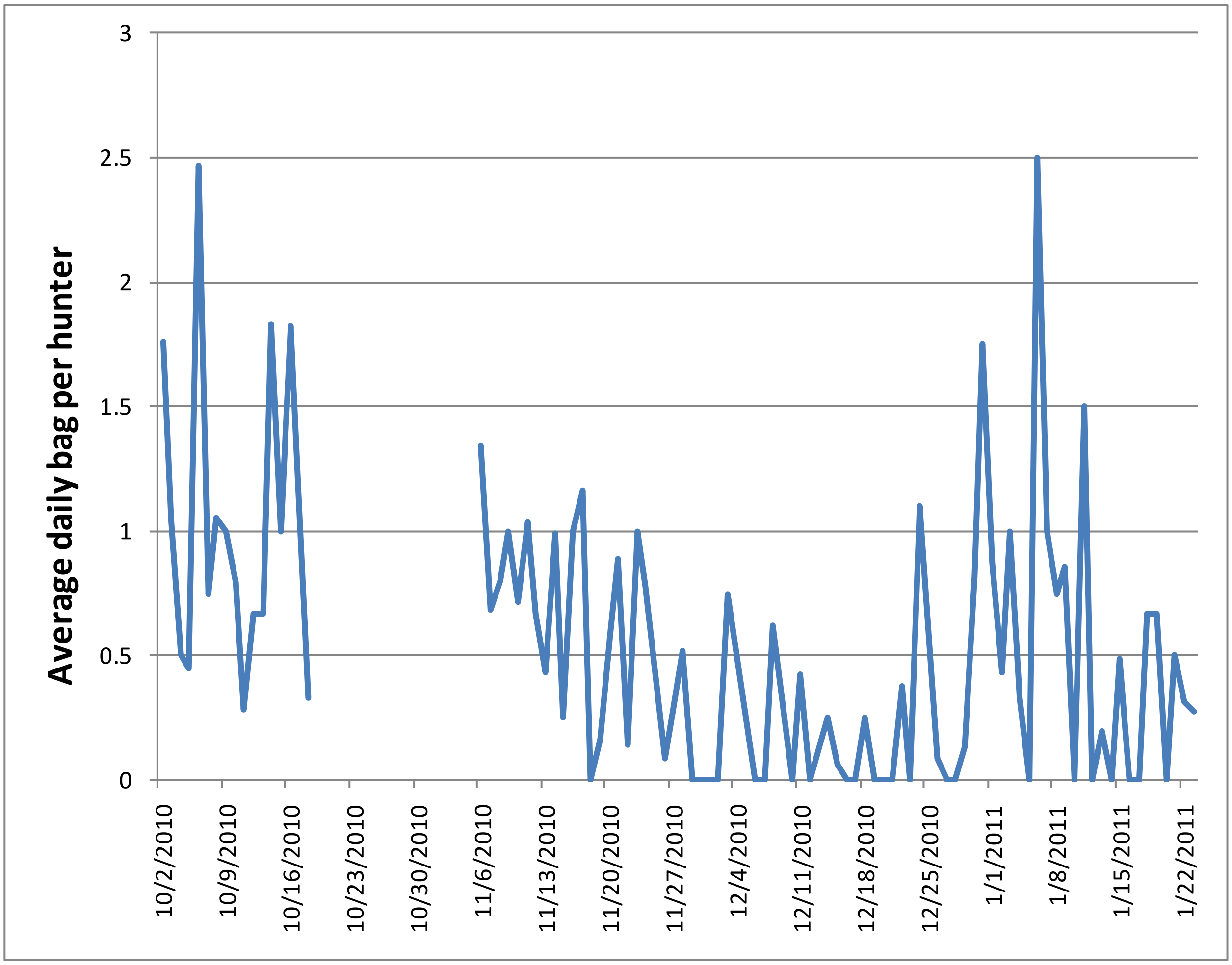
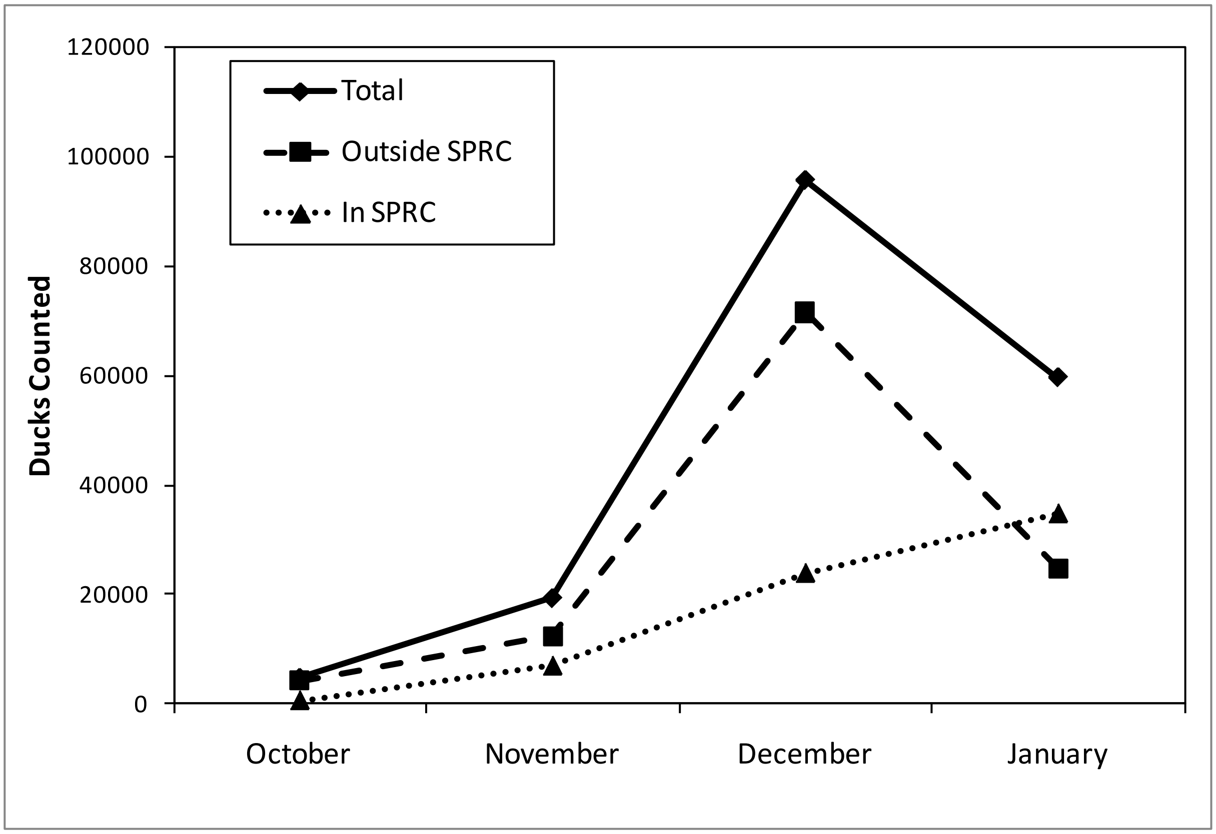


Figure 6. Estimates of duck numbers in the South Platte River Corridor (SPRC) area from October 2010 through January 2011.



Appendix A. Information collected from waterfowl and small game hunters on selected State Wildlife Areas along the South Platte River during the 2010-2011 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 ____________
Parking Lot/Hunt Zone___________________ License plates _____________________________________

CID number	Sex	Seasons out of last 5 hunted on SPR (counting this year, 1-5)?	Mostly public	Mostly private	Equal

Target Species (e.g., ducks, quail, squirrels, etc):

Harvest	Drake in plumage	Brown	Notes
Mallard			
Blue-winged teal			
American wigeon			
Gadwall			
Northern shoveler			
Wood duck			
Pheasant			
Bobwhite quail			

Decoys (# in dozens)? _____ Spinning-wing decoys (#)? ___ Dogs (#)? ______ Calls (Y/N)?_______ _______

Rank the following from 1 to 5 for today's hunt:

Crowding problems (1 = extreme crowding problems, 5 = no crowding problems) ________

Bird/game 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) ________

Current 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) ________

Approve/Disapprove of new regulations on this SWA next year? #Approve_______ #Disapprove _______

Will you hunt on this SWA next year? #Yes_______ #No_________

Appendix B. A selection of comments obtained from hunters at the 7 check stations, 2010-2011 regular duck season.

SWA	Hunt Zone	Date	Comment
Atwood	South Lot	12/8/2010	Would like to see milo on this SWA.
Atwood	East Lot	12/19/2010	Public property, if reservation, should have a board like Elliot & Brush Prairie Ponds. Total waste of land if people are not allowed to if no one reserves or does not show up.
Atwood	South Lot	1/15/2011	Would like to see shooting hours 1/2 hour past sunset.
Bravo	CR 370 Youth/Mentor	11/6/2010	Directions mailed wrong. Check-in station twice as far as stated. Not happy.
Bravo	CR 34	11/6/2010	Not happy with how reservations have to be made.
Bravo	CR 34	11/7/2010	No water in CR 34 this year, sloughs already dry.
Bravo	CR 370 Lot 2	1/1/2011	I have hunted this area for 20 years and never felt crowded. Reservations and area restrictions are stupid. 2pm checkout is also too restricting if you spend 4 hrs a day driving from Denver. You ought to be able to hunt all day.
Bravo	CR 370 Lot 2	1/8/2011	This gentleman was very upset! He got chased off of his spot by another hunter who is hunting Bravo STL. Apparently this other hunter parked in this parking lot and told him there were no restrictions for this piece of property. The hunter who had made reservations for this property said that he is never hunting here again and he doesn't know what we're doing and it's just making it harder to hunt anywhere.
Brush	South Lot	10/2/2010	Lots of trash by pond.
Brush	South Lot	10/2/2010	Would like to see more water.
Brush	South Lot	11/18/2010	Suggests to put land crops adjacent into WIA, also need rotating gates on SWA.
Brush	South Lot	12/11/2010	Would like to see official ID.
Brush		12/11/2010	First time here and not very satisfied. Never knew it I was hunting on public land. More signs/map would be helpful.
Brush	South Lot	1/16/2011	Crowding issue with fishermen.
Brush	South Lot	1/22/2011	Reservation system not fair the way it's set up.
Jackson	Area 3	10/9/2010	Area 3 and 5 overlap depending on where hunters are on each.
Jackson	Area 4	10/10/2010	Overgrowth is hard to set decoys.
Jackson	Area 1	10/17/2010	Complained about no positions that were not facing house.
Jackson	Area 1	11/10/2010	Area 1 and 2 are too close together.
Jackson	Area 8	11/20/2010	Not happy about having reservation end at 2pm.
Jackson	Area 9	11/25/2010	Need to have a better line between area 8 & 9, can't split a point for ducks.
Jackson	Area 3	12/4/2010	For current regulations, would rating possibly be better if reservations are different days?
Jackson		12/12/2010	Too much sky blasting.

Jackson		12/22/2010	Others came in small game area through N.E. side. Accessed from private property. Left when they saw other hunters.
Jean K Tool	East side & North	11/15/2010	Suggested to raise birds for release on SWAs.
Jean K Tool	Northwest Lot	11/24/2010	Jumbo, since they opened it for boating, no birds seen.
Jean K Tool		11/28/2010	One gentleman was not very happy with reservation system. He also thought that we posted these survey results online so that everybody knew where to hunt.
Jean K Tool		12/20/2010	Did not mind reservation system, but he did not approve of the weekends, Wednesdays and holidays.
Jean K Tool		12/24/2010	Hates leaving early for reservations - stops spontaneity.
Jean K Tool		12/28/2010	Would like to be 15 minutes after sunset - always see more ducks.
Jean K Tool		12/29/2010	Too many regulations, hard to be legal.
Jean K Tool	East side	1/1/2011	2pm restriction on reservations is undesirable.
Red Lion	West Lot	10/2/2010	Crowding from fishermen illegally fishing from canoe.
Red Lion	Southwest Lot	10/5/2010	Need duck blinds
Red Lion	Southwest Lot	10/5/2010	Would like to see them put blinds up.
Red Lion	Southwest Lot	10/17/2010	Need trash can, assigned blinds, can't stock pile birds.
Red Lion	West central Lot	11/12/2010	No hunting until noon for pheasants.
Red Lion	Southwest	11/13/2010	Expressed satisfied with current regulations except on opening weekend.
Red Lion	Southwest Lot	11/13/2010	Questioned why you can't geese on Jumbo Res.
Red Lion		11/13/2010	Feel oversupervised!
Red Lion	Southwest Lot	11/14/2010	Feels the HIP phone system is inefficient. Does not like reservation system, feels that since he's paying he should not be restricted by reservations. Likes the no charge on walk-ins and willing to pay more for license if he doesn't have to pay for walk-ins.
Red Lion	Southwest Lot	11/16/2010	Reservation system doesn't fit with work schedules.
Red Lion	East Central Lot	11/20/2010	Would rather see this stay open.
Red Lion	West central Lot	11/26/2010	Why closed to geese hunting?
Red Lion	Southwest Lot	11/26/2010	Would like DOW to update their maps
Red Lion		12/11/2010	Way overregulated to hunt.
Red Lion		12/18/2010	Unable to hunt 2011-2012 if I must hunt by scheduling. Poor choice DOW. You're now being selective!
Red Lion		12/23/2010	Goose boundary benefits private landowners and pay hunts not public lands.
Red Lion		12/28/2010	Thank you for protecting our wildlife.
Red Lion		1/16/2011	Ducks Unlimited and Fish & Game have done a wonderful job of making the area across the fence awesome.

COLORADO DIVISION OF PARKS AND WILDLIFE - AVIAN RESEARCH PROGRAM
PROGRESS REPORT
September 2011

TITLE: Intermountain duck habitat management – pilot study

AUTHOR: J. P. Runge

PROJECT PERSONNEL: J. Gammonley, J. Haskins, J. Yost, R. Basagoitia, B. Weinmeister, M. D'Errico, C. Aloia

Period Covered: May 15, 2010 – August 31, 2011

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ABSTRACT

Intermountain valleys such as North Park and the San Luis Valley account for the majority of ducks produced in Colorado. These areas therefore provide opportunity to investigate methods for increasing duck production. This pilot research is intended to determine optimal habitat disturbance schedules for different wetland habitats in North Park and the San Luis Valley in relation to duck production. I located and monitored duck nests in different habitats and measured nest density and survival. I also marked ducks with legbands and nasal tags to obtain information on survival rates, harvest rates and harvest distribution, and fidelity of breeding ducks to these areas. During 2008-2010, 447 nests were monitored and 4,596 ducks were banded on these study areas. Preliminary analyses indicate that duck nest density and success differs among major nesting habitat types, with highest densities and success in bulrush-dominated habitats. Additional analyses of nesting data and analyses of banding data will be conducted and a final report prepared in 2012.

INTERMOUNTAIN DUCK HABITAT MANAGEMENT – PILOT STUDY
Progress Report, May 15, 2010 – August 31, 2011
Jonathon P. Runge

PROJECT OBJECTIVES

The two main objectives of this project were 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.

SEGMENT OBJECTIVES

1. Locate and monitor duck nests in North Park and Russell Lakes State Wildlife Area (SWA), and measure vegetation associations with nest sites.

2. Mark ducks with legbands and nasal tags in North Park and Russell Lakes SWA.

INTRODUCTION

Duck production can serve as an index of wetland value, thus monitoring the effect of habitat management for ducks is important. Intermountain valleys such as North Park and the San Luis Valley account for the 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 during the successional process, vegetation becomes thick enough to preclude nesting. Thus, according to theory, 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 remove enough cover that it takes several years for ducks to begin nesting again 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 is intended to determine optimal disturbance schedules for different wetland habitats in North Park and the San Luis Valley. 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 attempted to estimate nest site fidelity and the form of density dependence in breeding intermountain ducks.

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 2008-2010, 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); and on 11 management units in the Russell Lake State Wildlife Area in the San Luis Valley (Table 1). 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. Nest searching was conducted by 2-9 observers dragging a rope through vegetation to flush hens from nests (Earl 1950). The observers either walked through nesting areas or, in several of the North Park units, 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 2008-2010, we initiated and continued banding efforts in an ongoing attempt to estimate survival and recovery 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. In 2008 and 2009, 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. Females were not nasal-tagged in 2010 due to low resighting rates from previous years. All males of the above 4 species, and all captured ducks of other species were also legbanded. Following marking, ducks were released immediately at the capture site.

In May-June of 2009 and 2010, 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). 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-July.

Nest success data from North Park collected in 2008 and 2009 were analyzed in program MARK (White and Burnham 1999), but data from Russell Lakes SWA and from North Park in2010 have not yet been analyzed for estimation of daily nest survival rate or overall nest success. Analysis has been conducted relating vegetation type and litter depth to production in management units, but further investigation of these relationships is necessary before results are presented. Analysis will include linear mixed models with hatchlings per ha. as a response variable, year as a random effect, and primary vegetation type, litter depth, and region (North Park or Russell Lakes) as fixed effects. Ongoing analysis will be conducted regarding how secondary vegetation type and vegetation heterogeneity within a management unit will be incorporated into the analysis.

RESULTS AND DISCUSSION

Nesting

During 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. Of the two models run to investigate nest success, 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 from nests with bulrush and Baltic rush as the proximate dominant vegetation 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 2009, we found 142 active nests in North Park (Table 2). 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 daily nest survival 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. Three hundred and sixty-seven eggs were known to hatch in the study area during 2009 (Table 3). One hundred and thirty-seven eggs hatched with Baltic rush as the proximate dominant vegetation (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.

During summer 2010, we found 116 active nests in North Park, including 5 nests in a privately owned hay meadow south of Hebron Slough (Table 2). Four hundred and seventy nine eggs were known to successfully hatch, including 469 eggs from nests found active (Table 3). One hundred and ninety eight hatched from nests with Baltic rush as the proximate dominant vegetation (36 active nests found), 126 from nests associated with wetland grasses and sedges (38 nests), 35 from bulrush (6 nests), 56 from greasewood (10 nests), 15 from rye (3 nests), 15 from forb associations (4 nests), 20 from sagebrush (2 nests) and 4 from spike rush (1 nest). No eggs hatched from nests found that were associated with upland grasses (1 nest) or willow (1 nest).

At Russell Lakes SWA in 2009, we found 87 active nests within the study area (Table 4). Three hundred and forty six eggs were known to hatch, including 136 from active nests (Table 5). One hundred and forty-one eggs hatched from nests associated with bulrush (22 active nests found), 96 eggs hatched from nests with Baltic rush as the proximate dominant vegetation (out of 33 active nests found), 32 eggs hatched from nests associated with wetland grasses and sedges (8 active nests), 22 eggs hatched from nests associated with cattail (5 nests), 18 eggs hatched from nests associated with equal amounts of bulrush and cattail (7 active nests), 17 eggs hatched from nests associated with greasewood (5 nests), 10 eggs hatched from nests associated with an even mix of Baltic and bulrush (2 active nests), and 10 eggs hatched from nests associated with spike rush (3 mests). No eggs hatched from active nests found associated with upland grasses (2 nests).

At Russell Lakes SWA in 2010, we found 49 active nests within the study area (Table 4). One hundred and forty one eggs were known to hatch, including 133 from active nests (Table 5). Sixty-two eggs hatched from nests with Baltic rush as the proximate dominant vegetation (out of 22 active nests found), 45 eggs hatched from nests associated with bulrush (16 active nests found), 26 eggs hatched from nests associated with an even mix of Baltic and bulrush (6 active nests), and 8 eggs hatched from nests associated with wetland grasses and sedges (3 active nests). No eggs hatched from active nests found associated with chairmaker's rush (1 nest) and greasewood (1 nest).

Productivity in bulrush dominated wetlands in North Park was much less in 2010 than in 2009 or 2008 (Table 3). This was likely due to cold temperatures in late spring that caused large blocks of ice to be present in bulrush stands in late May and early June, when many hens are usually initiating nests in bulrush. Nevertheless, wetlands dominated by bulrush remained the top producer of ducklings even in a 'down' year. Interestingly, in North Park, vegetation associations at the nest scale differed from those at the patch scale. In North Park in both 2009 and 2010, more nests occurred and more eggs hatched in proximate Baltic rush dominated microhabitat than in proximate bulrush dominated microhabitat. This pattern occurred at Lake John as well, which contains a majority of bulrush habitat. At Lake John, nests in Baltic rush are generally found close to bulrush stands. Whether this is due to increased cover in bulrush, availability of standing water, both, or some other factor is unknown. What is certain is that the Lake John complex, which contains both bulrush and Baltic rush, consistently produces more ducklings per hectare than any other area measured in North Park. The value of bulrush habitat is supported by data from Russell Lakes SWA. Management unit W7 was dominated by bulrush and produced the most ducklings in 2009, and nests associated with proximate bulrush microhabitat also produced the most ducklings in 2009. After nesting in 2009, unit W7 was mowed, and it is likely that the resulting loss of cover explains the reduced number of ducklings produced in 2010 (Table 5).

Banding

In 2008, we banded 741 ducks in North Park. Sex, age, and species-specific details are given in Table 6. 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 7). 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. In 2010, we banded 890 ducks in North Park, with the majority being mallard and gadwall (Table 8). No nasal tags were placed on birds.

At Russell Lakes SWA in 2008, we banded 597 ducks (Table 9). Sixty-five females received nasals discs including 34 mallard, 27 blue-winged/cinnamon teal, and 4 gadwall. In 2009 at Russell Lakes SWA, we banded 788 ducks (Table 10). One hundred and eighty-five females received nasal discs including 95 mallard, 62 blue-winged/cinnamon teal, and 28 gadwall. In 2010 at Russell Lakes SWA, we banded 516 ducks (Table 11). Eleven mallards received nasal discs before the nasal marking program was discontinued.

Summarizing 3 years of banding data, a total of 4,596 ducks were banded, including 2,129 mallard, 911 gadwall, 693 blue-winged/cinnamon teal (including 59 males positively identified as cinnamon teal and 5 positively identified as blue-winged teal), 245 redhead, 223 American green-winged teal, 153 northern shoveler, 96 American wigeon, 44 northern pintail, 43 canvasback, 40 lesser scaup, 15 ruddy duck, 3 ring-necked duck, and 1 bufflehead (Table 12).

Future analyses will include investigation of nest success and nest productivity as related to habitat factors, band-recovery estimation of survival and recovery rates, maps of recovery locations and numbers, and investigation of the effect of nasal tagging on survival rates.

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Table 1. Description of sampled wetland units. ANWR = Arapaho National Wildlife Refuge, RLSWA = Russell Lakes State Wildlife Area.

			Dominant vegetation		Vegetation plots containing water in May & June	
Unit	Area	Ha.	2009	2010	2009	2010
25a	ANWR	27.07	Grasses & sedges	Baltic rush	39%	58%
25b	ANWR	26.64	Grasses & sedges	Grasses & sedges	10%	35%
26	ANWR	55.97	Baltic rush	Grasses & sedges	34%	41%
27a	ANWR	20.60	Grasses & sedges	Grasses & sedges	9%	52%
27b	ANWR	29.33	Grasses & sedges	Grasses & sedges	26%	39%
12	ANWR	25.32	Grasses & sedges	Baltic rush	5%	24%
13	ANWR	39.38	Baltic rush	Baltic rush	16%	24%
A5	ANWR	214.24	Baltic rush	Baltic rush	44%	49%
A6	ANWR	38.43	Baltic rush	Baltic rush	46%	34%
C12w	ANWR	184.64	Grasses & sedges	Baltic rush	10%	38%
D2	Hebron	25.99	Grasses & sedges	Grasses & sedges	28%	52%
D1	Hebron	22.83	Grasses & sedges	Grasses & sedges	10%	20%
LJ East	Lake John	8.38	Baltic rush/bulrush	Bulrush	50%	64%
LJ West	Lake John	1.26	Bulrush	Bulrush	51%	67%
Argy 3	RL SWA	30.00	Baltic rush	Baltic rush	0%	11%
Argy 4	RL SWA	4.87	Baltic rush	Baltic rush	0%	88%
C Russell Crk	RL SWA	70.25	Baltic rush	Baltic rush	36%	38%
Delvegy East	RL SWA	26.30	Baltic rush	Grasses and sedges	6%	40%
Island Uplands	RL SWA	22.67	Grasses and sedges	Baltic rush	69%	78%
S Russell Crk	RL SWA	71.02	Baltic rush	Baltic rush	18%	62%
W Overflow	RL SWA	86.21	Grasses and sedges	Grasses and sedges	41%	48%
W1	RL SWA	7.45	Spike rush	Spike rush	8%	92%
W4	RL SWA	32.17	Grasses and sedges	Baltic rush	28%	44%
W6	RL SWA	25.84	Spike rush	Baltic rush	36%	78%
W7	RL SWA	8.56	Bulrush	Bulrush	12%	0%

Table 2. Number of active nests found in North Park 2009 and 2010 by species and management unit.

Mgmt. Unit	Area	Amwi	Bcte	Canv	Gadw	Lesc	Mall	Nopi	Nsho	Unsp	**Total**
2009											
12	ANWR										**0**
13	ANWR										**0**
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**
C12w	ANWR		2						4	1	**7**
D1	Hebron										**0**
D2	Hebron		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**
2009 Total		**0**	**40**	**1**	**32**	**14**	**25**	**0**	**16**	**14**	**142**
2010											
12	ANWR										**0**
13	ANWR						1				**1**
25a	ANWR				3						**3**
25b	ANWR	1					1		1		**3**
26	ANWR	3	3		4	3	2				**15**
27a	ANWR		1		1						**2**
27b	ANWR				1		1				**2**
A5	ANWR		8		13	1	4	1	5	1	**33**
A6	ANWR		6		7		1		1	1	**16**
C12w	ANWR		1								**1**
D1	Hebron				1				2		**3**
D2	Hebron		2		3		1				**6**
Mehring	Private		1		1		3				**5**
LJ East	Lake John		6			3	9			2	**20**
LJ West	Lake John				2	1	3				**6**
2010 Total		**4**	**28**	**0**	**36**	**8**	**26**	**1**	**9**	**4**	**116**

ANWR = Arapaho National Wildlife Refuge, Amwi = American wigeon, Bcte = blue-winged or cinnamon teal, Canv = canvasback, Gadw = gadwall, Lesc = lesser scaup, Mall = mallard, Nopi = northern pintail, Nsho = northern shoveler, Unsp = unknown species.

Table 3. Number of eggs confirmed to hatch in North Park in 2009 and 2010 by species and management unit.

Mgmt. Unit	Area	Amwi	Bcte	Gadw	Lesc	Mall	Nopi	Nsho	Unsp	**Total**
2009										
12	ANWR									**0**
13	ANWR									**0**
25a	ANWR		9							**9**
25b	ANWR		9	6						**15**
26	ANWR			10		9				**19**
27a	ANWR		9							**9**
27b	ANWR									**0**
A5	ANWR		19	8		12		10		**49**
A6	ANWR		43	34				15		**92**
C12w	ANWR		9					9		**18**
D1	Hebron									**0**
D2	Hebron		10	18						**28**
LJ East	Lake John		10	6	32	7			25	**80**
LJ West	Lake John		9	7	9	23				**48**
2009 Total		**0**	**127**	**89**	**41**	**51**	**0**	**34**	**25**	**367**
2010										
12	ANWR									**0**
13	ANWR									**0**
25a	ANWR			9						**9**
25b	ANWR	6						9		**15**
26	ANWR		19	18	9					**46**
27a	ANWR									**0**
27b	ANWR			10						**10**
A5	ANWR		52	91		19	7	44	7	**220**
A6	ANWR		28	33		7				**68**
C12w	ANWR									**0**
D1	Hebron		8	12						**20**
D2	Hebron			9				14		**23**
LJ East	Lake John		9		10	24				**43**
LJ West	Lake John			7		18				**25**
2010 Total		**6**	**116**	**189**	**19**	**68**	**7**	**67**	**7**	**479**

ANWR = Arapaho National Wildlife Refuge, Amwi = American wigeon, Bcte = blue-winged or cinnamon teal, Canv = canvasback, Gadw = gadwall, Lesc = lesser scaup, Mall = mallard, Nopi = northern pintail, Nsho = northern shoveler, Unsp = unknown species.

Table 4. Number of active nests found in Russell Lakes SWA 2009 and 2010 by species and management unit.

Mgmt. Unit	Bcte	Gadw	Mall	Nopi	Nsho	Redh	Unsp	**Total**
2009								
Argy 3								**0**
Argy 4								**0**
C Russell Creek			2		1			**3**
Delvegy East	3	1	1				1	**6**
Island Uplands	1	2	7			1		**11**
S Russell Creek	9		7		3			**19**
W Overflow	6	2	5		1			**14**
W1	2		3					**5**
W4								**0**
W6		2						**2**
W7	7	4	13	1			2	**27**
2009 Total	**28**	**11**	**38**	**1**	**5**	**1**	**3**	**87**
2010								
Argy 3	1							**1**
Argy 4								**0**
C Russell Creek	1		3					**4**
Delvegy East	1	2						**3**
Island Uplands		2	5		1			**8**
S Russell Creek	1	3	3					**7**
W Overflow	4	3	6		1			**14**
W1	1							**1**
W4	1	1	2					**4**
W6	1	1						**2**
W7		2	2	1				**5**
2010 Total	**11**	**14**	**21**	**1**	**2**	**0**	**0**	**49**

Bcte = blue-winged or cinnamon teal, Gadw = gadwall, Mall = mallard, Nopi = northern pintail, Nsho = northern shoveler, Redh = redhead, Unsp = unknown species.

Table 5. Number of eggs confirmed to hatch at Russell Lakes SWA in 2009 and 2010 by species and management unit.

Mgmt. Unit	Bcte	Gadw	Mall	Nopi	Nsho	Redh	Unsp	**Total**
2009								
Argy 3								**0**
Argy 4								**0**
C Russell Creek			9					**9**
Delvegy East	18						7	**25**
Island Uplands	10	10	15			7		**42**
S Russell Creek	28		24		22			**74**
W Overflow	27	7	32					**66**
W1								**0**
W4								**0**
W6		10						**10**
W7	65	26	20	9				**120**
2009 Total	**148**	**53**	**100**	**9**	**22**	**7**	**7**	**346**
2010								
Argy 3								
Argy 4								
C Russell Creek	9							**9**
Delvegy East	9							**9**
Island Uplands		8	25					**33**
S Russell Creek	7		18					**25**
W Overflow	10	27	13					**50**
W1								**0**
W4	8		7					**15**
W6								**0**
W7								**0**
2010 Total	**43**	**35**	**63**	**0**	**0**	**0**	**0**	**141**

Bcte = blue-winged or cinnamon teal, Gadw = gadwall, Mall = mallard, Nopi = northern pintail, Nsho = northern shoveler, Redh = redhead, Unsp = unknown species.

Table 6. Number of ducks banded in North Park, July-September, 2008.

		Sex Age														
		F				F Tot	M				M Tot	U			U Tot	Grand Total
Region	Species	AHY	HY	L	U		AHY	HY	L	U		AHY	HY	U		
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	36	39	2	128	122	64	23	45	254	2	1	3	6	387
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 7. Number of ducks banded in North Park, July-August, 2009.

		Sex Age										
		F				F Tot	M				M Tot	Grand Total
Region	Species	AHY	HY	L	U		AHY	HY	L	U		
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

Table 8. Number of ducks banded in North Park, July-August, 2010.

		Sex Age										
		F				F Tot	M				M Tot	Grand Total
Region	Species	AHY	HY	L	U		AHY	HY	L	U		
ANWR	AGWT	3	1	1		5	11	1			12	17
	AMWI	2		4		6	6	1	5		12	18
	BCTE	1	6	6		13		5	7		12	25
	CANV		1			1						1
	GADW	9	5	11		25	41	16	13		70	95
	LESC	1		10		11			9		9	20
	MALL	28	11	7		46	50	10	14		74	120
	NOPI	1	1			2		4			4	6
	NSHO	2	2	5		9		1	3		4	13
ANWR Total		47	27	44		118	108	38	51		197	315
Hebron	AGWT		3			3	1	2	1		4	7
	AMWI	1				1			5		5	6
	BCTE	1	2			3						3
	CANV			2		2			2		2	4
	GADW	1		23		24	2		28		30	54
	LESC	1		3		4						4
	MALL	32	18	11	1	62	9	21	14		44	106
	NOPI	3		3		6		2	5		7	13
	NSHO			2		2			1		1	3
Hebron Total		39	23	44	1	107	12	25	56		93	200
Lake John	AGWT						2				2	2
	AMWI						3				3	3
	BCTE	4	3			7	2	1			3	10
	GADW	2				2	7	2			9	11
	LESC	1		2		3			1		1	4
	MALL	34	13	1		48	185	16	1	1	203	251
	REDH						2				2	2
Lake John Total		41	16	3		60	201	19	2	1	223	283
Walden Res	BCTE	2	2	1		5		2	2		4	9
	CANV							1			1	1
	CITE						1				1	1
	GADW	21	1	14		36	21	1	17		39	75
	MALL	1				1		2			2	3
	NSHO			2		2		1			1	3
Walden Res Total		24	3	17		44	22	7	19		48	92
Grand Total		151	69	108	1	329	343	89	128	1	561	890

Table 9. Number of ducks banded at Russell Lakes SWA, July-August, 2008.

		Sex Age								
		F			F Total	M			M Total	Grand Total
Unit	Species	AHY	HY	L		AHY	HY	L		
Harrence Lake	AGWT					1			1	1
	GADW			1	1			1	1	2
	MALL	6	1	3	10	7		2	9	19
	NOPI	1			1		1		1	2
	NSHO		1		1		1		1	2
	REDH		1	1	2	1			1	3
	BCTE	1	1	1	3			2	2	5
Harrence Total		8	4	6	18	9	2	5	16	34
Island Lake	CITE					1			1	1
	GADW			1	1			2	2	3
	MALL	4	4	6	14	12	9	2	23	37
	REDH		3		3					3
	RNDU					1			1	1
	RUDU		1	1	2		1		1	3
	BCTE	2	1		3	8		1	9	12
Island Total		6	9	8	23	22	10	5	37	60
Trites Lake	AGWT	2	1		3	6	2		8	11
	AMWI	1			1	1			1	2
	CANV	2	3	2	7			3	3	10
	CITE					1	1		2	2
	GADW	6	17	8	31	7	20	10	37	68
	MALL	6	1		7	7	5		12	19
	NSHO	7	16		23		12	1	13	36
	REDH	5	5	10	20	2	3	12	17	37
	RUDU		2		2		2		2	4
	BCTE	4	3	1	8		10	1	11	19
Trites Total		33	48	21	102	24	55	27	106	208
W2	CITE					5	1		6	6
	GADW	1			1					1
	MALL	9	1		10	7	5		12	22
	BCTE	3	6	1	10	1	4		5	15
W2 Total		13	7	1	21	13	10		23	44

Table 9 (cont.). Number of ducks banded at Russell Lakes SWA, July-August, 2008.

		Sex Age								
		F			F Total	M			M Total	Grand Total
Unit	Species	AHY	HY	L		AHY	HY	L		
W3	CITE					16			16	16
	GADW			4	4					4
	MALL	21	7	4	32	3	6	5	14	46
	BCTE	13	4		17	2	12		14	31
W3 Total		34	11	8	53	21	18	5	44	97
W7	CITE					6			6	6
	MALL	2	1		3	7	5	2	14	17
	BCTE	6			6		1		1	7
W7 Total		8	1		9	13	6	2	21	30
W9	AGWT					2			2	2
	AMWI	1			1					1
	CITE					11	5		16	16
	MALL	15	5	1	21	17	3	1	21	42
	BCTE	17	15	2	34	6	19		25	59
W9 Total		33	20	3	56	36	27	1	64	120
Grand Total		135	100	47	282	138	128	44	311	597

Table 10. Number of ducks banded at Russell Lakes SWA, July-August, 2009.

		Sex Age								
		F			F Total	M			M Total	Grand Total
Area	Species	AHY	HY	L		AHY	HY	L		
Davey N	BCTE			2	2			1	1	3
Harrance Lake	MALL	3	1		4		1	2	3	7
	REDH	7		11	18	1		13	14	32
	BCTE	3			3			1	1	4
Harrance Lake Total		13	1	11	25	1	1	16	18	43
Island Lake	AGWT					1			1	1
	MALL	32	15	1	48	14	10	4	28	76
	REDH	2		1	3			3	3	6
	BCTE						1		1	1
Island Lake Total		34	15	2	51	15	11	7	33	84
Johnson Lake	BUFF	1			1					1
	MALL	26	3		29	37	1		38	67
	REDH	2		6	8			4	4	12
	BCTE	3			3	2	2		4	7
Johnson Lake Total		32	3	6	41	39	3	4	46	87
Kimmel Lake	GADW	1			1					1
	MALL	4	1		5	5	5		10	15
	NOPI					1			1	1
	REDH	5		24	29			20	20	49
	RUDU			1	1					1
	BCTE		2		2	1	2		3	5
Kimmel Lake Total		10	3	25	38	7	7	20	34	72
Trites Lake	AGWT	3			3	3	1		4	7
	CANV	2		1	3					3
	CITE					2			2	2
	GADW	5	23	17	45	1	20	20	41	86
	MALL	2	4	1	7	24	8	1	33	40
	NOPI		1		1					1
	NSHO	2	8	3	13		12	4	16	29
	REDH	3	1	14	18		1	13	14	32
	RUDU		1	1	2					2
	BCTE	16	11		27	22	24		46	73
Trites Total		33	49	37	119	52	66	38	156	275
W. Overflow	AGWT	1			1	1			1	2
	MALL		2		2					2
	BCTE	16	14	1	31	13	20		33	64
W. Overflow Total		17	16	1	34	14	20		34	68

Table 10 (cont.). Number of ducks banded at Russell Lakes SWA, July-August, 2009.

		Sex Age								
		F			F Total	M			M Total	Grand Total
Area	Species	AHY	HY	L		AHY	HY	L		
W1	REDH							1	1	1
W2	MALL	3	1	2	6		3	1	4	10
	REDH			2	2					2
	BCTE	3			3			1	1	4
W2 Total		6	1	4	11		3	2	5	16
W3	MALL	2	1	4	7	3		8	11	18
	REDH	3		1	4			3	3	7
	BCTE					1	1	2	4	4
W3 Total		5	1	5	11	4	1	13	18	29
W9	AGWT					1			1	1
	MALL	11	18	3	32	4	22	3	29	61
	NOPI		1	3	4	1			1	5
	REDH		1		1		1		1	2
	BCTE	11	11	1	23	5	7	3	15	38
W9 Total		22	31	7	60	11	30	6	47	107
W10	MALL							1	1	1
W11	MALL							1	1	1
W12	MALL						1		1	1
Grand Total		172	120	100	392	143	143	110	396	788

Table 11. Number of ducks banded at Russell Lakes SWA, July-August, 2010.

Count of Species		Sex Age									
		F			F Total	M			M Total	U	Grand Total
Location	Species	A	J	L		A	J	L		L	
Harrance Lake	AGWT		1	1	2	15	1		16		18
	BCTE	4	13	1	18		6	1	7		25
	CITE					2			2		2
	GADW		7	4	11	5	5	8	18		29
	MALL	8	1		9	12	1	1	14		23
	NSHO	1			1						1
	REDH	1	7	1	9	1	2		3		12
Harrance Total		14	29	7	50	35	15	10	60		110
Island Lake	BCTE	2	4		6		9		9		15
	MALL	5	1		6	8	1		9	2	17
	REDH							1	1		1
Island Lake Total		7	5		12	8	10	1	19	2	33
Island Uplands	MALL	1			1						1
Kimmel Lake	BCTE		3		3						3
	GADW	1			1						1
	MALL	8	6		14	10	3		13		27
Kimmel Total		9	9		18	10	3		13		31
Trites Lake	AGWT					4			4		4
	BCTE	7	24	8	39	6	42	3	51		90
	CANV			4	4	2	1	1	4		8
	CITE					2			2		2
	GADW	1	12	8	21		17	4	21		42
	MALL	9	9		18	17	11		28		46
	NSHO	1	4		5		4		4		9
	REDH	1	4	7	12		1	2	3		15
Trites Total		19	53	27	99	31	76	10	117		216
W2	MALL	4	4		8	1	4		5	5	18
	REDH		2	5	7		3	5	8		15
W2 Total		4	6	5	15	1	7	5	13	5	33
W3	BCTE	5	4		9	1	5		6		15
	CITE					2			2		2
	GADW	2	2	8	12		6	3	9		21
	MALL	3	4	2	9	3	3	1	7	1	17
	NSHO		1		1						1
	REDH							5	5		5
W3 Total		10	11	10	31	6	14	9	29	1	61

Table 11 (cont.). Number of ducks banded at Russell Lakes SWA, July-August, 2010.

W4	MALL	1			1						1
W8	AGWT		1		1						1
	BCTE		3		3		2		2		5
	MALL	5	1		6	1	2		3		9
	NOPI		2		2						2
W8 Total		5	7		12	1	4		5		17
W9	BCTE						2		2		2
	MALL	2			2	2	2		4		6
	RUDU		1	2	3		1		1		4
W9 Total		2	1	2	5	2	5		7		12
West Overflow	GADW	1			1						1
Grand Total		73	121	51	245	94	134	35	263	8	516

Table 12. Summary of ducks banded by area, species and year.

	North Park				Russell Lakes				
Species	2008	2009	2010	NP Total	2008	2009	2010	RL Total	Total
AGWT	1	148	26	**175**	14	11	23	**48**	**223**
AMWI	11	55	27	**93**	3	0	0	**3**	**96**
BCTE	4	72	47	**123**	148	203	155	**506**	**629**
BWTE	4	1	0	**5**	0	0	0	**0**	**5**
BUFF	0	0	0	**0**	0	1	0	**1**	**1**
CANV	8	8	6	**22**	10	3	8	**21**	**43**
CITE	1	2	1	**4**	47	2	6	**55**	**59**
GADW	194	223	235	**652**	78	87	94	**259**	**911**
LESC	8	4	28	**40**	0	0	0	**0**	**40**
MALL	438	541	480	**1459**	206	299	165	**670**	**2129**
NOPI	8	6	19	**33**	2	7	2	**11**	**44**
NSHO	54	2	19	**75**	38	29	11	**78**	**153**
REDH	6	3	2	**11**	43	143	48	**234**	**245**
RNDU	0	2	0	**2**	1	0	0	**1**	**3**
RUDU	1	0	0	**1**	7	3	4	**14**	**15**
Total	**738**	**1067**	**890**	**2695**	**597**	**788**	**516**	**1901**	**4596**

For Tables xx -xx, the following abbreviations are defined as: ANWR = Arapaho National Wildlife Refuge, NP = North Park, RL = Russell Lakes SWA, AGWT = American green-winged teal, AMWI = American wigeon, BCTE = blue-winged or cinnamon teal, BUFF = bufflehead, 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, RUDU = ruddy duck

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