AVIAN PROGRAM

SEPTEMBER 2013

WILDLIFE RESEARCH REPORT

WILDLIFE RESEARCH REPORTS

SEPTEMBER 2013

AVIAN RESEARCH PROGRAM

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

Colorado Division of Parks and Wildlife
September 2012 – September 2013

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Colorado Division of Parks and Wildlife
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WILIDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of Parks and Wildlife
Cost Center:	3420	:	Avian Research
Work Package:	0656	:	Columbian Sharp-tailed Grouse Conservation
Task No.:	N/A	:	Columbian sharp-tailed grouse chick and juvenile radio transmitter evaluation

Federal Aid
Project No. N/A

Period Covered: September 1, 2012 – August 31, 2013

Author: A. D. Apa

Personnel: J. Haskins, B. Petch, T Balzer, K. Griffin, L Rossi, J Yost, M. Warren, CPW; Brandon Miller, RMBO/NRCS/CPW

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ABSTRACT

The Columbian sharp-tailed grouse (CSTG, *Tympanuchus phasianellus columbianus*) is one of six subspecies of sharp-tailed grouse in North America. Current distribution ranges from British Columbia to Colorado. CSTG currently occupy 10% of their former range due to habitat loss. Since the initiation of the Conservation Reserve Program (CRP), CSTG have increased in distribution and density. CRP fields have low plant species diversity when compared to native shrubland or mineland reclamation habitat. Therefore, managers desire to improve existing or historically enrolled CRP fields. Research techniques to evaluate the population response of CSTG to habitat treatments (via understanding chick and juvenile demographic parameters) do not exist. Therefore, the objectives of my study are to: 1) evaluate the capture and transmitter attachment technique for day-old CSTG chicks, 2) evaluate the capture and transmitter attachment technique for 30-day-old CSTG chicks, and 3) evaluate the capture technique for > 120 day-old CSTG juveniles. My study occurred near Hayden, Routt County, Colorado from April - August 2013. I captured CSTG in the spring using walk-in funnel traps, fit females with 12 g necklace-mounted radio transmitters, monitoring survival, and nesting effort. I captured chicks from successful females and radio-marked a sample with 0.65 g backpack style transmitter sutured along the dorsal midline between the wings. I monitored survival and movement daily. I conducted summary statistics and Kaplan-Meier function estimates with staggered entry for female and chick survival. I captured 36 female CSTG and monitored survival and productivity from April through August. I documented a 5-month female survival rate of 0.33 which is lower than previously reported. Eight nests yielded an apparent nest success of 37.5%. Eleven chicks in three broods were radio-marked with a mean chick mass was 15.98 g. The total handling time by brood was 35, 20, and 44 minutes. No chicks survived past 9 days-of-age. The primary cause of female mortality was due to the transmitter design causing crop impaction limiting the overall accomplishment of the study objectives. Future research in Colorado should use exclusively an elastic necklace design or in combination with a different transmitter design shown to be successful in other CSTG research.

WILDLIFE RESEARCH REPORT

COLUMBIAN SHARP-TAILED GROUSE CHICK AND JUVENILE RADIO TRANSMITTER EVALUATION

ANTHONY D. APA

PROJECT OBJECTIVES

My project goal is to evaluate trapping and transmitter attachment methods on CSTG that have been previously used on GRSG. My study objectives are to:

1. Evaluate the capture and transmitter attachment technique for day-old CSTG chicks.
2. Evaluate the capture and transmitter attachment technique for 30-day-old CSTG chicks.
3. Evaluate the capture technique for > 120 day-old CSTG juveniles.

If the techniques are successfully developed they will be used in a future research project.

INTRODUCTION

The Columbian sharp-tailed grouse (CSTG, *Tympanuchus phasianellus columbianus*) is one of 6 subspecies of sharp-tailed grouse in North America. Current distribution ranges from British Columbia in the northwest to Colorado in the southeast. In-between populations exist in Washington, Idaho, Wyoming, Montana (extirpated), Utah, and Nevada (reintroduced) and Oregon (reintroduced). It currently occupies 10% of its former range across western North America (U.S. Department of the Interior 2000) and habitat loss is cited as the primary reason for its decline (Yocom 1952, Giesen and Braun 1997, McDonald and Reese 1998, Schroeder et al. 2000). Since the establishment of the Conservation Reserve Program (CRP) in 1985, CSTG have increased in distribution and density primarily in Idaho, Utah, and Colorado (U.S. Department of the Interior 2000).

The CSTG (Mountain Sharp-tail) is a game species in Colorado, and is designated as a species of state special concern. Management efforts to increase distribution in un-occupied but historic range of CSTG have occurred via reintroductions into Oregon and Nevada from source populations in Idaho. Additional reintroduction efforts have occurred within Utah and Colorado. Specifically, Colorado Parks and Wildlife has conducted reintroduction efforts within historic range in Dolores and Grand Counties.

Overview of Potential Future Research - Although management efforts continue to expand the range of CSTG, there is interest in improving habitat quality within occupied range. Improving habitat quality could: 1) increase densities and occupancy, 2) improve habitat in vacant and/or low quality CRP in unoccupied to expand distribution and/or, 3) be used as habitat improvements to mitigate impacts related to other habitat loss issues on the landscape (e.g., oil and gas exploration and development).

Although research in Colorado (Boisvert 2002, Collin 2004) suggests that CRP is generally beneficial to CSTG (over other agricultural practices), adjacent higher quality habitats in native or mineland reclamation provide higher quality habitat resulting in more productive CSTG populations. Poor quality CRP, consists of 1-2 grass and < 3 forb species (Boisvert 2002), with the grass species being predominantly sod-forming species (e.g. intermediate wheatgrass (*Thinopyrum intermedium*) and smooth brome (*Bromus inermis*)). These species tend to dominate sites and do not provide high quality CSTG nesting and brood-rearing habitat (Boisvert 2002).

Dasmann (1964: 59) stated "To manage wildlife we must first manage the habitat." Thus habitat management can range from complete protection from disturbance to improving quality so that the wildlife populations can be productive, maintained, and/or optimized to increase its carrying capacity (Dasmann 1964). Although Dasmann (1964) was correct in his statements nearly 50 years ago, the wildlife-habitat relationship is complex and differs widely among species and landscapes. Although our understanding of the wildlife-habitat relationship has improved, knowledge has evolved to define and assess habitat quality as it relates to population growth rates, density, and demographic rates (Van Horne 1983, Knutsen et al 2006, Johnson 2007). This is paramount when attempting to couple habitat quality change with wildlife population demographic changes.

CSTG provide a unique opportunity to evaluate a population response to habitat quality change. CSTG are a highly productive, generalist species (Apa 1998) having centralized breeding locations and limited movements during the breeding season (Boisvert et al. 2005). This behavior allows managers to target habitat improvements in nesting and brood-rearing areas. Since CSTG are breeding and brood-rearing habitat generalists and more productive (when compared to greater sage-grouse [GRSG; *Centrocercus urophasianus*]; Apa 1998), these characteristics can facilitate a relatively rapid response to habitat management. This allows managers and researchers to work cooperatively in attempting to couple landscape level habitat quality improvements in coordination with the demographic and population response of CSTG.

More information is needed to evaluate the demographic and population response of CSTG to breeding and summer/fall habitat improvements through more rigorous estimates of chick and juvenile (> 5 weeks-of-age) survival, dispersal, and recruitment. The field methods to obtain those estimates exist for surrogate species, but not for CSTG. Transmitter attachment and capture methods have been developed to estimate GRSG chick survival from hatch to 50 days (Burkepile et al. 2002, Greg and Crawford 2009, Dahlgren et al. 2010, Thompson 2012), but only one study investigated approaches to estimate GRSG juvenile survival (> 50 days-of-age for estimates of dispersal and recruitment; Thompson 2012). Additionally, one study (Manzer and Hannon 2007) has developed the field techniques to estimate plains sharp-tailed grouse (*T. p. jamesi*; PSTG) chick survival from hatch to 30 days-of-age, but PSTG are approximately 100 g larger (Sisson 1976) than CSTG (Collins 2004) and are not a perfect surrogate for my proposed field method evaluation.

STUDY AREA

My study was conducted near Hayden, Routt County, Colorado. It is interspersed with native sagebrush (*Artemisia tridentata spp.*)/grass or mountain shrub communities, dominated by private land that is currently, or was historically, enrolled in the Conservation Reserve Program. Primarily exotic grasses (smooth brome and intermediate wheatgrass) and forbs (alfalfa (Medicago sativa) dominate the habitat (Fig. 1). The average annual precipitation in Hayden, Colorado is 43.2 cm. The average minimum and maximum annual temperatures are -2.8^{o} C and 14.4^{o} C, respectively.

METHODS

Grouse Capture – I captured CSTG in the spring using walk-in funnel traps (Schroeder and Braun 1991) in the morning on dancing grounds and opened traps ½ hour before sunrise and closed/blocked them at the cessation of trapping each morning. I initiated trapping based upon the timing and peak of female attendance (Giesen 1987).

I fit females with a 12 g necklace-mounted radio transmitter (Model A3950, Advanced Telemetry Systems, Isanti, MN) equipped with a 4-hour mortality circuit having an 8.5 month nominal battery life. Each transmitter had its 16 cm antenna bent to lie down between the wings and down the back of the grouse. I classified grouse by gender (Snyder 1935, Henderson et al. 1967) and age (yearling or adult; Ammann 1944), placed them in a cotton bag, and for weighed them on an electronic balance. I fit all females with an individually numbered aluminum leg band (size 12) on the tarsus, and released them at the point of capture.

Nest Monitoring and Chick Capture - I monitored movements using triangulation from a ≥ 30 m distance (to minimize disturbance) using hand-held Yagi antenna attached to a receiver, and monitored nesting behavior to identify nest location. If a female was observed in the same location for two consecutive days, she was assumed to be incubating. I attempted a visual observations of the female, if vegetation concealment was conducive 7-10 days post-incubation confirmation and monitored nest fate using telemetry at a ≥ 30 m distance (24-26 day incubation period).

Once monitoring revealed a successful hatch (female movement away from the nest), I captured all chicks in the brood within 24 hours. I located females < 2 hours after sunrise during brooding and flushed the female. I captured all chicks by hand and confined them in a small cooler to maintain thermoregulation. I weighed (± 0.01 g) all chicks with an electronic scale and a random sample (depending on brood size) was selected for transmitter application. A 0.65 g backpack style (Model A1025; nominal battery life is 28 days; Advanced Telemetry Systems, Isanti, MN) transmitter was sutured along the dorsal midline between the wings (Burkepile et al. 2002, Dreitz et al. 2011, Manzer and Hannon 2007, Thompson 2012). Two 20-gauge needles were inserted subcutaneously and perpendicular to the dorsal mid-line, and monofilament suture (Braunamide: polyamide 3/0 thread, pseudo monofilament, non-absorbable, white) material was threaded through the needle barrel. I applied one drop of cryanocrylate glue on the knot, and released the chicks simultaneously at the brood site. Chick survival and movements were monitored 1-2 hours post-release to determine brood female affinity and post-handling chick behavior.

I monitored female and chick movements and survival daily until 14 days-of-age, by circling at a 25 m radius. I documented the position (i.e., distance) of radio-marked chicks in relation to the brood female, systematically searching the area for missing chicks/transmitters. I collected brood locations equally among 4 time periods: brooding (< 2 hour after sunrise or before sunset), morning (0800-1100), mid-day (1100-1400), and afternoon (1400-1800) throughout the study, increasing the location sampling period to every 1-3 days until the brood was 20-30 days of age.

I captured surviving juveniles at two different ages using spotlight techniques (Giesen et al. 1992, Wakkinen et al. 1992). The first capture was at 20-30 days-of-age. The chick transmitter was removed and the juvenile was fit with a 3.9 g back-pack style juvenile transmitter (Model A1080, nominal life 6-7 months; Advanced Telemetry Systems, Isanti, MN). The attachment method will be the same as described earlier for day-old-chicks (Burkepile et al. 2002, Dreitz et al. 2011, Manzer and Hannon 2007, Thompson 2012). I captured surviving juveniles 10-12 weeks following initial radio-marking in late-September and October, and fit juveniles with a12 g adult style necklace-mounted radio transmitter (Model A3950, Advanced Telemetry Systems, Isanti, MN) equipped with a 4-hour mortality circuit and have a nominal battery life of 8.5 months. I used techniques to capture juveniles using spotlight techniques described earlier.

Data Analysis - I conducted similar summary statistics and Kaplan-Meier (K-M) function estimates with staggered entry for female and chick survival (Kaplan and Meier 1958, Pollock et al. 1998).

RESULTS AND DISSCUSSION

I captured 36 female CSTG (29 adults: 6 yearlings: 1 unknown) from 27 April - 8 May 2013 on 4 dancing grounds (Big Elk 1 & 3, Stokes Gulch 2, and Postivit). Adult and yearling female mass ($\bar{x}$ ± SE) was 669.5 ± 8.5 g (*n* = 29) and 660.8 ± 35.6 g (*n* = 6), respectively. From April through August, I documented 28 female mortalities resulting in a 5-month female survival rate of 0.33 ± 0.01 (Fig. 2). I censored one female due to a dropped radio-collar, and documented five instances of radio-collar attachment caused mortality. The mortalities resulted from the necklace attachment causing crop restriction and impaction.

I documented 8 nests and experience a 37.5% apparent nest success. Only 3 nests provided opportunities to trap and radio-mark chicks. Eleven chicks in three broods were radio-marked with a mean chick mass was 15.98 ± 0.86 g (range 13.3 - 21.0; *n* = 11). The total handling time by brood was 35, 20, and 44 minutes for each of 4, 2, and 5 chicks telemetered resulting in an average handling time of 8.7, 10, and 8.8 minutes/chick, respectively. No chicks survived past 9 days-of-age (Fig. 3). One brood survived only to two days due to the depredation of the brood female, and no chicks survived to test additional juvenile transmitter replacement and attachment techniques.

Trapping commenced 13-17 days later than previously reported (Collins 2004). The adult:yearling capture ratio (4.8:1) was similar (5.0:1) to Collins (2004) but different (3.6:1) than reported by Boisvert (2002). Mass of adult and yearling females was similar to earlier research (Boivert 2002, Collins 2004). I experienced lower than reported survival, which is not explained by larger samples of yearling females or spring conditions that could cause breeding season stress. The low female survival rate was lower than reported by Collins (2004) (interpolated as 0.5-0.7 survival at 150 days post-capture). The reason for the lower survival rate was due to the transmitter design. Five mortalities were due to crop impaction caused by the transmitter necklace design. Although additional moralities could not be directly attributed to the necklace transmitter design the lower than normal survival rate is suspected as the casue of a majority of the mortality. I also considered that the necklace was fit too tight around the neck of the female, but previous research has not reported impacted crop issues with older non-elastic herculite poncho material (Amstrup 1980, Apa 1998) or other expandable or non-expandable necklace designs used previously in Colorado (Boisvert 2002, Collins 2004). Previous designs included an elastic necklace style (Model RI2BM4, Holohil Systems, LTD, Ontario, Canada) with weights of 15.2g and 12g or an unknown model style (assumed to be non-elastic necklace material) by and AVM Instrument Company, Ltd, Colfax, California weighing 14.5 g. There was no mention of impacted crop mortalities.

Upon further investigation, I contacted colleges in Idaho conducting CSTG research. In 2012, they experienced five mortalities resulting from an impacted crop (D. Musil and R. Smith, Idaho Department of Fish and Game, personal communication) that were related to the necklace design transmitter. The transmitter design used in 2012 was the necklace style ATS A3950. This was the only year this transmitter design was used. In 2013, the Idaho research project returned to a necklace design used previously, the ATS A4120. This transmitter design has the potting material formed into a cylindrical in shape rather than the disc shape of the ATS 3950. The disc shape causes a more restrictive necklace shape around the neck causing food in the crop to become restricted. To date, the Idaho research has not documented any instances of impacted crops, either currently or previously to the 2012 study year. This mortality rate did not allow the evaluation of several of my pilot project objectives, and future research in Colorado should use either the elastic necklace Holohil design exclusively or in combination with the ATS A4120.

I want to thank the CPW Area 10 staff for assistance in landowner contacts, logistics, and trapping. This study occurred exclusively on private land and I thank those private landowners for the assistance and cooperation. I specifically want to thank R. Stern and A. Stott for the many hours in the field conducting the field observations and data collection. Most importantly, I want to thank R. Hoffman for his assistance, professional guidance, and advice throughout all phases of this research.

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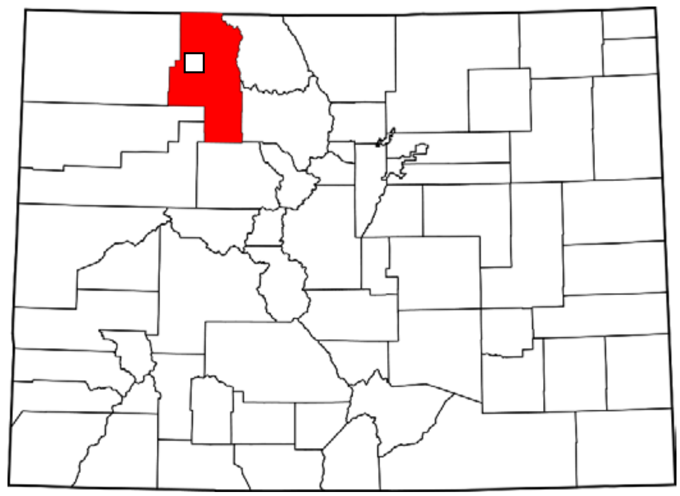

Figure 1. Columbian sharp-tailed grouse study area in Routt County, Colorado, 2013.

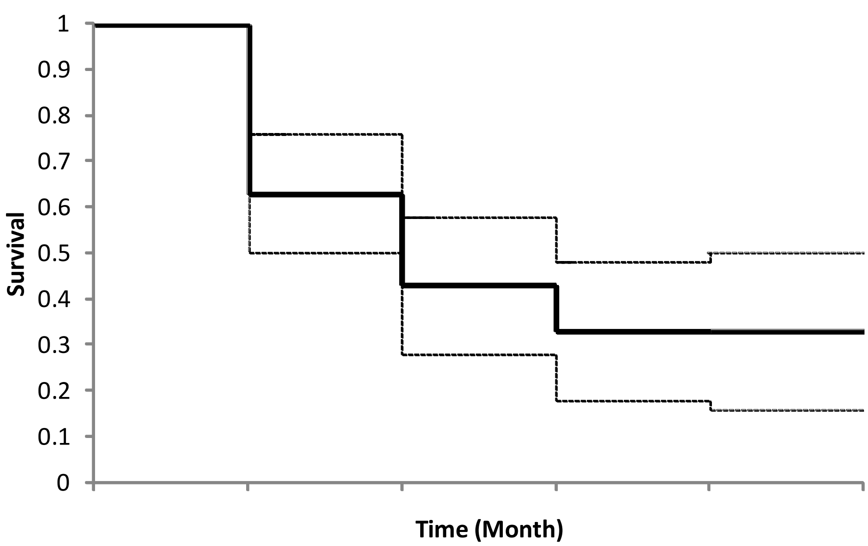

Figure 2. Kaplan-Meier product limit survival with staggered entry of female Columbian sharp-tailed grouse from April - August 2013 in Routt County, Colorado, 2013.

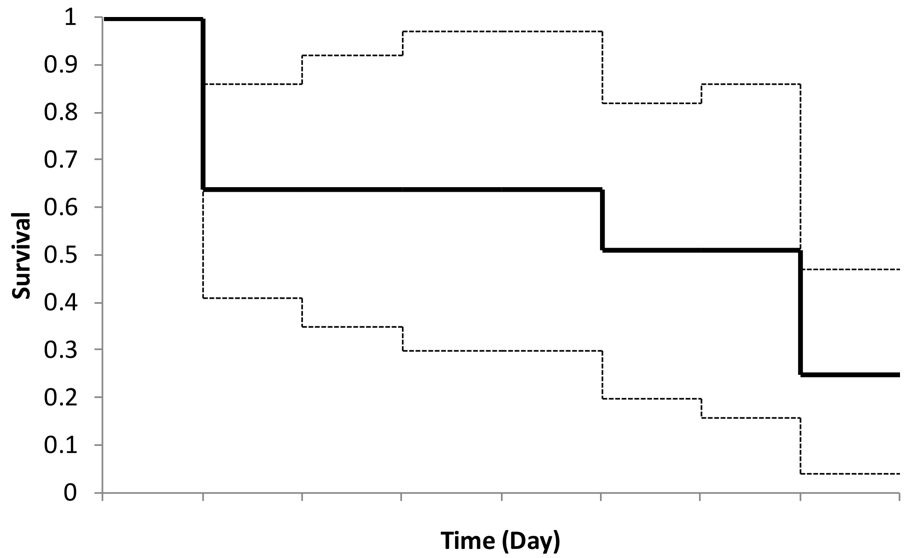

Figure 3. Kaplan-Meier product limit survival with staggered entry of Columbian sharp-tailed grouse chicks (n = 11) from 1 - 9 days-of-age in Routt County, Colorado, 2013.

Colorado Division of Parks and Wildlife
September 2012-September 2013

WILDLIFE RESEARCH REPORT

State of:	Colorado	: Division of Parks and Wildlife
Cost Center:	3420	: Avian Research
Work Package:	0658	: Lesser Prairie-chicken Conservation
Task No.:	N/A	: Lesser prairie-chicken demography, habitat use, and conservation practices in southeastern Colorado

Federal Aid
Project No. N/A

Period Covered: March 1, 2013 – October 14, 2013

Author**:** R. Yale Conrey

Personnel: J. Reitz, D. Klute, B. Dreher, J. Gammonley, CPW; D. Haukos, D. Sullins, Kansas State University.

ABSTRACT

Lesser prairie-chickens (*Tympanuchus pallidicinctus*: LEPC) exist in fragmented populations in Kansas, Oklahoma, Colorado, Texas, and New Mexico. Population trajectories vary in each area, but LEPC are declining in many locations, including southeastern Colorado, and are currently being considered for listing under the federal Endangered Species Act. Colorado Parks and Wildlife (CPW) is collaborating on a large research study led by David Haukos, Kansas State University. The larger study objectives are to measure impacts of energy development, conversion to agriculture, grazing, fire suppression, drought, herbicides, pesticides, fencing, invasive vegetation, and conservation projects on LEPC demography and habitat use. Plans are to estimate survival, recruitment, and seasonal resource selection for Kansas and Colorado using telemetry data from transmitters placed mainly on adult females and a smaller subset of males and chicks. In addition, CPW is measuring the response of vegetation and LEPC to ongoing habitat treatments (283,000 acres enhanced since 2009). This was the first year of a 4-year field study, with the overall project expected to extend from fall 2012 – spring 2017. During the 2013 season in Colorado, crews captured 29 birds on five leks and deployed 15 transmitters on all six hens that were captured and on nine males. As of early October 2013, over 15,789 LEPC locations have been recorded; 451 of these locations have been monitored, with ~900 random points providing vegetation comparisons. This was the third consecutive year of extreme drought, and a delayed, lengthy raptor migration period further contributed to mortalities (adult survival from April – July = 0.600). Of the four monitored nests, three failed and the fourth brood was lost within 2 weeks post-hatch; thus, we documented no recruitment for Colorado in 2013. Analysis of vegetation and telemetry data and habitat treatment effectiveness is ongoing. Plans for 2014 include further radio-marking of adult LEPC on leks with at least five males and continued vegetation sampling. CPW research staff have had peripheral involvement in this project thus far, helping to advise management staff regarding sampling and data collection, with the expectation of more direct involvement in data analysis and planning of future research.

COLORADO PARKS AND WILDLIFE RESEARCH REPORT

LESSER PRAIRIE-CHICKEN DEMOGRAPHY, HABITAT USE, AND CONSERVATION PRACTICES IN SOUTHEASTERN COLORADO

REESA YALE CONREY

PROJECT OBJECTIVES

The objectives of the larger study in Kansas and Colorado are to measure impacts of energy development, conversion to agriculture, grazing, fire suppression, drought, herbicides, pesticides, fencing, invasive vegetation, and conservation projects on LEPC demography and habitat use. Major objectives for Colorado are to

1. Compare adult, nest, and brood survival and habitat use in rangeland versus Conservation Reserve Program (CRP) lands.
2. Evaluate the effectiveness of habitat treatments for LEPC.
3. Assess population viability and evaluate the advisability of trap and transplant as a management tool.

SEGMENT OBJECTIVES

Objectives for Colorado in 2013 (first year of a 4-year study) were to: 1) Establish field techniques and relationships among collaborators on the larger study; 2) Record as many GPS locations and monitor the fate of as many individuals, nests, and broods as sample size allowed; 3) Estimate adult, nest, and brood survival; 4) Determine vegetation response to habitat treatments and evaluate LEPC use of treated areas versus other rangeland and CRP; 5) Collect enough baseline information to determine whether translocations should be included in the LEPC recovery plan.

INTRODUCTION

Lesser prairie-chickens (*Tympanuchus pallidicinctus*: LEPC) exist in fragmented populations in Kansas, Oklahoma, Colorado, Texas, and New Mexico. Population trajectories vary in each area, but LEPC are declining in many locations, including southeastern Colorado, and are currently being considered for listing under the federal Endangered Species Act. Colorado Parks and Wildlife (CPW) is collaborating on a large research study led by David Haukos, Kansas State University. The larger study objectives are to measure impacts of energy development, conversion to agriculture, grazing, fire suppression, drought, herbicides, pesticides, fencing, invasive vegetation, and conservation projects on LEPC demography and habitat use. Plans are to estimate survival, recruitment, and seasonal resource selection for Kansas and Colorado using telemetry data from transmitters placed mainly on adult females and a smaller subset of males and chicks. This was the first year of a 4-year field study, with the project expected to extend from fall 2012 – spring 2017.

An additional goal in Colorado is to measure the response of vegetation and LEPC to ongoing habitat treatments (283,000 acres enhanced since 2009). We currently have little information about the efficacy of CRP enhancement projects for vegetation, LEPC, or other wildlife. CPW also has grazing exclosures around rangeland leks and grazing deferment agreements with some landowners, but we can have the largest impact on vegetation by working with landowners involved in Farm Bill programs, such as CRP mid-contract management (MCM), and CPW conservation programs, such as State Acres for Wildlife Enhancement (SAFE). Within the next few years, > 600,000 CRP acres will be due for MCM, and there is a high probability that additional rangeland and CRP acres will be converted to crop production. In addition, the potential may exist for a trap and transplant program, moving LEPC from Kansas into the Comanche National Grasslands. The overall goal for research and management programs in Colorado is to halt the decline of LEPC and understand how to best invest our resources in effective habitat management.

CPW research staff have had peripheral involvement in this project thus far, helping to advise management staff regarding sampling and data collection, with the expectation of more direct involvement in data analysis and planning of future research.

METHODS

Study Area

LEPC study areas in southeastern Colorado encompass isolated patches of habitat within a matrix of agricultural lands approximately 200 x 100 km from southern Cheyenne County through Kiowa, Prowers, and Baca Counties south to the Oklahoma border and east to the Kansas border. The northernmost and southernmost locations in Cheyenne and Baca Counties were comprised of large tracts of sand sagebrush prairie, while habitat in Prowers County included pockets of CRP within a landscape of mainly dryland agriculture. The Baca County leks were located in the Comanche National Grasslands (U.S. Forest Service), but the rest were located on private land.

LEPC Sampling

Colorado leks have been monitored since 1977 with formal lek counts since 1981, during which time attending males and females have been counted (Smith 2012). Due to concerns about the safety of trapping and potential effects of transmitters on survival, CPW staff agreed that only leks with at least five attending males would be trapped. The goal was to capture hens on leks, with GPS transmitters providing data during lekking, nesting, and brood-rearing, but males would be radio-marked if the sample size of hens was low and transmitters were available. Two 2-person crews captured LEPC from the last week in March to the end of May 2013. LEPC were trapped using three methods: 40’ x 40‘ remotely-triggered drop nets, a net launcher, and a system of chicken wire drift nets that funneled birds into walk-in box traps. (Haukos 2013$_a$). Morphometric data and blood samples were collected from captured birds, and eight locations were recorded each day after capture. When mortalities occurred, transmitters were recovered for reuse or refurbishment. In addition, invertebrate sweeps were done as an index of food availability, fence surveys were conducted for signs of LEPC killed or injured by fence collisions, and egg shells were collected after nest completion for an isotope study of water sources. Concerns about the welfare of Colorado’s small LEPC population precluded some techniques used in Kansas, including flushing hens from nests, floating eggs for aging, putting iButtons in nests, or suturing transmitters on chicks. CPW staff monitored just those birds that lekked or nested in Colorado, as well as three birds on the Cimarron Grasslands near the Kansas/Colorado border whose locations were not previously monitored.

Vegetation Sampling

Vegetation was sampled at randomly-selected LEPC locations (two locations per week, with frame placed on LEPC mutes), random points (up to 10 points per habitat patch used by LEPC), nests, and brood locations. Initially, random points were selected within 300 m of LEPC locations to create paired points (used vs. available) but this protocol was changed in mid-June 2013 in favor of truly random (non-paired) points. We measured visual obstruction with a robel pole, percent ground cover with a Daubenmire frame, vegetation height, and species composition at the chosen location and at 4 m in each cardinal direction (Haukos 2013$_a$).

Vegetation was also sampled in LEPC habitat patches at least 10 acres in size, defined as distinct units of potentially suitable habitat with relatively uniform species composition and structure. Suitable habitat included all rangeland and CRP within 5 km of each lek. Crop fields were sometimes used by

LEPC, but crop patches are being characterized using an abbreviated protocol (not transects). We characterized vegetation on three 250 m transects per patch using a step-point method. We paced out each transect, recording the species, height, and growth characteristics for the plant at the end of our boot for each pace (~every 2 m for 126 points per transect). Initially, 500 m transects were used, but this protocol was changed in mid-June 2013 due to time constraints. Much of the vegetation sampling at random points and patches occurred in fall 2013, following the completion of all breeding activity, but in future years the goal will be to measure vegetation at random points during the breeding season and in patches twice per year, during the nesting season and again at the end of the growing season.

Data Analysis

Thus far, LEPC adult, nest, and brood survival have been estimated as proportion of radio-marked birds known alive, nests (belonging to radio-marked hens) to hatch at last one chick, and broods with at least one chick surviving 30 days post-hatch, respectively. Vegetation data have not yet been analyzed.

RESULTS

LEPC Captures and Monitoring

In the larger study, 265 LEPC were captured, 79 GPS transmitters were deployed (63 on hens), and 43 VHF transmitters were deployed (all on hens). No confirmed evidence of fence collisions was observed during 6527 min. surveying 465 km of fence (Haukos 2013_b), although feathers were found on a fence in Kansas.

In Colorado, 29 LEPC were captured on five leks during 130 total trap-days, likely representing 25 – 33% of the total population, and 15 GPS transmitters were deployed (six on hens). CPW provided 12 transmitters, and Andy Chappel with the USFS Cimarron Grasslands provided the other three. One fence collision was possible (carcass found under fence) but could not be confirmed. As of early October 2013, 15,789 LEPC locations have been recorded via the GPS transmitters. Research personnel conducted 170 insect sweeps.

Vegetation Monitoring

In the larger study, 293 habitat patches (64% rangeland and 36% CRP) were characterized (Haukos 2013_b).

In Colorado, we collected vegetation data at 451 randomly chosen LEPC locations, at 190 paired points, and as of early October 2013, at nearly 900 random points in patches used by LEPC. Of the 183 patches identified within 5 km of active leks, 70 patches (36% rangeland and 64% CRP) have been characterized thus far: 65 patches (195 transects) were monitored during the nesting season, and end-of-season patch vegetation monitoring is ongoing with 160 transects completed. Patch transect data have been collected on six fields that have been enhanced by one to four disking passes, followed by reseeding with mixes containing alfalfa, yellow sweet clover, and high forb diversity. An additional 17 enhanced fields, with treatments on 33 – 51% of the field area, will also be monitored.

Adult, Nest, and Brood Survival

In the larger study, survival of radio-marked adults from April – July 2013 was 0.491: male survival was 0.574 and female survival was 0.467. Survival was similar among GPS and VHF marked birds, but only 1% of GPS marked birds had unknown fate while 30% of VHF marked birds had unknown fate. Most nests were initiated < 2 km from the lek of capture. Of 52 monitored nests, apparent nest survival to hatching was 0.308. Of those 16 broods, survival to 30 days (of at least one chick) was 0.375 (Haukos 2013_b).

In Colorado, survival of radio-marked adults from April – July 2013 was 0.600, higher than the overall rate: male survival was 0.556 and female survival was 0.667. As of mid-October 2013, two males and four females remain alive for a 6-month survival rate of 0.400, with mortality higher for males than females. None of the three Kansas birds from Cimarron Grasslands survived the summer. Out of six radio-marked hens, four survived long enough to initiate nests, and one nest survived to hatching (Appendix 1). This brood was lost within 2 weeks post-hatch. The four Colorado LEPC nests were located in Cheyenne Co. (two failed nests) and at the Red Roof site near the Prowers Co./Baca Co./Kansas state line (one failed nest and one successful nest but failed brood). The successful nest was laid by a hen from the Red Roof lek in Colorado who traveled 2.2 miles into a Kansas CRP field before initiating her nest (Appendix 1).

Weather Conditions and Predator/Prey Abundance

This was the third consecutive year of extreme drought in southeastern Colorado. Coming out of the 2012 drought year, the only chicken area that had reasonably good nesting cover was the Comanche Grasslands. All other sites offered poor quality nesting cover. Of all the 2013 leks, the two in Cheyenne County were the only leks that received any spring moisture. All other leks had an exceedingly dry nesting period. The Comanche Grassland leks received a little moisture just after the nesting season. The Colorado study area experienced a very late spring and a delayed, lengthy raptor migration period that contributed to multiple avian-caused mortalities for adult LEPC during the lekking season.

The Cheyenne County site, where two failed nests were located, received a late snow storm that provided some insects and forbs. The Red Roof site, where one failed nest and one successful nest were located, received no moisture until the last week of July. Insect sweeps showed fairly good diversity and abundance at the Cheyenne site and virtually no insects at the Red Roof site.

DISCUSSION

This was the third consecutive year of extreme drought in southeastern Colorado, and both nesting cover and insect availability were poor, with relatively low survival of adults and nests. In addition, we had a very late spring in 2013, and a delayed, lengthy raptor migration period contributed to mortalities during the lekking season. Male survival was particularly low, and only two of nine radio-marked males remain alive in fall 2013, 6 months after capture. In the first year of this study and with a sample size of only 15 adult LEPC, it is difficult to know how to compare our 6-month survival rate of 0.400 with the annual survival rate of 0.31 – 0.53 from New Mexico (Campbell 1972). Survival is thought to be lowest during the breeding season, but additional birds will likely be lost overwinter and low numbers of birds are expected to attend leks in 2014. Female lek attendance was low in 2013, both in terms of hen numbers and length of time spent on the lek, so it was difficult to capture and radio-mark hens. Of the six radio-marked hens, four initiated nests. Three nests failed and the fourth brood was lost within 2 weeks post-hatch; thus, we documented no recruitment for Colorado in 2013. However, our nest success rate of 0.25 is comparable to the average rate of 0.28 from the literature (Giesen 1998). Our nest sites never reached the 43 cm vegetation height threshold that Giesen (1998) suggested as characteristic for LEPC.

Lek counts have been quite variable since being initiated in 1977, reaching a high of 448 birds in 1989 and a low of 74 birds in 2007 (Smith 2012). Perhaps LEPC populations have always fluctuated widely in Colorado, the northwestern periphery of their range. LEPC in Colorado may always have been in the position of waiting out frequent droughts until favorable weather conditions supported periodic banner reproductive years. However, droughts are increasing in frequency and severity (Ray et al. 2008), and there is now less high quality habitat to sustain populations.

Most of the landowners with property around active leks are willing to enroll in conservation programs, and many are involved in projects such as State Acres for Wildlife Enhancement (SAFE) or federal Farm Bill programs such as CRP. Since 2009, 283,000 acres have been enrolled in conservation programs, with ~15,000 acres enhanced through the SAFE program and a subset of CRP fields receiving enhancements. In addition, within the next few years, > 600,000 CRP acres will be due for mid-contract management, which could be targeted for LEPC production. Until now, there has been little evidence regarding the impacts of these programs on vegetation, LEPC, or other species. Data from this research project will inform future conservation planning and wise spending of conservation dollars. However, certain programmatic problems must also be addressed; for example, at $150/acre enrolled, landowners reach the $50,000 cap on enrollment after just ½ section.

Future research questions regarding habitat enhancements include: 1) Do LEPC prefer enhanced strips or fields for nesting or brood rearing? 2) Are desired grasses and forbs becoming established? 3) At what successional stage, and in what landscape configuration, do enhancements provide optimal LEPC habitat?

Our plans for 2014 include a continuation of 2013 efforts, but it may not be possible to trap LEPC if fewer than five males are in attendance at leks. We plan to continue the use of GPS transmitters, as they did not appear to contribute to higher mortality rates, but as expected, did perform much better than VHF transmitters in providing location data without signal loss (fewer birds with unknown fate). Patch level vegetation will continue to be characterized regardless, and enhancement fields will continue to be monitored. We are working on a rapid vegetation assessment for crop fields used by LEPC, and we will conduct power analyses to help determine optimal sample size for vegetation sampling. Trap and transplant of LEPC from Kansas into the Comanche National Grasslands is being assessed as a management tool. However, the undertaking of such a program would depend upon favorable weather (non-drought) and habitat conditions in Colorado, as well as a proven protocol. Missouri has had success with moving greater prairie-chickens, but at least 10 past efforts with LEPC in Colorado have not resulted in establishing or increasing populations (Giesen 1998).

The overall goal for research and management programs in Colorado is to halt the decline of LEPC and understand how to best invest our resources in effective habitat management. We will continue to collaborate with the larger research efforts of Haukos et al., and we hope to soon determine which analyses will be done by CPW staff and which by graduate students on the larger project. With the small sample size of birds and habitat in Colorado, access to the larger multi-state dataset will be necessary to address information gaps and formulate successful conservation programs in Colorado.

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APPENDIX 1: LEPC NEST FATE AND MORTALITIES

Four nests were initiated in Colorado in 2013. The Brown Mill lek is located in Cheyenne Co. The Red Roof lek is located near the Prowers Co./Baca Co. /KS state line.

Bird 416 (Cheyenne Co. lek) had her nest depredated. A snake was likely responsible, as no egg shell evidence was left.

Bird 784 (Cheyenne Co. lek) incubated her nest for ≥ 34 days. Average incubation time is 26 days, ranging from 23-28 days. On day 29, she was on a nest of six eggs. After the nest was abandoned, we found one intact egg in the nest with an embryo that was nearly full grown, and the egg shells from two other eggs were buried several inches deep a few feet from the nest.

Bird 411 (Red Roof lek) went 2.2 miles from the lek and nested in a CRP draw in Kansas. The nest was between an overgrazed CRP field and a sideoats monoculture CRP field. The draw itself had better grass, cover, and forbs than the two adjacent CRP fields. This hen hatched out 10 chicks. When flushed 14 days after her brood hatched, she had no chicks. We speculate that they died as a result of the scarcity of insects. She later traveled north to another CRP field when cows were introduced to this area.

Bird 414 (Red Roof lek) nested in a sideoats CRP field. Her nest was predated by a skunk after ~8 days of incubation.

Regarding mortalities: of the 15 birds in Colorado and the three Cimarron birds near Elkhart, KS, five birds were predated by raptors during the lekking season at the height of raptor migration. (The three Cimarron birds were initially captured in spring 2012 along with three other LEPC that died prior to the 2013 lekking season). Since that time, we have searched for a mortality approximately every three weeks. All mortalities since spring have apparently been caused by mammals: at least two predations by swift fox and one by coyote with the rest unknown. We had one mortality in early spring that may have been a fence collision. The LEPC had been fed on by birds but was found under a barbed wire fence (but with no feathers on the fence itself). So far, the survival rate has been similar between the two KS field sites and Colorado.

Colorado Division of Parks and Wildlife
September 2012-September 2013

WILDLIFE RESEARCH REPORT

State of:	Colorado	: Division of Parks and Wildlife
Cost Center:	3420	: Avian Research
Work Package:	0663	: Terrestrial Species Conservation
Task No.:	N/A	: Development of distribution models for management of greater sage-grouse in North Park Colorado
Federal Aid Project No.	N/A	

Period Covered: September 1, 2012 – August 31, 2013

Author: M. B. Rice

Personnel: A. Apa, L. Rossi

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

Rangewide population declines of greater sage-grouse (*Centrocercus urophasianus*) (GRSG) and energy development within sagebrush habitat has led to concern for conservation of GRSG populations across Colorado, including in North Park, which supports approximately 20% of the state's total GRSG. Seasonal variations in habitat use by GRSG can provide important information for biologists and managers on the ground. Seasonal GRSG distribution has been mapped at the statewide level, but not with local-scale data for the North Park population. GRSG habitat use is known to be influenced by both landscape-scale factors, such as extent of sagebrush habitat and topography, and by local factors, however, the relative importance of local vs. landscape scale variables in habitat selection remains unknown. We used telemetry data collected from April 2010-February 2012 to map habitat specific to the North Park GRSG population. Almost 4,000 locations were used to map breeding, winter, and summer habitat using a logistic regression in program R. Variables were chosen based on vegetation, topography, and oil/road development across North Park. The resulting maps for each season have not been validated and are in their initial assessment phase. All three seasonal models indicate a high probability of GRSG presence in areas where they currently reside. The breeding and winter models tend to be more similar, focusing on large expanses of sagebrush and little to no probability of presence in riparian areas. The summer model indicates more use of riparian areas and a more scattered high probability surface. As oil and gas development and other landscape changes occur in this portion of Colorado, it will become more critical to know where management and restoration actions can be most effective. These seasonal models provide data-driven, defensible distribution maps that managers and biologists can use for identification and exploration when investigating GRSG issues specific to North Park.

WILDLIFE RESEARCH REPORT

DEVELOPMENT OF DISTRIBUTION MODELS FOR MANAGEMENT OF GREATER SAGE-GROUSE IN NORTH PARK COLORADO

MINDY B. RICE

PROJECT OBJECTIVES

The goal of this study is to obtain detailed, current information on GRSG seasonal habitat use in North Park, Colorado based on new telemetry data and compare to the current statewide modeling previous completed (Rice et al. 2012).

SEGMENT OBJECTIVES

1. Produce models to predict the seasonal probability of GRSG presence in North Park, Colorado, using GRSG telemetry locations and environmental variables.
2. Compare the new North Park models to the recently completed northwest Colorado GRSG range map and determine the ability to update this population on the map.

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, 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 seven active GRSG leks as well as two active leks adjacent to the EOG RED project area. Colorado 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. GRSG 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. Current Colorado Parks and Wildlife (CPW) GRSG distribution models for North Park are based on broad vegetation features and virtually all of North Park is shown to be priority GRSG habitat (Fig. 1), so there is interest in more detailed data specific to the North Park population (Rice et al. 2012). 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 specific to this population.

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 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 potentially little impact to GRSG populations, thereby reducing costs of planning and mitigation. Conversely, fixed lek 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 critical 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. There are six major populations of GRSG in Northwestern Colorado including the North Park, Middle Park, Meeker/White River, North Eagle/South Routt, Northwest, and Parachute/Piceance/Roan populations (Fig. 1). Prior to this study, there were almost 20,000 GRSG telemetry locations in Northwestern Colorado, but none of those locations were in North Park. Recently, a North Park specific telemetry study was completed in order to investigate the habitat use for birds specific to this population. The newly collected telemetry data will allow us to analyze the seasonal habitat use of GRSG specifically in the North Park range for more effective management in that area.

STUDY AREA

The study area is located within the North Park population of greater sage-grouse in Jackson County in Northwestern Colorado (Fig. 2).

METHODS

Data Layers

A total of 3,985 locations from GRSG in North Park were collected from April 2010 until February 2012 from 95 birds radio-marked during the first year and 22 additional birds in the second year. Locations were recorded during breeding (April – July 15, 1,480 locations), summer (July 16-September, 874 locations), and winter (October-March, 1,631 locations) seasons.

Average movements for each individual were calculated and averaged over all the birds in each season (Table 1). The average weekly movement for each season was used to buffer all presence locations. We randomly generated a sample of 5000 “available” locations which were not allowed to overlap the presence locations. We utilized the average weekly movement for each season to buffer all presence and available locations within each season. All data was summarized within these buffered locations.

Vegetation classification was obtained from the basinwide vegetation layer and was classified according to biologically meaningful groupings resulting in 15 vegetation groups (Table 2). We obtained elevation and aspect data from the USGS digital elevation model. We calculated the topographic position index as a variable to measure roughness across the landscape according to Sappington et al. (2007). We used the national hydrography dataset to measure the average distance to perennial water sources as well as the density of water within each buffer.

Due to the lack of digital transportation data in Jackson County, Colorado, we needed to create a database of historical road networks versus roads created for energy development purposes. From the Colorado Department of Transportation (CDOT), we were able to obtain shapefiles with existing highways, major county roads, and local roads, however, the remaining road data (oil and gas roads, ranch roads, unnamed county roads, etc.) would need to be digitized by hand with the assistance of hard copy maps and digital topographic maps (USGS, ESRI, National Geographic Society 2011, Google Earth 1999-2013). With the existing maps at hand, we used ArcGIS 10.0 to digitize existing roads in Jackson County and created a ranking system for each road that would separate historical roads (highways, county roads, ranch roads, less maintained roads, etc.) from roads that have been created specifically for oil and gas production (Table 3).

In order to determine which roads should be classified as oil and gas roads, we obtained historical digital well pad locations from the Colorado Oil and Gas Conservation Commission's (COGCC) website as a shapefile. In all, there were 677 historical oil and gas wells in Jackson County; some are currently producing, while others have been abandoned for decades (Table 4). With these well pad coordinates, we identified which roads were leading towards oil fields and/or oil wells and were thus classified as roads created for the purpose of oil and gas production. Roads that are not specifically meant for energy development were also categorized, such as highways, named major county roads, local maintained roads (unnamed), and unknown roads and railroads.

To investigate impacts that oil/gas development might have on GRSG in North Park, we created a layer including data from the Colorado Oil and Gas Conservation Commission's website for each individual well. A shapefile was obtained from the COGCC website which outlined locations for wells, ownership, and well ID information. The next step was to determine historical dates for all 677 wells from the COGCC website including well status, spud date, completion date, first production date, last production date, and expiration date.

We measured the nearest distance from each presence and available location to each road and oil well, as well as the density of oil wells (wells/acre) and the density of roads (km/km^2) within the buffers. This resulted in four variables added to the model to investigate possible human effects on GRSG in North Park.

Use Versus Nonuse Dataset

IWe created a grid layer of 1-km^2 cells across the study area (Fig. 3), and then selected individual grid cells based on a spatially balanced random sample in which we would search for GRSG use or non-use. During the breeding season, the use grid cells were associated with the locations of GRGS nests across the area. Next, an equal number of grid cells was selected from the spatially balanced random sample and each cell was searched for sign, sightings, telemetry locations, or other indications of GRSG activity within the cell. If there was evidence of use found, the grid was placed in the "use" category. If no evidence of use was found, it was placed in the "nonuse" category. We cannot determine completely whether there was not use in a specific grid cell, but attempting to detect or not detect activity may increase our ability to describe GRSG habitat use in the area. The process was repeated during the winter season except that "use" during the winter was based on a telemetry location rather than a nest.

We investigated oil well and road effects in a separate analysis. We used a *t*-test to compare use versus non-use grid cells in the breeding and the winter season separately. We included all roads, highways, county roads, rural roads, and oil roads for both the average distance (m) to roads for each grid cell as well as the density of each type within the grid cell (km/km^2). For the oil well analysis, we measured both the average distance within the grid cell as well as the density (wells/acre) of active wells, inactive wells, and all wells (see activity in Table 4). Only comparisons that were considered significantly different were included in the breeding or winter season models below.

Model Building

Due to the large number of variables included in the analysis, we wanted to reduce the number included in the modeling process to avoid spurious effects. We first calculated Pearson correlation coefficients and removed all variables that had a correlation > 0.6. The variable with the least amount of support was removed. We also removed those variables that had zero proportion in either the presence or available buffers. This applied to residential and bitterbrush categories in all seasons. Finally, only variables found to be significantly different between the means of the presence and absence buffers in each season were used. We repeated this process for each season, so variables in each season may be different. Those that were included in the final model building analysis are noted in Tables 6, 8, and 10.

All variables were centered which indicates that the mean of each variable was subtracted from all values in the dataset. We used a logistic generalized linear model with a logit link using program R. We ran a forward stepwise selection process in order to remove any other variables that could not explain the difference between presence and absence buffers.

The best model after forward selection was used to create a prediction surface in ArcMap 10.1. We applied the logistic equation in the following form to create the probability of GRSG presence across North Park:

$$w^*(x_i) = \frac{\exp\{\log_e(p_{un} / P_u) + b_0 + b_1 x_1 + \ldots + B_p x_{ip}}{1 + \exp\{\log_c(p_{un} / p_u) + B_0 + B_1 x_{i1} + \ldots + B_p x_{ip}}$$

Where observations i=1…η, β_0 is the mean intercept and and β_η are the estimates for covariates χ_{η}. The logistic function was used to create a probability of presence surface with values between 0 and 1 across the study area (1=high, 0=low).

RESULTS

GRSG in the North Park population tended to move more during the winter season and less during the summer season (Table 1). On average we were able to collect a telemetry location on each radio-marked GRSG every 12.5 days. In general, nest locations were closer to all road types except to highways and winter distances were closer in all categories compared to the non-use grids (Table 5). There were more significant differences in both distances and densities in the breeding season than in the winter season (Table 5). The only significantly different variable in the winter season was rural road distance (Table 5).

For the breeding season, variables that were significantly different between use and non-use categories included grass, bare, sagebrush/grass, aspen, forest, talus, alpine, riparian, herbaceous riparian, aspect, density of water, distance to all oil wells, distance to roads, and density of all roads (Table 6). Irrigated agriculture, distance to water, grass, alpine, and greasewood were removed due to correlation and bare, sagebrush/grass, talus, elevation, and oil well density were removed due to non-significance. The final variables included in the model building were sagebrush, aspen, forest, riparian, herbaceous riparian, distance to oil wells, distance to water, and aspect. Herbaceous riparian was removed during forward selection. The resulting averaged model indicated a negative relationship with aspen, forest, riparian, distance to oil, and aspect whereas there is a positive relationship with sagebrush and distance to water (Table 7). The breeding prediction surface indicates large areas with high probabilities of use except in the riparian areas (Fig. 4).

For the summer model, bare, sagebrush, sagebrush/grassland, aspen, forest, herbaceous riparian, tpi, aspect, elevation, and distance to water were significantly different (Table 8). Water density, irrigated agriculture, grassland, riparian, and greasewood were removed due to correlation. Talus, alpine, aspen, forest, and riparian were removed due to non-significance. Final variables included were bare, sagebrush, sagebrush/grassland, aspect, herbaceous riparian, tpi, elevation, and distance to water. Elevation was removed during the forward selection process (Table 9). The model indicated a positive relationship with bare, sagebrush, sagebrush/grassland, and herbaceous riparian and a negative relationship with tpi, aspect, and distance to water (Table 9). During the summer prediction surface, GRSG seem to move across more of the North Park area and utilize those riparian areas a bit more (Fig. 5).

Sagebrush, bare, sagebrush/grassland, riparian, herbaceous riparian, tpi, aspect, distance to water, and distance to all roads were significant during the winter (Table 10). Riparian, irrigated agriculture, grassland, riparian, and greasewood were removed due to correlation. Talus, alpine, aspen, forest, and riparian were removed due to non-significance. The variables included in the model were bare, sagebrush, riparian, aspen, herbaceous riparian, tpi, distance to roads, aspect, distance to water, elevation, and sagebrush/grassland. Elevation and sagebrush/grassland were removed during forward selection. The model shows a positive relationship with bare, sagebrush, and herbaceous riparian and a negative relationship with riparian, aspen, tpi, distance to roads, aspect, and distance to water (Table 11). During the winter, GRSG seem to have high probability of use in areas similar to the breeding season and do not use the riparian areas (Fig. 6).

DISCUSSION

This analysis was successful in identifying more detail for probability of habitat use for GRSG specific to the North Park study area. We were able to use more detailed variables to help explain habitat use across the population, allowing biologists and managers to directly address issues specific to the North Park GRSG population. The ability to make more informed decisions regarding development in areas considered higher probability of use by GRSG will greatly increase our ability to manage the population effectively.

The lack of significant effects of roads or oil wells during the winter season is unexpected. This result might be due to the heavy winter experienced by GRSG during the first winter in which most of the roads and possibly some oil wells would have been covered during the season. Although our models indicate GRSG nest closer to roads during the breeding season than non-used sites, all nests were >400 m from roads. Overall there were few significant effects of roads and/or oil wells on GRSG distribution in North Park, but this may be due to the relatively low level of development thus far in the region.

There was a positive association with sagebrush in all three models which is indicative of the GRSG life history. This effect was strongest during the winter season when GRSG are almost completely dependent on sagebrush. There was a large negative effect of aspen and forest in the breeding season which may be due to the use of sagebrush for nesting purposes. The major effects in the summer were a positive association with bare ground and a negative association with tpi. During the summer, GRSG are more likely to utilize other vegetation types and tend to be in the lower and less terrain areas of North Park. In the winter, there was a strong negative correlation with riparian and tpi as GRSG avoid areas that might collect snow.

The breeding and winter prediction maps indicate similar probability of use in North Park whereas the summer prediction surface is more scattered and goes into the riparian zones. Each of the seasonal models indicates a high probability of GRSG in areas currently populated. More detailed validation is necessary and will be completed as a next step in the analysis. Interestingly, it GRSG distribution appears to be more similar fashion between the winter and breeding seasons than in the summer. This could be due to the birds not reliant on a specific vegetation type during the summer and their use of the riparian areas during warm temperatures.

Problems associated with these resource selection methods include pseudo-absences whose absolute presence or absence is not known with certainty (Johnson et al. 2006), contamination and overlap in used and available locations (Johnson et al. 2006), and unequal sampling of the species range (Latimer et al. 2006). In addition, many methods for evaluating logistic regression model predictions are inappropriate for presence/available data because used sites are drawn directly from the distribution of available sites (Boyce et al. 2002). We attempted to alleviate some of these issues by directly sampling areas where no GRSG sign could be found and comparing that to areas where presence had been confirmed. This approach can help minimize the errors associated with pseudo-absences.

Analyses have not been completed and there have been some changes to variables that will eventually be used within the final models. For example, we have decided to separate active versus inactive oil wells as model variables. Other changes include reducing the number of vegetation categories based on biological needs of GRSG in North Park. In addition, we will explore analyses at finer scales such as using a daily movement buffer rather than the weekly buffer used in this present analysis. Finally, we conduct a validation using both leks as well as cross validation within the whole dataset to determine the success of our model predictions. Once these steps are complete, we will compare our more detailed North Park seasonal distribution maps to the overall Colorado GRSG mapping effort to assess the management value of more detailed analyses.

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Table 1. Movement statistics for North Park GRSG telemetry data from April 2010 to February 2012.

	Average movement (m)	Average days between locations	Movement per day (m)	Movement per week (m)
Overall	2170.42	12.55	172.94	1210.58
Breeding	1934.87	12.83	150.81	1055.67
Winter	3234.99	15.89	203.59	1425.13
Summer	883.95	10.64	83.08	581.56

Table 2. Vegetation classifications based on the basinwide vegetation layer.

Basinwide classification	Class used for North Park GRSG model
High density residential areas, lawns, planted trees.	residential
Irrigated crops and fields.	irrigated agriculture
Rangeland dominated by annual and perennial grasses.	grassland
Rangeland codominated by grasses and forbs.	grassland
Disturbed or overgrazed rangeland.	grassland
Sparsely vegetated grasslands, 10-40% vegetation.	bare ground
Sagebrush with rabbitbrush, bitterbrush.	sagebrush
Low elevation shrubland dominated by greasewood.	greasewood
Shrubland dominated by PUTR2 (Bitterbrush).	bitterbrush
Codominate sagebrush shrubland and perennial grassland.	sagebrush/grassland
Codominate sagebrush/Mesic Mtn shrub mixed with grass/forb.	sagebrush
Deciduous forest dominated by Aspen.	aspen
Codominate Aspen and Gambel oak deciduous woodland.	aspen
Coniferous forest dominated by PSME.	forest
Coniferous forest dominated by PICO.	forest
Coniferous forest dominated by PIFL.	forest
Coniferous forest co-dominated by PICO, PIEN, and ABCO.	forest
Mixed forest codominated by Aspen and PICO.	forest
Talus and scree slopes, nearly 100% rock.	talus
Bare soil and fallow agriculture fields.	bare
High elevation meadows co-dominated by grass and forbs	alpine
Shrub riparian areas consisting primarily of shrub willows.	riparian
Shrub riparian areas dominated by shrub willow species.	riparian
Non-woody riparian areas consisting primarily of sedges.	herbaceous riparian
Lakes, reservoirs, rivers, streams.	water

Table 3. Definitions of the different road classes used in the North Park analysis.

Road Ranking	Road Type	Definition
0	**Unknown road**	A road that could not be confidently labeled as #1-3 roads. Usually, these consist of long, straight roads acting as "short-cuts," however, there is no historical record of them from any source.
1	**COGCC Roads**	Clearly an oil and gas road because it leads straight to an oil well, or to an oil well complex (it may branch off of a #3 or #2 road to get to the oil complex). Some of these roads are marked as "double-hatched" roads on paper and digital topographic maps because they are historical COGCC roads.
2	**UNNAMED Local Maintained Roads**	This is a UNNAMED county road that **can easily be seen from imagery** (1:10,000) and may cut in between named major roads, lead to residential areas, ranches, reservoirs, hayfields, etc. They are often noted as a "double hatched" roads from hardcopy and digital topography maps. Note: These roads are **NOT two-track roads (**usually 1:3,000 is needed to see two-tracks).
3	**NAMED Major Road**	Clearly a major county road, as named by CDOT (see shapefile) and/or from topographic maps, google maps, or paper maps. This includes NAMED county roads, and **excludes highways**
4	**Highways**	Major highways, such as HWY 14, HWY 125, etc. as named by CDOT. This does not include other potential "black top" roads, only highways.
5	**Railroad**	A railroad

Table 4. Status of wells from the Colorado Oil and Gas Commission list of oil wells located in the North Park Study area.

Status	Name	# of wells	Definition	Activity
PR	Producing	119	currently producing oil, gas, and/or water	active
DA	Dry and Abandoned	232	well is no longer productive and was abandoned	inactive
PA	Permanently abandoned	146	well was permanently plugged and abandoned	inactive
AL	Abandoned Location	82	well was abandoned	inactive
IJ	Injection Well	39	a well used for pumping water or gas into reservoir	active
XX	Proposed location	30	a new or proposed location	on hold
SI	Shut-in well	25	a well capable of producing, but not currently	on hold
DG	Drilling	3	a well being used with rigs and crews	active
WO	Waiting on completion	1	status undetermined and waiting	on hold

Table 5. Oil and road data analysis for the grids surveyed for GRSG presence in both the breeding and winter seasons.

	Nest	Nonnest	ttest	p-value	Winter	Nonwinter	ttest	p-value
highway distance	23375.7400	20272.3900	1.4454	0.1498	15584.0900	18952.8400	-0.9541	0.3440
county road distance	4301.4200	5059.6800	-1.3617	0.1747	3844.3000	4598.5700	-0.7954	0.4295
rural road distance	2495.2800	3479.4900	-3.0874	0.0023	2429.1900	3825.3900	-2.0174	0.0491
oil road distance	8975.1900	9405.9800	-0.3854	0.7004	8163.6000	8689.3400	-0.3547	0.7241
all road distance	403.2500	634.8400	-4.0854	0.0001	451.1600	608.3700	-1.3592	0.1797
highway density	0.0309	0.0646	-2.4438	0.0154	0.0922	0.0616	0.9615	0.3404
county road density	0.3115	0.2642	1.3105	0.1914	0.2761	0.3112	-0.5696	0.5711
rural road density	0.5226	0.3856	2.8628	0.0046	0.4075	0.3433	0.8691	0.3883
oil road density	0.2950	0.1120	2.5912	0.0108	0.0728	0.2734	-1.2750	0.2109
all road density	1.0676	0.6953	3.4110	0.0008	0.8223	0.9800	-0.6562	0.5145
distance to oil wells	1678.9400	2084.4600	-2.2249	0.0271	2055.6500	2189.2800	-0.4033	0.6881
dist to active oil wells	3949.6600	4883.8500	-2.1041	0.0370	5937.0100	4730.9700	1.4798	0.1451
dist to inactive oil wells	1689.4000	2110.8500	-2.3259	0.0210	2056.1400	2200.1400	-0.4351	0.6650
density of oil wells	0.0026	0.0008	2.6847	0.0083	0.0004	0.0028	-1.4644	0.1524
density active oil wells	0.0013	0.0002	2.2752	0.0255	0.0001	0.0022	-1.2946	0.2064
density inactive oil wells	0.0015	0.0007	2.6222	0.0096	0.0004	0.0014	-1.6229	0.1137

Table 6. List of variables originally included in the North Park GRSG breeding model.

	Variable	presence mean	available mean	t-test	p-value	included in model building
Vegetation						
	Residential	0.0000	0.0000	NA	NA	no
	Irrigated agriculture	0.0571	0.1219	12.36	0.000	no
	Grass	0.0471	0.0833	13.45	0.000	no
	Bare	0.0134	0.0128	0.708	0.479	yes
	Sagebrush	0.7419	0.6277	12.57	0.000	yes
	Greasewood	0.0011	0.0015	1.251	0.211	no
	Bitterbrush	0.0000	0.0002	1.55	0.122	no
	Sagebrush/grass	0.1032	0.0992	1.35	0.179	yes
	Aspen	0.0026	0.0098	6.76	0.000	yes
	Forest	0.0026	0.0076	5.40	0.000	yes
	Talus	0.0004	0.0005	0.77	0.439	yes
	Alpine	0.0001	0.0006	4.84	0.000	yes
	Riparian	0.0084	0.0154	9.13	0.000	yes
	Herbaceous riparian	0.0072	0.0096	1.83	0.068	yes
	Water	0.0149	0.0098	3.01	0.003	no
Topography						
	TPI	0.0025	0.0027	1.86	0.063	no
	Elevation	2512.63	2514.80	1.13	0.257	no
	Aspect	173.40	176.54	3.27	0.001	yes
	Distance to water	259.86	233.91	5.88	0.000	no
	Density of water	1.617	1.912	9.34	0.000	yes
Human elements						
	Distance to oil well	1790.57	1926.48	2.94	0.003	yes
	Distance to roads	399.56	516.82	7.83	0.000	yes
	Density of oil wells (wells per acre)	0.5120	0.5510	0.66	0.509	no
	Density of roads (km/km^2)	572.36	472.49	7.22	0.000	yes

Table 7. Coefficients used in the breeding season model for North Park.

Variable	Estimate	SE	z-value	p value
Intercept	-0.038	0.039	-0.993	0.321
Aspen	-8.423	2.930	-2.875	0.004
Sage	1.482	0.203	7.295	0.000
Forest	-4.37	2.741	-1.594	0.111
Riparian	-4.160	2.368	-1.757	0.079
Distance to oil	-0.094	0.031	-3.062	0.002
Aspect	-0.009	0.002	-5.530	0.000
Distance to water	0.898	0.346	2.595	0.009

Table 8. List of variables originally included in the North Park sage grouse summer model.

	Variable	presence mean	available mean	t-test	p-value	included in model building
Vegetation						
	Residential	0.0000	0.0002	1.02	0.310	no
	Irrigated agriculture	0.1677	0.1659	-0.173	0.863	no
	Grass	0.1129	0.0996	-2.589	0.010	no
	Bare	0.0168	0.0100	-6.09	0.000	yes
	Sagebrush	0.5130	0.5801	4.694	0.000	yes
	Greasewood	0.0024	0.0017	-0.90	0.368	no
	Bitterbrush	0.0000	0.0000	NA	NA	no
	Sagebrush/grass	0.1209	0.0975	-4.79	0.000	yes
	Aspen	0.0032	0.0042	1.26	0.209	yes
	Forest	0.0019	0.0022	0.886	0.376	yes
	Talus	0.0002	0.0003	1.652	0.099	no
	Alpine	0.0001	0.0001	0.0954	0.924	no
	Riparian	0.0237	0.0216	-1.16	0.248	no
	Herbaceous riparian	0.0253	0.0112	-4.34	0.000	yes
	Water	0.0120	0.0055	-3.67	0.000	no
Topography						
	TPI	0.0017	0.0025	7.95	0.000	yes
	Elevation	2500.57	2510.14	3.87	0.000	yes
	Aspect	174.75	177.25	1.70	0.089	yes
	Distance to water	187.10	216.73	4.704	0.000	yes
	Density of water	2.395	2.088	-5.909	0.000	no

Table 9. Coefficients used in the summer seasonal model for North Park.

Variable	Estimate	SE	z-value	p-value
Intercept	0.0017	0.050	0.033	0.973
Bare	12.20	2.386	5.114	0.000
Sage	0.024	0.019	1.256	0.209
Sage/grass	3.043	0.572	5.321	0.000
Herbaceous riparian	3.226	0.893	3.612	0.000
Tpi	-218.3	28.32	-7.708	0.000
Aspect	-0.0037	0.0017	-2.240	0.025
Distance to water	-0.0016	0.0004	-3.533	0.0004

Table 10. List of variables originally included in the North Park GRSG winter model.

	Variable	presence mean	available mean	t-test	p-value	included in model building
Vegetation						
	Residential	0.0000	0.0002	1.88	0.061	no
	Irrigated agriculture	0.0875	0.1581	12.98	0.000	no
	Grass	0.0633	0.0940	11.66	0.000	no
	Bare	0.0149	0.0113	-5.10	0.000	yes
	Sagebrush	0.6761	0.5849	-10.79	0.000	yes
	Greasewood	0.0084	0.0014	-9.18	0.000	no
	Bitterbrush	0.0000	0.0005	2.87	0.004	no
	Sagebrush/grass	0.0928	0.0975	2.10	0.036	no
	Aspen	0.0018	0.0069	8.77	0.000	yes
	Forest	0.0014	0.0062	8.26	0.000	no
	Talus	0.0003	0.0005	3.23	0.001	no
	Alpine	0.0001	0.0004	5.71	0.000	no
	Riparian	0.0103	0.0208	12.06	0.000	yes
	Herbaceous riparian	0.0258	0.0084	-9.87	0.000	yes
	Water	0.0173	0.0093	-6.35	0.000	no
Topography						
	TPI	0.0022	0.0025	4.95	0.000	yes
	Elevation	2503.47	2513.05	5.68	0.000	no
	Aspect	177.47	177.75	0.36	0.716	yes
	Distance to water	220.78	229.49	2.67	0.007	yes
	Density of water	1.964	2.043	2.67	0.008	no
Human elements						
	Distance to roads	458.74	491.85	3.25	0.001	yes

Table 11. Coefficients used in the winter seasonal model for North Park.

Variable	estimate	SE	z value	pvalue
Intercept	-0.0168	0.038	-0.433	0.6649
Bare	10.87	2.061	5.274	0.0000
Sage	2.131	0.234	9.092	0.0000
Riparian	-13.04	2.685	-4.858	0.0000
Aspen	-9.176	4.055	-2.263	0.0240
Herbaceous riparian	8.750	1.121	7.809	0.0000
Tpi	-151.9	26.05	-5.830	0.0000
Distance to roads	-0.0002	0.0001	-1.492	0.1357
Aspect	-0.0044	0.0018	-2.471	0.0135
Distance to water	-0.0030	0.00046	-6.504	0.0000

Figure 1. PPH/PPG map for Greater sage-grouse across their range in Colorado.

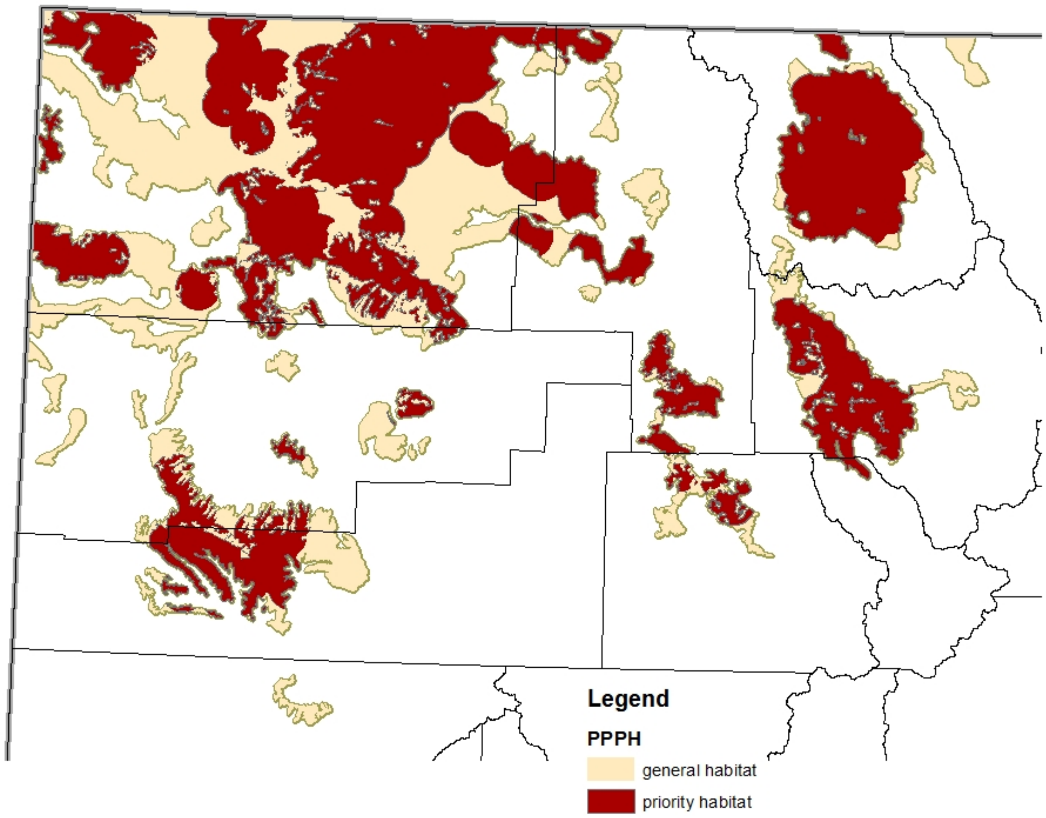


Figure 2. North Park Study area.

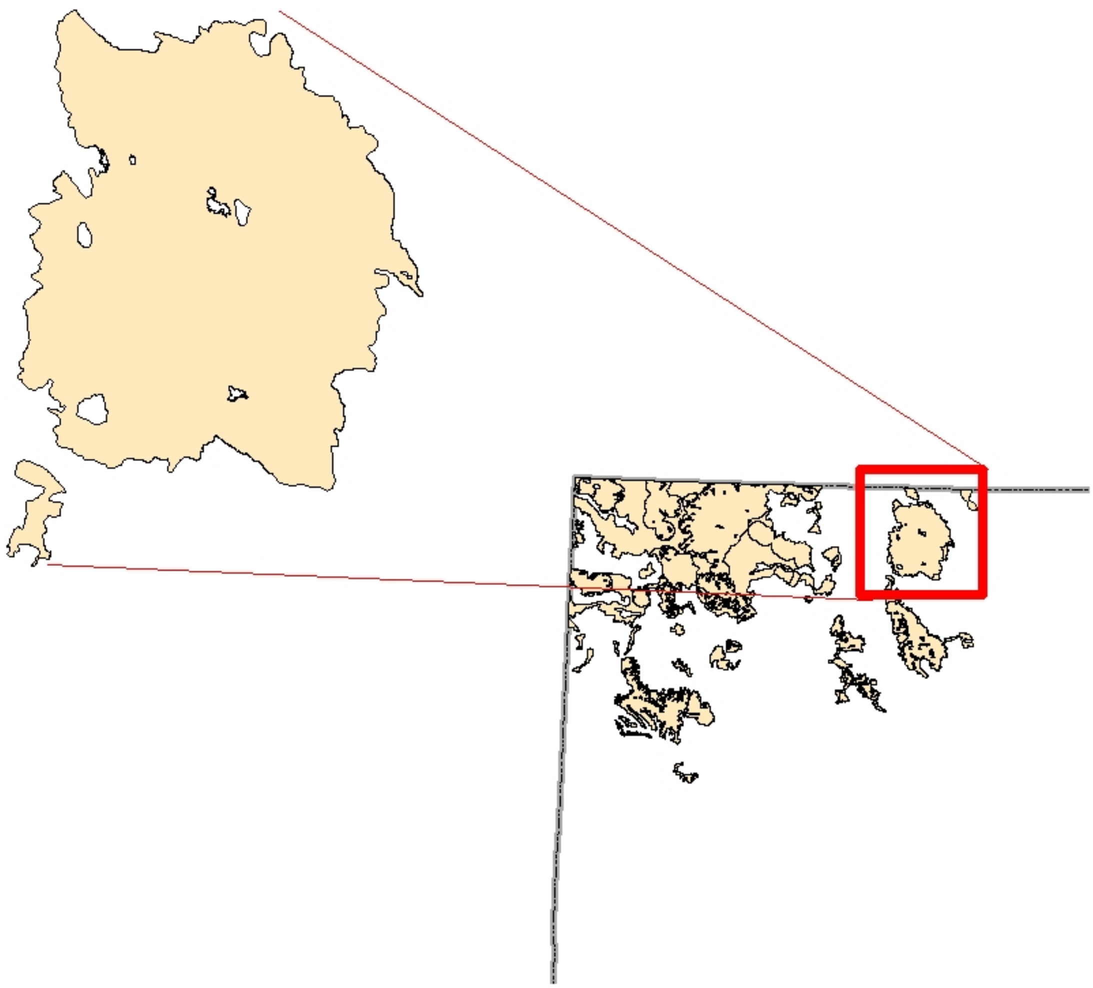


Figure 3. Nest, non-nest, winter, and non-winter grid locations where vegetation and “use” was determined based on GRSG sign.

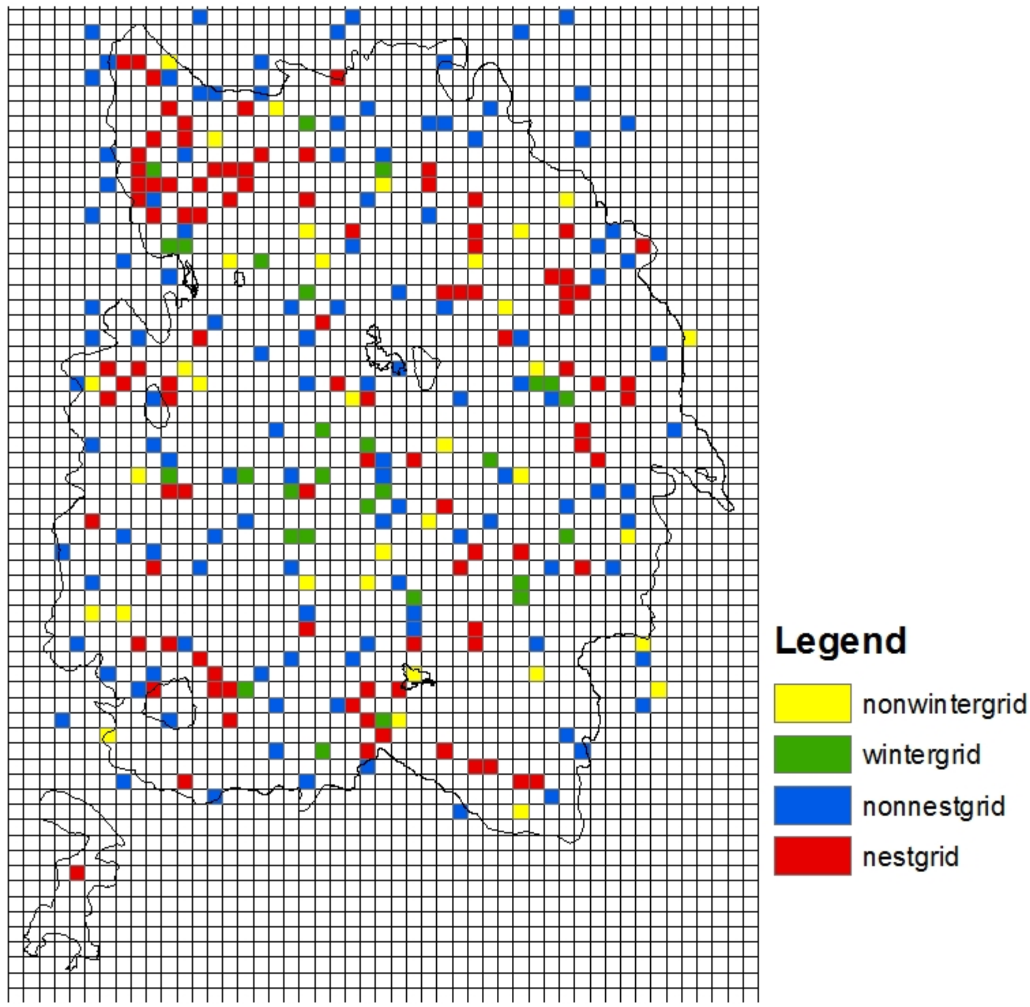


Figure4. Probability of GRSG presence during the breeding season in North Park.

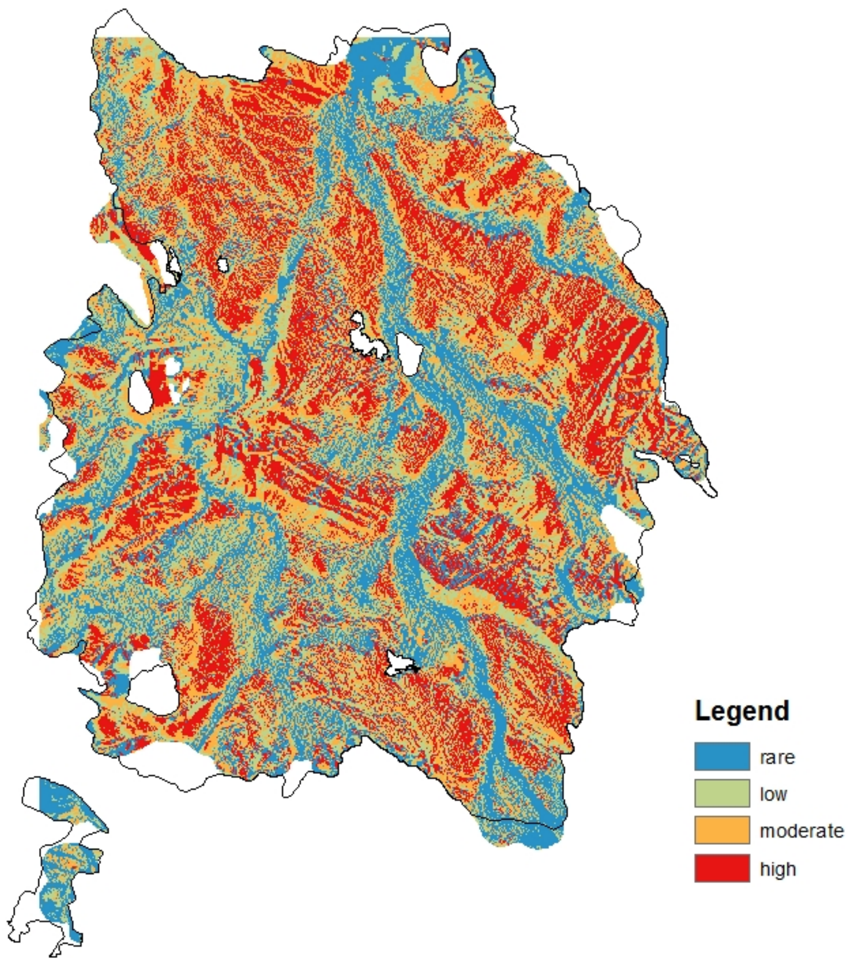
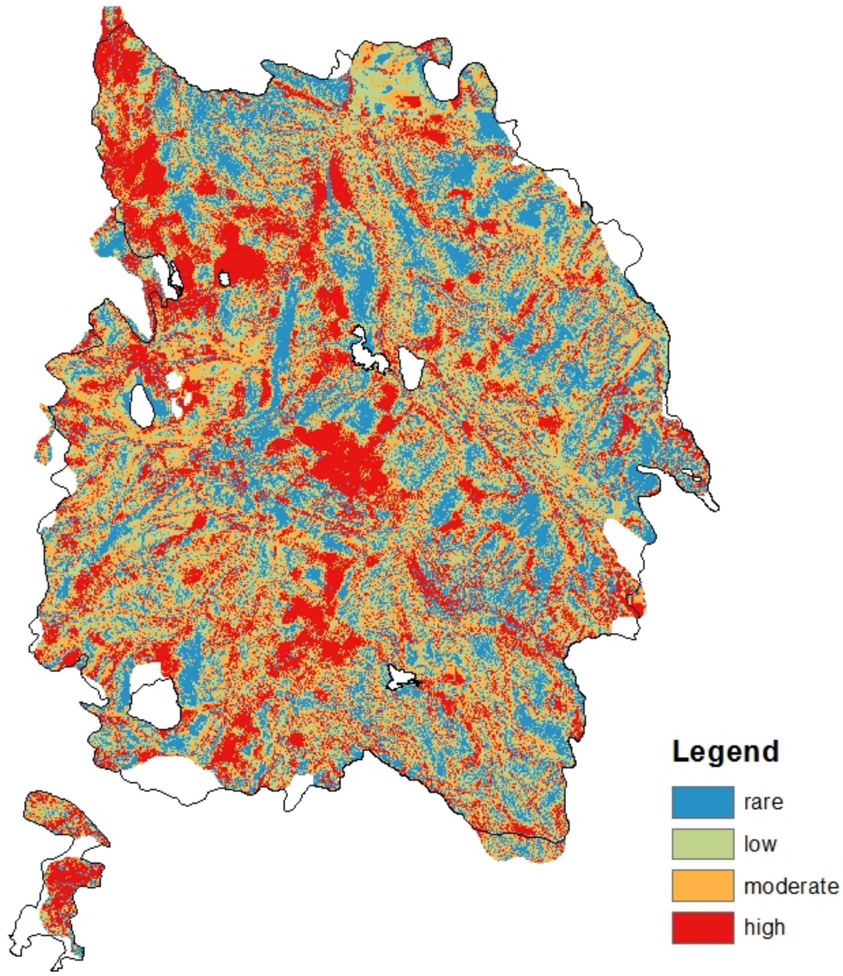


Figure 5. Probability of GRSG presence during the summer season in North Park.



Colorado Division of Parks and Wildlife
September 2012-September 2013

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of Parks and Wildlife
Cost Center:	3420	:	Avian Research
Work Package:	0660	:	Greater Sage-grouse Conservation
Task No.:	N/A	:	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

Federal Aid
Project No. N/A

Period Covered: September 1, 2012 – August 31, 2013

Author: B. L. Walker

Personnel: B. Holmes, B. Petch, B. deVergie

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

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. 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. Lek locations are also commonly used to identify and protect important sage-grouse habitat. However, the use of lek counts and lek locations to monitor and manage sage-grouse populations remains controversial because it is unknown how closely lek-count data track actual changes in male abundance from year to year, or if lek buffers are effective at reducing disturbance to male sage-grouse and their habitat during the breeding season. Colorado Parks and Wildlife is color-banding and deploying solar-powered 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. These data will allow us to evaluate whether GPS transmitters have an impact on males, whether current lek-based monitoring methods provide reliable information about sage-grouse population trends, and whether current lek buffers are effective for conserving greater sage-grouse. Field crews captured and deployed GPS transmitters on a total of 34 non-juvenile (yearling or adult) males from Oct-Dec 2012 and on 23 juvenile and 3 adult males from February-March 2013. We documented instances in which birds' back feathers covered the solar panels on GPS transmitters and caused transmitters to fail. This problem necessitated improvements in transmitter design in fall 2012. Location data from GPS males facilitated the discovery of 3 new leks in 2011, 2 new leks in 2012, and 4 new leks in 2013. In spring 2013, field crews conducted

157 standard lek counts at 34 leks, 63 mornings of resighting on 16 different leks, 113 unreconciled double-observer counts at 28 leks, and 80 paired display rate observations on GPS and non-GPS males. Problems with color-band retention first observed in spring 2012 were widespread by spring 2013 and precluded mark-resight analyses to compare color-banded vs. GPS male survival. There were 37 GPS males still transmitting as of 1 September 2013 that will be monitored through spring 2014 to obtain data on lek attendance and within and between-year inter-lek movements and fidelity.

COLORADO PARKS AND WILDLIFE RESEARCH REPORT

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

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 deploy GPS transmitters on non-juvenile (adult or yearling) males in fall 2012 to maintain sample sizes for spring 2013.
2. Capture and deploy GPS transmitters on 30 juvenile males in Feb-Mar 2013.
3. Locate, verify, and count new leks confirmed during the 2011, 2012, and 2013 breeding seasons.
4. Collect data on local factors influencing lek attendance of GPS males
5. Resight color-banded and GPS males at leks attended by GPS males.
6. Conduct standard lek-counts and unreconciled double-observer counts at leks
7. Enter and proof spring 2013 field data.

INTRODUCTION

Greater sage-grouse (*Centrocercus urophasianus*) are a 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 Wildlife, 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

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 an individual 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, we need daily and annual estimates of the proportion of males alive over the course of the breeding season, the proportion of those males present in the study area, the proportion of males attending leks, the proportion of males detected on lek counts, 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

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.

Testing GPS Transmitters

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 contiguous with 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. At the start of the project in fall 2010, there were nine known leks within the study area plus 13 more immediately adjacent to the study area. 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

Most males are 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). A small number males trapped early in the breeding season are used to estimate inter-lek movements and habitat use around leks. Trapping effort and GPS unit deployment 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 and on 30 yearling male sage-grouse in February each year. 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 and 30 yearling male sage-grouse in February each year. 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 followed standard operating procedures established for sage-grouse (Appendix A), with two exceptions: we were approved to use Super Talon® and MagNet® hand-held net guns for captures, and decisions about whether injured birds should be released or euthanized was made in the field (rather than transporting the bird to a rehabilitation center) because no known rehabilitators in Colorado currently have the facilities to care for wild sage-grouse. We used night-time spotlighting and hoop-netting (Wakkinen 1992) or hand-held net guns for all captures. 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 used a rump-mount attachment for GPS transmitters based on the method B design described in Bedrosian and Craighead (2007) modified for sage-grouse (Fig. 2). Transmitters were manufactured with a medium-brown, sand-textured finish to reduce reflected light. A thin layer of neoprene (either 0.125 in. or 0.25 in. thick) was glued to the bottom side of the transmitter to ensure that contact between the transmitter material and the bird's lower back was padded and insulated. Harness material was 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 was sewn into the center of a 75-cm (36-inch) length of Teflon ribbon such that 4-6 cm of stretchy Teflon ribbon extended 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 were sewn with more elastic (16 cm) to accommodate possible increases in body size over time. In fall 2012, we documented that transmitters sometimes failed when back feathers near the front and sides of the transmitter covered the solar panel prevented the transmitter from charging and transmitting. This led us to develop an improved design with thicker neoprene (1/4") to raise the units higher off the back and with longer and wider neoprene padding under the front half of the transmitter to prevent feathers from covering the solar panel (Fig. 3). The transmitter sides, front, and back were painted with brown, tan, black, and white camouflage to decrease visibility to predators (Fig. 4). Harnesses were fit with birds held in a standing position in fall 2010, but in spring 2011 we switched to holding birds on their sides to improve our ability to correctly fit the harness. Transmitters were 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. 4). Harnesses were fit down, around, and underneath the legs and attached to the rear loop of the transmitter 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 were also marked with black ink before release to reduce reflected light. The Teflon ribbon is trimmed at an angle and left with just enough excess ribbon on each side (~3 cm) to allow us to refit or enlarge the harness if necessary. 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 was successfully used with rump-mount transmitters on female sage-grouse for >36 months without breaking or deteriorating. The life of the elastic cord is unknown. Transmitters were fitted just snugly enough to prevent birds from dropping transmitters.

The GPS transmitters units were 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 were 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 were 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. We did not remove or replace GPS transmitters unless there was an indication of transmitter failure or incorrect fit. GPS transmitters recovered from mortalities were cleaned and re-deployed on additional males to maximize sample sizes and reduce the cost of transmitters. Brett Walker was trained in the initial 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. Raw text files are then parsed using "DSDCODE" software provided by Northstar Science and Technology. This software automatically amends new locations from GPS birds to an ArcGIS shapefile for each individual. I amended the parsed data (in .dbf format) to an existing Microsoft Excel® spreadsheet of GPS bird locations and removed duplicate records, flagged date and location errors, and identified records signifying important events (e.g., mortality).

Lek and Lek Attendance Definitions

I defined 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 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

CDOW 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 CDOW 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 CDOW 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.

In winter and spring 2012, we discovered that color-bands older than one year were deteriorating and either expanding and sliding down over the metal band or breaking and falling off. Field crews conducting resighting at leks in spring 2012 reported numerous cases of incomplete or incorrect band combinations caused by color-bands breaking and falling off or expanding and slipping down over metal bands. Even more males with incorrect band combinations were recorded on leks in spring 2013. It was logistically impossible to recapture all previously color-banded males, and we wouldn't have been able to capture sufficient numbers of new males in fall 2012 to estimate differences in return rates or survival. For that reason, we opted not to mark a separate sample of color-banded only males in fall 2012 or spring 2013 and instead marked all males with color-bands and GPS transmitters.

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 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, which in most cases precludes determining proximate cause of death.

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.

Several males with GPS transmitters disappeared without any evidence of mortality in 2011-2012. In some cases, we documented that transmitters had failed due to feathers on the bird's back covering the solar panel on the transmitter (i.e., males with covered transmitters were recaptured and transmitters were removed and tested). In other cases, it was unclear whether transmitters had failed, whether the transmitters were destroyed or lost power following mortality, or whether the transmitters slipped and failed to transmit their last location. Because random censoring is an assumption of survival analysis, we attached miniature VHF mortality transmitters (Advanced Telemetry Systems, Model A2720, Isanti, MN) underneath all GPS transmitters starting in fall 2012 to test whether GPS males whose transmitters stopped transmitting data were alive or dead (Fig. 3).

Objective 1b: Leg-loop size comparison – Leg loops were 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 was 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 no. 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: $\text{northing}_{\text{male}} = \text{northing}_{\text{observer}} + \cos(\theta) * \text{distance}$ and $\text{easting}_{\text{male}} = \text{easting}_{\text{observer}} + \sin(\theta) * \text{distance}$. 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 CDOW 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, color-banded, and deployed GPS transmitters on a total of 34 non-juvenile (i.e., adult or yearling) male greater sage-grouse from Oct-Dec 2012 and 23 juvenile males from Feb-Mar 2013 within or adjacent to the Hiawatha Regional Energy Development boundary. Three additional adult males were deployed with GPS transmitter at the start of the breeding season in early April, for a total of 57 males captured and marked prior to or during the 2013 breeding season.

As of 31 Aug 2013, 37 GPS males were still alive with functioning transmitters. These males will be monitored through spring 2014 to obtain data on lek attendance and within and between-year inter-lek movements and fidelity.

Males whose status could not be determined may have: (1) died and their transmitters destroyed before transmitting the location of the mortality, (2) lived but their transmitters slipped off face down and could not charge and transmit their last location, (3) lived but the transmitters failed due to malfunction or defect, or (4) lived but the transmitters failed because back feathers covered the solar panels and prevented the unit from charging and transmitting. We confirmed that feathers covering the solar panel were a significant factor in transmitter failure using our original transmitter design (Fig. 2) in fall 2012. We recaptured a GPS male that had been missing for >6 months whose back feathers were covering the

GPS transmitter. When the transmitter was removed and charged, it immediately resumed transmitting. For that reason, we implemented an improved transmitter design in fall 2012 to keep back feathers in front and on the sides of the transmitter from covering the solar panel (Fig. 3).

I monitored the locations of all GPS males every three days throughout the spring breeding season in 2013 (11 March – May 23) to examine: (a) locations of potential new leks for crews to check, (b) each male's status (alive or dead), (c) which males remained within the study area, (d) which males were attending leks, (e) which leks they attended, (f) inter-lek movements, and (g) nocturnal and diurnal habitat use around leks.

Field crews checked numerous potential lek locations and located, verified, and counted four previously unknown leks in 2013 (Carson Springs East, Dry Ridge, Eagle Rock Draw, East Potter Mountain; Fig. 1). Crews also confirmed strutting at all three leks discovered in 2011 (North Kinney Rim, Owl Bench 2, and Central Sand Wash) and at both leks discovered in 2012 (North Scrivner and Cow Creek Reservoir).

Field crews conducted standard lek counts, unreconciled double-observer counts, and resighting at leks from 19 March through 23 May 2013. This effort resulted in 49 standard counts at 14 leks in Colorado, 108 standard counts at 20 leks in Wyoming, 63 mornings of resighting on 16 different leks, 113 unreconciled double-observer counts at 28 leks, and 80 paired display rate observations. Field crews entered and proofed all field data by 30 June 2013.

A cursory review of location data suggests that yearling males started attending leks later in the season, moved significantly further, and visited more leks during the breeding season than adult males, but further analysis is needed to quantify these differences.

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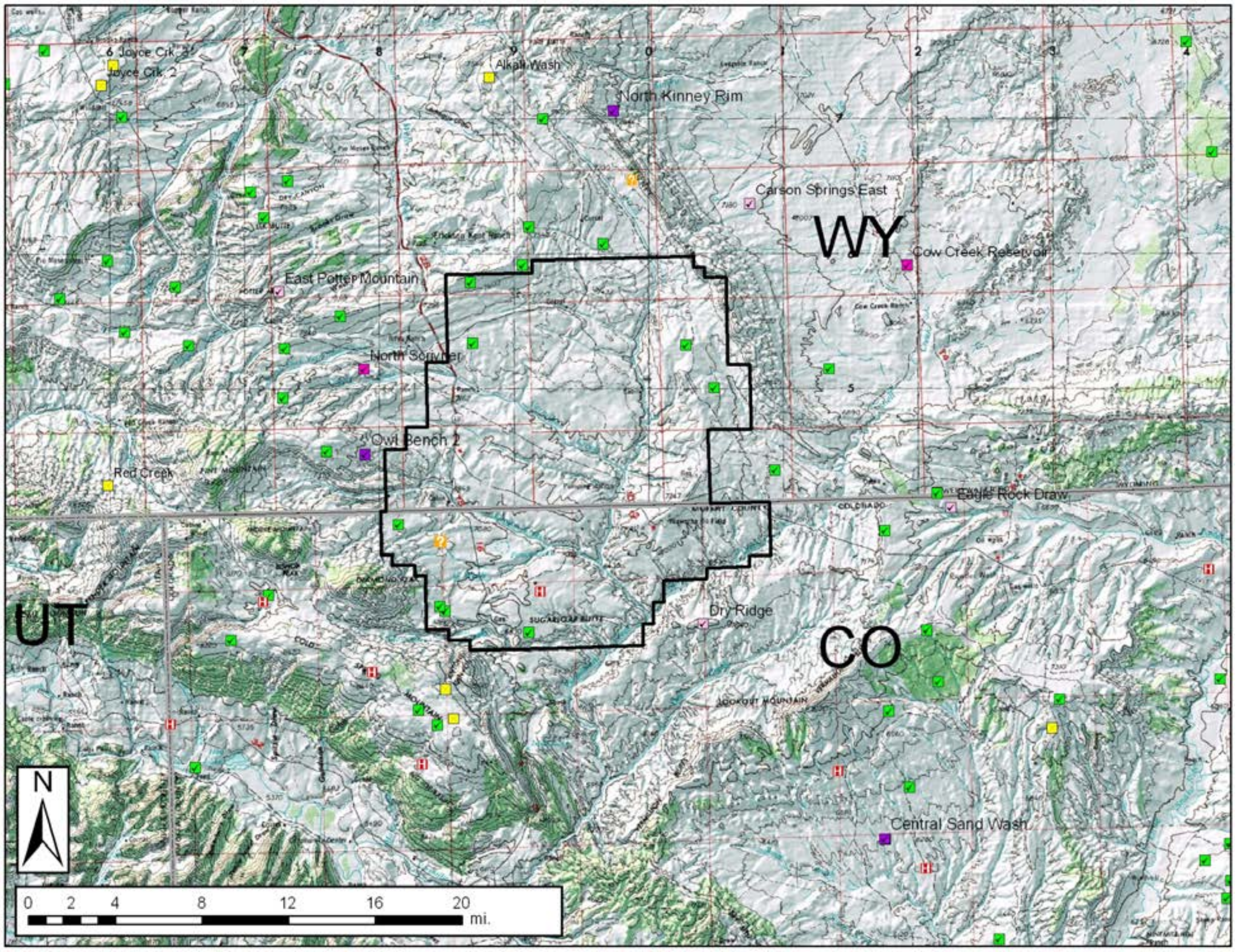

Figure 1. Hiawatha Regional Energy Development project area, Colorado and Wyoming greater sage-grouse core areas, and surrounding region showing known active, inactive, and unknown status greater sage-grouse leks as of 2013, plus new leks discovered by monitoring and checking early-morning locations of GPS males in 2011 (purple squares), 2012 (hot pink squares), and 2013 (light pink squares).

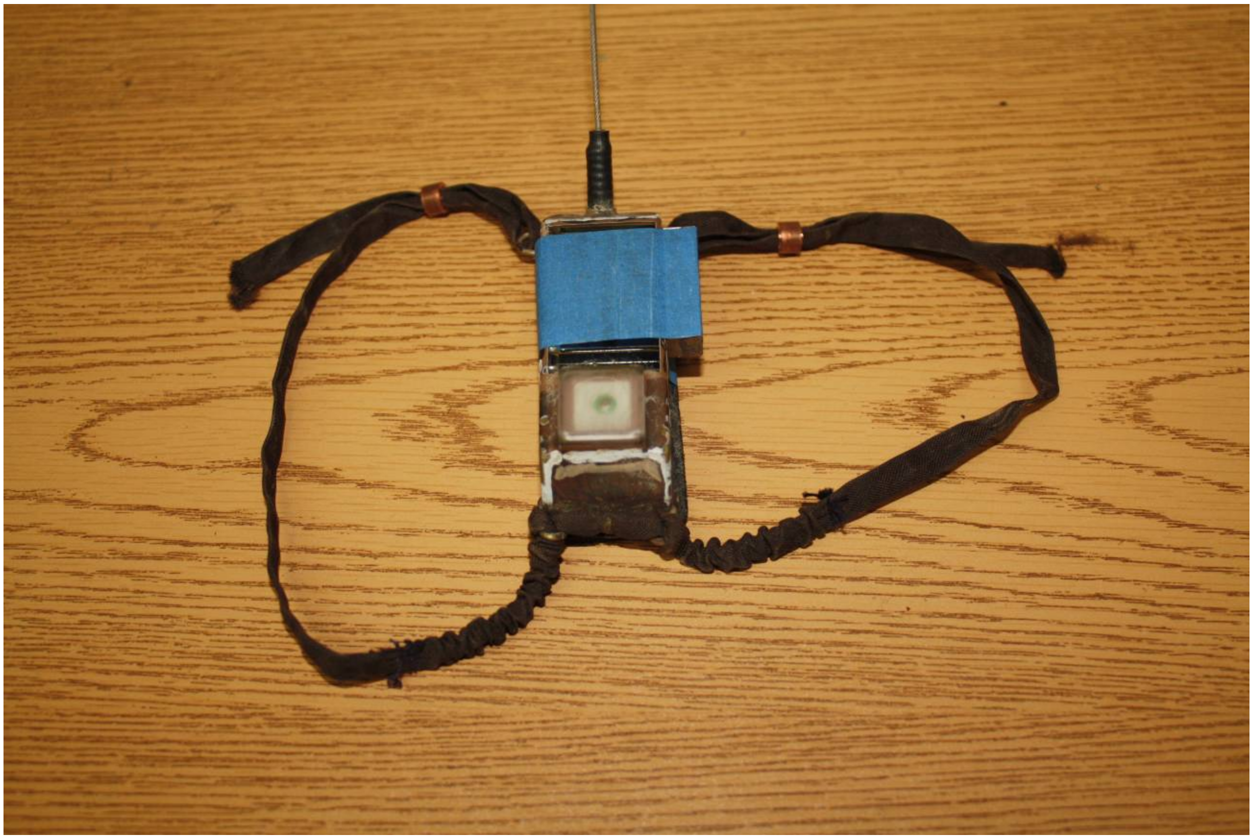

Figure 2. Harness design for rump-mounted leg-loop attachment of solar-powered GPS satellite PTT transmitters to male greater sage-grouse.

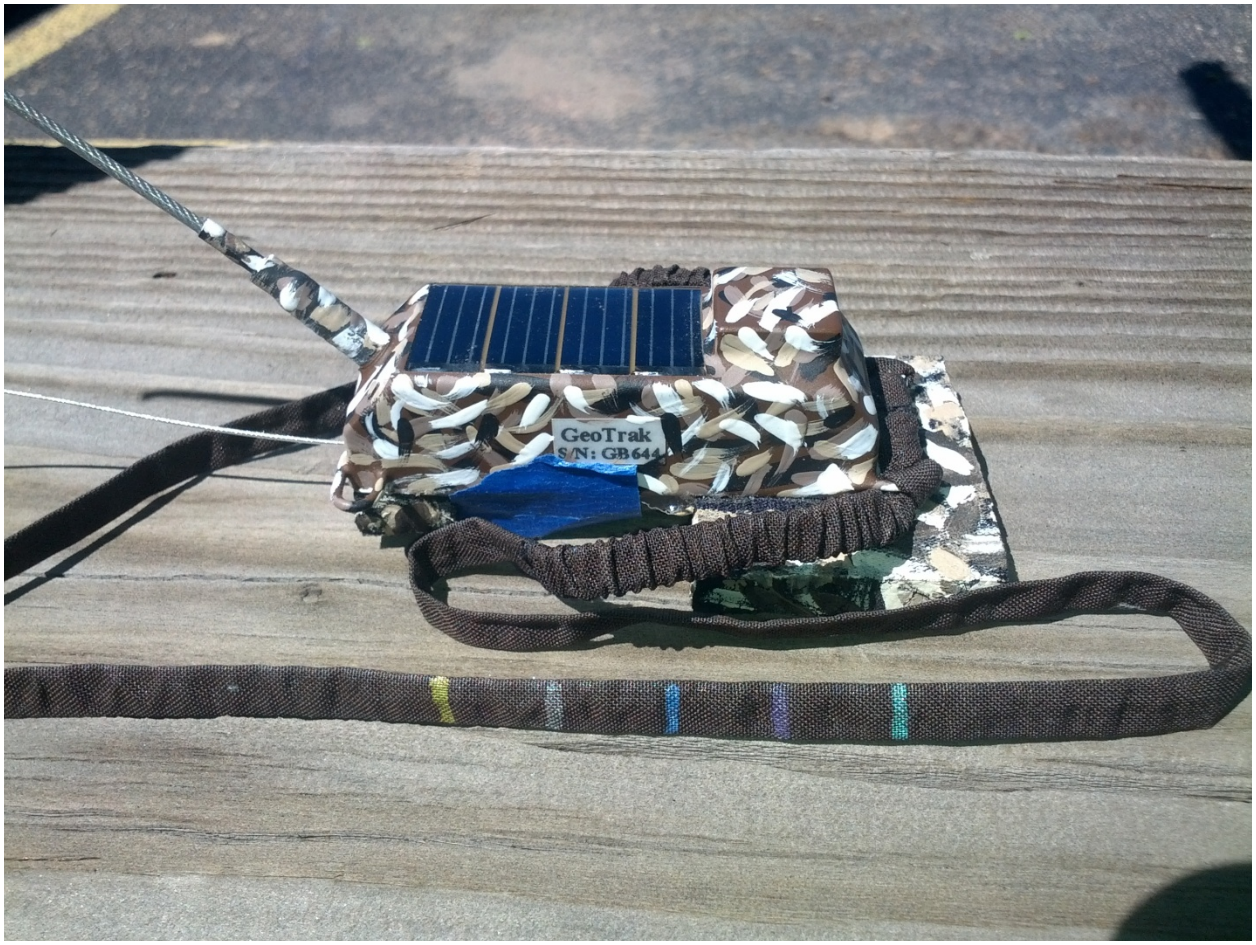

Figure 3. Improved harness and transmitter design for rump-mounted leg-loop attachment of solar-powered GPS satellite PTT transmitters for male greater sage-grouse. This photo also shows the underside placement of a micro-VHF mortality sensor/transmitter (with the magnet held in place with blue painter's tape).


Figure 4. Attachment, placement, and camouflage of rump-mounted, solar-powered, GPS satellite PTT transmitters for male greater sage-grouse.

Colorado Division of Parks and Wildlife
September 2012-September 2013

WILDLIFE RESEARCH REPORT

State of:	Colorado	: Division of Parks and Wildlife
Cost Center:	3420	: Avian Research
Work Package:	0660	: Greater Sage-grouse Conservation
Task No.:	N/A	: Evaluating lek-based monitoring and management strategies for greater sage-grouse in the Parachute-Piceance-Roan Population in northwestern Colorado

Federal Aid
Project No. N/A

Period Covered: September 1, 2012 – August 31, 2013

Author: B. L. Walker

Personnel: B. Holmes, S. Duckett, B. Petch, B. deVergie, J. T. Romatzke

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

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. 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. Lek locations are also commonly used to identify and protect important sage-grouse habitat. However, the use of lek counts and lek locations to monitor and manage sage-grouse populations remains controversial because it is unknown how closely lek-count data track actual changes in male abundance from year to year or if lek buffers are effective at reducing disturbance to male sage-grouse during the breeding season. Colorado Parks and Wildlife is deploying solar-powered GPS satellite transmitters on male greater sage-grouse to obtain data on male survival, lek attendance, inter-lek movements, and diurnal and nocturnal habitat use around leks and conducting double-observer lek counts to estimate detectability of males on leks during the breeding season in the Parachute-Piceance-Roan population in northwestern Colorado. These data will allow us to evaluate whether current lek-based monitoring methods provide reliable information about sage-grouse population trends and whether current lek buffers are effective for protecting breeding males. Fourteen GPS males marked prior to 1 Sept 2012 were monitored for part or all of the 1 September 2012 - 31 August 2013 period. Field crews also captured and deployed GPS transmitters on 4 additional males in fall 2012 and 13 additional males during the 2013 March -May breeding season. No new leks were found tracking GPS males in 2013. Small sample sizes of males captured off lek precluded estimating population-level lek attendance or male breeding-season survival in spring 2013. Poor access to parts of the study area limited the number of double-observer and paired helicopter and ground counts that were conducted. Field crews conducted 52 standard lek counts at 22 different leks, 16 unreconciled double-observer counts at 10 leks, and 15 paired

ground and helicopter counts at 8 leks. We obtained breeding-season location data for a total of 27 GPS males in spring 2013. We will emphasize capture of GPS males using new trapping techniques in fall 2013 and spring 2014 to maximize data on diurnal and nocturnal habitat use around leks and inter-lek movements by males during the 2014 breeding season.

COLORADO PARKS AND WILDLIFE RESEARCH REPORT

EVALUATING LEK-BASED MONITORING AND MANAGEMENT STRATEGIES FOR GREATER SAGE-GROUSE IN THE PARACHUTE-PICEANCE-ROAN POPULATION IN NORTHWESTERN COLORADO

BRETT L. WALKER

PROJECT OBJECTIVES

(1) Use locations of GPS males to find, verify, and count new leks
(2) Estimate the number of known and unknown leks in the population
(3) Estimate age-specific rates of male lek attendance
(4) Estimate the frequency, timing, and distance of inter-lek movements by males
(5) Estimate detectability of males attending leks using paired helicopter and ground counts and paired ground counts
(6) Use these parameters in simulations to quantify how variation in lek attendance, inter-lek movements, detectability, and count effort affect lek-count data and estimates of population trends collected using standardized protocols
(7) Quantify male habitat use around leks to inform use of lek buffers

SEGMENT OBJECTIVES

(1) Capture and deploy solar GPS PTT transmitters on enough non-juvenile males prior to or during the spring 2013 breeding season to reach a sample size of 30 GPS adults and 25 GPS yearlings.
(2) Capture and deploy VHF transmitters on up to 15 juvenile males in summer-fall 2012 for recapture and remarking with GPS transmitters in spring 2013.
(3) Use locations of GPS males to locate, verify, and count new leks in and around the study area during the 2013 breeding season
(4) Conduct standard lek-counts, unreconciled double-observer counts, and paired ground and helicopter counts at leks attended by GPS males
(5) Enter and proof spring-summer field data

INTRODUCTION

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 (Connelly et al. 2004, Schroeder et al. 2004, CGSSC 2008, USFWS 2010). This concern is heightened in oil and gas fields due to recent studies based on lek-count data that suggest negative impacts of development on sage-grouse abundance (Holloran 2005, Walker et al. 2007, Doherty et al. 2010*b*, Harju et al. 2010, Tack 2010) and identification of energy development as a threat factor in the eastern portion of the species' range (USFWS 2010). However, the use of lek-count and lek location data to monitor and manage sage-grouse populations remains controversial. This uncertainty, in turn, has 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 data that evaluate whether current lek-based monitoring methods provide reliable information about population trends and whether current lek-based management strategies are effective for conserving greater sage-grouse in areas with expanding energy development.

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 changes in sage-grouse abundance (Connelly et al. 2004, CGSSC 2008, WAFWA 2008, Fedy and Aldridge 2011). Lek-count data are also commonly used to investigate how regional and range-wide populations respond to changes in habitat and to anthropogenic stressors (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). However, the use of lek-count data as an index of abundance has been called into question because the quantitative relationship between lek counts and population size has never been clearly established. The use of lek counts to measure population size rests on untested assumptions about that proportion of leks in the population that are known and counted, the proportion of males that attend leks, the proportion of males on leks that are detected by observers, and how often males move between leks during the breeding season (Beck and Braun 1980; Applegate 2000; Walsh et al. 2004, 2010; CGSSC 2008; WAFWA 2008).

At present, too few quantitative data are available to estimate these parameters and their associated variances. CPW initiated a project to estimate the number of leks and the proportion of known leks in each population around the state using dual-frame sampling (Haines and Pollock 1998). Preliminary data from the first three years of that project indicate that the proportion of known leks in each population varies depending on their size and how well surveyed the population was prior to sampling (P. Lukacs, CPW, unpublished data). Male lek attendance varies with age, time of day relative to sunrise, date, weather, annual snowpack, renesting rates of females, predator activity, and human disturbance, but previous studies of male lek attendance have not reported data in ways that allow us to quantify how variation in male lek attendance influences annual lek-counts (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). Although standardization of lek-count protocols minimizes some sources of variation in lek attendance (e.g., time of day, weather, date), a substantial amount of variation is not accounted for. In the most rigorous studies to date, Walsh et al. (2004, 2010) emphasized the importance of individual heterogeneity, age, sex, time of day, and date in determining lek attendance, but because results were based on only one year of data from one small, geographically isolated population, they concluded that additional research is needed before we can develop a comprehensive understanding of annual and geographic variation in lek attendance. No published studies have quantified variation in detectability of males on leks from year to year or how much detectability varies among observers, or with weather, 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). 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 annual lek count data has not been quantified. Methodological considerations may also affect lek counts. The sample of leks counted in any given year may depend on which leks are accessible due to road conditions, snowpack, landowner permission, etc. This may bias count data if access and attendance are correlated (e.g., if attendance is lower in areas with more roads). Count effort (i.e., the number of counts per lek per breeding season) can also influence trend estimation because often only the maximum count of males is recorded in state-wide databases. A maximum count based on more visits is likely to be higher because additional visits are more likely to coincide with peak male attendance (Walsh et al. 2004, CGSSC 2008, Fedy and Aldridge 2011).

Investigating the reliability of lek-count data for monitoring changes in actual population size is a range-wide research priority for greater sage-grouse (Naugle and Walker 2007). Despite numerous criticisms, lek-count data continue to be widely used as an index of abundance. Large decreases in lek counts or disappearance of leks over large areas over time are thought to indicate population decline or range contraction in response to anthropogenic stressors (Walker et al. 2007, Aldridge et al. 2008, Doherty et al. 2010*b*, Harju et al. 2010). The fact that state and regional core areas have been established based largely on counts of males on leks and of lek density also reflects that state and federal agencies consider higher lek counts, on average, to represent larger populations (CGSSC 2008, NRCS 2009, Doherty et al. 2010*a*, Hagen 2010, State of Wyoming 2010). Indeed, lek counts remain the only widely-used method for monitoring populations of greater sage-grouse and there is general agreement among wildlife professionals that they have inherent value for monitoring (Connelly et al. 2003, Naugle and Walker 2007, CGSSC 2008). This raises an important question. Because state agencies and others continue to use lek counts for monitoring, and because lek counts are affected to an unknown degree by variation in attendance, inter-lek movements, and detectability, how much of a change in lek-count data is required to reliably detect an actual change in male population size? In other words, how much do lek-count data bounce around due to unexplained variation in these parameters even when we follow standardized count protocols even if male population size remained the same? Understanding the uses and limitations of lek-count data will require both empirical field data from marked males and simulations that illustrate how much standard lek counts vary when lek attendance, inter-lek movements, and detectability are not accounted for.

Lek-based management strategies for greater sage-grouse also require evaluation. Leks are typically centrally located within nesting areas and often overlap with other seasonal habitats (Connelly et al. 2000, Doherty et al. 2010*c*, Aldridge et al. 2011, Fedy et al. 2012), so lek locations are commonly used to help identify and protect important sage-grouse habitat. There is also concern that disturbance at leks may cause abandonment of those leks or reduce rates of nest initiation or reproductive success (Lyon and Anderson 2003, Holloran et al. 2010). For these reasons, state and federal agencies typically recommend restrictions on surface occupancy, timing restrictions during the breeding season, or both, within a certain buffer distance around leks in oil and gas fields (CGSSC 2008). Agencies have also delineated “core areas” or “priority breeding habitats” by placing buffers around leks that meet minimum male count and lek density criteria (e.g., CGSSC 2008, Doherty et al. 2010*a*, Hagen 2010, State of Wyoming 2010). However, these types of lek-based management strategies are subject to two major criticisms.

First, lek-based management strategies incorrectly assume that all lek locations are known (CGSSC 2008). New lek locations are discovered each year in northwestern Colorado (CPW, unpublished data) and hundreds of new leks have been discovered in the past decade throughout the species’ range (WAFWA 2008). Because lek-based oil and gas lease stipulations (e.g., lek buffers) can only be applied to leks whose locations are known, the presence of undiscovered leks in oil and gas fields may result in inadequate protection for populations. Although lek-based monitoring data can be adjusted to account for unknown leks, lek-based management strategies cannot. For this reason, appropriately managing sage-grouse in oil and gas fields using a lek-based approach requires estimating the total number of leks in the field, estimating the proportion of those leks that are known, identifying where unknown leks are most likely to occur, and finding, verifying, and counting new leks.

A second criticism of lek-based management strategies is that they have not been empirically validated for specific local populations. Current federal oil and gas leases typically contain stipulations for 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 protect habitat that males use during the breeding season, with the overall intention of minimizing long-term population declines and preventing extirpation in areas with development (CGSSC 2008). However, a 0.25-mi. stipulation has no credible scientific basis (p. B-5, Appendix B, CGSSC 2008). More recently, a review of six 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). This criterion is now recommended by state and federal agencies in Colorado (CGSSC 2008). However, some studies have questioned whether lek buffers designed to protect males are adequate to prevent sage-grouse populations in oil and gas fields from declining below desired thresholds (Holloran 2005, Walker et al. 2007, Harju et al. 2010). In contrast, other authors have questioned whether it is appropriate to apply a one-size-fits-all lek buffer based on range-wide data to local populations with different topography and vegetation and subject to different types and intensities of energy development (Harju et al. 2010). Lek buffers are also sometimes criticized for including habitat within the buffer that is clearly unsuitable for sage-grouse or being so large so as to effectively preclude energy development. No studies to date have empirically tested how large buffers actually need to be to protect habitat for males during the lekking season or quantified what level of protection buffers of different sizes provide for year-round habitat in any given local population. It remains unclear whether a 0.6 mi. buffer is too large, adequate, or too small, or whether other buffer sizes would be more appropriate. For this reason, field research is needed that quantifies the size of lek buffer required to adequately protect male sage-grouse during the breeding season in local populations subject to oil and gas development by intensively tracking both diurnal and nocturnal habitat use of males around leks. These data will allow us to develop scientifically defensible recommendations regarding the appropriate size and use of lek buffers for specific oil and gas fields.

Recent technological advances have led to production of 30 g, solar-powered, global positioning system (GPS) satellite transmitters suitable for use with greater sage-grouse. GPS transmitters have several advantages over traditional VHF transmitters that make it possible to generate the data needed to resolve lek-based monitoring and management issues. GPS transmitters can be programmed to record multiple locations at specific times of day, logistical problems that prevent crews from locating birds on the ground (e.g., bad weather, poor road conditions, truck breakdowns, lack of access, etc.) do not bias data collection, data are gathered without disturbing the bird or its flock mates, and the units provide the high-resolution data needed to estimate male lek attendance, inter-lek movements, and diurnal and nocturnal habitat use around leks.

This study will directly complement a second, overlapping research project sponsored by CPW and Colorado State University (Fort Collins) and funded by Exxon-Mobil to examine alternative methods of population monitoring, including: dual-frame sampling of leks and non-invasive genetic sampling for sex ratio and population estimation.

Data collected on this project will allow us to judge the reliability of lek-count data for producing defensible estimates of male population size and trend over time as energy development proceeds, thereby directly informing whether sage-grouse management and conservation efforts by industry, agencies, and other stakeholders in oil and gas fields are effective. This research will also provide insight into the ecological and methodological factors that need to be considered when collecting and analyzing lek-count data and appropriate uses and limitations of lek-count data for monitoring. This research will also provide local data that landowners and managers can use to test and make informed decisions about the effectiveness of lek buffers for mitigation. These expected results, in conjunction with studies in other parts of NW Colorado, will in turn have both state-wide and region-wide implications for monitoring and managing both greater sage-grouse and Gunnison sage-grouse (*C. minimus*).

STUDY AREA

The study area encompasses the current occupied range of greater sage-grouse in the Parachute-Piceance-Roan (PPR) population (Fig. 1), one of 7 geographically distinct populations in northwestern

Colorado. The PPR population is experiencing rapid changes to sage-grouse habitat due to expanding oil and gas development (CGSSC 2008). Ownership within occupied range in the PPR is 65% private (primarily ranches and energy companies), 33% federal (primarily Bureau of Land Management), and 2% State of Colorado (PPR-GSGWG 2008). Based on 2007 lek-count data, the PPR population represents approximately 4% of the total population of greater sage-grouse in Colorado (CGSSC 2008). The population appears to have experienced a recent decline since 2006; counts in 2011 totaled 106 males on 32 leks, for an average of 3.3 males per active lek (CPW, unpublished data; Neubaum 2011). Count data in 2011 are approximately one-half the known high count of 204 males on 28 leks in 1976 (7.3 males/active lek; Krager 1977) or the high count of 226 males in 2006 (PPR-GSGWG 2008). Many of the 88 known lek locations in the PPR population are unoccupied (Fig. 1), but new leks have been found recently, in part due to greater aerial survey effort since 2005 and intensive tracking of marked birds by research crews since 2006 (PPR-GSGWG 2008, Apa 2010).

Sage-grouse in the PPR population inhabit the tops of ridges and plateaus dominated by mountain big sagebrush (*Artemisia tridentata vaseyana*) and mixed sagebrush and "mountain shrubs" (e.g., serviceberry, *Amelanchier* spp.; Gambel oak, *Quercus gambelii*; snowberry, *Symphoricarpus* sp.; antelope bitterbrush, *Purshia tridentata*; and mountain mahogany, *Cercocarpus* sp.). These habitats occur between 6,500-9,000 feet and are often interspersed with patches of aspen (*Populus tremuloides*) and conifer forest. These ridges and plateaus are intersected by relatively steep drainages and bordered at lower elevations by pinyon-juniper woodland. Birds only use certain areas that have suitable local topography and local- and landscape-scale vegetation features (Apa 2010, Walker 2010), so sage-grouse habitat in the PPR is actually more restricted than indicated by the occupied range boundary (CGSSC 2008). Due to the elevation, males display slightly later in the PPR than in lower-elevation populations. Males in the PPR typically begin to display on leks in late March or early April (depending on the year) and may continue to display though early June, with a peak of lek activity from mid-April to mid-May. Snowpack depth and duration in the PPR varies from year to year, and strutting is thought to start later following winters when snowpack lasts longer, presumably because snow covers potential nest sites and delays forb growth important for females prior to incubation (Gregg et al. 2008).

METHODS

Capture and Handling

I plan to capture and attach 30-g, rump-mounted solar-powered GPS PTT satellite transmitters (Northstar Science and Technology, King George, VA) on adult male greater sage-grouse in October-November and on yearling males in March of each year. Adult males will be captured in fall prior to the onset of the breeding season to prevent biasing data on lek attendance the following spring (Walsh et al. 2004). Yearling males will be captured in March-April to allow them to reach larger body size prior to deploying the transmitter, thereby reducing the chance that they will outgrow the harness. Trapping effort will be distributed across the population so that it is, as much as possible, proportional to, and representative of, the amount of local breeding habitat present as identified in seasonal habitat models (Walker 2010). I selected 30-g transmitters because they have larger battery capacity than 22-g models, which decreases risk of transmitter failure under low-light conditions (e.g., during winter, or if birds burrow under the snow during storms). A 30-g GPS transmitter with harness (38 g total) represents ~1.1-1.9% of male body mass, depending on age. GPS males will also receive individually numbered aluminum leg bands (size 16). Transmitters from birds that die may be recovered, cleaned, refurbished, and redeployed as necessary to maintain sample sizes.

Capture and handling methods will follow standard CPW operating procedures established for sage-grouse, with the exception that field crews will deploy GPS transmitters (as described in detail below), and the decision whether injured birds will either be released or euthanized will be made by the PI rather than transporting birds back to Fort Collins. No known rehabilitators in western Colorado currently have the facilities to care for wild sage-grouse. Crews will capture males using net launchers (Giesen et al. 1982), night-time spotlighting and hoop-netting (Wakkinen et al. 1992), walk-in traps modified for sage-grouse (Schroeder and Braun 1991), Super Talon® net guns (Advanced Weapons Technology, La Quinta, CA), MagNet® net guns (Wildlife Capture Services, Flagstaff, AZ), or throw nets, all of which have been approved for capture of greater sage-grouse in this population by CPW's Animal Care and Use Committee.

Sample Size

I selected a sample size of 20 adults and 15 yearlings for the first year of the study as a compromise between getting sufficient data to ensure I can estimate the parameters needed and minimizing impacts on the population should GPS transmitters have any possible detrimental effect on males. Once data are available from a concurrent study regarding impacts of GPS transmitters on male survival and for variance estimates for lek attendance, inter-lek movements, and detectability parameters, I will conduct a power analysis to assess whether sample sizes should be increased in the future. Deploying more than 35 GPS transmitters in the first year might be considered an unacceptable risk to the population and may not be supported by stakeholders or cooperators until we know from other studies whether GPS transmitters affect annual survival. I will increase sample sizes in the second and third years of the project to 30 adults and 25 yearlings if the first year of data from PPR or if data from an existing study in the Hiawatha region in northwestern Colorado indicate no obvious impacts of GPS transmitters on male survival. I will report survival rates of GPS males in my annual reports to the ACUC committee as those data become available. I will also report the number of injured or euthanized birds to ACUC. This will help establish standardized protocols for the use of GPS transmitters with greater sage-grouse. 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). I plan to deploy 20 transmitters on adults in fall because I anticipate some level of transmitter failure and mortality (possibly as many as 5 units) prior to the spring breeding season, thereby resulting in approximately equal sample sizes of adults and yearlings (~15 each) in spring 2012.

GPS Transmitter Attachment

I will use a rump-mounted, leg-loop harness attachment for GPS transmitters based on the method B design described in Bedrosian and Craighead (2007) modified for sage-grouse (Figs 2, 3). GPS transmitters cannot be used with necklace collars because solar cells under the neck receive insufficient sunlight to charge the battery. A thin layer of neoprene (1/8") 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 12-16 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 expandable 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 were sewn with more elastic (16 cm) to accommodate any possible increase in body size over time. Transmitters are manufactured with a medium-brown, sand-textured finish to reduce reflected light and the sides, front, and back are painted with a camouflage pattern to decrease visibility to predators (Fig. 3). Problems with back feathers near the front and sides of the transmitter covering the solar panel and leading to transmitter failure led us to develop an improved design that uses thicker neoprene (1/4") and longer and wider neoprene under the front half of the transmitter (Fig. 3). The new design should prevent feathers in front of, and on the sides of, the transmitter from covering the solar panel. I selected a light, flexible antenna to minimize interference with the bird's upright tail display while strutting. 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. 4). Harness leg-loops on each side are fitted while the bird is held on its side to allow careful placement of the Teflon ribbon under body feathers and under the leg. The leg-loop is fitted down, around, and underneath the legs, then back up and through the attachment loops on the transmitter, then secured in place using a small section of 0.55-cm (0.25-inch) diameter copper tubing as a crimp (Fig. 2). The final fit is checked with the bird held in a normal, standing position. Transmitters are fitted as loosely as possible, but just snugly enough to prevent birds from dropping transmitters. Copper crimps quickly become tarnished with exposure to the elements, but as a precaution, crimps are marked with black ink before release to reduce reflection. Field crews will trim the Teflon ribbon at an angle and leave just enough excess ribbon on each side (~3 cm) to allow refitting or enlargement of the harness should it become necessary. 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 and elastic inserts has not been experimentally tested, but harnesses from transmitters on females recaptured after >30 months in the field show no signs of fraying, wear, or deterioration.

The GPS transmitters 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 transmitters are pre-programmed to collect 8 locations per day from March-May to gather data on early morning lek attendance (6 am, 6:30 am, 7 am, 7:30 am, 8 am), mid-day feeding/loafing areas (12 pm), evening feeding areas (6 pm), and night roost locations (12 am). Transmitters are 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, so I do not plan to remove GPS transmitters from males until summer 2014 following the final breeding season. I will clean and redeploy GPS transmitters recovered from mortalities on additional males as needed to maintain sample sizes. I was trained in attachment techniques in the field by Bryan Bedrosian, who has used GPS transmitters with raptors, corvids, and sage-grouse (Craighead and Bedrosian 2009). I have successfully deployed GPS transmitters on 34 females and 35 males from March 2009 - March 2011.

There is some concern that GPS transmitters attached using a rump-mount harness may negatively affect male survival, movement, or strutting. Annual survival of female greater sage-grouse with GPS transmitters in northwestern Colorado was lower than females with VHF transmitters from 5 April 2009 to 23 June 2010 (0.494 ± 0.109 SE, n = 40 for VHF vs. 0.346 ± 0.109 SE, n = 52 for GPS) (B. Walker, unpublished data). However, harnesses have since been made more flexible by sewing in extra elastic, transmitter camouflage was improved (Fig. 3), and 30-g transmitters (38 g including harness and crimps) represent proportionally less of the body mass of males (1.1-1.9%, depending on male age; ~2000-2400 g for yearling males, ~2800-3300 g for adult males; Beck and Braun 1978) than of females, all of which should minimize possible negative impacts of transmitters. CPW deployed GPS transmitters and color-bands on male greater sage-grouse in fall 2010 and spring 2011 as part of a similar study in the Hiawatha Regional Energy Development project area in northwestern Colorado. Preliminary data from the Hiawatha project indicate that a lower proportion of color-banded GPS males (0.59 of 32 adults; 0.44 of 18 yearlings) were resighted at least once on leks in spring 2011 than were color-banded only males (0.77 of 43 adults; 0.60 of 5 yearlings), but estimates of annual survival of color-banded GPS males versus color-banded only males won't be available until after resighting data are collected in spring 2012. A recent comparison of movement data from greater sage-grouse females with GPS vs. VHF transmitters throughout Wyoming found no evidence of a difference in distance traveled during seasonal or migratory movements (Fedy et al. 2012). Observers at leks in Hiawatha in spring 2011 noted that transmitter antennas are pushed to the side during strutting and do not appear to interfere with the bird's upright tail display. Moreover, 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).

Several males with GPS transmitters have disappeared both in this study and in another study in the Hiawatha region. To improve our ability to determine the fate of GPS males whose transmitters stop transmitting and to relocate transmitters that disappear, we added a 5.3-g auxiliary VHF mortality micro-transmitter (Advanced Telemetry Systems, Model A2720, Isanti, MN) on the underside of most GPS transmitters starting in fall 2012 (Fig. 3).

Lek and Lek Attendance Definitions

I define a lek as any restricted geographic area within which ≥ 2 males have displayed during the breeding season in ≥ 2 years (over any number of years), which is consistent with previous state-wide and range-wide definitions (Connelly et al. 2000, 2004; 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). It is possible that one-time use locations are important in small populations like the PPR (S. Duckett, CPW, pers. comm.). If so, this will cause us to underestimate lek attendance because we are unable to confirm strutting at these locations based on a single morning GPS location. 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 are documented to have displaying males in ≥ 2 years, they will be classified as new leks and assigned a name based on local geography. Field crews will delineate a "count boundary" for each known lek. 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 size, 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, 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 as the presence of the male at a location that falls inside within 26 m 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 1.0 hr after sunrise) during the breeding season (15 March – 15 June). A male is not considered to have attended a lek 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 or outside the breeding season. 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 positional accuracy of locations derived from GPS transmitters is typically ≤ 26 m. GPS males with early morning locations within 26 m of the count boundary will be considered inside the count boundary.

Lek Counts

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. Although no specific guidelines are given for the distance at which leks should be surveyed, an informal survey of NW region biologists and wildlife managers suggest that they typically count leks from 50-400 m, depending on topography, access, and to avoid disturbing birds at the lek. Observers 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.

Field crews will focus on collecting double-observer count data at leks at least once a week. In the PPR, not all leks are accessible early in spring due to snowpack and road conditions. Observers will work in pairs, and each pair will conduct a 30-minute lek count during the standard count period at two leks per day, if possible. 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 record any GPS males present on the lek. Counters will also record when and how many birds of each sex 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 to be consistent with how surveys are conducted by CPW biologists and wildlife managers. All observers will be trained in standard lek-count protocols and aging and sexing; they will practice counting under supervision prior to collecting field data; and they will collect data on standardized forms to ensure consistency. 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 from a helicopter (the pilot plus an observer). Aerial observers will focus first on counting birds at leks simultaneously being counted by ground crews, and then conduct standard counts and search for potential new leks at specific locations indicated by GPS male location data. Aerial observers will record the total number of males at a lek but cannot distinguish adults from yearlings.

Objectives

Objective 1: Use locations of GPS males to find, verify, and count new leks – Early morning locations of GPS males will be compared against locations of known leks as the data come in to identify potential lek locations. Males that make ≥ 2 early morning visits to the same approximate location (within 100 m) on consecutive mornings during the breeding season will be considered to have visited a potential lek location. The field crew will then visit those locations or they will be checked from the air at least once during the next 7 days under suitable weather conditions to document whether displaying males or their sign (e.g., pellets, tracks, feathers) are present. If displaying males or sign are present at a newly discovered lek, then the new lek will be added to the list of regularly counted leks following standard protocols, and the count boundary determined as soon as practicable. A GPS male that previously used a location within the count boundary of a newly discovered lek during the standard morning count period will be considered to have attended that lek on that date.

Objective 2: Estimate the no. of known and unknown 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. Leks not attended by GPS-marked males are considered un-marked leks. 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) in program MARK (McClintock et al. 2008, White 2010).

Objective 3: Estimate age-specific lek attendance by males – I will use the GPS male dataset to estimate lek attendance as a function of male age and variables that can be measured without directly observing attending males. I will compare early morning locations of males with GPS transmitters against count boundaries for all known lek locations to determine whether or not GPS males attended leks (see definition of “attending a lek”, 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, etc.). Daily lek attendance for males will be modeled as a function of date, weather, previous day weather, nearest lek size, and the male's previous lek attendance (as a measure of a male's prior reproductive effort). 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 by the total number of days for which each individual was alive and its early morning location was known. Males that move outside the study area prior to the breeding season will be excluded from the analysis.

Objective 4: Estimate rates of inter-lek movements of males – I will use location data from GPS males overlaid with locations of count boundaries for all known active leks to estimate the frequency, timing, and distance of inter-lek movements by yearling and adult males.

Objective 5: Estimating detectability of males on leks – 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). However, this is typically impossible to do with lek counts because there may be numerous males on the lek and most males are unmarked and cannot be individually identified. Unreconciled double-observer models use raw maximum counts of the number of individuals detected (in each age class or from both age classes combined) 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 only difference that data from each observer are considered independent "visits" (Riddle et al. 2010). Benefits of this approach are that leks do not actually have to be visited twice on separate occasions, and the closed population assumption is met because surveys are conducted at the same time (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 if detectability is low (P. Lukacs, CPW, 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*) 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, weather (temperature, wind speed, precipitation, visibility, illumination), and any other disturbances (e.g., vehicle traffic, planes, deer/elk, etc.) at the end of each 5-minute interval. Predator activity will be broken into three classes (no predator detected; predator visible from the lek; predator on, over, or attacking males) based on observations of potential predators of adult sage-grouse (eagles, hawks, falcons, owls, coyote, red fox, bobcat, mountain lion, etc.) near 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), observer, 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.

To estimate the effect of counting males from the air on detectability, I will compare maximum counts of males conducted on the same date at the same time from a single observer on the ground against a single observer in a helicopter using an unreconciled double-observer approach. Crews will attempt to conduct at least 3 paired counts per lek per year during the standard lek-count period in April, at least for leks that are accessible to ground-based observers. Ground observers will count leks over the full standard morning count period (0.5 hrs before sunrise to 1.0 hrs. after sunrise) and will note when the helicopter flew over and any changes in the count (e.g., departures) or behavior (e.g., crouching) of males caused by the helicopter that might affect count data or male detectability. Observers will continue to count until the end of the standard morning count period (1.0 hr after sunrise) to assess how helicopter flyovers would affect count data collected from the ground following a flyover (McRoberts et al. 2011).

I will first compare the maximum count from the helicopter versus the maximum count from either observer on the ground collected over the 30-minute count period prior to arrival of the helicopter. Helicopters tend to flush males off leks and are likely influence counts made immediately after the flyover (S. Duckett, CPW, unpublished data; McRoberts et al. 2011), so I will only include data collected prior the helicopter's arrival in the comparison. In this case, the difference in detection probability among observers (ground vs. air) represents the difference in detectability on a typical standard ground count versus a typical count from a helicopter. This comparison is appropriate because ground counts based on data from a 30-minute count period and flight counts based on data from a 1-3 minute count period are recorded with equal weight in statewide count databases.

I will also compare counts recorded from the helicopter versus just the last count recorded on the ground in the 3 minutes prior to arrival of the helicopter. This allows us to estimate the effect of just the count method (helicopter vs. ground) based on a similar time period.

It is unclear whether detectability will be higher or lower on helicopter counts. Detectability may be lower because data are derived from only 1-2 passes over 1-3 minutes rather than a full 30-minute period. However, it is possible that observers in helicopters may count more males if topography prevents observers on the ground from detecting hard-to-see males around the periphery of a lek.

Objective 6: Simulate lek-count data – I will use estimates of the proportion of known vs. unknown leks in the population, age-specific means and variation in male lek attendance, the frequency and distance of inter-lek movements, estimated detectability, and variation in 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, even in the absence of population change, when conducted according to standardized protocols. I will simulate data for the estimated total number of leks in the population. 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 during that period. I can use these data to simulate what proportion of the simulated population of adult and yearling males would actually attend each lek during each time period of the morning on each day of the breeding season 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) at various distances from leks; (d) in good versus marginal weather conditions; (e) with a variable 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 or a biased sample of leks counted to mimic normal problems with access encountered in the field. Simulations will be set up in program R (version 2.11.0, R Development Core Team 2010).

Objective 7: Test 0.6-mile lek buffer – During the breeding season, I will measure distances of three off-lek locations per day (at noon, 6 pm, and midnight) for each GPS male to the center of the lek attended that morning, 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. During other seasons, I will measure distances of two off-lek locations per day (at noon and midnight) for each GPS male to the center of the nearest known active lek (as recorded in CPW databases or by field crews). 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 areas within a specific distance around leks (D. Walsh, CPW, pers. comm.). I will also compare the effectiveness of conserving areas within different circular lek buffers to similar areas of high priority breeding habitat of similar size already identified using VHF locations of females (Walker 2010).

RESULTS AND DISCUSSION

Captures

Field crews captured and deployed GPS transmitters on 4 males (1 yearling, 1 adult, 2 non-juveniles) from September through November 2012 and on 13 males (10 adults, 3 yearlings) during the March through May 2013 breeding season. Crews also captured three juvenile males in late summer-fall 2012 and fitted them with VHF collars. However, all three juvenile males with VHF collars died prior to spring 2013.

Males have proven difficult to capture. Field crews adopted new trapping methods in spring 2012 (Super Talon® and MagNet® net guns) that dramatically increased trapping success. We also redesigned net launcher mounting frames so that bumper-mounted CODA® net launchers could be rotated 90° left or right from the inside the vehicle to increase trapping efficiency. We also successfully used drop nets for capturing males in spring 2013 (Fig. 5). We have also been approved to start testing lightweight throw nets for captures in September 2013.

GPS Transmitters

Of the 41 males successfully deployed with GPS transmitters from March 2012 through August 2013, 12 were still alive with functioning transmitters, 21 were known to have died, 4 are likely dead but have not been recovered, and the status of 4 have not be determined as of 31 Aug 2013. Males whose status could not be determined may have: (1) died and their transmitters destroyed before transmitting the location of the mortality, (2) lived but their transmitters slipped off face down and could not charge and transmit their last location, (3) lived but the transmitters failed due to malfunction or defect, or (4) lived but the transmitters failed because back feathers covered the solar panels and prevented the unit from charging and transmitting. Transmitters on the 4 birds with unknown status all transmitted data intermittently prior to disappearing. We suspect that feathers covering the solar panel are a significant factor in transmitter failure with our original transmitter design (Fig. 2). In fall 2012, we developed and implemented an improved transmitter design using thicker neoprene to prevent back feathers in front and on the sides of the transmitter from covering the solar panel (Fig. 3).

Locations of all GPS males were monitored every 3 days during the spring breeding season (~10 Mar – 25 May) in 2013 to determine: (a) locations of potential new leks for crews to check, (b) which males were alive, (c) which males remained within the study area, (d) which males were attending leks, (e) inter-lek movements, and (f) nocturnal and diurnal habitat use around leks.

Lek Searching and Lek Counts

Field crews located, verified, and counted only one previously unknown lek location in spring 2013 (Garden Gulch Pipeline). However, this lek was found opportunistically during the course of field work on the ground (during standard or double-observer lek counts, while trapping, etc.) rather than by monitoring locations of GPS males.

Field crews conducted standard lek counts, unreconciled double-observer counts, and paired ground and helicopter counts at leks within the study area from 18 March - 26 May 2013. The breeding season in 2013 was longer than in 2012. This effort resulted in data from 52 standard lek counts at 22 leks, 16 unreconciled double-observer counts at 10 leks, and 15 paired ground and helicopter counts at 8 leks. Field crews entered and proofed all field data by June 2013.

Survival, Lek Attendance, and Inter-lek Movement

Small sample sizes of birds captured off lek precluded estimating population-level breeding-season survival or lek attendance for GPS males in spring 2013. Data on inter-lek movements will be analyzed following the third and final field season in spring 2014.

Male Habitat Use Around Leks

We collected breeding-season location data on a total of 27 GPS males in spring 2013. Preliminary analyses of male habitat use around leks from 2012 and 2013 are underway in conjunction with data from the Hiawatha study.

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FIGURES

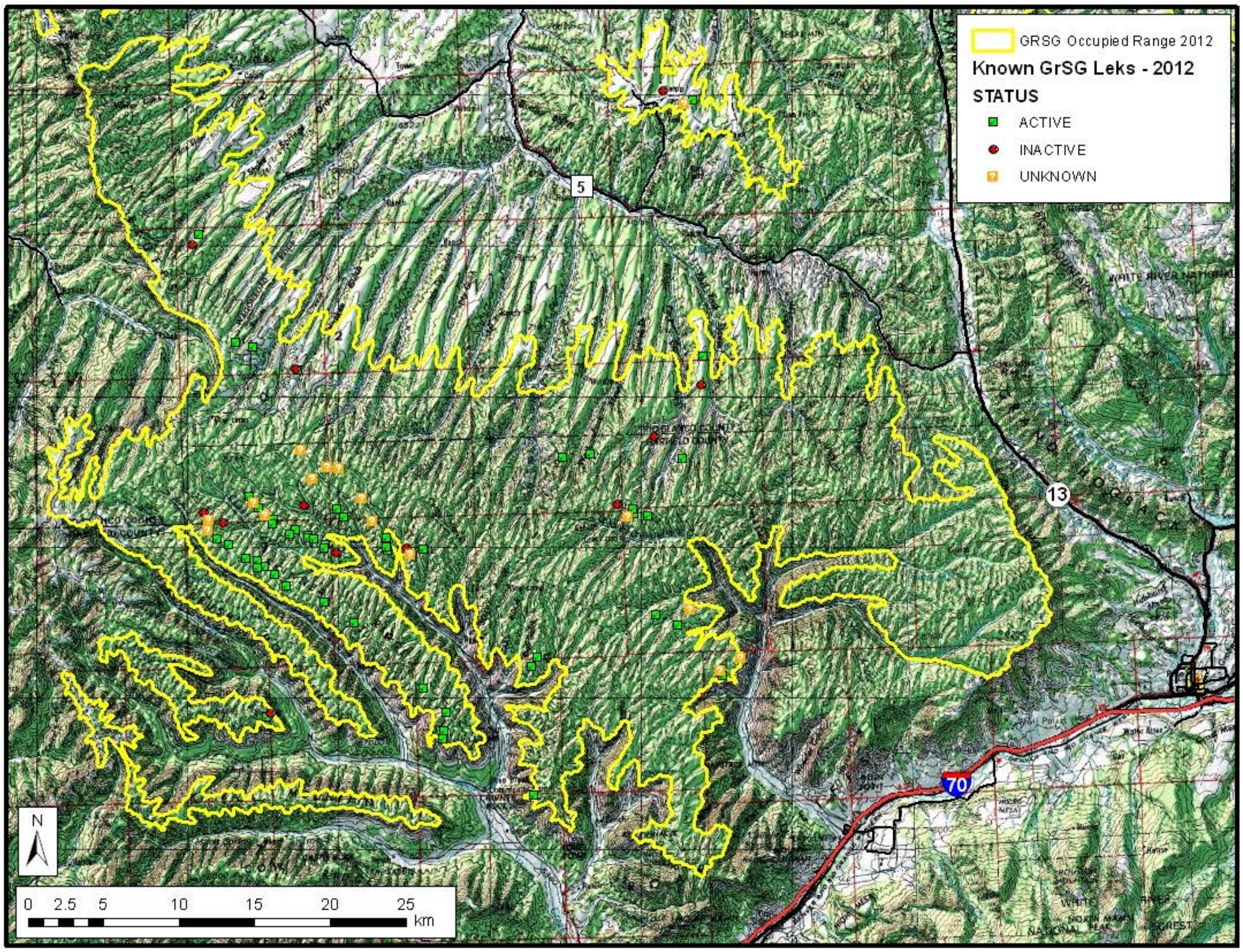

Fig. 1. Greater sage-grouse leks (as of Feb 2013) and occupied range (as of Feb 2012) in the Parachute-Piceance-Roan population of northwestern Colorado, USA (including the isolated "Magnolia" section).

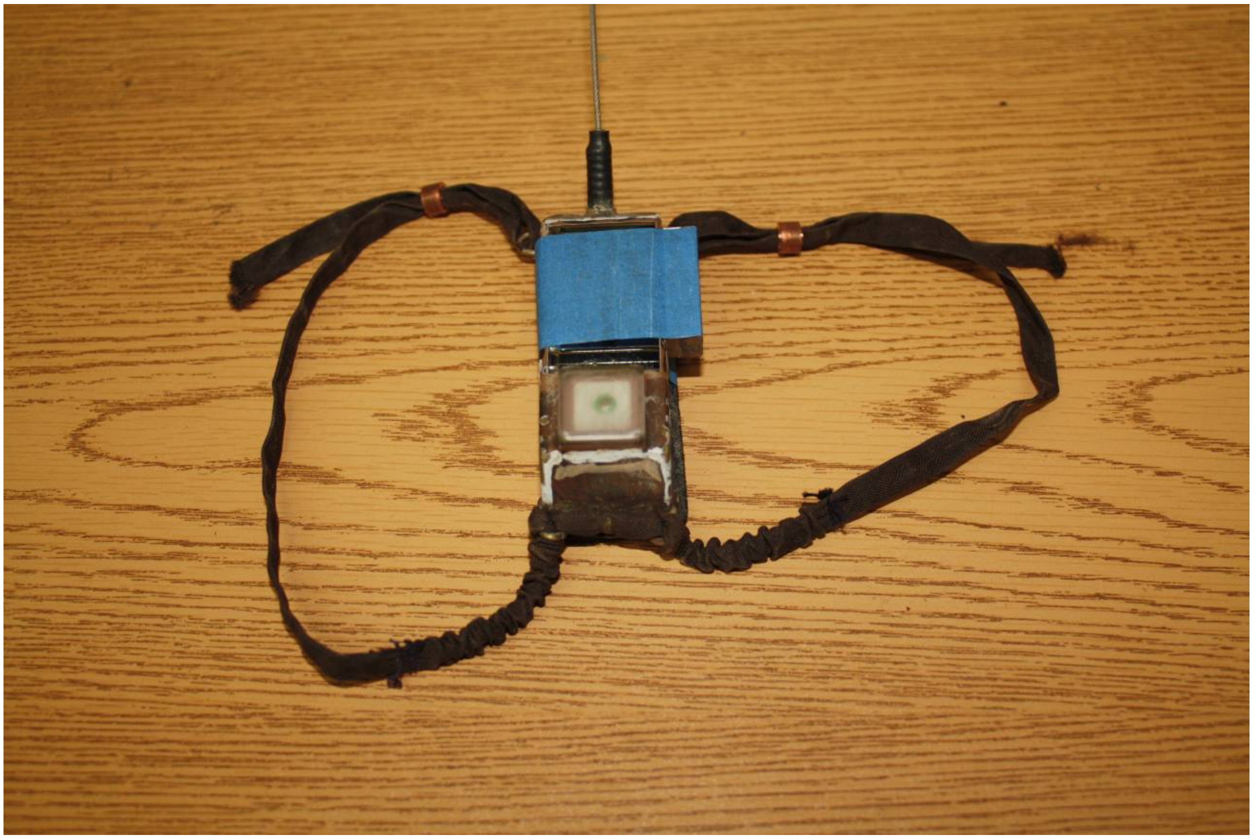
Figure 2. Original harness and transmitter design for rump-mounted leg-loop attachment of solar-powered GPS satellite PTT transmitters to male greater sage-grouse.

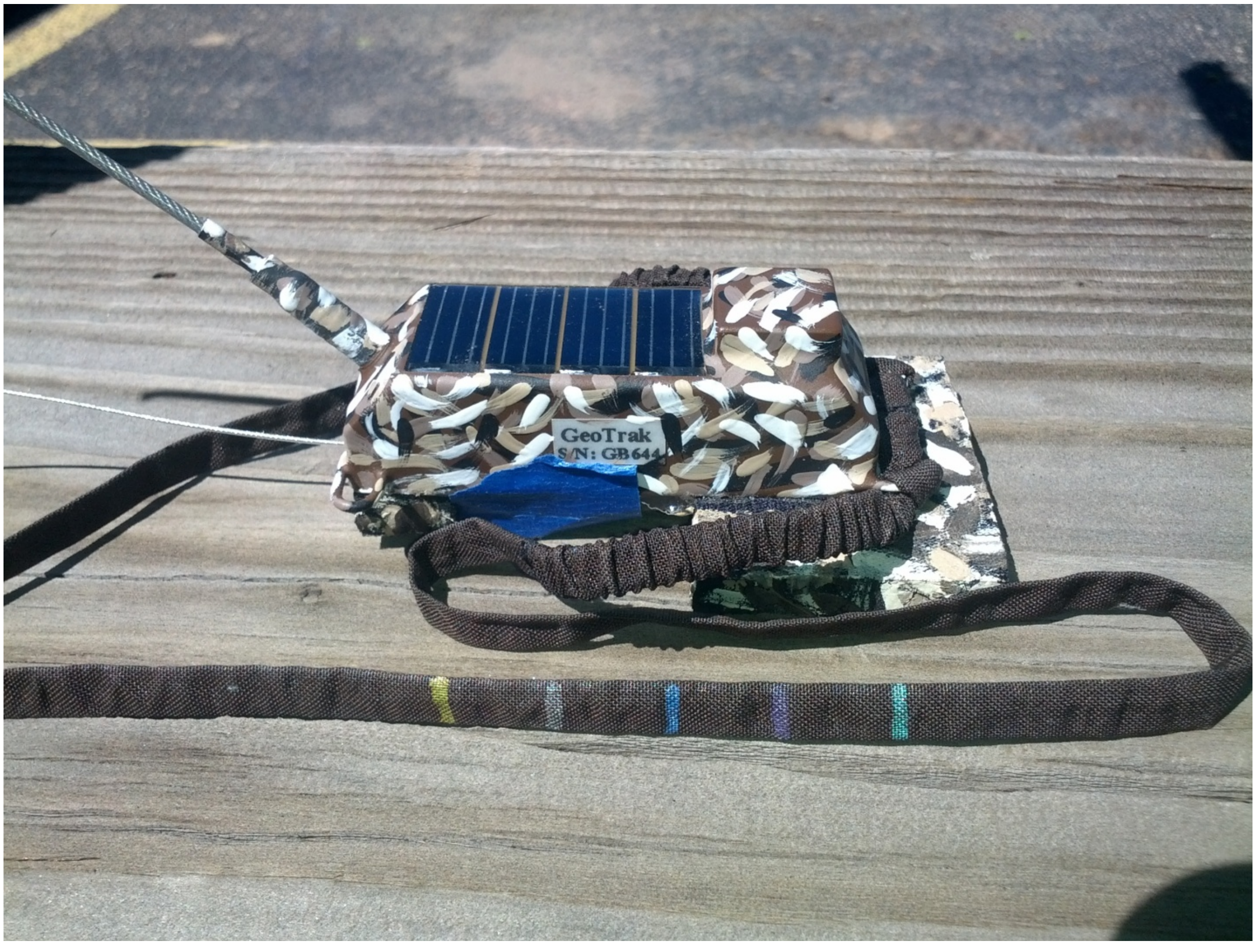

Figure 3. Improved harness and transmitter design for rump-mounted leg-loop attachment of solar-powered GPS satellite PTT transmitters for male greater sage-grouse. This photo also shows the underside placement of a micro-VHF mortality sensor/transmitter.


Figure 4. Attachment, placement, and camouflage of rump-mounted, solar-powered, GPS satellite PTT transmitters for male greater sage-grouse.


Figure 5. Drop net design for capturing male greater sage-grouse.

Colorado Division of Parks and Wildlife
September 2012-September 2013

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of Parks and Wildlife
Cost Center:	3420	:	Avian Research
Work Package:	0660	:	Greater Sage-grouse Conservation
Task No.:	N/A	:	Assessment of greater sage-grouse response to pinyon-juniper removal in the Parachute-Piceance-Roan Population of northwestern Colorado

Federal Aid
Project No. N/A

Period Covered: September 1, 2012 – August 31, 2013

Author: B. L. Walker

Personnel: B. Holmes, B. Petch, T. Knowles, B. deVergie

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

Greater sage-grouse (*Centrocercus urophasianus*) in the Parachute-Piceance-Roan (PPR) region of western Colorado face at least two major potential stressors: projected habitat loss from energy development and a long-term decline in habitat suitability associated with pinyon-juniper (PJ) encroachment. PJ removal may be a useful mitigation tool to offset potential habitat losses associated with energy development. Although PJ removal is commonly used to improve habitat for greater sage-grouse, no studies to date have quantified the timing or magnitude of how birds respond to treatments. Since 2008, Colorado Parks and Wildlife (CPW) has cooperated with industry and landowner partners to investigate the effectiveness of PJ removal in restoring sage-grouse habitat in the PPR. In fall 2008, I established nine "survey" 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 in 2010 and 2011. Pellet surveys over five summers (2009-2013) indicated that the mean proportion of sample units containing pellets was higher on sagebrush control plots (range across years = 0.197-0.449) than on plots with encroaching PJ across all years (range = 0.023-0.076). The proportion of sample units containing pellets increased within two years after PJ removal on one plot treated in 2010 (Upper Galloway) and within one year on a plot treated in 2011 (Ryan Gulch) and has generally remained higher than on untreated PJ plots. There has been no increase in pellets on the third survey plot treated in 2010 (Black Sulphur).Twelve additional transect plots were added in fall 2010 and two more transect plots were added in summer 2011. All 14 transect plots were surveyed for pellets in summer 2011, 2012, and 2013. Transect data indicated low mean pellet densities on the four PJ-Control plots over three years (range across years = 0.00-0.58 pellet piles/km) and on PJ-Treatment plots in the one year prior to treatment (mean = 0.03 pellet piles/km). Estimates of mean pellet density were substantially higher on four Sagebrush-Control transect plots over three years (range across years = 11.10 - 27.14 piles/km) and on one transect plot 4-6 years after treatment (Lower Barnes; range across years = 2.89 - 25.71 piles/km). However, estimates of proportion of sample units with pellets (from survey plots) and of pellet density (from transect plots) also varied substantially among

Sagebrush-Control plots within years and among years within plots, indicating substantial baseline variation in pellet occupancy, in observers' ability to detect pellets, or both. There has been no increase in mean pellet density on four treated transect plots within two years after PJ removal (range across years = 0.00 - 1.04 pellet piles/km).

WILDLIFE RESEARCH REPORT

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

BRETT L. WALKER

PROJECT OBJECTIVES

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

SEGMENT OBJECTIVES

Objectives of this study from 1 Sept 2012 through 31 August 2013 were to:
1. Conduct pellet surveys on 9 survey plots.
2. Conduct repeat surveys on 9 survey plots to estimate detectability at the sample unit level.
3. Conduct pellet transects on 14 transect plots.
4. Summarize results of pellet surveys and transects from 2008-2013.

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 a long-term reduction in habitat suitability caused by encroachment of pinyon pine (*Pinus monophylla*) and juniper (*Juniperus scopularum* and *Juniperus utahensis*) 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 and offset future potential habitat losses from energy development. Pinyon-juniper encroachment into sagebrush over the last 150 years has been identified as a threat to the species' habitat in the PPR, in Colorado and range-wide (CGSSC 2008). Encroachment 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 increase available habitat and offset impacts from energy development.

Since 2008, the Colorado Division of Wildlife, now Colorado Parks and Wildlife (CPW), and industry and landowner partners have been cooperating on research to assess the value of removing encroaching PJ as a mitigation strategy in the PPR. The main objective of this study is to measure short-term (<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 2013.

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 largely precludes 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

I used vegetation, topography, marked bird locations, aerial photography, and on-site visits to identify nine study plots in 2008 and 14 additional study plots in 2010 and 2011 (see previous annual reports for study plot locations). Two of the plots added in 2010 (Upper and Lower Bar D) were treated by the Bureau of Land Management and were included opportunistically in our study. Study plots were selected based on: (1) density of PJ; (2) shrub composition, density, and height; (3) topography; (4) proximity to areas of known use by greater sage-grouse; and (5) proximity to, and likelihood of, energy development within five 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 limited development nearby.

Assessing Response to Pinyon-Juniper Removal

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 suitable sagebrush habitat and 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 and variation in track and pellet occupancy in areas with encroaching PJ in the absence of treatment. Sagebrush-Control plots allow us to estimate background changes and variation in track and pellet occupancy in habitats already suitable for sage-grouse. Most plots were surveyed for one to three years prior to PJ removal and will be surveyed for two to five years following removal. I established three study plots per treatment in fall 2008 for a total of nine original "survey" plots. 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 (nine survey, 14 transect).

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) using two different sampling methods based on square sample units (Becker et al. 1994, 1998) or with a transect-intercept probability estimator (Becker 1991, Becker et al. 1994). However, winter track surveys were discontinued in 2012 due to lack of snow and ongoing logistical problems associated with using a time-sensitive survey methodology (see Results and Discussion, below). See previous annual reports for details of winter track survey methodology.

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. I used two different sampling techniques for pellet surveys. The first technique involves surveying a systematic random sample of 30 x 30 m sample units on each "survey" plot. The second technique involves surveying for pellets within 1.5 m on either side of linear transects spaced 50 m apart that ran the length of each "transect" study plot.

With both sampling methods, field crews 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, field crews 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. Field crews identified those containing intact insect parts and flower heads as "summer" pellets (April-October) and those containing only digested sagebrush leaves as "winter" pellets (November-March) (Wallestad et al. 1975). Field crews recorded single pellets, pellet piles (i.e., day or night roost piles), and cecal droppings separately. Observers recorded 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 three month 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 instead change the "survey period" (i.e., the period during which birds can deposit pellets) from three months to 12 months. Field crews marked all sample unit centers and transect lines with aluminum tags, high-visibility stakes and high-visibility flagging to ensure consistency in sampling locations across years. On survey plots, each observer carefully and thoroughly surveyed 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 and searching within 1.5 m on either side of the line. Observers recorded anecdotal evidence of occupancy while surveying (e.g., clockers, 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 anssumption 3, crews differentiated pellets in the field based on condition (bleached and crumbly vs. hard and dry vs. fresh and green/moist). I am 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 anssumption 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 12-month survey period.

Pellet Detectability

Detectability of sage-grouse pellets is typically low (Dahlgren et al. 2006) and may vary among observers or with pellet condition or appearance. I estimated variation in detectability of individual pellets/pellet piles among observers by having each observer survey eight test sample units in which I placed piles of fresh pellets of various sizes at random directions and distances within the sample unit from the sample unit center. Pellet piles 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 in 2011. Test piles 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 or appearance.

Vegetation Sampling

Field crews 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 2011 to determine whether local-scale habitat on study plots would be suitable for wintering sage-grouse once the PJ overstory was removed. At each sampling point, field crews laid out two 30-m perpendicular tapes running N-S and E-W and measured: shrub canopy cover by species using the line-intercept method (Canfield et al. 1941); and species and height of the nearest shrub (excluding inflorescences) within 2.5 m every 5 m along each tape.

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, Upper and Lower Bar D plots were treated by BLM in January 2011, and three plots (Cottonwood, Magnolia South, and Lower Wagonroad) were treated in August-November 2011.

RESULTS AND DISCUSSION

Winter Track Surveys and Transects

Winter track surveys and transects were discontinued after winter 2011-2012.

Summer Pellet Surveys

Field crews conducted one round of pellet surveys in July-August in each year from 2009-2013 on each of the nine original survey plots (Tables 1-5). Observers also conducted a repeat, consecutive survey of all 9 survey plots in 2013. Pellet survey data from 2009-2013 indicated substantially higher mean seasonal and year-round pellet occupancy on Sagebrush-Control survey plots than on PJ-Control (no treatment) plots or on PJ-Treatment plots prior to treatment. Year-round pellet occupancy increased on the Upper Galloway and Ryan Gulch plots and has remained slightly higher following treatment on both plots (Fig. 2, Tables 1-5). However, there was no observed increase in year-round pellet occupancy on the Black Sulphur plot within two years following treatment.

We did not conduct surveys on test sample units to estimate detectability of individual pellet piles in 2013. Instead, observers conducted consecutive repeat surveys of the original nine survey plots on the same dates to allow us to estimate detectability of pellets at the sample unit level. Those data are still being analyzed, but a preliminary comparison of resulting estimates suggests substantial variation in different observers' ability to detect pellets within 30 x 30 m sample units (Table 6).

Summer Pellet Transects

Field crews conducted one round of pellet surveys on each of 14 transect plots in July-August in each year from 2011- 2013 (Tables 6-8). No transect plots showed a detectable increase in pellet occupancy within two years following treatment. Pellet density on the Lower Barnes plot (treated by BLM in 2007-2008) was comparable to Sagebrush-Control plots.

Overall, preliminary data from summer pellet surveys during the pre-treatment phase of the project were as expected, with substantially greater use of Sagebrush- Control plots than either PJ-Control plots or PJ-Treatment plots prior to treatment. There was an increase in the proportion of sample units containing pellets on two of three treated survey plots within 1-2 years following treatment, but no increase on the third survey plot. There was no increase in the density of pellets detected on transect plots within 2 years following treatment. Current post-treatment data are insufficient to draw conclusions about short- or long-term responses of greater sage-grouse to PJ removal other than there was no immediate or dramatic increase in sage-grouse use of treated areas. However, response to PJ treatments may take longer than 2-3 years to document if few yearlings are available to colonize newly created habitat.

We anticipate conducting two additional years of pellet surveys (through summer 2015) to ensure we document grouse response for at least 4-5 years post-treatment. We may continue pellet surveys beyond 2015 if interest and funding are available to treat some or all of the seven current PJ-control study plots in 2014 or 2015.

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Table 1. Preliminary estimates of proportion of sample units (p ± SE) containing 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				**PJ - Control (No Treatment) Plots**				**Sagebrush - Control Plots**			
	Pre-treatment											
	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 set (e.g., Set 1 = Upper Galloway, Dry Ryan, Dry Gulch, etc.).

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

[c] N refers to no. of study plots contributing to the mean.

[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 2. Preliminary estimates of proportion of sample units (p ± SE) containing 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.).

[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 contributing to the mean.

[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 3. Preliminary estimates of proportion of sample units (p ± SE) containing 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 set (e.g., Set 1 = Upper Galloway, Dry Ryan, Dry Gulch, etc.).

[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 contributing to the mean.

[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 4. Preliminary estimates of proportion of sample units (p ± SE) containing greater sage-grouse pellets on survey plots in the Parachute-Piceance-Roan population of western Colorado, USA in 2012. Values presented do not account for variation in pellet detectability.

	PJ - Treatment Plots (Post-treatment)				PJ - Control (No Treatment) Plots				Sagebrush - Control Plots			
	1-Upper Galloway[a]	2-Black Sulphur[a]	3-Ryan Gulch[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 = 49[c]	n = 38[c]	n = 48[c]	N = 3[d]	n = 35	n = 50	n = 38	N = 3	n = 43	n = 41	n = 42	N = 3
p_S[e]	0.061	0.000	0.000	0.020	0.000	0.040	0.000	0.013	0.279	0.000	0.071	0.117
	± 0.034	± 0.000	± 0.000	± 0.02	± 0.000	± 0.028	± 0.000	± 0.013	± 0.068	± 0	± 0.04	± 0.084
p_W[e]	0.204	0.026	0.188	0.139	0.029	0.020	0.000	0.016	0.581	0.341	0.214	0.379
	± 0.058	± 0.026	± 0.056	± 0.057	± 0.028	± 0.020	± 0.000	± 0.008	± 0.075	± 0.074	± 0.063	± 0.108
p_{YR}[e]	0.245	0.026	0.188	0.153	0.029	0.040	0.000	0.023	0.605	0.341	0.262	0.403
	± 0.061	± 0.026	± 0.056	± 0.065	± 0.028	± 0.028	± 0.000	± 0.012	± 0.075	± 0.074	± 0.068	± 0.104

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

[b] Data represent 1 year post-treatment. Treatment on Ryan Gulch was completed in summer 2011.

[c] n refers to the number of sample units per study plot.

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

[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 of sample units (p ± SE) containing greater sage-grouse pellets on survey plots in the Parachute-Piceance-Roan population of western Colorado, USA in 2013. Values presented do not account for variation in pellet detectability.

	PJ - Treatment Plots (Post-treatment)				**PJ - Control (No Treatment) Plots**				**Sagebrush - Control Plots**			
	1-Upper Galloway[a]	2-Black Sulphur[a]	3-Ryan Gulch[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 = 49[c]	n = 38[c]	n = 48[c]	N = 3[d]	n = 35	n = 50	n = 38	N = 3	n = 43	n = 41	n = 42	N = 3
p_S[e]	0.000 ± 0.000	0.000 ± 0.000	0.042 ± 0.029	0.014 ± 0.014	0.000 ± 0.000	0.040 ± 0.028	0.000 ± 0.000	0.013 ± 0.013	0.023 ± 0.023	0.024 ± 0.024	0.071 ± 0.040	0.040 ± 0.016
p_W[e]	0.082 ± 0.039	0.000 ± 0.000	0.125 ± 0.048	0.069 ± 0.037	0.000 ± 0.000	0.080 ± 0.038	0.000 ± 0.000	0.027 ± 0.027	0.605 ± 0.075	0.195 ± 0.062	0.333 ± 0.073	0.378 ± 0.120
p_{YR}[e]	0.082 ± 0.039	0.000 ± 0.000	0.188 ± 0.056	0.090 ± 0.054	0.000 ± 0.000	0.100 ± 0.042	0.000 ± 0.000	0.033 ± 0.033	0.605 ± 0.075	0.220 ± 0.065	0.381 ± 0.075	0.402 ± 0.112

[a] Data represent 3 years 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).

[b] Data represent 2 years post-treatment. Treatment on Ryan Gulch was completed in summer 2011.

[c] n refers to the number of sample units per study plot.

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

[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. Observer-related variation in estimates of proportion of sample units with year-round greater sage-grouse pellets on survey plots from repeat surveys in the Parachute-Piceance-Roan population of western Colorado, USA in 2013. Values presented do not account for variation in pellet detectability. Surveys of each sample unit were conducted by a different observer within 20-30 minutes of each other on the same date.

	PJ - Treatment Plots (Post-treatment)				**PJ - Control (No Treatment) Plots**				**Sagebrush - Control Plots**			
	1-Upper Galloway	2-Black Sulphur	3-Ryan Gulch	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[a]	n = 38[a]	n = 48[a]	N = 3[b]	n = 35	n = 50	n = 38	N = 3	n = 43	n = 41	n = 42	N = 3
p_{YRB}[e]	0.082	0.000	0.188	0.090	0.000	0.100	0.000	0.033	0.605	0.220	0.381	0.402
	± 0.039	± 0.000	± 0.056	± 0.054	± 0.000	± 0.042	± 0.000	± 0.033	± 0.075	± 0.065	± 0.075	± 0.112
p_{YRA}[e]	0.224	0.000	0.167	0.130	0.000	0.040	0.000	0.013	0.465	0.195	0.238	0.299
	± 0.06	± 0.000	± 0.054	± 0.067	± 0.000	± 0.028	± 0.000	± 0.013	± 0.076	± 0.062	± 0.066	± 0.084

[a] n refers to the number of sample units per study plot.

[b] N refers to the no. of study plots contributing to the mean.

[c] 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 7. 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 were 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 8. 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 2012. Values presented do not account for variation in pellet detectability.

	PJ - Treatment Plots (Post-treatment)						**PJ - Control (No Treatment) Plots**				**Sagebrush - Control Plots**			
	Magnolia South[a]	Cotton-wood[a]	Lower Wagon-road[a]	Lower Bar D[b]	Upper Bar D[b]	Lower Barnes[c]	Bar D Split	Magnolia North	Sprague	Upper Wagon-road	Bar D Control	Magnolia Control	Upper Barnes Control	Wagon-road Control
x_S [c]	0.20	0.00	0.00	0.00	0.00	7.31[b]	0.00	0.00	0.00	0.10	9.52	11.91	0.00	2.72
X_S [d]		0.07 ± 0.07		0.00 ± 0.00[e]				0.03 ± 0.02				6.04 ± 2.80		
x_W [c]	2.65	0.27	0.00	0.00	0.63	18.20[b]	0.00	2.02	0.00	0.20	13.44	34.12	7.94	28.91
X_W [d]		0.97 ± 0.84		0.31 ± 0.31[e]				0.56 ± 0.42				21.10 ± 6.21		
x_{YR} [c]	2.86	0.27	0.00	0.00	0.63	25.51[b]	0.00	2.02	0.00	0.31	22.96	46.03	7.94	31.63
X_{YR} [d]		1.04 ± 0.91		0.31 ± 0.31[e]				0.58 ± 0.42				27.14 ± 7.97		
km[f]	9.80	7.52	7.64	9.58	6.36	5.88	4.68	6.44	12.52	9.80	5.88	6.80	5.92	5.88

[a] Treatments on Magnolia South, Cottonwood, and Lower Wagonroad were completed in Oct-Nov 2011. Data represent ~8-10 mo. post-treatment.

[b] Treatments on Lower Bar D and Upper Bar D were completed in January 2011. Data represent ~18 mo. post-treatment.

[c] Data on Lower Barnes were collected opportunistically and are presented for comparison only. Data represent 5-6 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 were available.

[d] x = no. pellet piles detected per km of transect. Subscripts refer to season (x_S = summer; x_W = winter; x_{YR} = year-round).

[e] X = mean no. pellet piles detected per km of transect across study plots in each treatment. Subscripts refer to season.

[f] Post-treatment mean values were calculated separately for the Upper and Lower Bar D plots and for the Lower Barnes plot.

[g] Total kilometers of transect line surveyed per plot. Portions of transects on Cottonwood and Sprague conducted in 2011 were eliminated in 2012 because they had shrub understory or topography unsuitable for greater sage-grouse.

Table 9. 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 2013. Values presented do not account for variation in pellet detectability.

	PJ - Treatment Plots (Post-treatment)						**PJ - Control (No Treatment) Plots**				**Sagebrush - Control Plots**			
	Magnolia South[a]	Cotton-wood[a]	Lower Wagon-road[a]	Lower Bar D[b]	Upper Bar D[b]	Lower Barnes[c]	Bar D Split	Magnolia North	Sprague	Upper Wagon-road	Bar D Control	Magnolia Control	Upper Barnes Control	Wagon-road Control
x_S[d]	0.00	0.00	0.00	0.00	0.00	0.51[b]	0.00	0.00	0.00	0.00	42.18	2.50	0.68	0.51
X_S[e]		0.00 ± 0.00		0.00 ± 0.00[f]				0.00 ± 0.00				11.47 ± 10.25		
x_W[d]	0.31	0.00	0.00	0.52	0.00	2.38[b]	0.00	0.00	0.00	0.00	17.86	16.03	0.34	11.05
X_W[e]		0.10 ± 0.10		0.26 ± 0.26[f]				0.00 ± 0.00				11.32 ± 3.93		
x_{YR}[d]	0.31	0.00	0.00	0.52	0.00	2.89[b]	0.00	0.00	0.00	0.00	60.03	18.53	1.01	11.56
X_{YR}[e]		0.10 ± 0.10		0.26 ± 0.26[f]				0.00 ± 0.00				22.79 ± 12.93		
km[g]	9.80	7.52	7.64	9.58	6.36	5.88	4.68	6.44	12.52	9.80	5.88	6.80	5.92	5.88

[a] Treatments on Magnolia South, Cottonwood, and Lower Wagonroad were completed in Oct-Nov 2011. Data represent ~20-22 mo. post-treatment.
[b] Treatments on Lower Bar D and Upper Bar D were completed in January 2011. Data represent ~30 mo. post-treatment.
[c] Data on Lower Barnes were collected opportunistically and are presented for comparison only. Data represent 5-6 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 were available.
[d] x = no. pellet piles detected per km of transect. Subscripts refer to season (x_S = summer; x_W = winter; x_{YR} = year-round).
[e] X = mean no. pellet piles detected per km of transect across study plots in each treatment. Subscripts refer to season.
[f] Post-treatment mean values were calculated separately for the Upper and Lower Bar D plots and for the Lower Barnes plot.
[g] Total kilometers of transect line surveyed per plot.

Table 10. Timeline for research on greater sage-grouse response to pinyon-juniper removal in the Parachute-Piceance-Roan population, western Colorado, 2008-2015.

Task	Initiation	Completion
Identification of plots for PJ removal	COMPLETE	COMPLETE
Remove encroaching PJ on survey treatment plots (2009-2011)	COMPLETE	COMPLETE
Remove encroaching PJ on transect treatment plots (2011)	COMPLETE	COMPLETE
Pellet surveys (annually)	25 June	31 Aug
Prepare cumulative report (annually)	1 Sep	30 Sep
Prepare cumulative final report	1 Aug 2015	30 Sep 2015

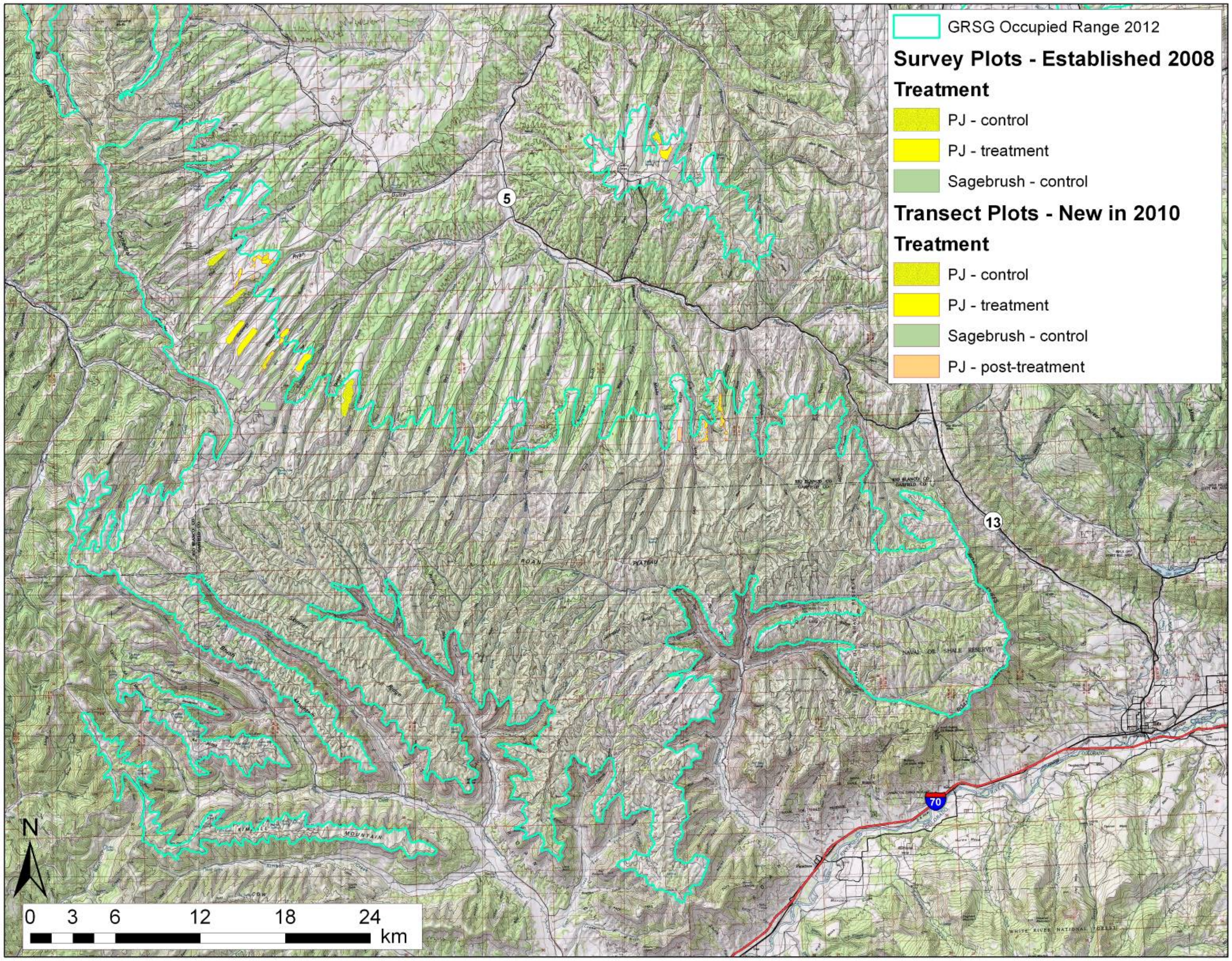

Fig. 1. Map of greater sage-grouse occupied range (as of 2012) showing study plot locations for the pinyon-juniper removal experiment in the Parachute-Piceance-Roan population of western Colorado, USA.

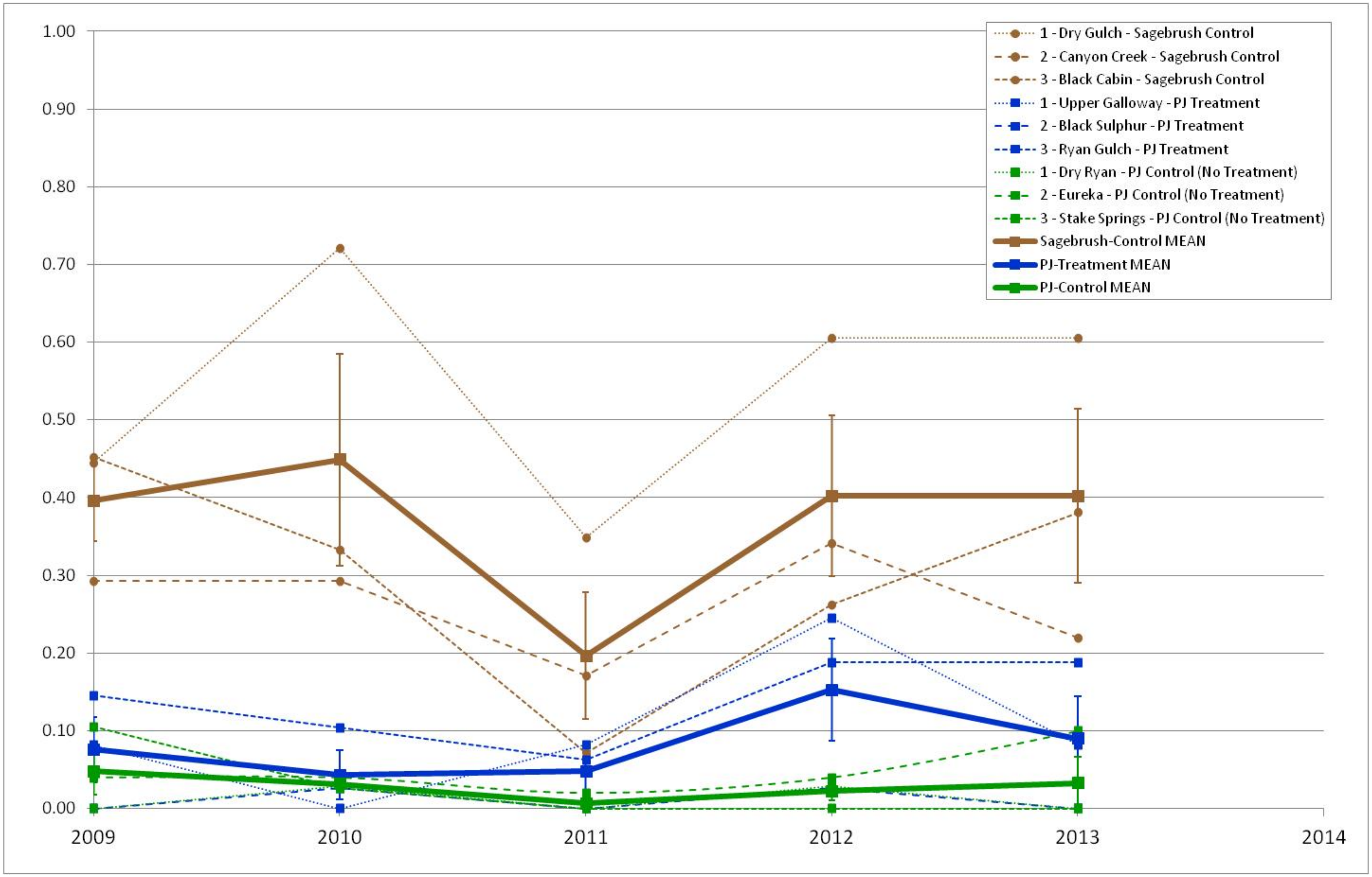

Fig. 2. Trends in the proportion of sample units detected with greater sage-grouse pellets by study plot and means for treatments across study plots in the Parachute-Piceance-Roan population of western Colorado, USA, 2009-2013. Values presented do not account for variation in pellet detectability.

Colorado Division of Parks and Wildlife
September 2012-September 2013

WILDLIFE RESEARCH REPORT

State of:	Colorado	: Division of Parks and Wildlife
Cost Center:	3420	: Avian Research
Work Package:	0660	: Greater Sage-grouse Conservation
Task No.:	N/A	: Evaluation of alternative population monitoring strategies for greater sage-grouse (*Centrocercus urophasianus*) in the Parachute-Piceance-Roan population of northwestern Colorado

Federal Aid
Project No. N/A

Period Covered: September 1, 2012 – August 31, 2013

Author: B. L. Walker, CPW; J. S. Brauch, Colorado State University

Personnel: B. Holmes, B. Petch, B. deVergie, CPW

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ABSTRACT

Robust estimates of population size and population trends provide the scientific basis for managers to make appropriate and defensible recommendations regarding land-use decisions, harvest regulations, and mitigation efforts to conserve wildlife. When linked with environmental variables, robust monitoring programs also allow managers to examine wildlife responses to disease, land-use patterns, habitat treatments, weather, ecological succession, and disturbance. Significant progress has been made over the past three decades in sampling methodology, statistical analysis, and tracking technology to estimate wildlife abundance. However, many wildlife monitoring programs continue to use uncorrected population indices, even though they may or may not provide reliable information on population status or trends. For this reason, it is essential to evaluate alternative approaches to population monitoring in terms of estimator precision, cost, practicality, and level of disturbance to wildlife. Lek counts are the primary index used by all state wildlife agencies in the western U.S. to monitor changes in greater sage-grouse (*Centrocercus urophasianus*) abundance, but lek counts rely on untested assumptions about male lek attendance, detectability, inter-lek movement, sex ratio, and the proportion of leks in the population that are counted. Colorado Parks and Wildlife (CPW) currently uses maximum counts of males from multiple uncorrected counts at each lek as the basis for estimating 3-year running averages for each lek and population zone. Given the availability of new methodological and statistical approaches for estimating wildlife populations, it is worth comparing the use of uncorrected lek counts with other potential monitoring methods. Both dual-frame sampling of leks and non-invasive genetic mark-recapture methods appear suitable and promising for monitoring trends in greater sage-grouse populations. The purpose of this study is to evaluate and compare the reliability and efficiency of dual-frame sampling, genetic mark-recapture, and standard lek counts for estimating population size and trend and to estimate sex ratios in the Parachute-Piceance-Roan (PPR) population of greater sage-grouse in northwest Colorado. The second of three years of dual-frame sampling by helicopter was successfully completed in April-May 2013, with

each of 152 list- and area-frame cells surveyed three times. We discovered five new active lek locations in list-frame cells, no new leks in area-frame cells, and two other leks while in transit between cells. The first year of pellet sampling for genetic mark-recapture analysis occurred from November 2012 through early March 2013, with samples collected within 5 random sampling plots and at 114 additional incidental locations for a total of 1027 pellet and 34 feather samples collected. The second year of pellet sampling will occur in fall-winter 2012-2013. We captured and marked 18 females with VHF collars and banded and released 27 juveniles (18 females, 8 males, 1 unknown) during the period 1 September 2012 through 31 August 2013.

WILDLIFE RESEARCH REPORT

EVALUATION OF ALTERNATIVE POPULATION MONITORING STRATEGIES FOR GREATER SAGE-GROUSE (*Centrocercus urophasianus*) IN THE PARACHUTE-PICEANCE-ROAN POPULATION OF NORTHWESTERN COLORADO

BRETT L. WALKER AND JESSICA S. BRAUCH

PROJECT OBJECTIVES

1. Estimate proportion of known leks, the average number of males attending known leks and the total number of male greater sage-grouse attending leks in the population during three consecutive lekking seasons using dual-frame sampling from helicopter.
2. Estimate population size using genetic mark-recapture during two consecutive fall/winter seasons.
3. Estimate sex ratio using genetic sampling during two consecutive fall/winter seasons.
4. Compare and contrast methods for estimating population size and evaluate the application of auxiliary data for improving estimations based on standard lek-count data.

SEGMENT OBJECTIVES

1. Conduct the second year of dual-frame sampling of leks from helicopter in April - May 2013.
2. Capture and mark VHF females starting July 15, 2013 to augment existing sample of VHF females.
3. Conduct winter pellet sampling from Nov 2012 - Mar 2013 for genetic mark-recapture analyses.
4. Monitor VHF-marked females to test to test assumptions of genetic mark-recapture analyses.

INTRODUCTION

Population monitoring programs are essential for the proper management of wildlife species. Well-designed monitoring strategies allow researchers to determine the status of species of interest; these are often keystone, umbrella, threatened or endangered, candidate, game, or invasive species. For candidate species under the Endangered Species Act, effective monitoring plays a critical role in determining their appropriate conservation status. Additionally, data from monitoring programs informs managers and allows for adjustment of land use strategies, federal or state legal status, hunting regulations, and mitigation plans in response to current population status and trend. Monitoring programs also allow investigators to identify key factors such as disease, human land use, or natural disturbances that influence populations. To provide the information needed to evaluate the status of a population and inform management decisions, researchers need to provide accurate and defensible estimates of population size and trend.

Significant progress has been made in wildlife population estimation since the 1970s, driven by the practical need to estimate abundance and monitor populations over time (Burnham 2004). Advancements in methodology, statistical analysis and technology have been paramount in improving population size estimation and monitoring. Methods have expanded to include stratified and cluster sampling, mark-recapture, occupancy, dual-frame sampling, line intercept, adaptive cluster sampling, distance sampling, and indices from point or lek count data, among others. The development of technologies such as radio telemetry, satellite telemetry, global positioning systems (GPS), global information systems, genetic analysis and computer programs also represent major advances that contribute to improved monitoring strategies for wildlife species. Progress has also been made in the development of methods that reduce or eliminate disturbance to wildlife species, such as genetic mark-recapture and track surveys. Additionally, innovations in the size and design of radio and satellite transmitters have reduced the impact on study animals, allowed researchers to evaluate habitat use and management in a greater variety of species, and reduced the cost of monitoring per individual.

Despite recent progress, generating accurate and defensible estimates of population size and trends remains a key challenge for wildlife biologists and managers. This is particularly true for monitoring rare species and populations at low densities. Researchers investigating populations at low density face numerous challenges including: a lack of appropriate methods, greater susceptibility to estimation bias, issues with imperfect detectability, clustering of animals, and insufficient funding. As a result of these logistic challenges, investigators often turn to population indices to estimate abundance or monitor populations. While indices may be easier to obtain, they are often based on assumptions or unknown variables. Therefore, their relation to the true population may be unclear (Witmer 2005) or inaccurate. As a result, indices may be inadequate when accurate estimates of abundance and trend are required to determine proper management of a wildlife population.

Recent declines in greater sage-grouse populations and substantial restriction of pre-settlement distribution of the species have been observed nationwide (Connelly and Braun 1997, Schroeder et al. 2004). These declines, in combination with habitat loss and human land use conflicts, have prompted repeated petitions for federal listing. In 2010, the species status was designated as warranted, but precluded under the Endangered Species Act (Leonard et al. 2000, Connelly et al. 2004, Schroeder et al. 2004, Braun et al. 2005, Aldridge et al. 2008, USFWS 2010). This decision by the U.S. Fish and Wildlife Service (USFWS) has created a critical need for accurate, defensible population estimations based on sound monitoring techniques. The development of innovative, yet practical methods for estimating populations of rare or cryptic animals, such as the sage-grouse, is essential to accurately determining population size, monitoring trends in abundance and instituting proper management practices.

During the spring breeding season, male greater sage-grouse gather to display on traditional strutting grounds (Patterson 1952), known as leks. These leks offer a unique opportunity to observe and count individuals, particularly males. Historically, lek counts have been considered to be the best, if not the only, means for monitoring populations of lekking species and are currently used by state wildlife agencies throughout the western United States (Connelly et al. 2004). These counts are based on standard protocols (Patterson 1952) and are assumed to provide information on population trends (Fedy and Aldridge 2011). However, lek counts are subject to numerous sources of sampling bias and do not generate rigorous and defensible population estimates required for protection and management of species (Walsh et al. 2010). Standard state lek count indices, like those used by Colorado Parks and Wildlife (CPW), are based on seasonal high counts of males attending leks to estimate population size. The use of lek-count indices to estimate population size and trend rely on untested assumptions and do not account for spatial and temporal variation in detectability. Implicit in lek count indices are assumptions about the proportion of leks that are known and counted, the proportion of males that attend leks, the proportion of males on leks that are detected by observers, the frequency of inter-lek movements by males, and the sex ratio of the population. Each of these factors affects the accuracy of greater sage-grouse abundance estimates to an unknown degree. Therefore, there is a great need to either quantify these variables and adjust lek count index estimates accordingly or develop new methods for estimating population size and trends over time.

Despite legitimate criticism, lek-count indices continue to be the primary means for monitoring changes in sage-grouse population size. Investigations into the reliability of lek-count data for monitoring changes in population size are a research priority for greater sage-grouse (Naugle and Walker 2007) and the development of alternative population monitoring methods is essential for greater sage-grouse population monitoring and management, both in the PPR population and range-wide.

In recent years, attempts have been made to evaluate or improve lek count protocols for greater sage-grouse in order to generate more robust estimates of population size and trends. In addition to projects which evaluate the reliability of standard lek counts, alternative population estimation methods are being developed. These include survey methods that reduce disturbance to the species by employing non-invasive techniques. Recent advances in genetic mark-recapture using sources of DNA such as scat, feathers and hair have created new, innovative opportunities using mark-recapture theory (Lukacs and Burnham 2005a). Sampling of fecal DNA was first attempted in coyotes (Kohn et al. 1999) and has since been used in a variety of other species, including grizzly and brown bears (Mowat and Strobeck 2000, Boulanger et al. 2004, Bellemain et al. 2005), black bears (Coster et al. 2011), northern pike (Miller et al. 2001), northern goshawks (Bayard de Volo et al. 2005), Gunnison sage-grouse (Oyler-McCance, unpublished data) and humpback whales (Palsboll 1997). Genetic mark-recapture is a promising strategy for estimating and monitoring greater sage-grouse populations.

This study will allow us to evaluate the efficacy of using novel techniques for estimating population size and observing trends in the small, isolated population of greater sage-grouse in northwest Colorado. These techniques will be conducted in the field, assessed for reliability of estimates and evaluated for feasibility in long-term population monitoring. These monitoring strategies will also be compared to traditional methods for monitoring sage-grouse populations (i.e. lek counts), focusing on the benefits and disadvantages of each.

STUDY AREA

The Parachute-Piceance-Roan (PPR) population of greater sage-grouse is located northwest of Rifle and southwest of Meeker in western Colorado (Fig. 1). It is recognized as one of six distinct populations in the state (CGSSC 2008). Occupied range in the PPR is characterized by high-elevation ridges and plateaus broken up by steep canyons and drainages. Vegetation is dominated by mountain big sagebrush (*Artemisia tridentata vaseyana*), mixed sagebrush-mountain shrub habitat and pinyon-juniper (*Pinus edulis, Juniperus spp.*) woodlands with occasional patches of aspen (*Populus tremuloides*). Mixed sagebrush-mountain shrub is primarily comprised of mountain big sagebrush and serviceberry (*Amelanchier* spp.) with Gambel oak (*Quercus gambelii*), snowberry (*Symphoricarpus* sp.), antelope bitterbrush (*Purshia tridentata*), mountain mahogany (*Cercocarpus* sp.), and wild rose (*Rosa* sp.). Greater sage-grouse are largely restricted to elevations from 7,000-9,000-ft. (PPR-GSGWG 2008). Approximately 35% of the occupied range is managed by state or federal agencies with the remaining 65% privately owned, primarily by energy companies and ranches. Approximately 4% of the total male greater sage-grouse counted on known leks in Colorado are located in the PPR (CGSSC 2008, PPR-GSGWG 2008).

The PPR population of greater sage-grouse was estimated to have approximately 340 total males in 2007 based on lek-count data (PPR-GSGWG 2008). This small population is experiencing substantial landscape changes, including energy development and pinyon-juniper encroachment into areas of formerly suitable sagebrush habitat (PPR-GSGWG 2008). The PPR population may be especially vulnerable due to its small size and imminent reductions in suitable habitat resulting from the ongoing changes in land use. However, reliable information on population size or trends is not currently available to accurately assess the level of risk to the population. The limited data available to estimate long-term trends in the PPR population include estimates of male population size based on state lek counts conducted by helicopter dating back to 2005 (CGSSC 2008). Unfortunately, the utility of lek count data for reliably estimating population size or monitoring trends in lekking species has been heavily criticized (Beck and Braun 1980, Applegate 2000, Walsh et al. 2004, Walsh et al. 2010) and there is currently no scientifically defensible population estimate available for the PPR (PPR-GSGWG 2008).

METHODS

Dual-Frame Sampling

Dual-frame sampling of leks estimates the proportion of 1-km^2 cells covering occupied range that contain one or more greater sage-grouse leks as well as the average number of males attending those leks. This information can be used to estimate: (1) the proportion of known leks, (2) the average number of males attending known leks, and (3) the population size of male greater sage-grouse attending leks. We will conduct dual-frame sampling of 1-km^2 cells from helicopter during three consecutive spring lekking seasons in 2012, 2013, and 2014.

We will survey for leks and count any leks found within two distinct sampling frames, the list frame and the area frame. The *list* frame consists of all 1-km^2 cells known to contain an active lek. The *area* frame consists of a spatially balanced random selection of 1-km^2 cells generated using a Reversed Randomized Quadrant-Recursive Raster (RRQRR; Theobald et al. 2007). Active leks are defined by Colorado Parks and Wildlife (CPW) as a location on the ground where one to two strutting males have been observed in two or more of the past five years. Leks of unknown status are those that have been recently identified and require a second year or observation before they can be defined as active. For the purposes of dual-frame sampling, unknown leks will be sampled as active leks. We will sample 39 1-km^2 list-frame cells in the PPR population (excluding the "Magnolia" portion) known to contain 49 known active leks (as of February 2012) and approximately 100 area-frame cells (Fig. 1). Any leks newly discovered in 2012 or 2013 will be added to the list frame for sampling in a subsequent year.

We investigated the statistical power to detect a 5%, 7.5% and 10% change in occupancy (the proportion of sample units containing one or more leks) based on lek activity observed during dual-frame sampling using simulations in Program Mark (White and Burnham 1999). We used input parameter values expected to represent the true population occupancy and anticipated sampling effort for the list and area frames. Capture histories were simulated based on input data (expected occupancy rate, detection probability and number of sample units surveyed) and analyzed in Program Mark to obtain standard errors (Runge et al. 2007). Power calculations were generated using Program R. Results indicate that with expected sampling effort (125-140 total 1-km^2 cells per season), power to detect a minimum of 7.5% annual rate of decline in occupancy will be approximately 0.95 with 15 years of surveillance.

All sampling will be conducted by helicopter. Helicopter sampling protocols are based on methods developed by Dr. Paul Lukacs (formerly with the Colorado Division of Wildlife, now at the University of Montana) with slight modifications to address logistical problems unique to the PPR. Surveys will be conducted from mid-April to early May, the primary lekking period for sage-grouse in the PPR, and from 30 minutes before local sunrise to 2 hours after sunrise in accordance with standard CPW lek-count protocols. Observers will count leks by circling the lek, scanning with binoculars, and recording the sex of all birds present. A minimum of three rounds of surveys and counts will be conducted in each cell sampled. This allows estimation of detectability of leks and adheres to standard state lek-count protocols that stipulate at least three counts per year. If leks are discovered incidentally while flying to or from area or list-frame cells, those lek locations will be recorded and used to improve the following year's list frame.

For area-frame cells, observers will survey the entire cell and count any newly discovered leks. A waypoint will be marked at the center of the lek and the location will be added to the list frame the following year. New leks located in area-frame cells will be sampled on any subsequent survey of those cells. Observers will survey list-frame cells the same way as area-frame cells, but observers will also check and, if birds are present, count all previously known lek locations. If new leks are located within list-frame cells, those leks will also be counted and a waypoint marked at the center of the lek.

Dual-frame sampling data will be analyzed in an occupancy framework. Equations modified from Haines and Pollock (1998) will also be used to estimate population size using lek counts and the proportion of known vs. unknown leks.

Genetic Mark-Recapture

This project will use genetic mark-recapture methods to estimate population size. Birds will be captured, marked and have feathers sampled from July to October of each year within occupied range. Fecal pellets obtained from sampling in fall-winter will be genotyped to identify individual sage-grouse. While fecal pellets will predominantly consist of sagebrush DNA, traces of DNA from the intestinal walls of sage-grouse are transferred to the pellets and can be used to amplify microsatellites for genotyping.

Sage-grouse pellets are expected to be at low density due to the apparently small population size of birds in the Piceance and the relatively large size of the study area (1,473 km^2). In addition, unpredictable winter weather conditions, including snowfall and blowing snow, may obscure or bury tracks and pellets. In order to increase the number of samples collected, pellet samples will be obtained using several sampling strategies, including pellet collections from: (1) a random sampling scheme; (2) incidental locations of roost sites or pellets; and (3) back-tracking of incidentally located greater sage-grouse tracks in order to locate roost sites and pellets.

Roosting behavior of greater sage-grouse allows collection of high-quality pellet samples. Sage-grouse roosting at night (and often also during the middle of the day) typically remain at a single location on the ground, regularly dropping fecal pellets. This results in condensed piles of pellets referred to as "roost piles" (Patterson 1952) (Fig. 2). Greater sage-grouse are a gregarious species with both males and hens forming flocks, particularly in the non-breeding or winter months (Patterson 1952). The average flock size of the PPR population is estimated at five to six birds with flocks as large as 24 birds observed (CPW, unpublished data). In the winter months when snow is abundant and temperatures often remain below freezing, fecal DNA is expected to remain viable for several days, particularly for those pellets concealed in roost piles and protected from sun and desiccation.

In addition to the collection and analysis of fecal pellets, feather samples from captured birds will also be collected and used as a source of DNA for individual identification. A related project currently involves the capture of male greater sage-grouse in the PPR and the attachment of 30 g rump-mounted, solar-powered GPS PTT satellite transmitters (Northstar Science and Technology, King George, VA). Up to 35 GPS transmitters per year will be attached to males during 2012 and 2013. We will capture and attach 22 g battery-powered VHF necklace collars equipped with mortality sensors (Advanced Telemetry Systems, Isanti, MN) to an equal number of hens (up to 35 per year) in 2012 and 2013.

Capture and marking of greater sage-grouse in the PPR serves two purposes. First, feathers collected during capture will be genotyped to identify (or "mark") individual birds and the resulting capture data will constitute the first mark-recapture occasion. The addition of this initial capture occasion will increase precision of population abundance estimates generated from mark-recapture data based on the sampling of fecal pellets. Second, systematic monitoring of marked birds with radio-collars will allow us to assess the assumption of demographic and geographic closure of the population (i.e. no death or emigration) during sampling periods, a crucial assumption for the use of closed mark-recapture models.

Random transects will be generated using a spatially balanced (GRTS) sample design (e.g. Reversed Randomized Quadrant-Recursive Raster (RRQRR) (Theobald et al. 2007)). Spatially balanced samples allow for more complete coverage of the study area while increasing the probability of sampling clustered individuals, such as winter flocks of sage-grouse. Approximately 65% of the study area is privately owned (mostly by energy companies or private ranches). Spatially balanced sampling is likely to be advantageous as it will avoid clustering of random points in locations where it may be difficult to gain access for sampling. Spatially balanced sampling will also allow greater coverage of the study area and should aid in reducing heterogeneity in detection probability of individual sage-grouse. Stratification of random samples may be achieved using RRQRR with the incorporation of relative probability of use maps developed for greater sage-grouse in the PPR (Walker 2010). The number of random plots to be sampled will ultimately be constrained by funding and logistics.

Sampling plots will be surveyed for roost piles or other evidence of grouse, particularly tracks in the snow. Fecal piles identified at roost sites or along tracks will be sampled with roost sites being the preferred source for pellet sampling whenever they are available. Roost sites or pellets encountered outside of the random sampling scheme will also be included as incidental sampling locations. When tracks from flocks or individual birds are encountered, they will be followed in an attempt to locate a roost site for sampling. If a roost piles are unavailable, pellets will be sampled along the tracks.

The location of each roost pile will be clearly marked by a staked flag to facilitate sampling. Following an initial search, a 30-meter buffer surrounding roost piles will be searched for additional piles and the buffer reset around the new location until no additional piles are identified within the buffer. This search strategy was developed during the 2011 pilot work conducted at roost site locations near Hiawatha, CO and was designed to maximize pellet detection. At each roost pile, a total of four to five pellets will be collected with a focus on pellets in the best condition (i.e. least exposed or least desiccated). Caecal piles will not be sampled and pellets having contact with caecum will be avoided. When sampling pellets from tracks, the number of birds present in the flock will be counted and an attempt made to collect several pellets from each individual.

Pellet samples will be placed in sterile Whirlpak® bags with a single FTA® desiccant pouch, sealed, labeled for individual identification and stored on ice or snow until they can be transferred to a -20°F non-frost-free freezer at the Little Hills SWA bunkhouse). Pellets will be later transported on dry ice to the USGS Fort Collins Science Center Molecular Ecology Laboratory for DNA extraction.

Capture, Handling, Transmitter Attachment, and Feather Sampling

We plan to capture adult and yearling female greater sage-grouse in July-November in each year. All captured females will be sexed, aged, weighed, and fitted with individually-numbered, aluminum leg bands (size 20) and will have a 22-g, necklace-style, battery-powered VHF transmitter attached (Model A4060, Advanced Telemetry Systems, Isanti, MN). VHF transmitters have a 4-hour mortality switch, a guaranteed life of 15 months, and a range of several miles both from the ground and from the air (depending on terrain and radio age). Transmitters from birds that die may be recovered, cleaned, refurbished and redeployed as necessary to maintain sample sizes. Crews will capture females using CODA net launchers (Giesen et al. 1982), night-time spotlighting and hoop-netting (Wakkinen et al. 1992), walk-in traps modified for sage-grouse (Schroeder and Braun 1991), Super Talon® net guns (Advanced Weapons Technology, La Quinta, CA), MagNet® net guns (Wildlife Capture Services, Flagstaff, AZ), or throw nets, all of which have been approved for capture in this population. The trapping effort will be distributed across the population so that it is proportional to and representative of the amount of local breeding habitat present as identified in preliminary seasonal habitat models (Walker 2010). Otherwise, capture and handling methods will follow standard CPW operating procedures established for sage-grouse. The decision whether injured birds will either be released or euthanized will be made in the field rather than transporting birds back to Fort Collins. No known rehabilitators in western Colorado currently have the facilities to care for wild, injured sage-grouse.

Feather samples will be collected from each captured bird following modified protocols based on those previously used by the USGS Fort Collins Science Center Molecular Ecology Laboratory (MEL) for collection of Gunnison sage-grouse feathers for DNA analysis.

Sample Analysis

DNA extraction and microsatellite analysis will be conducted using protocols developed by the MEL and demonstrated to be reliable for genotyping DNA from fecal pellets of the Gunnison sage-grouse (*Centrocercus minimus*) (Oyler-McCance and St. John, unpublished report). Protocols used for genotyping Gunnison sage-grouse from fecal pellets will be equivalent to those used for greater sage-grouse. DNA extraction will be performed using the QIAmp DNA stool mini kit (Qiagen, Germantown, MD) following protocols for "Isolation of DNA from stool for human DNA analysis" with a slight modification that decreases the final elution volume to 60 ul. Polymerase Chain Reaction (PCR) for amplification of DNA will be performed using a 2-step, pre-amplification method (Piggot et al. 2004) based on primer recipes and thermal profiles currently used by the MEL for genotyping from fecal samples of sage-grouse (pers. comm. Sara Oyler-McCance and Jennifer Fike, USGS). Microsatellite analysis will focus on loci previously identified by the USGS laboratory as reliable for use in identifying individual sage-grouse. Genetic analysis of feather samples will be performed using similar methods developed by the MEL for use in genotyping individual sage-grouse.

A major challenge for researchers conducting genetic mark-recapture studies using non-invasive samples such as feces is the potential for genotyping error. Non-invasively collected samples are often characterized by low quantity or quality of DNA (Broquet et al. 2007), which may be highly variable among samples (Miquel et al. 2006). Problems facing analysis of these samples include amplification failure, allelic dropout and mutation during amplification (Lukacs and Burnham 2005a), each of which may result in genotyping error and violation of a critical assumption of closed models that "marks" are correctly identified and recorded. Lukacs and Burnham (2005b) showed that genotyping error may result in biased abundance estimates from closed mark-recapture models.

To address these concerns, actions will be taken in the field and laboratory to reduce genotyping error and estimate the rate at which it occurs. Throughout this project, special care in the collection and storage of samples will be taken to prevent contamination and maintain sample integrity. In the laboratory, genotyping error rates can be greatly decreased or eliminated with proper training of personnel, careful protocols, the systemization and automation of methods and the use of a reliable set of microsatellite loci (Paetkau 2003). In addition to these measures, each pellet sample will be analyzed twice to monitor for and estimate rates of genotyping error. Sample pairs that fail to match (indicating that potential genotyping error has occurred) will be resampled. Additionally, occasional inclusion of blind duplicate samples will be employed to validate the accuracy of laboratory methods.

Data Analysis

All greater sage-grouse in the study population possess a unique genetic fingerprint and are therefore inherently marked. DNA from fecal pellets will be genotyped, referenced to unique individuals in the population and used to generate encounter histories for those individuals. Encounter history data will be analyzed using closed mark-recapture models in program MARK (White and Burnham 1999). Analysis using closed capture models requires that fecal pellets be sampled across several unique temporal occasions and that closed model assumptions (i.e. demographic and geographic closure, no mark loss or misidentification) are satisfied.

Power Analysis

Simulations were performed in program MARK, using the *Closed Captures* and *Full Closed Captures with Heterogeneity* data types to estimate the sampling effort required to achieve acceptable levels of precision and bias in abundance estimates. Simulations of 500 repetitions were run using a range of probable values for true population size (N), detection probability (p), heterogeneity mixtures (p_i), and the number of sampling occasions. Results from these simulations indicate that, in the absence of individual capture heterogeneity, at least 10% of individuals (p=0.1) in the population should be encountered during each sampling occasion for a minimum of four to five occasions to obtain abundance estimates with acceptable accuracy (i.e. CV < 0.15 and 95% coverage of N). These results were used, in combination with current expectations for population size and considerations for sampling with replacement, to compute cost estimates for the project reported in the budget section of this proposal.

Simulations also indicated that heterogeneity in detection probabilities may make it difficult to obtain unbiased estimates of abundance when using closed mark-recapture models. As a result, emphasis will be placed on sampling strategies that reduce heterogeneity in encountering pellets of individual sage grouse. These strategies include the use of spatially balanced random sampling (RRQRR) to improve sampling coverage of the study area and generation of a unique set of random sampling transects for each occasion to reduce the chance of repeatedly encountering individual birds with fidelity to certain locations.

Sex Ratio

Sex ratios of greater sage-grouse populations have been estimated in several states. However, the majority of data used for these estimates were obtained from hunter harvest efforts such as wing-barrel programs (Connelly et al. 2011) which may have bias due to hunter behavior or preference. Sex ratio of the PPR greater sage-grouse population will be estimated using genetic samples from the genetic mark-recapture component of this project that allows us to determine sex of individual birds. Sex ratio will be estimated using data from two sources of DNA (fecal pellets and/or feathers) collected during sampling efforts for Objective 2. The genetic data obtained from this project will also provide an opportunity to investigate variation in sex composition of greater sage-grouse winter flocks.

Method Comparison

Following the conclusion of the sampling periods and data analysis, a comparison of key population estimation methods investigated in this study will be conducted. Population size estimates from dual-frame sampling, genetic mark-recapture and standard state lek count techniques will be compared. Factors, including variance of population size estimates, cost, practicality of methods, and disturbance to birds associated with each method will be evaluated and recommendations made regarding continued monitoring of the species, both in the PPR and range-wide.

Additionally, we will discuss the efficacy and potential consequences of employing these methods to estimate greater sage-grouse population size and/or determine trends in population size. We will also discuss opportunities for the improvement of lek count-based population estimations through the use of supplemental population information. Sex ratio, inter-lek movements of male sage-grouse and the proportion of known versus unknown leks will be estimated by this project. Related research being conducted in the Piceance by Dr. Brett Walker will additionally provide estimates of male lek attendance rates and detectability. Combined efforts from the two studies will generate estimated values the five unknown variables which are lacking, or assumed, in traditional state lek count estimations.

RESULTS AND DISCUSSION

Dual-frame Sampling

We surveyed 55 list-frame and 97 area-frame cells (152 cells total) for greater sage-grouse leks from helicopters (Bell 47 Soloy and McDonnell-Douglas 500D) from one-half hour before sunrise to two hours after sunrise three times each from April 19 to May 4, 2013 on three rounds of five flights (15 flights total). During these flights, we confirmed 23 active leks in 19 of 55 list-frame cells (including five new lek locations) but found no new leks in area-frame cells. Two additional leks were found while in transit between cells for a total of seven new leks identified on spring 2013 dual-frame sampling flights.

Capture and Monitoring

Field crews captured and marked 18 VHF females (adult or yearling) and banded and released 27 juveniles (18 females, 8 males, 1 unknown) from 1 September 2012 through 31 August 2013. Field crews tracked ~30 VHF females and an additional 14 non-juvenile (adult or yearling) male greater sage-grouse with GPS transmitters were monitored (as part of Dr. Brett Walker's GPS male project) from Nov 2012 - Mar 2013 to test closure assumptions for mark-recapture analyses.

Genetic Mark-recapture

The first year of pellet sampling for genetic mark-recapture analysis occurred from November 2012 through early March 2013, with samples collected within 5 random sampling plots and at 114 additional incidental locations for a total of 1027 pellet and 34 feather samples collected. Lack of access to portions of the study area limited the geographic extent of sampling. The second year of pellet sampling (fall-winter 2012-2013) is scheduled to resume in November 2013.

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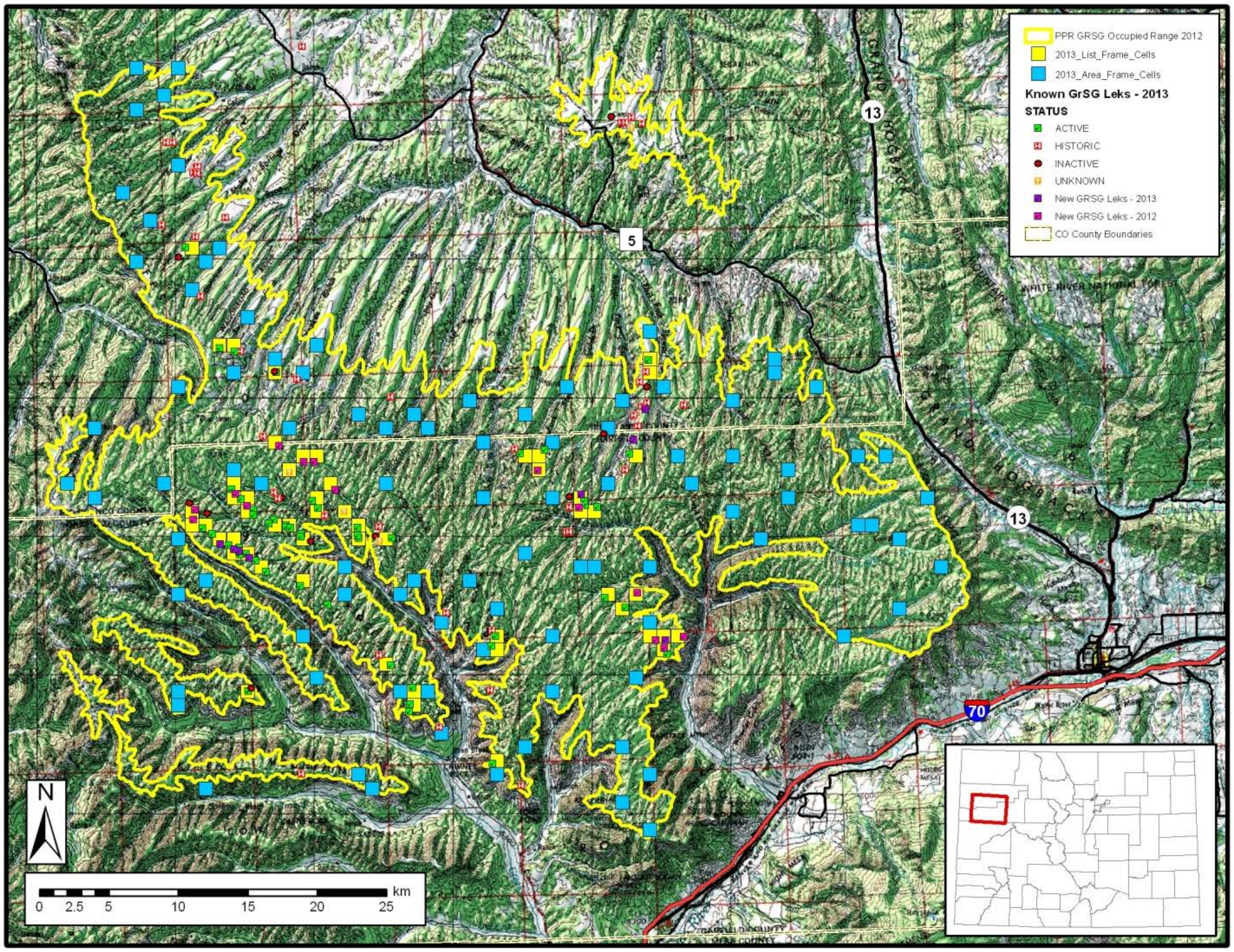

Figure 1. The Parachute-Piceance-Roan population study area showing Colorado Parks and Wildlife's greater sage-grouse occupied range boundary (as of February 2012) as well as known greater sage-grouse leks (as of February 2013) that were either active (within the past five years), inactive (inactive in the past 5 years), historic (inactive for at least the past 10 years), or newly discovered in 2012 or 2013. Newly discovered leks are assigned "Unknown" status until confirmed active again in a subsequent year. The map also shows list-frame (yellow squares) and area-frame (blue squares) 1-km^2 cells used for dual-frame sampling in April-May 2013. Seven of the 15 newly discovered leks in spring 2012 and 7 of the 8 newly discovered leks in spring 2013 were found on dual-frame sampling flights, either within sampled cells or incidentally while in transit between cells.


Figure 2. Greater sage-grouse roost location in the snow with a roost pile and cecal droppings.

Colorado Division of Parks and Wildlife
July 2012-June 2013

WILDLIFE RESEACH REPORT

State of:	Colorado	:	Division of Parks and Wildlife
Cost Center:	3420	:	Avian Research
Work Package:	0680	:	Bird Conservation
Task No.:	N/A	:	Avian response to plague management on Colorado prairie dog colonies

Federal Aid
Project No. N/A

Period Covered: April 1, 2013 – August 31, 2013

Author**:** R. Yale Conrey

Personnel: D. Tripp, J. Gammonley, CPW; A. Panjabi, E. Youngberg, Rocky Mountain Bird Observatory.

ABSTRACT

Range-wide declines in prairie dog (*Cynomys* sp.) populations have occurred, and the largest limiting factor in recent decades appears to be the high mortality and colony extirpation associated with plague (Antolin et al. 2002), caused by the bacterium *Yersinia pestis*. Prairie dog colonies support a diverse community of associated species, many of which are not susceptible to plague but may be indirectly affected. In order to conserve prairie dogs and species associated with their colonies, principally the black-footed ferret (*Mustela nigripes*), a plague vaccination program is being developed, which may also benefit a suite of species listed in the Conservation Plan for Grassland Species in Colorado (Colorado Division of Wildlife 2003) and the Colorado Sagebrush Conservation Assessment and Strategy (Boyle and Reeder 2005). In Colorado, CPW researchers led by Dan Tripp are surveying colonies before and after bait distribution and conducting a mark-recapture study of prairie dogs and associated small mammal species. As an extension to this already funded project, we initiated research on the effects of plague management on avian species associated with prairie dog colonies, with particular focus on species of concern. The objective of the 2013 pilot study was to test protocols, collect baseline pre-treatment data, and begin to demonstrate whether avian species associations exist for colonies of Gunnison's prairie dogs (*Cynomys gunnisoni*: GPD); most evidence for associated species comes from black-tailed prairie dogs (*C. ludovicianus*: BTPD). In 2013, we detected 100 bird species during 1048 point counts, many of which were unique to BTPD, GPD colonies, or GPD off-colony sites. We documented 155 plant species during surveys at 596 points, 83 transects (with 1077 stop points) and 68 nests, most of which were unique to either BTPD or GPD sites. Colonies contained a much higher bare ground component than off-colony sites, with shortgrasses dominant at BTPD sites and a more even distribution of plant types and greater vegetation height at GPD sites. We detected 10 raptor species during 3390 minutes of counts, with burrowing owls and golden eagles showing the strongest preference for colonies. Apparent nest success was 53%, with an average of 2.5 fledglings per successful nest for 68

nests of 11 bird species. Our 63,360 remote camera photos documented coyote, badger, fox, and bobcat use of vaccine project areas. This was the first year of data collection on the project, and as avian field work occurred prior to vaccine bait drop, it is not yet possible to draw any conclusions regarding the effects of plague management on the avian community. However, data from point counts, vegetation surveys, and raptor counts suggest that GPD colonies may have an avian community that differs from that in the surrounding area. Work will continue in 2014 with further improvements to protocols.

COLORADO PARKS AND WILDLIFE RESEARCH REPORT

AVIAN RESPONSE TO PLAGUE MANAGEMENT ON COLORADO PRAIRIE DOG COLONIES

REESA C. YALE CONREY

PROJECT OBJECTIVES

The main long-term objective is to determine whether treated and untreated areas differ in their avian communities. Over time, avian communities on vaccinated prairie dog colonies may differ from those on dusted colonies or those with continued exposure to plague. Shorter-term objectives are to:

4. Determine whether avian species associations exist for Gunnison's and white-tailed prairie dog colonies.
5. Determine whether insecticidal dusting influences bird density or nest survival.
6. Evaluate response of avian community to other land management that may occur on study areas, such as cattle grazing or flood irrigation.

SEGMENT OBJECTIVES

This was the first year of data collection (pilot study) with an overall goal of developing protocols and collecting baseline pre-treatment data. Specific objectives for 2013 included: 1) Familiarize project staff with study areas and with cooperators. 2) Develop grid of points on towns and randomly-chosen off-town locations. 3) Develop all protocols, plant codes, and datasheets. 4) Inventory equipment. 5) Conduct avian point counts and vegetation surveys at points. 6) Sample vegetation on transects. 7) Quantify raptor use at treatment and control sites. 8) Find and monitor success of nests for passerines, mountain plover, burrowing owls, and other raptors; characterize vegetation at nests. 9) Sample predators and other species using remote cameras. 10) Create site-specific keys for identification of vegetation and aging of nestlings 11) Create a SQL server database with Access interface.

INTRODUCTION

Wildlife diseases are important to conservation and population dynamics of susceptible species and may also have large indirect effects on non-susceptible species (Antolin et al. 2002). Introduced pathogens have the potential for far-reaching effects on native ecosystems that go beyond the mortality of infected individuals, particularly when a keystone species (Paine 1969) or ecosystem engineer (Jones et al. 1994) is infected. Range-wide declines in prairie dog (*Cynomys* sp.) populations have occurred, and the largest limiting factor in recent decades appears to be the high mortality and colony extirpation associated with introduced plague (Antolin et al. 2002), caused by the bacterium *Yersinia pestis*. Plague epidemics were first reported in the western United States in 1899 (Dicke 1926) and in northern Colorado in 1948 (Ecke and Johnson 1952). Instead of living in extensive colonies as they once did, prairie dogs exist in metapopulations of smaller colonies that periodically go extinct and are recolonized (Antolin et al. 2002, Stapp et al. 2004). Prairie dog colonies support a diverse community of associated species (Lomolino and Smith 2004, Smith and Lomolino 2004, Hardwicke 2006, Stapp et al. 2008), many of which are not susceptible to plague but may be indirectly effected.

In order to conserve prairie dogs and species associated with their colonies, principally the black-footed ferret (*Mustela nigripes*), a plague vaccination program is being developed. Additional species that may benefit from this program include those listed in the Conservation Plan for Grassland Species in Colorado (Colorado Division of Wildlife 2003): burrowing owl (*Athene cunicularia*: BUOW), mountain plover (*Charadrius montanus*: MOPL), ferruginous hawk (*Buteo regalis*: FEHA), and swift fox (*Vulpes velox*) and in the Colorado Sagebrush Conservation Assessment and Strategy (Boyle and Reeder 2005): Brewer's sparrow (*Spizella breweri*: BRSP), green-tailed towhee (*Pipilo chlorurus*: GTTO), sage sparrow (*Artemisiospiza belli*: SAGS), sage thrasher (*Oreoscoptes montanus*: SATH), vesper sparrow (*Pooecetes gramineus*: VESP), and kit fox (*Vulpes macrotis*), as well as BUOW. BUOW and MOPL are known to decline or disappear on colonies that are not reoccupied by prairie dogs after plague epizootics (Butts and Lewis 1982; Sidle et al. 2001; Augustine et al. 2008; Tipton et al. 2008; Conrey 2010), and horned lark, McCown's longspur, golden eagle, and prairie falcon may benefit from active colonies.

From 2013–2015, researchers in several western states will be field-testing the uptake and efficacy (SPV Subcommittee 2011) of a new sylvatic plague vaccine (SPV) for prairie dogs (Rocke et al. 2010). In Colorado, CPW researchers led by Dan Tripp are surveying colonies before and after bait distribution and conducting a mark-recapture study of prairie dogs and associated small mammal species (Tripp and Rocke 2012). As an extension to this already funded project, we proposed research on the effects of plague management on avian species associated with prairie dog colonies, with particular focus on species of concern. A pilot study was needed to test protocols, collect baseline pre-treatment data, and begin to demonstrate whether avian species associations exist for colonies of Gunnison's prairie dogs (*Cynomys gunnisoni*: GPD); most evidence for associated species comes from black-tailed prairie dogs (*C. ludovicianus*: BTPD; Lomolino and Smith 2004, Smith and Lomolino 2004). During the initial years of the vaccination project, avian monitoring can also contribute information on responses to climate, grazing, and insecticidal dusting. This proposed project could aid in the development of a standardized protocol for monitoring species associated with prairie dog colonies that could be used state-wide, as called for in the Conservation Plan for Grassland Species in Colorado (Colorado Division of Wildlife 2003).

This project involves cooperators from Rocky Mountain Bird Observatory (RMBO), City of Fort Collins, Bureau of Land Management (Gunnison office), National Park Service Florissant Fossil Beds National Monument, and CPW wildlife managers and biologists from Areas 4, 14, and 16.

METHODS

Study Area

Study areas focused on BTPD colonies in north-central Colorado and GPD colonies in central Colorado. Baited sites received either vaccine or placebo baits in a blind procedure. Project areas that were selected for the prairie dog vaccine study had adequate numbers of prairie dogs and good access.

BTPD (Larimer and Weld Co.) – Study colonies were located in Larimer and Weld Co. adjacent to the Wyoming border at Soapstone Prairie Natural Area (SOAP), managed by City of Fort Collins Natural Areas Program and Meadow Springs Ranch (MSR), managed by City of Fort Collins Utilities Department. These sites are characterized by shortgrass and mixed-grass prairie dominated by grasses (blue grama *Bouteloua gracilis* and buffalograss *B. dactyloides*) with smaller amounts of native (scarlet globemallow *Sphaeralcea coccinea*) and non-native forbs, shrubs, and cactus. Sites were sometimes grazed by cattle at low densities, and some non-baited sites were dusted with deltamethrin to control fleas (and plague). Both properties were closed to recreational shooting. Mark-resight estimates of BTPD density on shortgrass prairie in Colorado average approximately 10 prairie dogs/acre (Magle et al. 2007).

Bird and vegetation surveys were conducted on five SOAP colonies and 19 MSR colonies. There were nine vaccine project areas where raptors, predators, and passerine nests were surveyed: three prairie dog complexes each received vaccine, placebo, and dusting treatments (3 treatments*3 complexes = 9 project areas). 1) The Jack Springs (Jac) colony spanning the SPNA/MSR border contained 100 vaccine acres, 100 control acres, and 281 dusted acres separated by 200 - 400 m buffer zones. 2) The Barton complex in MSR contained 130 vaccine acres and 182 control acres, encompassing the entire Barton south and west colonies (BarS and BarW). Raptor, predator, and passerine nest surveys were also done in the 140 acre Barton east colony (BarE), but the prairie dog crew was unable to dust this colony in 2013 and plans to instead pair a dusted portion of the Ferret Center colony (Fer) with the Barton complex. 3) The Ferret Center complex in MSR contained 40 vaccine acres, 40 control acres, and 478 dusted acres, encompassing the entire North Benson south colony (NBenS) and half of the Ferret Center (Fer) colony, with a 400 m buffer zone separating those treatments.

GPD (Gunnison Basin and Woodland Park) – Study colonies were located in the Gunnison Basin (Gunnison, Saguache, and eastern Montrose Co.) and in the Woodland Park area (Teller Co.). Gunnison Basin (GUNN) sites were managed by the Bureau of Land Management (BLM), Colorado Parks and Wildlife (Miller Ranch State Wildlife Area and Cabin Creek SWA), and the U.S. Forest Service Rio Grande National Forest. Woodland Park area (WOOD) sites were managed by the National Park Service Florissant Fossil Beds National Monument (FFB) and Colorado Parks and Wildlife (Dome Rock SWA). These sites are characterized by a mixture of big sagebrush (*Artemisia tridentata*), rabbitbrush (*Chrysothamnus viscidiflorus*), prairie grasses and forbs (fringed sagebrush *A. frigida*) in a matrix of pasture, pine and spruce-fir forests. WOOD sites were accessed exclusively from 6/17 – 21 during 2013 because we did not have a field crew stationed there. Sites were sometimes grazed by cattle or sheep at low densities, and all non-baited sites were dusted with deltamethrin to control fleas (and plague). All properties except FFB were open to recreational shooting, but shooting was not prevalent and signage discouraged shooting in vaccine project areas. The study area is within the known range of plague with plague epizootics occurring near the study colonies in 2010 (Tripp et al. unpublished data). Visual counts of Gunnison's prairie dogs on colonies in Colorado averaged 6.1 prairie dogs/acre in 2010.

Bird and vegetation surveys were conducted on 13 GUNN colonies and two WOOD colonies. There were nine vaccine project areas receiving vaccine, placebo, and dusting treatments where raptors, predators, and passerine nests (GUNN only) were surveyed. Because of their small size, entire colonies were treated. 1) The 33 acre Miller Ranch (MR) and 26 acre Kenny Moore (KM) colonies north of Gunnison received vaccine and control treatments, and the 62 acre Power Line (PL) colony 16 km to the south was designated as the paired dusted treatment. 2) The 46 acre Cabin Creek (CC), 37 acre BLM-15 (B15), and 27 acre BLM-5 (B5) colonies southeast of Gunnison received vaccine and control treatments, and the 69 acre BLM-18 (B18) colony was designated as the paired dusted treatment. B5 was baited in addition to B15 due to concerns that GPD sample size would be too low. All these colonies are within the same complex. 3) The 16 acre Florissant Fossil Beds (FFB) and 24 acre Dome Rock (DR) colonies southwest of Woodland Park (150 km east of Gunnison Basin) received vaccine and control treatments. There was no available colony to use as the paired dusted treatment. The FFB colony was later discarded as a treatment area due to issues with adjacent private land, and this colony was replaced with two different small FFB colonies; however, this occurred after avian surveys had already been completed, so all 2013 avian data collection was on the original colony.

At the GPD study sites, we have an additional objective of determining whether avian species associations exist; therefore, we selected off-colony sites for comparison of data from avian point counts, vegetation surveys, and raptor counts. Time and financial constraints precluded nest searching or camera use off colonies. We extended the 250 m point grid off colonies and created a doughnut-shaped region that extended 500 – 1500 m from 2012 colony boundaries. Within these doughnut regions, we randomly chose grids of nine points (3 x 3) to serve as off-colony study areas on public lands. Some grids had fewer than nine points due to land ownership boundaries. For each colony, we surveyed at least two off-colony sites. Some off-colony sites were located in sagebrush, but others were located in forested areas, especially in areas where forest was the dominant cover type (FFB, DR, and USFS property in the Gunnison Basin).

Avian Point Counts

At the BTPD study sites, a 250 m grid of points had already been established and surveyed by RMBO since 2006. We collaborated with RMBO to complete avian point counts and vegetation assessments at survey points located on BTPD colonies in SOAP and MSR. Each BTPD point was surveyed twice in 2013, from late April to mid-May and again from late May to mid-June. At GPD study sites, we created a 250 m grid of points on colonies and within a 500 – 1500 m doughnut-shaped region off colonies. Within each off-colony grid, we randomly chose a minimum of four points to survey. Two off-colony grids were randomly chosen to pair with each colony, so that we surveyed a minimum of eight off-colony points per paired colony. For larger colonies containing more than eight survey points, we completed as many point counts off colony as we did on colony. GPD points were surveyed twice and off-colony points were surveyed once from mid-May to mid-July, except that FFB, DR, and NP colonies were surveyed only once, and technicians accidentally omitted several off-colony counts in the BLM/CC complex. Points were considered to be "on colony" if located within 100 m of the boundary and with good views of the colony. Most point counts were conducted between dawn and 10:00 and were never conducted in rain, hot temperatures (above 30°C), or high winds that made it difficult to hear birds. Regardless of time or weather, we did not conduct counts if we noticed that bird activity (especially singing and calling) was dropping off.

We conducted 6-min. point counts, recording each bird's species, horizontal (radial) distance, sex (if known), use of the prairie dog colony (yes or no), minute of detection (1 – 6), and how it was detected (visual, singing, calling, drumming, fly-over, or other). Membership in a cluster was noted, typically for male-female pairs. After completing the bird count, we recorded weather and site characteristics at each point, including time, temperature, wind speed, cloud cover, management type (typically cattle grazing, sometimes dusting) and whether it was current, from this season or last season, and the presence of excessive noise, roads (primary or secondary), and cliffs or rock outcroppings within 100 m. Within a 50 m radius, we recorded characteristics of tall nesting and perching substrate, including percent cover, height, and dominant species for overstory plants ≥ 3 m and shrubs > 30 cm but < 3 m. Within a 5 m radius, we recorded characteristics of ground cover, including percent cover of grasses (including sedges and rushes), forbs, bare ground, cactus, rock, scat, shrubs, other cover such as lichen, and exotic species. We also recorded the mean height of forbs, dominant exotic species, and the mean height and species of the dominant two grasses.

We used the point count protocol designed for Integrated Monitoring of Bird Conservation Regions (IMBCR: Hanni et al. 2012), except that we conducted bird surveys prior to vegetation surveys. This helped to ensure that birds displaced by the observer, including those located at the point itself, were recorded. We also altered IMBCR vegetation survey protocols slightly to make the protocol specific to low stature prairie dog colonies, shortgrass prairie, and sagebrush systems. This was designed to be a quick, visual assessment; a more involved protocol using a Daubenmire frame and robel pole was used on transects and at nests.

Vegetation Transects

In addition to a visual assessment of vegetation at points, we sampled vegetation on transects and at nests. We completed two transects on vaccine project colonies and paired off-colony sites and at least one transect on non-project sites (both on and off colonies). To locate each transect, we randomly chose a start and an end point from those used in avian point counts. From the start point, we walked along the bearing toward the end point for 240 m, stopping every 20 m to collect vegetation data for a total of 13 points per transect. Transect data were collected during the growing season.

At each stop point, we recorded the presence of active or inactive prairie dog burrows within 10 m, ground cover, dominant species, and visual obstruction. Percent ground cover was measured within a 50 cm square Daubenmire frame. We recorded the percent bare ground, rock, litter, scat, grass (including sedges and rushes), forb, shrub, cactus, exotic, and other cover. We also recorded the dominant species for each plant category present in the frame. Visual obstruction data were recorded by holding a robel pole at the stop point on the transect and making observations from a distance of 4 m in each cardinal direction with eye level at 1 m. The observer then noted which portions of the 122 cm (4 ft) pole were obstructed by vegetation, identified the plant species obstructing the pole, and noted whether the pole was substantially obstructed or was covered by just a wisp of vegetation (typically a blade of grass). We estimated the height of any structures taller than the pole (a few trees at GPD off-colony sites).

Raptor Counts

Raptors were sometimes sighted during avian point counts, but point counts are not an ideal method for detecting raptors or other uncommon species. Therefore, we chose 1 – 3 locations per vaccine project area (on and off-colony), positioning observers so that the entire treatment area could be viewed simultaneously. We conducted 30-min. raptor counts, recording each bird's species, horizontal (radial) distance, sex (if known), time of entry and exit, and behavior (high soar, low soar, directed flight, hover, dive, call, perch, or nest). Membership in a cluster was noted, typically for male-female pairs. This produces a time metric for assessing raptor use of treatment areas and colonies. At the start and end of the count, we recorded weather characteristics, including time, temperature, wind speed, and cloud cover. Raptor counts were conducted after 9:30 from May to August and were never conducted in rain. As a supplement to the formal raptor counts, we recorded incidental raptor observations.

Nest Searching and Monitoring

We searched for MOPL and BUOW nests throughout the study area through visual observation of adult birds, typically in the morning and not in rainy conditions or high winds. MOPL nest in scrapes on the ground in areas with a relatively high bare ground component. BUOW nest in prairie dog burrows, often near colony edges and in burrows with low to moderately-sized mounds. Because these species react more to humans on foot than to vehicles, we conducted surveys from a vehicle whenever possible. When MOPL were detected, we observed the bird, sometimes backing away from the site, and waited for the bird to sit down on a nest. When BUOW were detected, we searched for nests in the vicinity of their perching location; typically males perched conspicuously near the nest burrow during the day.

We searched for passerine nests on colonies in vaccine project areas only, because the rope dragging technique (Yackel Adams 2000) that works best for secretive birds and camouflaged nests is time-consuming. Most prairie passerines nest in woven cups on the ground, while shrubland passerines typically place their nests on branches or under shrubs. At the GPD project areas, each entire colony was searched via rope dragging one time. At the BTPD project areas ≤ 40 acres, we searched the entire area; at project areas > 40 acres, we haphazardly selected an area ~40 acres for rope dragging, based initially on ease of access and field boundaries (roads, fence lines, etc.). BTPD project areas were searched during two rounds of rope dragging; during the second search, we returned to areas where clumps of nests had been found during the first round of searches but selected new search areas if we found no nests during the first search. This protocol was designed to find as many nests as possible for estimation of nest survival and was not designed to estimate density of nests on the landscape. Passerine nest searching was typically done after 9:30, because grassland birds are more likely to be in attendance at their nests during the heat of the day, and not in rainy conditions or high winds. At BTPD sites, we dragged a 100 ft (30 m), ½ inch gauge rope with two people at each end, watching for flushing birds in the area ahead of and under the rope. Because the GPD sites contained a much higher shrub component, it was not possible to drag a heavy rope without continuously getting snagged on vegetation; therefore, we used a 50 ft, ¼ inch gauge rope, held above the vegetation, with heavy hex nuts suspended from smaller ropes to disturb vegetation slightly and flush birds.

Additional nests were found during point counts and nest monitoring. When we were unable to find a nest during the initial search, we marked the GPS location and returned at a later date. We likely found the majority of BUOW nests on the landscape using this method (Conrey 2010), but a smaller and unknown proportion of MOPL and passerine nests were found. Nests of larger raptors (SWHA, FEHA) were large, conspicuous structures placed in trees, which were relatively rare within prairie dog colonies, so we likely found all those nests located within vaccine project areas. These protocols are being revised for 2014 to find more nests, especially for shrubland birds, and to possibly estimate abundance of nests in a subset of project areas.

MOPL and passerine nests were defined as structures containing at least one egg. Because BUOW nests are underground, we defined their nests as burrows with shredded manure present at the entrance (Garcia and Conway 2009), with feathers, regurgitated pellets, and prey remains providing additional evidence of a nest attempt. At the time of nest discovery, we recorded the same weather information that we recorded at points. We also did a rapid visual assessment of vegetation, with more detailed data to be collected at nest completion when overheating of eggs and nest abandonment was no longer a concern. We described the nest structure and vegetation immediately around the nest and estimated vegetation height, percent bare ground within a 1 m radius, and whether all, ≥ 50%, < 50%, or none of the nest could be seen from vantage points 5 m to the north and south. BUOW nests were marked with brightly painted wooden stakes placed 10 m north of the nest burrow. MOPL and passerine nests were marked with two small unpainted wooden stakes placed 5 m north and south of the burrow. We collected any pellets that we observed near BUOW nests for possible future dietary analysis.

MOPL and BUOW nests, with relatively long incubation and nestling periods, respectively, were monitored at least once per week. Passerine nests were monitored every 2 – 3 days. Starting with the first visit when the nest was discovered, we recorded the time, any management activities (such as cattle grazing), age of eggs and juveniles, and number of eggs, juveniles, and adults present. MOPL and passerine eggs were aged by floating: eggs closer to hatch float higher in the water column. Juveniles were aged according to keys (Priest 1997, Yackel Adams Unpub. data), and we created our own photographic keys for all species for use in 2014.

Passerine nests were considered successful if at least one fully-feathered juvenile left the nest. Evidence of success included juveniles outside the nest cup, mutes at the edge of the nest, and/or displaying and calling adults, coupled with an intact nest and appropriate timing based on nest age. MOPL nests were considered successful if at least one egg hatched, because their chicks are precocial and can leave the nest area within hours of hatch. Evidence of MOPL success included pip chips, coupled with an intact nest and appropriate timing based on nest age. BUOW nests were considered successful when at least one fledgling aged ≥ 35 days was observed (Thomsen 1971, Davies and Restani 2006, Conrey 2010), because they leave the nest burrow (but may return to it many times) at 10 – 14 days and well before flight or independence are attained. Failed nests were destroyed, contained broken eggs, and/or had eggs or nestlings that disappeared before their expected hatch (MOPL) or fledge (BUOW and passerines) date. For analysis purposes, nests with unknown fate will have their histories truncated back to the last date when the nest was active and will be coded as successful at that time.

At nest completion, we recorded the same vegetation data that were collected at points along vegetation transects: presence of prairie dog burrows within 10 m, percent ground cover, and visual obstruction. We placed the Daubenmire frame at 1 m in each cardinal direction and observed the robel pole (placed at the nest) from 4 m in each cardinal direction, producing four readings of each metric. For ground and shrub nests, we also recorded the height of the nest cup above (or below) ground and the plant species or structure type (such as cow paddy) in which (or adjacent to which) the nest was located.

Camera Traps

One remote camera (Reconyx Hyperfire Covert IR model PC800) was placed in each vaccine project area to document use by mammalian predators and other wildlife. These cameras take photos when triggered by motion from an object that is warmer than ambient temperature. Camera locations were selected to maximize the potential for detections of mammalian predators without the use of baits or lures, which might have acted as attractants and altered the sampling region beyond treatment areas and prairie dog colonies. Cameras were positioned along game trails, aimed at coyote height, and tested before they were armed. Cameras targeted water sources, fence lines, and other features of the landscape such as the causeway that once dammed the now dry Kenny Moore reservoir. We set the cameras to take three photos when triggered, with no quiet period between photos.

Cameras were deployed between 4/30 - 6/21/2013, except for one camera that had to be moved between sites and was deployed at a BTPD site (Barton south) on 7/2/2013. We checked batteries and changed SD cards every 2 - 4 weeks whenever possible. The two cameras at the WOOD colonies could not be checked for the 2.5 months they were deployed, because we only accessed that site from 6/17 – 21. Cameras were removed from GUNN sites on 9/3/2013 and from WOOD sites on 9/20/2013, prior to the advent of winter weather or GPD hibernation. We plan to remove cameras from BTPD sites in early November, prior to the advent of winter weather. These cameras were left in place longer because those sites are easier to access and BTPD do not hibernate, so we expect continued predator use of those colonies during winter. As a supplement to the camera data, we recorded incidental observations of coyotes, foxes, badgers, and rattlesnakes.

Database Development

We designed a database for this project using Microsoft SQL Server 2012 with the data entry interface in Microsoft Access 2007. The database was designed by R. Conrey and D. Conrey, a professional database developer who volunteered his time, to run on the Fort Collins CPW research server. This allows multiple users to simultaneously access the database, while providing for daily back-ups and improved data security. Users can access a master list of codes for vegetation species, bird species, management types, observers, sites, towns, and points that if changed, will update throughout the database. Users also access data entry forms for each data type described above. Data entry is ongoing, and we have yet to include incidental observations, nest search effort, or camera deployment in the database.

We collaborated with RMBO to conduct point counts at BPD sites, and as part of the agreement, we entered those point count data in their online database. This database has been queried, producing a spreadsheet in Microsoft Excel that must be processed and loaded into our project database. if this proves to be difficult or time-consuming, we will enter all data directly in the CPW database in 2014.

The Reconyx photo database was created by Eric Newkirk while he was working for CPW. This database catalogs photos and stores the metadata associated with them, displaying (but not storing) the photos themselves within Access forms. It eliminates the need to move back and forth between programs while processing photos. We have just begun loading our photos into the database, but in 2014 we will upload photos during the field season directly from SD cards into the database.

Data Analysis

Thus far, 2013 pilot data have been summarized, but data entry is incomplete and statistical analyses have not yet been completed. We have completed bird and vegetation species lists and summarized ground cover and visual obstruction data collected at transects. For raptor counts, we have calculated a proportional use index, dividing the usage minutes by the total survey minutes for each species and site. Apparent nest success has been calculated as the proportion of nests fledging (BUOW and passerines) or hatching (MOPL) at least one chick. Apparent fledging success has been calculated as the maximum number of known fledglings (hatchlings for MOPL). For BUOW, fledglings were observed directly. For MOPL and passerines that quickly leave the nest area, the count was based on observations leading up to the fledge date, subtracting out any eggs or nestlings that were known to have been lost. Data will eventually be analyzed using Program DISTANCE (point counts), Program MARK (nest survival and possibly occupancy), and R, or a similar statistical package, for other data types.

RESULTS

We conducted 1048 avian point counts at 596 points in 2013 and detected 100 bird species (Table 1, App. 1). The most common birds detected were horned lark, lark bunting, McCown's longspur, and western meadowlark at BTPD sites and Brewer's sparrow, vesper sparrow, and western meadowlark at GPD sites. Sage thrasher, sage sparrow, and horned lark were fairly common at GPD sites; Gunnison's sage-grouse were notable, and mountain plover were not known to occur this far west. We detected 58 species on BTPD colonies, 54 species on GPD colonies, and 55 species off GPD colonies. Of the 71 species at GPD sites, 38 were found both on and off colonies, while 16 were unique to colonies and 17 were unique to off-colony sites.

We characterized vegetation at 596 point count locations, 68 nests, and 1077 stop points along 83 transects (Table 1). Vegetation transect data (Table 2) suggested that BTPD colonies were dominated by grass (mainly blue grama), litter, and bare ground, with twice the grass coverage of GPD sites. In contrast, GPD sites had a more even distribution among cover types; only scat, other (mainly lichen), and cactus were uncommon. Bare ground comprised 23% and 33% of the ground cover on BTPD colonies and on GPD colonies in GUNN, respectively; this amounted to twice as much bare ground as we observed off colonies in GUNN or at WOOD. At the GPD sites, shrub cover (mainly big sagebrush) was much higher in GUNN while litter cover was much higher in WOOD, but there was little difference between on- and off-colony locations. Exotic cover was < 2% at all sites but was higher on (1.3%) than off colonies (0.1%). Dominant plant species of each type are listed in Table 3, with a complete plant species list in App. 2.

Visual obstruction by vegetation was three times higher at GPD sites (12 – 18% of the robel pole), which were dominated by sagebrush, than at BTPD sites (4% of the pole), which were dominated by shortgrasses. Less than 5 cm were obstructed on BTPD colonies, with grasses responsible for most of the obstruction. Obstruction height was much higher at GPD sites, both in terms of the proportion of the pole that was obstructed and the highest obstructed point on the pole. There was little difference between on- and off-colony locations at GPD sites. There tended to be gaps in the vegetation at GPD sites caused by different structural types: grasses, forbs and litter close to the ground, and branches of shrubs higher up.

We conducted raptor counts at 32 locations for a total of 3390 minutes (Table 1) and detected 10 species (Table 4). During raptor counts, BUOW were detected only on BTPD colonies, but one individual was detected during nest searches on a GPD colony (he did not nest). Swainson's hawks and turkey vultures were also much more common on BTPD colonies that at GPD sites. In contrast, ravens were much more common at GPD sites, especially off colonies. Red-tailed hawk use was highest on GPD colonies; they were not detected during off-colony surveys. Golden eagles showed the strongest preference for prairie dog colonies during our surveys (Table 4).

We monitored 68 nests of 11 bird species in 2013 (Tables 1, 5). Most passerine nests were discovered while rope dragging over ~1150 acres, but some were found during visual searches or other research activities. Overall apparent nest success was 53%, with an average of 2.5 fledglings (hatchlings for precocial MOPL and killdeer) per successful nest (Table 5). Nest success was average to high for most species, but fledging success was not, and sample size was small.

We had 18 remote cameras at vaccine project areas in 2013: nine cameras on BTPD colonies and nine cameras on GPD colonies (Table 1). The cameras took 63,360 photos, which are still being processed. Predator photos included coyotes, badgers, foxes, and one bobcat. As expected, many photos recorded humans, cows, and prairie dogs. Other photographed species included pronghorn, elk, deer, rabbits, birds, and a domestic dog.

DISCUSSION

This was the first year of data collection on the project, and as avian field work occurred prior to vaccine bait drop, it is not yet possible to draw any conclusions regarding the effects of plague management on the avian community. However, the data from point counts, vegetation surveys, and raptor counts suggest that GPD colonies may have an avian community that differs from that in the surrounding area. BTPD increase bare ground and alter plant species composition and nutrient cycling rates (Whicker and Detling 1988; Johnson-Nistler et al. 2004); effects of GPD on vegetation are not well-studied. GPD do provide refugia and nests for BUOW, kit fox, and small mammals (Miller et al. 1994, Meaney et al. 2006). However, their impact appears less dramatic than that of BTPD (Grant-Hoffman and Detling 2006), perhaps because of differences in habitat, less above-ground activity, little clipping of vegetation, and lower burrow densities (Seglund and Schnurr 2010). An additional two years of data collection on and off GPD colonies seems warranted.

Data entry is ongoing, and some statistical analyses will be conducted after this has been completed, including estimation of density for avian species. Other preliminary analyses will follow, but full analysis of avian associations, raptor use, nest survival, and predator occupancy must wait until we have collected additional years of data under varying weather conditions, plague, and land management, and increased our sample size. We plan to continue data collection initiated in 2013, with several changes. First, a new white-tailed prairie dog (*C. leucurus*: WTPD) vaccine area may be added in 2014 in southern Moffat and/or northern Rio Blanco County. If so, and if resources permit, we will use the same techniques there as at GPD sites and investigate avian associations with WTPD colonies. If not, we will have more resources to direct toward BTPD and GPD sites, such as additional time nest searching and additional visits to WOOD sites. Second, we will refine protocols for nest searching. Other investigators also reported low nest numbers in 2013 (D. Augustine, pers. comm.), and we consulted with experts to design nest searching protocols at shortgrass prairie (BTPD) sites; therefore, our low sample size was not entirely a result of poor search techniques. However, we plan to consult with shrubsteppe bird experts to improve our nest sample at GPD sites. Third, we will do only one round of point counts (in early morning), which will allow us to begin nest searching and raptor counts (in later morning and afternoon) at the beginning of the field season and increase sample size. Fourth, we are considering winter raptor counts in BTPD colonies to study usage by wintering species such as rough-legged hawks; FEHA associations with BTPD colonies have also mainly been documented in fall and winter (Smith and Lomolino 2004). We are also considering whether any off-colony data should be collected at BTPD sites. Overall, efficiency should be higher in 2014 now that protocols and species keys have been developed.

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TABLES

	BTPD on	GPD on	GPD off	TOTAL
Points	323	170	103	596
Point counts	646	299	103	1048
Point count bird species	58	51	55	100
Vegetation transects	37	23	23	83
Vegetation transect points	481	297	299	1077
Raptor count locations	9	9	14	32
Raptor count minutes	1560	1200	630	3390
Nest searching area (acres)	850	300	N/A	1150
Nests	57	11	N/A	68
Remote cameras	9	9	N/A	18
Remote camera photos	39513	23847	N/A	63360

Table 1. 2013 sample sizes for BTPD and GPD sites, on and off prairie dog colonies.

	BTPD	GPD			
% Cover	SOAP & MSR on	GUNN on	GUNN off	WOOD on	WOOD off
Grass	36.67	13.59	15.33	16.18	14.52
Litter	27.24	13.31	14.79	34.44	38.06
Bare	22.79	32.90	14.52	14.72	13.42
Rock	3.99	14.89	17.13	17.05	17.17
Forb	3.92	5.75	10.84	12.34	10.94
Scat	2.65	2.82	3.59	1.88	1.37
Cactus	1.02	0.00	0.33	0.00	0.00
Shrub	1.00	14.31	17.65	1.40	1.48
Other	0.73	2.42	5.82	1.99	3.05

Table 2. Ground cover percentages from vegetation transects conducted on BTPD and GPD sites, on and off prairie dog colonies in 2013.

	BTPD	GPD			
Type	SOAP & MSR on	GUNN on	GUNN off	WOOD on	WOOD off
Grass	blue grama	western wheatgrass	needle & thread	kentucky bluegrass	kentucky bluegrass
Forb	scarlet globemallow	fringed sagebrush	spiny phlox	fringed sagebrush	fringed sagebrush
Shrub	spreading buckwheat	big sagebrush	big sagebrush	common juniper	common juniper
Cactus	plains pricklypear	N/A	brittle pricklypear	N/A	N/A
Other	lichen	lichen	lichen	lichen	lichen
Exotic	netseed lambsquarter	russian thistle	pinnate tansy mustard	smooth brome	smooth brome

Table 3. Dominant plant species detected on vegetation transects at BTPD and GPD sites, on and off prairie dog colonies in 2013. Close seconds included quackgrass (grass at GUNN on), squirreltail (grass at GUNN off), and netseed lambsquarter (forb at BTPD sites).

Species	Minutes BTPD on	GPD on	GPD off	% BTPD on	GPD on	GPD off
American crow	0	0	2	0.00	0.00	0.32
American kestrel	37	15	16	2.37	1.25	2.54
burrowing owl	220			14.10	0.00	0.00
common raven	101	292	281	6.47	24.33	44.60
ferruginous hawk	3			0.19	0.00	0.00
golden eagle	33	58	1	2.12	4.83	0.16
northern harrier	2			0.13	0.00	0.00
red-tailed hawk	13	38	0	0.83	3.17	0.00
Swainson's hawk	139	0	21	8.91	0.00	3.33
turkey vulture	304	6	2	19.49	0.50	0.32
unknown raptor	38	26	1	2.44	2.08	0.00
TOTAL	1560	1200	630			

Table 4. Raptor use of vaccine project areas at BTPD and GPD sites, on and off prairie dog colonies in 2013. Use was quantified as time spent in project areas, and use rate = use minutes/total minutes on BTPD, on GPD, and off GPD colonies.

Species	# Nests BTPD	GPD	TOTAL	Known Fate	Successful	% Success	# Fledged per successful nest
Brewer's sparrow	3	5	8	7	7	1	2.5
burrowing owl	7	0	7	7	5	0.71	4.1
ferruginous hawk	1	0	1	1	0	0	N/A
horned lark	12	1	13	11	6	0.55	2.3
killdeer	1	0	1	1	1	1	*4.0
lark bunting	2	0	2	2	2	1	1.8
McCown's longspur	26	0	26	25	7	0.28	2.0
mountain plover	3	0	3	3	3	1	*2.3
sage thrasher	0	1	1	1	0	0	N/A
Swainson's hawk	2	0	2	2	2	1	1.0
vesper sparrow	0	4	4	2	0	0	N/A
TOTAL	57	11	68	62	33	0.53	2.5

Table 5. Nest numbers, fate, and fledging success in vaccine project areas on BTPD and GPD colonies in 2013. * = number hatched for precocial species.

APPENDIX 1: BIRD SPECIES LIST

Code	Common Name	BTPD on	GPD on	GPD off
AMCR	American crow		x	x
AMGO	American goldfinch	x	x	
AMKE	American kestrel	x	x	
AMRO	American robin	x	x	x
AWPE	American white pelican	x		
BANS	bank swallow	x		
BARS	barn swallow	x		x
BBMA	black-billed magpie	x	x	x
BCCH	black-capped chickadee		x	x
BGGN	blue-gray gnatcatcher			x
BHCO	brown-headed cowbird	x		
BHGR	black-headed grosbeak			x
BLGR	blue grosbeak	x		
BRBL	Brewer's blackbird	x	x	
BRSP	Brewer's sparrow	x	x	x
BTAH	broad-tailed hummingbird		x	x
BUOR	Bullock's oriole	x		
BUOW	burrowing owl	x	x[+]	
CAFI	Cassin's finch			x
CANG	Canada goose	x	x	
CASP	Cassin's sparrow	x		
CCLO	chestnut-collared longspur	x		
CHSP	chipping sparrow	x	x	x
CLNU	Clark's nutcracker		x	x
CLSW	cliff swallow	x	x	x
COFL	Cordilleran flycatcher		x	x
COGR	common grackle	x		
COHA	Cooper's hawk		x	
CONI	common nighthawk	x		
CORA	common raven	x	x	x
DCCO	double-crested cormorant	x		
DEJU	dark-eyed junco		x	x
DOWO	downy woodpecker			x
DUFL	dusky flycatcher			x
EAME	eastern meadowlark	x		
EUST	European starling	x		
EVGR	evening grosbeak		x	x
FEHA	ferruginous hawk	x		

GOEA	golden eagle	x	x	
GRSP	grasshopper sparrow	x		
GTTO	green-tailed towhee		x	x
GUSG	Gunnison sage-grouse			x
HETH	hermit thrush		x	x
HOLA	horned lark	x	x	
HOSP	house sparrow	x		
HOWR	house wren			x
KILL	killdeer	x		
LARB	lark bunting	x		
LASP	lark sparrow	x		
LBCU	long-billed curlew	x		
LISP	Lincoln's sparrow		x	
LOSH	loggerhead shrike	x	x	x
MALL	mallard	x		
MCLO	McCown's longspur	x		
MGWA	MacGillivray's warbler			x
MOBL	mountain bluebird		x	x
MOCH	mountain chickadee		x	x
MODO	mourning dove	x	x	x
MOPL	mountain plover	x	x	
NOFL	northern flicker		x	x
NOHA	northern harrier	x		
NRWS	northern rough-winged swallow	x		
PISI	pine siskin		x	x
PRFA	prairie falcon	x		
PYNU	pygmy nuthatch		x	x
RBGU	ring-billed gull			x
RBNU	red-breasted nuthatch		x	x
RCKI	ruby-crowned kinglet		x	x
RNSA	red-naped sapsucker			x
ROPI	rock pigeon	x		
ROWR	rock wren	x	x	x
RTHA	red-tailed hawk	x	x	x
RWBL	red-winged blackbird	x	x	x
SACR	sandhill crane	x		
SAGS	sage sparrow		x	
SAPH	Say's phoebe	x		
SATH	sage thrasher	x	x	
SAVS	savannah sparrow		x	
SOSP	song sparrow	x		x
SPTO	spotted towhee	x		
STJA	Steller's jay		x	x

SWHA	Swainson's hawk	x	x*	
TOSO	Townsend's solitaire			x
TRSW	tree swallow	x		
TUVU	turkey vulture	x	x*	x
VESP	vesper sparrow	x	x	x
VGSW	violet-green swallow		x	x
WAVI	warbling vireo		x	x
WBNU	white-breasted nuthatch		x	x
WCSP	white-crowned sparrow			x
WEBL	western bluebird		x	x
WEKI	western kingbird	x	x	
WEME	western meadowlark	x	x	x
WESJ	western scrub-jay			x
WETA	western tanager		x	x
WEWP	western wood-pewee	x	x	x
WISA	Williamson's sapsucker			x
WISN	Wilson's snipe	x	x	
YRWA	yellow-rumped warbler			x
YEWA	yellow warbler		x	x
TOTAL		58	54	55

Table A1. Bird species list for BTPD and GPD sites in 2013. These species were detected during avian point counts with three exceptions. ⁺ = detected while nest searching. * = detected during raptor count.

APPENDIX 2: PLANT SPECIES LIST

Code	Family	Scientific Name	Common Name	Exotic?	BTPD	GPD
Grasses, Sedges, and Rushes						
ACHY	Poaceae	*Achnatherum hymenoides*	Indian Ricegrass			x
AGCR	Poaceae	*Agropyron cristatum*	Crested Wheatgrass	x	x	x
SCSC	Poaceae	*Schizachyrium scoparium*	Little Bluestem			x
ARPU	Poaceae	*Aristida purpurea*	Purple Threeawn		x	
BODA	Poaceae	*Bouteloua dactyloides*	Buffalograss		x	x
BOGR	Poaceae	*Bouteloua gracillis*	Blue Grama		x	x
BRIN	Poaceae	*Bromus inermis*	Smooth Brome	x		x
CALO	Poaceae	*Calamovilfa longifolia*	Prairie Sandreed			x
ELEL	Poaceae	*Elymus elymoides*	Squirreltail		x	x
ELRE	Poaceae	*Elymus repens*	Quackgrass			x
ELTR	Poaceae	*Elymus trachycaulus*	Slender Wheatgrass			x
HECO	Poaceae	*Hesperostipa comata*	Needle & Thread Grass		x	x
KOMA	Poaceae	*Koeleria macrantha*	Junegrass			x
MUHL	Poaceae	*Muhlenbergia Spp.*	Muhlenbergia Spp.			x
NAVI	Poaceae	*Nassella viridula*	Green Needlegrass			x
PASM	Poaceae	*Pascopyrum smithii*	Western Wheatgrass		x	x
PIMI	Poaceae	*Piptatherum micranthum*	Littleseed Ricegrass			x
POPR	Poaceae	*Poa pratensis*	Kentucky Bluegrass	x		x
POAS	Poaceae	*Poa Spp.*	Poa Spp. (Unidentified)			x
CARE	Cyperaceae	*Carex Spp.*	Sedge Spp. (Unidentified)		x	x
CAIN	Cyperaceae	*Carex inops ssp. heliophila*	Sun Sedge			x
JUBA	Juncaceae	*Juncus balticus*	Baltic Rush			x
LUPA	Juncaceae	*Luzula parviflora*	Small-flowered Woodrush			x
Forbs						
ACMI	Asteraceae	*Achillea millefolium*	Common Yarrow			x
ALAC	Liliaceae	*Allium acuminatum*	Wild Onion			x
ALTE	Liliaceae	*Allium textile*	Wild Onion/ Textile Onion		x	

ANMI	Asteraceae	*Antennaria microphylla*	Littleleaf Pussytoes			x
ARUV	Ericaceae	*Arctostaphylos uva-ursi*	Bearberry (Kinnikinnick)			x
ARPO	Papavaraceae	*Argemone polyanthemos*	Crested/ Annual Pricklepoppy		x	
ARAN	Rosaceae	*Argentina anserina*	Silver Weed			x
ARAB	Asteraceae	*Artemisia absinthium*	Absinth Wormwood			x
ARFR	Asteraceae	*Artemisia frigida*	Fringed Sagebrush		x	x
ASBI	Fabaceae	*Astragalus bisulcatus*	Two-grooved Milkvetch			x
ASDR	Fabaceae	*Astragalus drummondii*	Drummond's Milkvetch			x
ASPA	Fabaceae	*Astragalus parryii*	Parry's Milkvetch			x
BASC	Chenopodiaceae	*Bassia scoparia*	Kochia/ Mexican Fireweed	x	x	
BEPL	Scrophulariaceae	*Besseya plantaginea*	White River Coral Drops			x
CALI	Scrophulariaceae	*Castilleja linariifolia*	Narrowleaf Paintbrush			x
CAMI	Scrophulariaceae	*Castilleja miniata*	Scarlet Paintbrush			x
CHGL	Euphorbiaceae	*Chamaesyce glyptosperma*	Small Ribseed Sandmat			x
CHSE	Euphorbiaceae	*Chamaesyce serpyllifolia*	Thyme-leaf Spurge/ Sandmat		x	
CHAM	Euphorbiaceae	*Chamaesyce Spp.*	Sandmat		x	
CHBE	Chenopodiaceae	*Chenopodium berlandieri*	Netseed Lambsquarter		x	x
CHEN	Chenopodiaceae	*Chenopodium Spp.*	Goosefoot Spp. (Unidentified)			x
CHWA	Chenopodiaceae	*Chenopodium watsonii*	Watson's Goosefoot		x	x
CICA	Asteraceae	*Cirsium canescens*	Prairie/ Plains/ Creamy Thistle		x	
CIUN	Asteraceae	*Cirsium ungulatum*	Wavyleaf Thistle			x
CLSE	Capparaceae	*Cleome serrulata*	Rocky Mountain Beeplant		x	
DESO	Brassicaceae	*Descurainia sophia*	Pinnate Tansy Mustard	x		x
EQAR	Equisetaceae	*Equisetum arvense*	Field Horsetail			x
ERCA	Asteraceae	*Erigeron canus*	Hoary Fleabane			x
ERSP	Asteraceae	*Erigeron speciosus*	Showy Fleabane			x
ERST	Asteraceae	*Erigeron strigosus*	Prairie Fleabane			x
ERRA	Polygonaceae	*Eriogonum racemosum*	Redroot Buckwheat			x
ERUMA	Polygonaceae	*Eriogonum umbellatum var. aureum*	Sulphur Buckwheat			x
ERUMM	Polygonaceae	*Eriogonum umbellatum var. majus*	Creamy Buckwheat			x
ERAS	Brassicaceae	*Erysimum asperum*	Western Wallflower			x

FRVE	Rosaceae	*Fragaria vesca*	Woodland Strawberry			x
FRSP	Gentianaceae	*Frasera speciosa*	Monument Plant			x
GABO	Rubiaceae	*Galium boreale*	Bedstraw			x
GECA	Geraniaceae	*Geranium caespitosum*	Pineywoods Geranium			x
GETR	Rosaceae	*Geum triflorum*	Old Man's Whiskers			x
GRSQ	Asteraceae	*Grindelia squarrosa*	Curlycup Gumweed			x
GUSA	Asteraceae	*Gutierrezia sarothrae*	Broom Snakeweed		x	x
HAFL	Boraginaceae	*Hackelia floribunda*	Many-Flowered Stickseed			x
HEVI	Asteraceae	*Heterotheca villosa*	Hairy False Golden Aster/ Golden Aster		x	
HEPA	Saxifragaceae	*Heuchera parvifolia*	Littleleaf Alumroot			x
HEUC	Saxifragaceae	*Heuchera Spp.*	Alumroot Spp. (Unidentified)			x
IPAG	Polemoniaceae	*Ipomopsis aggregata*	Scarlet Gilia			x
IRMI	Iridaceae	*Iris missouriensis*	Rocky Mountain Iris			x
LAOC	Boraginaceae	*lappula occidentalis*	Western Sticktight/ Flatspine Stickweed		x	
LEDE	Brassicaceae	*Lepidium densiflorum*	Common Pepperweed	x		x
LEVU	Asteraceae	*Leucanthemum vulgare*	Ox Eye Daisy			x
LIPU	Asteraceae	*Liatris punctata*	Gayfeather/ Dotted Blazing Star		x	
LIVU	Scrophulariaceae	*Linaria vulgaris*	Yellow Toadflax	x		x
LILE	Linaceae	*Linum lewisii*	Blue Flax			x
LUSP	Fabaceae	*Lupinus*	Lupine Spp. (Unidentified)			x
LUAR	Fabaceae	*Lupinus argenteus*	Silvery Lupine			x
LUWY	Fabaceae	*Lupinus Wyethii*	Wyeth's Lupine			x
LYJU	Asteraceae	*Lygodesmia juncea*	Skeletonweed/ Rush Skeleton Plant		x	
MAPI	Asteraceae	*Machaeranthera pinnatifida*	Lacy Tansyaster		x	
MATA	Asteraceae	*Machaeranthera tanacetifolia*	Tanseyleaf Tansyaster		x	
MARE	Berberidaceae	*Mahonia repens*	Oregon Grape			x
MARA	Liliaceae	*Maianthemum racemosum*	Feathery False Solomon's Seal			x
MAST	Liliaceae	*Maianthemum stellatum*	Starry False Solomon's Seal			x
MEOF	Fabaceae	*Melilotus officinalis*	Yellow Sweetclover	x		x
MELA	Boraginaceae	*Mertensia lanceolata*	Prairie Bluebells			x
OECA	Onagraceae	*Oenothera caespitosa*	Tufted Evening Primrose			x

OECO	Onagraceae	*Oenothera coronopifolia*	Crownleaf Evening primrose		x	
OXLA	Fabaceae	*Oxytropis lambertii*	Lambert Crazyweed			x
OXSE	Fabaceae	*Oxytropis sericea*	White Locoweed			x
PEBA	Scrophulariaceae	*Penstemon barbatus*	Beardlip Beardtongue			x
PEST	Scrophulariaceae	*Penstemon strictus*	Rocky Mountain Beardtongue			x
PHHO	Polemoniaceae	*Phlox hoodii*	Spiny Phlox			x
PHSP	Polemoniaceae	*Phlox Spp.*	Phlox Spp. (Unidentified)			x
PIOP	Asteraceae	*Picradeniopsis oppositifolia*	Opposite Leaf Bahia		x	
PLMA	Plantaginaceae	*Plantago major*	Common Plantain	x		x
PLPA	Plantaginaceae	*Plantago patagonica*	Woolly Plantain		x	x
POOL	Portulacaceae	*Portulaca oleracea L.*	Common Purslane/ Little Hogweed	x	x	
POGR	Rosaceae	*Potentilla gracilis*	Slender Cinquefoil			x
QULO	Solanaceae	*Quincula lobata*	Purple Groundcherry/ Chinese Lantern		x	
RHRO	Crassulaceae	*Rhodiola rosea*	King's Crown	x		x
SATR	Chenopodiaceae	*Salsola tragus*	Russian Thistle / Tumbleweed	x	x	x
SAXI	Saxifragaceae	*Saxifraga Spp.*	Saxifrage Spp. (Unidentified)			x
SELA	Crassulaceae	*Sedum lanceolatum*	Spearleaf Stonecrop			x
SENE	Asteraceae	*Senecio Spp.*	Groundsel Spp. (Unidentified)			x
SOTR	Solanaceae	*Solanum triflorum*	Cutleaf Nightshade		x	x
SOMI	Asteraceae	*Solidago missouriensis*	Missouri Goldenrod			x
SPCO	Malvaceae	*Sphaeralcea coccinea*	Scarlet Globemallow		x	x
TAOF	Asteraceae	*Taraxacum officinale*	Dandelion			x
THRH	Fabaceae	*Thermopsis rhombifolia*	Golden Pea			x
THAR	Brassicaceae	*Thlaspi arvense*	Field Pennycress	x		x
TRAD	Commelinaceae	*Tradescantia Spp.*	Spiderwort		x	
TRPR	Fabaceae	*Trifolium pratense*	Red Clover	x		x
URDI	Urticaceae	*Urtica gracilis*	Stinging Nettle			x
VIAM	Fabaceae	*Vicia americana*	American Vetch			x
VICI	Fabaceae	*Vicia Spp.*	Vetch Spp. (Unidentified)		x	
WYAM	Asteraceae	*Wyethia amplexicaulis*	Mule's Ears			x
<u>Shrubs</u>						

AMAL	Rosaceae	*Amelanchier alnifolia*	Serviceberry			x
ARTR	Asteraceae	*Artemisia tridentata*	Big Sagebrush			x
ATCA	Chenopodiaceae	*Atriplex canescens*	Fourwing Saltbush		x	
CEMO	Rosaceae	*Cercocarpus montanus*	Mountain Mahoganey			x
CHVI	Asteraceae	*Chrysothamnus viscidiflorus*	Douglas Rabbitbrush			x
DAFR	Rosaceae	*Dasiphora fruticosa*	Shrubby Cinquefoil			x
ERNA	Asteraceae	*Ericameria nauseosa*	Rubber Rabbitbrush / Grey Rabbitbrush		x	x
EREF	Polygonaceae	*Eriogonum effusum*	Spreading Buckwheat		x	
JUCO	Cupressaceae	*Juniperus communis ssp. alpina*	Common Juniper			x
JUSC	Cupressaceae	*Juniperus scopulorum*	Rocky Mountain Juniper			x
KRLA	Chenopodiaceae	*Krascheninnikovia lanata*	Winter Fat		x	x
PRAM	Rosaceae	*Prunus americana*	American Plum	x		x
PRVI	Rosaceae	*Prunus virginiana*	Western Chokecherry			x
PUTR	Rosaceae	*Purshia tridentata*	Bitter Brush			x
RHTR	Anacardiaceae	*Rhus trilobata*	Skunkbrush Sumac/ Squawbrush		x	
RIAU	Grossulariaceae	*Ribes aureum*	Golden Currant			x
RICE	Grossulariaceae	*Ribes cereum*	Wax Currant			x
ROAR	Rosaceae	*Rosa arkansana*	Prairie/ Wild/ Porter Prairie Rose		x	
ROWO	Rosaceae	*Rosa woodsii*	Woods' Rose			x
SALI	Salicaceae	*Salix Spp.*	Willow Spp. (Unidentified)			x
SYOC	Caprifoliaceae	*Symphoricarpos occidentalis*	Western Snowberry			x
TECA	Asteraceae	*Tetradymia canescens*	Spineless Horsebrush			x
YUGL	Agavaceae	*Yucca glauca*	Great Plains Yucca/ Soapweed Yucca		x	x
RASP	Asteraceae	*Chrysothamnus/ Ericameria Spp.*	Rabbitbrush Spp. (Unidentified)			x
<u>Trees</u>						
ABLA	Pinaceae	*Abies lasiocarpa*	Sub-Alpine Fir			x
PIEN	Pinaceae	*Picea engelmannii*	Engelmann Spruce			x
PIPU	Pinaceae	*Picea pungens*	Blue Spruce			x
PIPO	Pinaceae	*Pinus ponderosa*	Ponderosa Pine			x
PIFL	Pinaceae	*Pinus flexilis*	Limber Pine			x
POAN	Salicaceae	*Populus angustifolia*	Narrow-leaved Cottonwood			x

PODE	Salicaceae	*Populus deltoides ssp. wislizenii*	Rio Grande Cottonwood			x
POTR	Salicaceae	*Populus tremuloides*	Quaking Aspen			x
PSME	Pinaceae	*Pseudotsuga menziesii*	Douglas Fir			x
<u>Cacti and Other Plants</u>						
ESVI	Cactaceae	*Escobaria vivipara*	Pincushion Cactus		x	
OPPO	Cactaceae	*Opuntia polyacantha*	Plains Pricklypear		x	x
OPFR	Cactaceae	*Opuntia fragilis*	Brittle Pricklypear			x
LICH			Lichen		x	x
Total				15	45	130

Table A2. Plant species list for BTPD and GPD sites in 2013.

Colorado Division of Parks and Wildlife
September 2012-September 2013

WILDLIFE RESEARCH REPORT

State of:	Colorado	: Division of Parks and Wildlife
Cost Center:	3420	: Avian Research
Work Package:	3006	: Other Small Game
Task No.:	N/A	: Evaluating relationships between hunting regulations, habitat conditions, and duck hunting quality on State Wildlife Areas in northeastern Colorado

Federal Aid
Project No. N/A

Period Covered: September 1, 2012 – August 31, 2013

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ABSTRACT

The lower South Platte River (SPR) 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 SWAs along the SPR corridor (Figure 1). We will also examine how the influence of regulations on these responses varies among SWAs with differing habitat conditions. The 2012-2013 regular duck season was the fifth field season of the project. We selected three pairs of SWAs representing different habitat conditions along the SPR corridor, and assigned one 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 2012-2013 duck season, we obtained information from 1,004 hunting parties on study SWAs, of which 717 were duck hunting parties. Brush and Jean K. Tool SWAs (restricted regulations) had the highest use, with 188 duck hunting parties and 386 duck hunter-days, and Overland Trail SWA (unrestricted regulations) had the lowest use, with 31 duck hunting parties and 56 duck hunter-days. From interview data, season-long harvest success, measured as average ducks bagged per hunter per day, was greater at

restricted areas than unrestricted areas of similar size and habitat type: season-long harvest success was twice as high at Atwood SWA than Overland Trail SWA, 2.1 times greater at Jean K. Tool/Brush SWAs than Bravo SWA, and 1.5 times greater at Red Lion SWA than Jackson Lake SWA. 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 or slightly satisfied with duck numbers. Numbers of migrating/wintering ducks in the SPR corridor increased steadily over the course of the season, and large numbers of ducks used open water in large reservoirs. This study is expected to continue for one additional field season.

COLORADO PARKS AND WILDLIFE RESEARCH REPORT

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

JAMES H. GAMMONLEY

PROJECT OBJECTIVES

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

1. Compare duck hunter success (ducks bagged per hunter) on selected SWAs with different hunting regulations and habitat conditions.
   - Hypothesis 1: Average hunter success will be higher on properties with more restrictive hunting regulations than on properties with similar habitat conditions where hunting regulations are less restrictive.
   - Hypothesis 2: Average hunter success will be lower on properties with more restrictive hunting regulations than on properties with similar habitat conditions where hunting regulations are less restrictive.
   - Hypothesis 3: Differences between the two types of areas will be statistically indistinguishable.
2. Compare hunter activity (hunter use-days, party size, hunting methods, number of hours per day when hunters are present on the property) on selected SWAs with different hunting regulations and habitat conditions.
   - Hypothesis 1: Properties with more restrictive hunting regulations will have less intensive use than properties with similar habitat conditions where hunting regulations are less restrictive.
   - Hypothesis 2: Differences between the two types of areas will be statistically indistinguishable.
3. Compare self-reported indices of waterfowl hunter satisfaction on selected SWAs with different hunting regulations and habitat conditions.
   - Hypothesis 1: Average indices of hunter satisfaction will be significantly higher on properties with more restrictive hunting regulations than on properties with similar habitat conditions where hunting regulations are less restrictive.
   - Hypothesis 2: Average indices of hunter satisfaction will be lower on properties with more restrictive hunting regulations than on properties with similar habitat conditions where hunting regulations are less restrictive.
   - Hypothesis 3: Differences between the two types of areas will be statistically indistinguishable.
4. Correlate overall duck numbers, climate data (temperature, precipitation), and indices of habitat conditions (river flows, percent of area flooded, percent of area frozen) with results from objectives 1-4.
   - Prediction: These measures will explain a high proportion of the variation observed over space and time in the response variables for Objectives 1-4.

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

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

SEGMENT OBJECTIVES

1. Collect information on hunting activities, harvest, and satisfaction levels from all waterfowl and small game hunting parties on seven SWAs along the SPR corridor during the 2012-2013 regular duck hunting season.
2. Conduct periodic aerial surveys of waterfowl numbers and distribution along the SPR corridor throughout the 2012-2013 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 five 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 one to three 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 two 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 one of three alternative bag limit regulations (a two-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 fifth year of a six-year management experiment on 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 seven 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 four 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 fall turkey hunting. The study design calls for Restricted (R) and Unrestricted (U) regulations will be applied to the selected properties for six years as described in the table below. A cross-over design is being used to account for site-specific influences on response variables for each pair of properties. Note that the crossover began 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 seven 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.

In past years, significant ice buildup was noted on the ponds at Jackson Lake and Red Lion SWAs by the end of November. In 2012-13, the duck season dates were October 6 – November 26 and December 15 – January 27, with the season closed during November 27 – December 14. For comparative purposes, data from the first and second season segments are summarized separately for Jackson Lake and Red Lion SWAs. During the second season segment, check station attendants were only occasionally assigned to Jackson Lake and Red Lion SWAs, and we relied primarily on hunters filling out voluntary check-out cards.

Check station attendants recorded the license plate numbers of all vehicles at all study SWA parking lots daily throughout the season, and recorded license plate numbers gain as hunting parties checked out at check station. Whenever possible, attendants identified vehicles that belonged to people other than waterfowl and small game hunters (e.g., deer hunters). We used the proportion of total vehicles (excluding vehicles present for other uses) that checked out as an index to compliance with the requirement that all waterfowl and small game hunters check out during the regular duck station at study SWAs.

Aerial surveys of the SPR corridor from Greeley to the state line were conducted monthly during the regular duck hunting season (October 1, November 5, December 4, and January 9) 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.

RESULTS AND DISCUSSION

During the 2012-13 waterfowl hunting season, we obtained harvest and satisfaction measures from 1,004 hunting parties. Of these, 717 (71%) were duck hunting parties. These totals are slightly higher than during the 2011-12 season, but still lower than the average number of total parties (1,246) and duck hunting parties (941) during the four previous years of the study. Dry conditions at many wetland impoundments along the South Platte corridor during the 2012-13 season might have contributed to relatively low number of hunting parties, and particularly duck hunting parties. Impoundments at Jackson Lake SWA were completely dry at the start of the duck season, and impoundments at Red Lion SWA had relatively low water levels.

During the 2012-13 season we interviewed 659 duck hunting parties, and 58 additional duck hunting parties left checkout cards at unmanned check stations. Jean K. Tool/Brush SWAs (restricted regulations) had the highest number of duck hunting parties (188), whereas Jackson lake SWA had the highest number of hunter-days (399((Table 1). Overland Trail SWA (unrestricted regulations) had the lowest use, with 31 duck hunting parties and 56 duck hunter-days (Table 1).

Overall, 40% of duck hunters at the seven study SWAs were in their first year of hunting the lower SPR corridor, 15% had hunted the area for two years, 7% for three years, 3% for four years, and 34% for five years or more. Most (81%) of the duck hunters surveyed hunted mainly public lands, 7% hunted mainly private lands, and 12% said they hunted both public and private lands equally. The average duck hunting party size ranged from 1.7 on Bravo SWA to 2.4 on Atwood Trail SWAs (Table 1). Across all 7 SWAs, 81% of all duck hunting parties used standard decoys, 50% used spinning wing decoys, 44% used dogs, and 83% of used duck calls.

A total of 1,659 ducks was reported harvested on the seven study SWAs during the 2012-13 season (Table 2). The species was identified for 1,604 (97%) of the ducks harvested, and of the identified ducks, six species of dabbling ducks (mallard, northern shoveler, green-winged teal, gadwall, blue-winged teal, and American wigeon) comprised 87% of the duck harvest. Waterfowl hunters also harvested 129 geese at study SWAs, and small game hunters harvested a variety of other migratory game birds, upland game birds, and small mammals at these 7 SWAs (Table 2).

Season-long duck harvest success was measured for each SWA as ducks bagged per hunter per party per day over the 2012-2013 regular duck season. From interview data, harvest success was greater at restricted areas than unrestricted areas of similar size and habitat type: season-long harvest success was twice as high at Atwood SWA than Overland trail SWA, 2.1 times greater at Jean K. Tool/Brush SWAs than Bravo SWA, and 1.5 times greater at Red Lion SWA than Jackson Lake SWA (Table 1). Over all SWAs and across the season, average daily bag per hunter averaged 1.1.

As in previous years, 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 hunting parties with no ducks bagged and most successful hunting parties on these areas bagged less than two ducks per hunter (Figure 2). Hunters experienced slightly fewer zero bag days on the large on-channel properties (Jean K. Tool/Brush and Bravo SWAs) and a greater percentage of hunting parties bagged greater than two ducks per hunter (Figure 3). Hunters had greater success on off-channel properties (Red Lion and Jackson Lake SWAs), with fewer zero bag days and more hunting parties with greater than two ducks bagged per hunter (Figure 4). Across all study areas, average daily duck bag per hunter was variable over the course of the season, with generally higher success early in the season, and lower success late in the season (Figure 5a). Duck hunter activity was also variable across the season, with generally greater numbers of hunters per day on study SWAs early in the season, and fewer hunters in January (Figure 5b). The maximum number of duck hunting parties on the seven study SWAs occurred on opening day of the regular duck season (October 6) at 31.

Satisfaction with number and proximity of other hunters (i.e., 'crowding') was high at all areas, ranging from an average rank of 4.1 (on a scale of 1-5) at Jackson Lake SWA (unrestricted) to an average of 5.0 at Overland Trail SWA (unrestricted) (Table 3). Satisfaction with property-specific hunting regulations was generally favorable at all areas, ranging from an average rank of 4.0 at Atwood and Jean K. Tool/Brush SWAs (restricted) to an average of 4.4 at Jackson Lake SWA (unrestricted) (Table 3). Satisfaction with bird numbers was ranked lower than other measures at all SWAs, whereas satisfaction with habitat conditions was ranked favorably at all SWAs (Table 3). Habitat conditions were ranked lowest (3.1) at Jackson Lake SWA, where the wetland impoundments were dry but the reservoir was filled through the duck season. Overall satisfaction with the day's hunt was generally ranked favorably at all study SWAs (Table 3). Overall satisfaction ranks were moderate to favorable at all SWAs; overall satisfaction with the day's hunt averaged lowest at Atwood and Jackson Lake SWAs (3.5) and highest at Overland Trail SWA (3.9) (Table 3).

We estimated correlation coefficients between average ranks of satisfaction for crowding, hunting regulations, duck numbers seen, overall satisfaction, and average ducks shot per hunter per day on each study SWA (Table 4). 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. Although there were no strong correlations among various measures of satisfaction, satisfaction with bird numbers was most closely positively correlated with overall satisfaction with a day's hunt on all SWAs (range 0.36 – 0.52) (Table 4).

Our index to compliance with the requirement that all waterfowl and small game hunters check out at check stations was slightly lower than that seen in previous years. Compliance was lowest (71%) at Bravo SWA, and was 82% across all study SWAs (Table 5).

Indices of ducks during aerial surveys of the SPR corridor increased over the course of the season (Fig. 6). Large proportions of ducks were concentrated on open water in large reservoirs along the SPR corridor during each count.

This study is expected to continue for one more year, with assignments of regulations to study SWAs the same as in the 2011-2012 hunting season. Data collection will resume in October 2013.

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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 2012-2013. Percent statistics are the percent of parties that used standard 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 (R)	63	157	2.5	2.4	1.0	94	74	33	92
Overland Trail (U)	27	51	1.9	0.7	0.5	32	15	38	32
Jean K Tool /Brush (R)	174	365	2.1	3.0	1.5	91	49	55	91
Bravo (U)	135	243	1.8	1.1	0.7	62	36	35	62
Red Lion (R)	114	262	2.3	3.3	1.5	90	57	53	90
Jackson Lake (U)	146	394	2.7	2.7	1.1	90	62	38	90
Check-out Cards									
Atwood (R)	4	8	2.0	2.8	1.4	100	50	50	100
Overland Trail (U)	4	5	1.3	1.0	0.9	25	25	75	25
Jean K Tool /Brush (R)	14	21	1.5	0.7	0.5	79	29	64	79
Bravo (U)	17	26	1.5	2.9	0.2	53	29	24	47
Red Lion (R)	5	9	1.8	0.4	0.4	75	0	75	100
Jackson Lake (U)	2	5	2.5	8.5	2.8	100	50	0	100
Interviews & Cards									
Atwood (R)	67	165	2.4	2.4	1.0	94	73	34	92
Overland Trail (U)	31	56	1.8	0.7	0.6	31	17	43	47
Jean K Tool /Brush (R)	188	386	2.1	2.9	1.4	90	48	56	90
Bravo (U)	152	269	1.7	1.0	0.6	61	35	34	66
Red Lion (R)	119	271	2.3	3.1	1.5	88	54	53	87
Jackson Lake (U)	148	399	2.7	2.7	1.1	90	61	37	91
After ice-up									
Red Lion (R)	17	41	2.4	1.3	0.9	63	19	53	71
Jackson Lake (U)	16	37	2.3	1.1	0.4	79	50	7	86

Table 2. 2012-2013 harvest totals for all waterfowl and small game reported at the 7 study SWAs during the regular duck season.

Species	Atwood	Overland	JKT	Brush	Bravo	Red Lion	Jackson	**Total**
Ducks								
Mallard	75	9	164	37	50	67	104	**506**
Green-winged teal	19	1	50	7	17	83	81	**258**
Blue-winged teal	30	9	48	21	35	55	57	**255**
Gadwall	8	0	41	23	17	48	15	**152**
American wigeon	7	0	43	25	16	37	18	**146**
Northern shoveler	4	0	6	0	1	35	35	**81**
Northern pintail	2	0	2	1	1	20	9	**35**
Wood duck	0	0	16	13	0	6	0	**35**
Redhead	0	0	1	0	0	13	13	**27**
Mergansers	2	0	8	2	3	2	8	**25**
Scaup	0	0	1	2	0	2	19	**24**
Goldeneyes	1	0	3	2	7	4	7	**24**
Bufflehead	2	0	0	6	0	0	8	**16**
Ring-necked duck	0	0	5	0	0	2	6	**13**
Ruddy duck	0	0	0	2	0	0	1	**3**
Canvasback	0	0	0	0	0	0	2	**2**
Scoter	0	0	0	0	0	0	2	**2**
Unspecified duck	11	5	6	2	6	3	22	**55**
Total Ducks	**161**	**24**	**394**	**143**	**153**	**377**	**407**	**1,659**
Geese								
Canada goose	9	2	11	8	13	56	17	**116**
Snow goose	0	0	0	0	0	10	2	**12**
Ross's goose	0	0	0	0	0	1	0	**1**
Other small game								
Quail	5	13	7	34	80	0	0	**139**
Dove	0	0	0	0	18	0	16	**34**
Rabbit	1	1	3	0	18	4	4	**31**
Pheasant	5	1	0	4	1	7	3	**21**
American coot	0	0	0	0	0	17	0	**17**
Squirrel	0	0	3	3	1	0	0	**7**
Snipe	0	0	1	0	0	2	1	**4**

Table 3. Average satisfaction measures of duck hunting parties on selected State Wildlife Areas (SWAs) along the South Platte River corridor during 2012-2013. 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 (R)	63	4.4	2.9	4.3	4.0	3.5
Overland Trail (U)	27	5.0	2.7	4.5	4.3	4.0
Jean K Tool /Brush (R)	174	4.5	2.9	4.1	4.1	3.8
Bravo (U)	135	4.7	2.5	3.9	4.1	3.7
Red Lion (R)	114	4.4	3.4	4.0	4.1	3.8
Jackson Lake (U)	146	4.0	3.3	3.1	4.4	3.5
Check-out Cards						
Atwood (R)	4	2.7	1.8	3.8	4.3	3.3
Overland Trail (U)	4	4.7	1.3	4.0	4.7	2.7
Jean K Tool /Brush (R)	14	4.5	2.6	4.1	3.4	3.5
Bravo (U)	17	4.3	1.7	3.1	3.5	2.9
Red Lion (R)	5	3.4	2.2	2.8	4.2	3.2
Jackson Lake (U)	2	2.0	4.5	3.0	3.0	3.0
Interviews & Cards						
Atwood (R)	67	4.3	2.8	4.3	4.0	3.5
Overland Trail (U)	31	5.0	2.5	4.4	4.3	3.9
Jean K Tool /Brush (R)	188	4.5	2.9	4.1	4.0	3.7
Bravo (U)	152	4.6	2.4	3.8	4.1	3.6
Red Lion (R)	121	4.3	3.3	4.0	4.2	3.8
Jackson Lake (U)	153	4.1	3.3	3.1	4.4	3.5
After ice-up (Cards)						
Red Lion (R)	17	4.5	4.1	3.7	3.6	3.9
Jackson Lake (U)	16	3.6	3.7	3.5	4.4	2.9

Table 4. Correlation coefficients between some of the satisfaction measures from duck hunting parties at selected State Wildlife Areas (SWAs) along the South Platte River corridor during the 2012-2013 regular duck season.

SWA	Factor	Crowding	Bird numbers	Hunting regulations	Avg. ducks /hunter /day
Atwood (R)	Bird numbers	0.29			
	Hunting regulations	0.18	0.25		
	Avg. ducks /hunter /day	0.01	0.16	0.00	
	Overall	0.45	0.49	0.52	0.24
Overland Trail (U)	Bird numbers				
	Hunting regulations		0.10		
	Avg. ducks /hunter /day		0.35	0.14	
	Overall		0.56	-0.01	0.35
Jean K Tool / Brush (R)	Bird numbers	0.12			
	Hunting regulations	0.06	0.09		
	Avg. ducks /hunter /day	0.06	0.44	0.25	
	Overall	0.26	0.45	0.35	-0.13
Bravo (U)	Bird numbers	-0.05			
	Hunting regulations	0.22	0.04		
	Avg. ducks /hunter /day	-0.04	0.36	0.17	
	Overall	0.25	0.36	0.22	0.32
Red Lion (R)	Bird numbers	0.09			
	Hunting regulations	0.04	0.09		
	Avg. ducks /hunter /day	0.17	0.39	0.04	
	Overall	0.37	0.52	0.18	-0.01
Jackson Lake (U)	Bird numbers	0.13			
	Hunting regulations	0.23	0.04		
	Avg. ducks /hunter /day	0.22	0.31	0.16	
	Overall	0.25	0.47	0.16	0.49

Table 5. Compliance index, based on vehicles recorded as checking out or not checking out at check stations, during the 2012-2013 regular duck season.

SWA	Number of vehicles: Checked out	Number of vehicles: Did not check out	Number of vehicles: Total	% compliance
Atwood (R)	90	20	110	82
Overland Trail (U)	45	17	62	73
Brush (R)	87	26	113	77
Jean K. Tool (R)	125	20	145	86
Bravo (U)	253	104	357	71
Red Lion (R)	153	1	154	99
Jackson (U)	194	16	210	92
Total	947	204	1,151	82

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

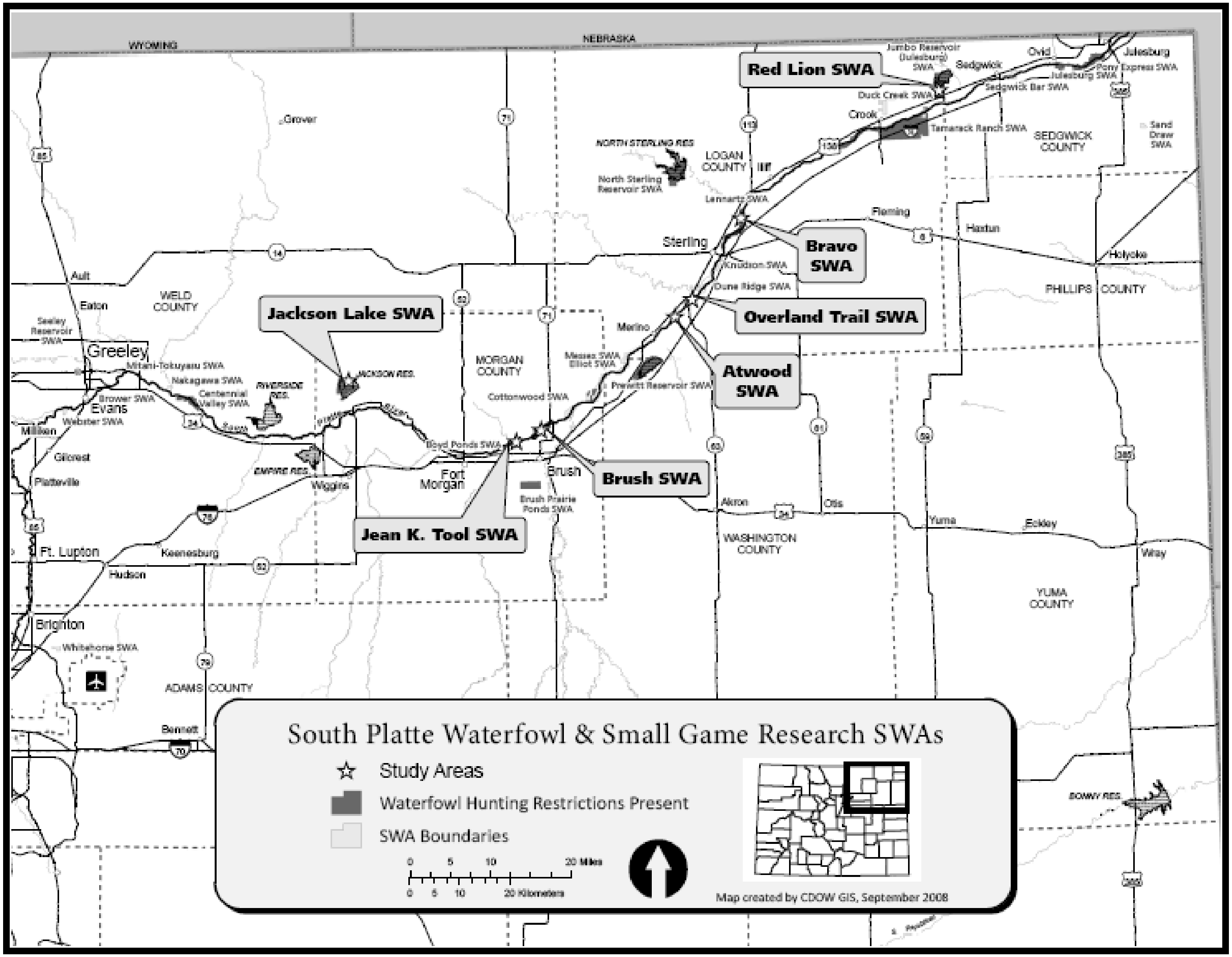


Figure 2. Distribution of average ducks harvested per hunter per day for parties hunting Atwood (Restricted) and Overland Trail (Unrestricted) SWAs during the 2012-2013 regular duck season.

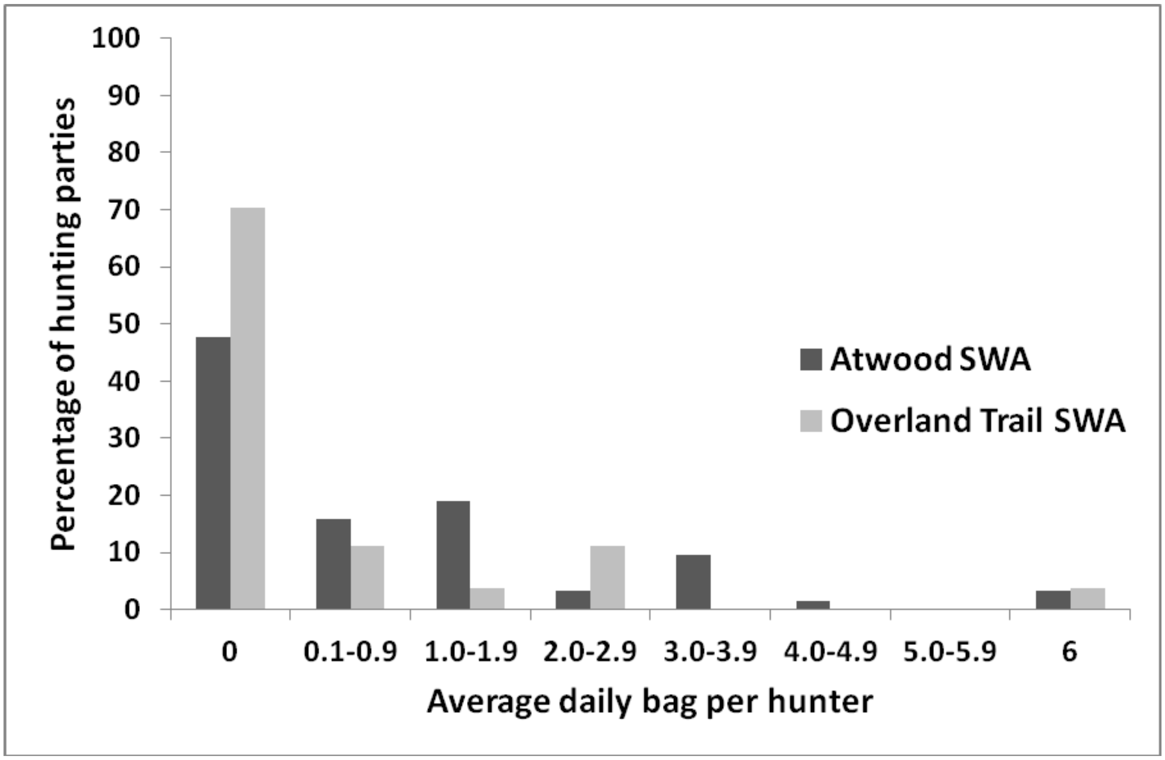


Figure 3. Distribution of average ducks harvested per hunter per day for parties hunting Jean K. Tool/Brush (Restricted) and Bravo (Unrestricted) SWAs during the 2012-2013 regular duck season.

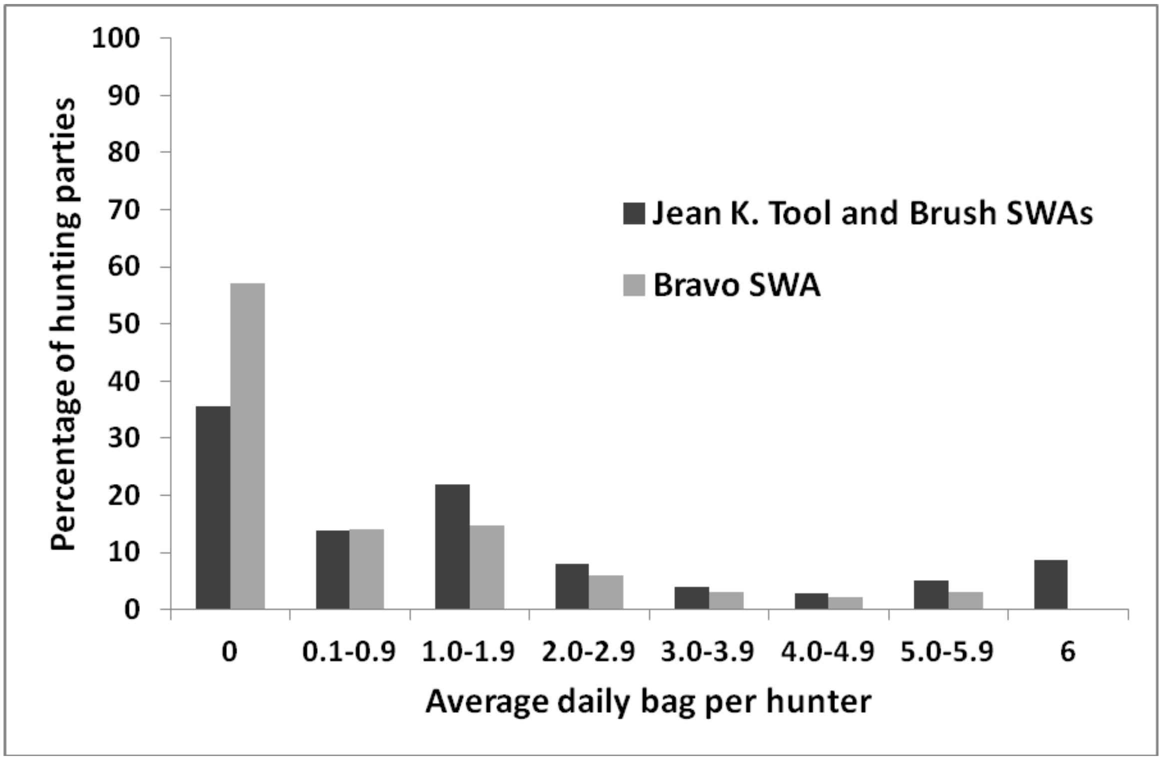


Figure 4. Distribution of average ducks harvested per hunter per day for parties hunting Red Lion (Restricted) and Jackson Lake (Unrestricted) SWAs during the 2012-2013 regular duck season.

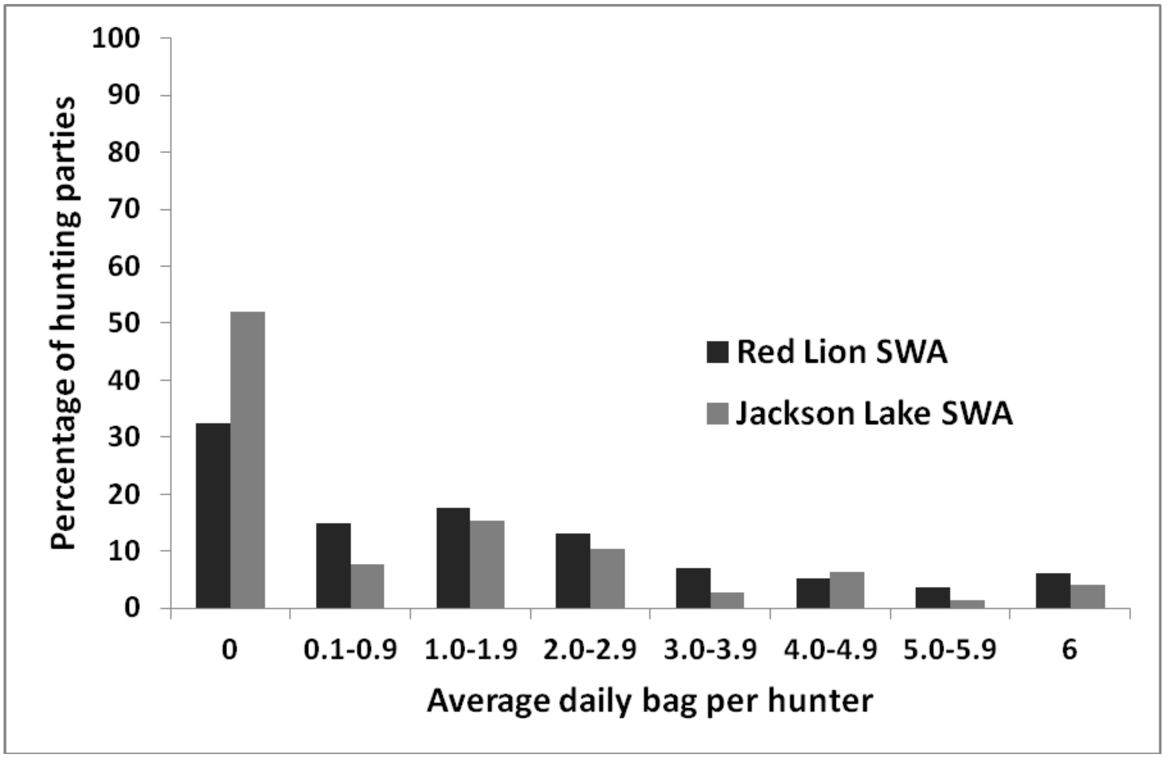
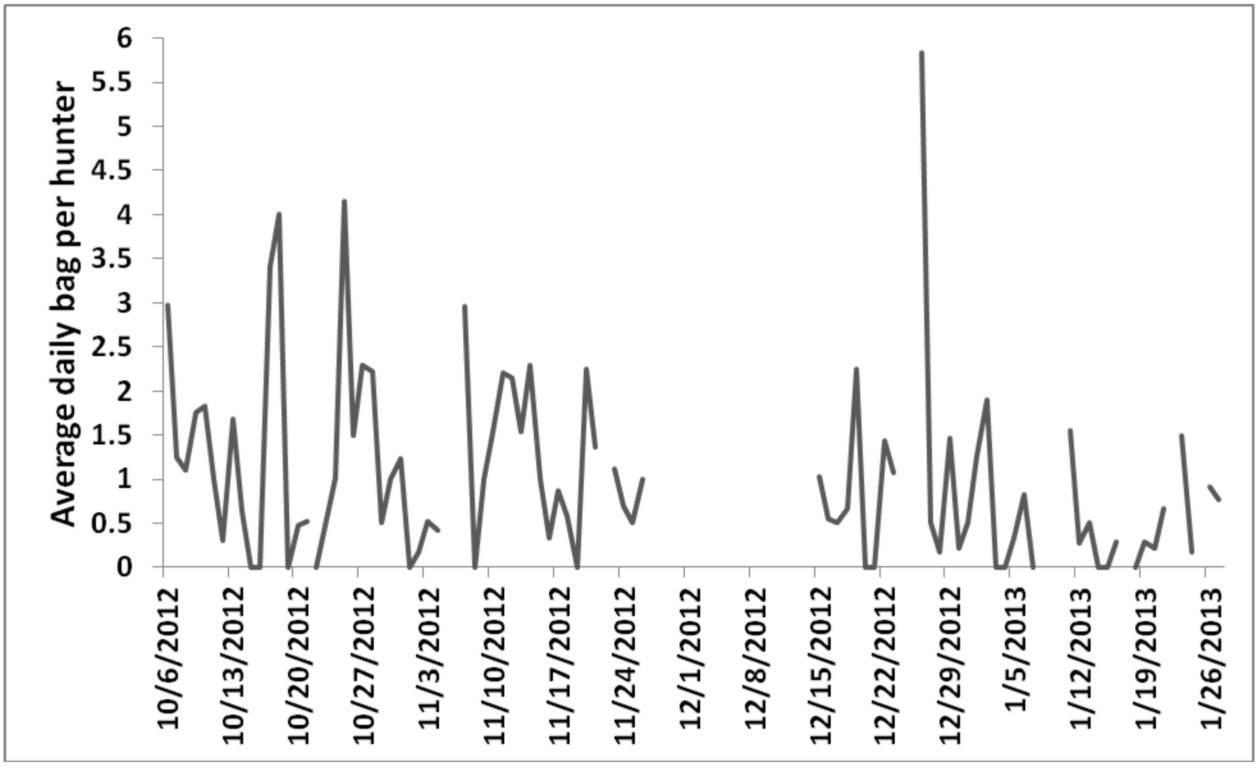


Figure 5. Daily duck hunting success (a) and (b) hunter activity on 7 SWAs along the South Platte River corridor during the 2012-2013 regular duck season, based on hunter interviews by check station attendants. The season was closed during 27 November -14 December.

a.



b.

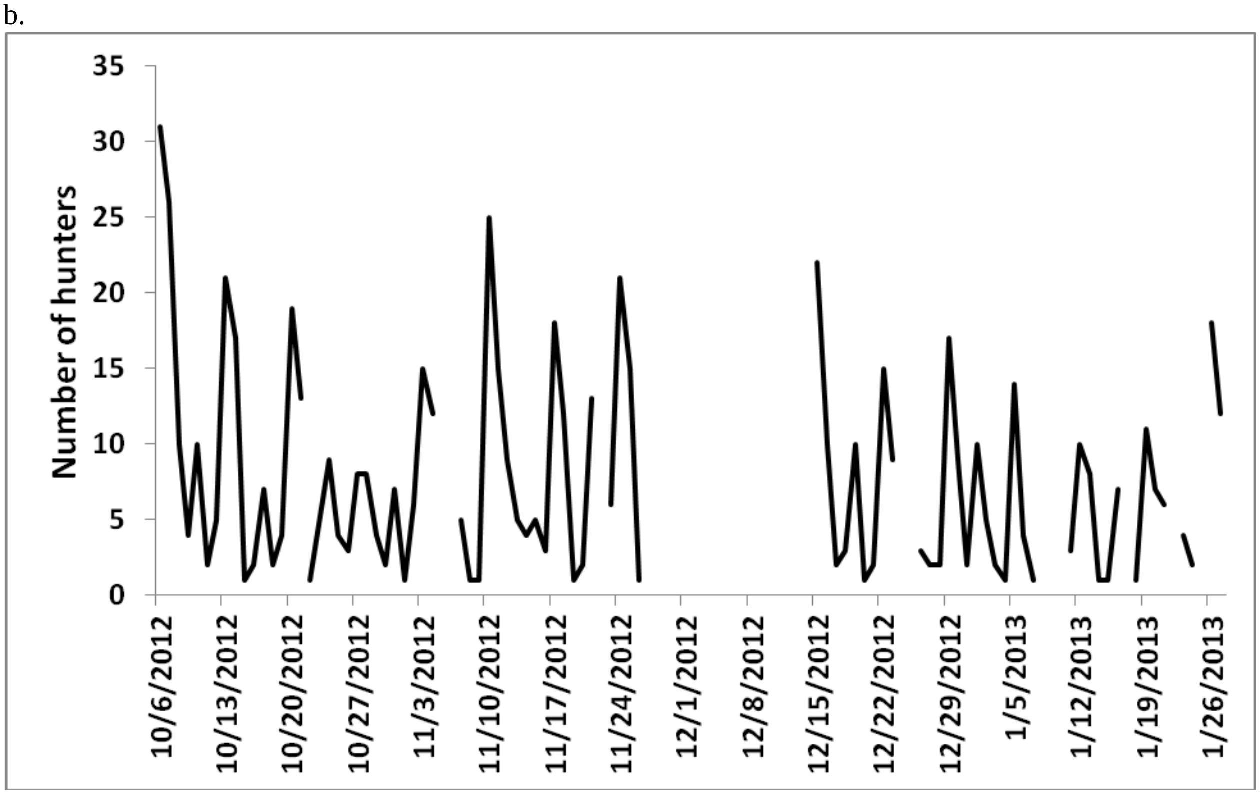
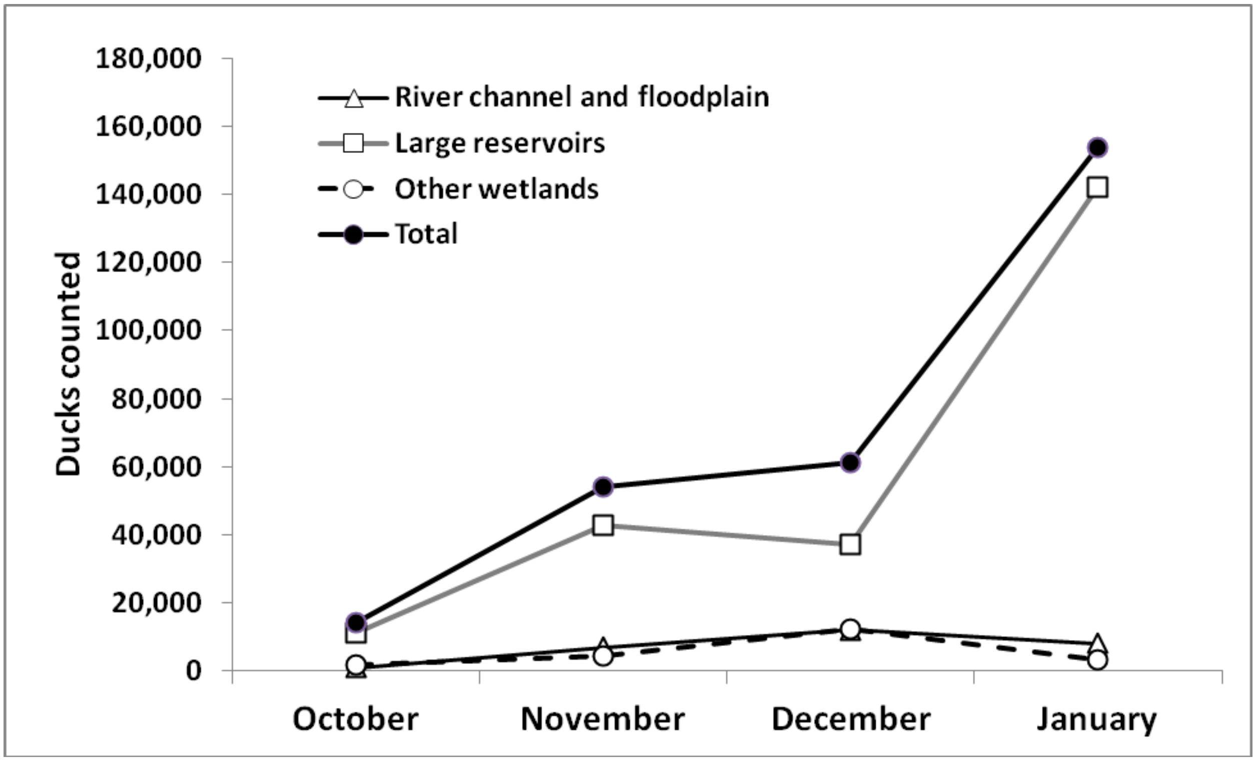


Figure 6. Monthly indices of duck numbers in the South Platte River (SPR) corridor from October 2012 through January 2013.



Appendix A. Information collected from waterfowl and small game hunters on selected State Wildlife Areas along the South Platte River during the 2012-2013 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) _______

Colorado Division of Parks and Wildlife
January 2012 – January 2013

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of Parks and Wildlife
Cost Center:	3420	:	Avian Research
Work Package:	0663	:	Terrestrial Species Conservation
Task No.:	N/A	:	Restoring energy fields for wildlife
Federal Aid Project No.	N/A		

Period Covered: January 16, 2012 – January 15, 2013

Author: D. B. Johnston

Personnel: B. deVergie, J.T. Romatzke, J.C. Rivale, and R. Velarde

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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 (*Odocoileus hemionus*), greater sage-grouse (*Centrocercus urophasianus*), and other wildlife. At elevations less than ~ 2100 m (7000 ft.), 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 elevation near 2100 m, 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 six experiments was implemented in 2008, 2009, and 2012 on simulated well pads and pipelines covering the wide range of precipitation and ecological conditions represented in the Piceance Basin gas field.

The Pipeline experiment began in 2008 on simulated pipeline disturbances at six lower elevation locations. It compares two approaches to controlling cheatgrass and promoting native plants: applying Plateau™ herbicide (ammonium salt of Plateau, BASF corporation, *hereafter* Plateau) at 105 g ai/ha (6 oz/ac) just prior to seeding, and using soil tillage treatments. The tillage treatments examined were disking, rolling, disking with rolling, and vibratory drum rolling. The tillage treatments were of interest because cheatgrass has been shown to be sensitive to seed burial and soil compaction. Vegetation response was quantified by assessing seedling density in 2009 and percent cover in 2010 and 2011 (no measurements were taken in 2012). Three years post-application, Plateau plots had 7-fold higher shrub cover, over 2-fold lower cheatgrass cover, with similar perennial grass and forb cover to no-Plateau plots. Disking reduced initial cheatgrass density, but by the end of the experiment had little effect on cheatgrass cover. Disking slightly improved perennial grass cover, however other tillage treatments were ineffective. Initial cheatgrass density was greatly impacted by the pipeline disturbances, regardless of treatment, and this is attributed to the timing of the disturbance, which maximized cheatgrass seed burial.

The Competition experiment began in 2009 on simulated well pad disturbances at two 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 known. The treatments were: addition of a super-absorbent polymer called Luquasorb® (BASF Corporation), addition of a soil binding agent called DirtGlue® (DirtGlue® Enterprises), and rolling with a heavy lawn roller. In 2012, vegetation response was quantified by percent cover. Super-absorbent polymer reduced cheatgrass cover from 2.9% to 0.7%, and effects were similar where applied at 31 g/m^2 as where applied at 7 g/m^2. The binding agent and rolling had no effects, and no treatments impacted 2012 perennial grass cover.

As a further test of the effect of SAP on plant community development, a new study called the Competition 2 experiment was initiated in 2012. It was located at the same middle-elevation sites as the Competition experiment, and included only the SAP treatment. The experiment differs from the original Competition experiment in having a larger plot size, a more diverse seed mix, and higher cheatgrass propagule pressure.

The Gulley experiment began in 2009 on simulated well pad disturbances at four 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 three 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), and surrounding plots with seed dispersal barriers composed of aluminum window screen secured to oak stakes. Unfallowed plots were seeded in 2009 and fallowed plots were seeded in 2010. In 2012 vegetation was assessed by percent cover. Fallowed plots had drastically lower perennial grass, shrub, and cheatgrass cover, much higher annual forb cover, and higher perennial forb cover than unfallowed plots. Some of these differences can be attributed to the 1-year lag in seeding time between fallowed and unfallowed plots, although the increase in perennial forbs suggests that residual effects of the chemical fallow impacted the plant community. Plateau application increased shrub cover, reduced perennial forb and annual grass cover, was neutral with respect to perennial grasses, and either decreased or increased annual forbs, depending on site and fallow treatment. Barriers increased perennial grass and forb cover, and either decreased or increased annual forbs, depending on site and fallow treatment.

The Mountain Top experiment began in 2009 at four 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 degree to which current seeding practices help or hinder this outcome. Plots left unseeded are compared to plots seeded with a mixture containing a typical density of rhizomatous grass seeds, and these treatments are crossed with treatments designed to create favorable microsites for germination: a rough soil surface treatment consisting of mounds and holes, and a brush mulch treatment. In 2012 vegetation response was quantified by percent cover. Seeding increased perennial grass and forb cover, and reduced shrub, annual forb, and annual grass cover three years post treatment. The rough soil surface treatment increased perennial forb cover at two sites, reduced annual forbs, and controlled annual grasses at the one site which had sufficient annual grasses for analysis. The brush treatment improved shrub and perennial grass cover, and reduced cover of annuals.

The Strategy Choice experiment was implemented in 2009 on simulated well pad disturbances at four middle elevation sites with surrounding plant communities that 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 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 brush mulch versus a flat soil surface with straw mulch, and a balanced seed mix, including a typical density of rhizomatous grass seed, versus a high-forb seed mix. Vegetation response in 2012 was assessed by percent cover. The Plateau treatment successfully controlled cheatgrass, but caused an increase in annual forbs, and had either neutral or negative effects on perennials. The rough/brush surface controlled cheatgrass in certain instances: at a site with high cheatgrass propagule pressure, the rough/brush surface reduced cheatgrass biomass 6-fold when applied with Plateau, and at another site with low cheatgrass propagule pressure, the rough/brush surface reduced cheatgrass biomass 10-fold in the absence of Plateau. Annual cover and biomass were similar with both seed mixes, but perennial forb cover and biomass were higher with the high-forb mix.

Results of Plateau application are mixed, generating beneficial results in one experiment, mixed results in another experiment, and largely detrimental results a third experiment. Successful use of this herbicide requires accurately applying a light rate, and focusing on areas with cheatgrass cover prior to disturbance. In areas where cheatgrass is a threat, but is not evident prior to disturbance, using a roughened soil surface may provide adequate cheatgrass control, as was shown at three sites in two different experiments in this study. The rough soil surface may be effective because when cheatgrass seeds are few in number, they may be trapped within holes, where they experience a wetter microclimate in which they are less competitive. The super-absorbent polymer provided cheatgrass control in 2012, as in prior years, and investigation of the use of super-absorbent polymer in rangeland restoration is continuing in a new experiment. The seed mix lacking rhizomatous grass seed performed well, producing high forb cover without allowing weed infestation. Where unseeded and seeded plots were compared, annual forbs were higher, and perennial grasses and forbs were lower in unseeded plots. However, unseeded plots also had higher shrub cover than seeded plots, which may ultimately produce a more desirable plant community for wildlife.

Throughout the elevation range of this suite of experiments, treatments were found which improved post-reclamation wildlife habitat. Excellent recovery of wildlife habitat value should be the goal for oil and gas disturbances. The Competition, Competition 2, Gulley, and Mountaintop, experiments will be monitored in 2013.

WILDLIFE RESEARCH REPORT

RESTORING ENERGY FIELDS FOR WILDLIFE

DANIELLE B. JOHNSTON

PROJECT OBJECTIVES

1. Develop reclamation techniques for big sagebrush (*Artemisia tridentata*) 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.
2. 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.
3. Determine which techniques are effective at promoting plant community diversity in reclamation. Test techniques such as use of a high-forb/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 six separate experiments with different objectives for this reporting year:

1. *Pipeline experiment:* No monitoring done in 2012; a synthesized report was presented in 2011 for the initial phase of this experiment. Monitoring is now planned for every third year, with the next monitoring year in 2014.
2. *Competition experiment:* Assess vegetation three years following soil additive and compaction treatments by measuring plant cover in 60 plots at each of two research sites.
3. *Competition 2 experiment:* Take baseline data, prepare seedbed, implement super-absorbent polymer treatment, and plant seed at two research sites.
4. *Gulley experiment:* Assess vegetation two years post-implementation of a fallowing treatment, and three years post-treatment in non-fallowed plots. Measure plant cover in 24 plots at each of four research sites.
5. *Mountain Top experiment:* Assess vegetation three years following seeding, soil surface roughening, and brush mulch treatments by measuring plant cover in 24 plots at each of four research sites.
6. *Strategy Choice experiment:* Assess vegetation three years following herbicide, soil surface roughening, and seed mix treatments by measuring plant cover and biomass in 12-24 plots at each of 4 research sites. Synthesize results with prior year and prepare final report.

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 native 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 which 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 and mule deer (*Odocoileus hemionus*) habitat use may decline within large buffer areas surrounding development (Sawyer et al. 2006, Walker et al. 2007). 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.

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 six experiments, each repeated at two to six sites. Each experiment tests three to six treatments, and some treatments are tested in multiple experiments. 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 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 four lower elevation experiments are the Pipeline experiment (implemented at 6 sites ranging from 1561 to 2216 m in elevation), the Competition and Competition 2 Experiments (implemented at two sites of elevations 2004 and 2216 m), and the Gulley experiment (implemented at four sites ranging from 1561 to 2084 m in elevation). The remaining two experiments, conducted at high or middle elevations, emphasized maximizing plant community diversity. The Mountain Top experiment was implemented at the four highest elevation sites, ranging from 2342 to 2676 m. The Strategy Choice experiment was implemented at four moderate elevation sites ranging from 1662 to 2216 m.

The Pipeline experiment, which has been completed and was synthesized in a prior report (Johnston 2011b), evaluated 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). 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 were disking, rolling with a static roller, rolling with a vibratory drum roller, or disking plus compaction with a static roller. The herbicide investigated was Plateau ™ (ammonium salt of Plateau, 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).

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® 1280 RM (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 purported 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 that might hinder cheatgrass emergence.

The original Competition experiment utilized small plot sizes and a very simple seed mix containing only wheatgrasses. In 2012, the Competition 2 experiment was implemented which examined the effects of super-absorbent polymer with larger plots and a more complex seed mix.

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 six 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 CPW study demonstrated that a sufficient number of cheatgrass seeds may disperse from the edges of disturbance to compromise reclamation efforts (Johnston 2011a).

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 three 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, creates microsites of higher moisture availability, and traps dispersing seeds (Chambers 2000).

Similarly, brush mulch creates favorable germination conditions by causing snow to drift, creates shade, entraps seeds (Kelrick 1991), and perhaps also provides a source of seed. These two treatments are applied with and without seeding in order to address the question: If the adjacent undisturbed area is desirable, how important is seeding versus creating soil heterogeneity and encouraging natural seed dispersal in order to establish a diverse plant community?

The Strategy Choice experiment was conducted at middle-elevation sites where the degree of threat from invasive weeds is ambiguous. Such situations raise the question: 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 high-forb/high diversity seed mix with a minimal fraction of rhizomatous grasses, avoiding the use of 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 two 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 balanced versus high-forb seed mix.

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 on big sagebrush communities, because of the need for better techniques for re-establishing these communities (Lysne 2005), their widespread distribution, and their importance to wildlife (Davies et al. 2011).

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. Lower elevations are characterized by Wyoming big sagebrush, cheatgrass, Indian ricegrass (*Achnatherum hymenoides*), western wheatgrass (*Pascopyron smithii*), prairie junegrass (*Koeleria macrantha*), 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. Higher elevations are characterized by mountain big sagebrush, mountain brome (*Bromus marginatus*) and diverse forbs in flatter areas, serviceberry (*Amelanchier alnifolia*), snowberry (*Symphoricarpos rotundifolius*), 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, 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 (*Artemisia* *tridentata* ssp. *tridentata*). 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 in order 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 three weeks, and then the subsoil was replaced and the topsoil spread evenly over the site. This work was completed in six 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 to which subsoil disturbance 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 spread 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. The Competition 2 experiment was implemented on the well pad disturbance in 2012 in areas which had been seeded in 2009. The vegetation which had grown between 2009 and 2012 was removed by ripping, disking, and raking the soil in early September, 2012.

All sites were fenced with 2.4 m (8 ft) fencing in late fall 2009. This eliminated variability from site to site in the degree of browsing and grazing pressure from wildlife and livestock.

PIPELINE EXPERIMENT

Overview

- Goal: Compare effectiveness of Plateau herbicide and tillage treatments for controlling cheatgrass and promoting perennial plants.
- Conducted at 6 sites: YC1, YC2, RYG, WRR, GVM and SKH (Figure 1, Table 1).
- Treatments:
    - Herbicide (two levels): Plateau applied (Plateau) or no Plateau applied (no Plateau)
    - Tillage (five levels): disking, compaction with a static roller, compaction with a vibratory drum roller, disking plus compaction with a static roller, or control
- Design: Factorial split-plot. Herbicide treatments were randomly assigned to whole plots, and tillage treatments were randomly assigned to subplots.
- Plot size: 11 m X 10 m
- Responses measured: seedling density (2009) and plant cover (2010 and 2011)

The pipeline experiment was not monitored in 2012, and a full report on the first 3 years of results (2009-2011) was included in last year's annual report. Here follows a brief summary of key results from that report.

The Plateau treatment reduced cheatgrass seedling density and cover, and effects were still evident three years post-treatment. The Plateau treatment also greatly increased shrub cover three years post-treatment, and had no effect on forb or grass cover. These results contrast with some other studies in Wyoming big sagebrush plant communities, in which cheatgrass cover in plots where Plateau was applied rebounded to levels as high (Owen et al. 2011) or higher (Morris et al. 2009) than that of control plots in 2-3 years, or in which Plateau negatively affected forbs (Baker et al. 2009, Owen et al. 2011). The effects of Plateau on shrub and cheatgrass cover are likely intertwined. In a study of competitive dynamics between cheatgrass and big sagebrush, sagebrush and cheatgrass competed for soil water, and cheatgrass cover increased when sagebrush was removed (Prevey et al. 2010). In plots where Plateau was applied, sagebrush appears to have established well enough to limit cheatgrass cover, resulting in a long-term effect of Plateau on the composition of the plant community.

The timing of the pipeline disturbances may have reduced cheatgrass propagule pressure, acting additively with the herbicide to provide enough cheatgrass control for desirable perennial plants to establish. In the spring following the pipeline disturbances, in the absence of Plateau, cheatgrass seedling density was 5-fold lower in disturbed versus undisturbed locations. This may have been due to the timing of the disturbances the prior year. Cheatgrass seed distribution in the study areas peaks in June and continues until September (Appendix 1), and the pipeline disturbances were completed in September. Topsoil removal, stockpiling, and replacement likely buried the majority of cheatgrass seeds which had fallen on the soil surface during the 2008 growing season. Prior work has shown that Plateau is more effective on annual grasses when applied after disturbances such as burning (Sheley et al. 2007, Davies and Sheley 2011). This study indicates that a well-timed soil disturbance such as pipeline installation can serve a similar function.

The disking treatment was only moderately effective at reducing cheatgrass seedling density and improving perennial grass cover, and the rolling treatments were not effective.

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 (three 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 (two 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 whole plot factor was rolling, subplot factor was super-absorbent polymer, and the sub-subplot factor was binding agent (Figure 2).
- Plot size: 2.4 m X 2.4 m
- 5 replicates per site
- Responses measured: Cover of perennial grasses and cheatgrass

METHODS

Cheatgrass seed was collected using a lawnmower with a bagging attachment from monocultures or near-monocultures in four 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 three 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 sub-subplot. Seed was hand-broadcast in early October, 2009, and then immediately lightly raked to incorporate seed into the soil. The 300 seeds/m^2 seeding rate is about 25% of the 2009 cheatgrass seed production 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 2) 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, Luquasorb® 1280 RM granulated super-absorbent polymer (a cross-linked copolymer of Potassium acrylate and acrylic acid in granulated form; BASF Corporation, Ludwigshafen, Germany), 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 agricultural purposes.

Next, whole plots receiving the rolling treatment were rolled 10 times with a static roller supplying a linear load of 36.5 N/cm (20.8 lbs/in). Binding agent sub-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, percent cover by species was quantified in late July/early August, 2012, in a 1m x 1m sampling frame centered within each plot. The sampling frame was a grid containing thirty-six intersections, and point-intercept hits were measured at each intersection using a laser point-intercept sampling device (Synergy Resource Solutions, Bozeman MT). All layers of vegetation were identified to species at each hit. When calculating percent cover of perennial grasses, overlapping hits of different species within that functional group (for instance, western wheatgrass overlying Sandberg bluegrass) were counted as a single instance of the functional group.

The cover of perennial grasses and cover of cheatgrass in response to rolling, super-absorbent polymer (SAP), and binding agent treatments was analyzed in SAS PROC MIXED for a split-split plot structure with completely randomized whole plots. Site was included as a fixed effect, and interactions between treatments and site were also considered. Cover data was transformed by an arcsine [square root (x)] transformation to improve normality. Main effects and all possible interactions were included as fixed effects in the initial model, and a backwards model selection process was used to determine the final model. A significance level of $\alpha = 0.05$ was used to determine significantly different means, and a level of $\alpha = 0.10$ for interactions was used to determine which means to compare.

RESULTS

Across sites and treatments, 100% of perennial grass cover was native, and 100% of annual grass cover was non-native.

Perennial grass cover was not influenced by site or by any treatment effects ($p > 0.13$). Perennial grass cover averaged 55.5% at SGE and 58.2% at WRR.

Cheatgrass cover was very low in 2012, averaging only 2.0% at SGE and 1.7% at WRR. Unlike 2011 (when cheatgrass cover was 11% at SGE and 34% at WRR), there were no differences by site or site by treatment interactions in 2012. Cheatgrass cover was influenced by SAP ($p = 0.04$) and a probable interaction between SAP and binding agent ($p = 0.09$). SAP lowered cheatgrass cover from 3.5% to 0.4% with the moderate level of binding agent ($p = 0.008$), but there was no significant effect of SAP when combined with either the no binding agent or high binding agent treatments ($p > 0.09$). Even so, there was a trend for lower cheatgrass cover with SAP at all levels of binding agent (Figure 3).

DISCUSSION

As seen in 2011, SAP reduced 2012 cheatgrass cover. The effect of SAP was somewhat moderated by the binding agent in 2012, although the effect has now been seen over multiple sites, years, and levels of binding agent.

The hypothesized mechanism for SAP effect on cheatgrass is that SAP favors perennial grasses and thereby reduces resources available for cheatgrass. However, similar to what was seen in 2011, there was no effect of SAP on 2012 perennial grass cover. Thus the action of SAP on controlling cheatgrass is somewhat mysterious. It is possible that perennial grasses benefit from SAP, but the benefits are not evident in cover data. The aboveground response of cheatgrass may be more sensitive to SAP because cheatgrass fluctuates more widely in response to resource variability than do perennial plants (Bradley 2009). Another possibility is that there is some direct negative influence of SAP on cheatgrass. 2013 fieldwork includes assessment of both perennial grass and cheatgrass biomass, which may help clarify how SAP diminishes cheatgrass cover.

The effect of binding agent on cheatgrass has been inconsistent. In 2010, cheatgrass cover increased with the low level of binding agent at SGE. In 2011, lower cheatgrass cover was apparent in plots with the high binding agent treatment, and in 2012, binding agent had no main effect on cheatgrass cover. Binding agent application is expensive; in order to apply the binding agent in the manner tested in this study, 3200 gal/ac of water is needed, requiring a water truck. This study does not support the use of DirtGlue binding agent as a method of cheatgrass control, athough the product may have other benefits.

Rolling was applied in order to understand if creating a slightly compacted soil surface could reduce the competitive ability of cheatgrass. However, rolling had no effect. This finding corroborates results from the pipeline experiment, and together, these studies indicate that rolling is not a practical means of controlling cheatgrass.

Cheatgrass has adapted to complete its life cycle before the dry period of the summer in the intermountain west (Rice et al. 1992), making it an effective competitor in arid ecosystems with variable soil moisture (Chambers et al. 2007). By absorbing water and then gradually releasing it into the soil, SAPs can reduce the variability in soil moisture over time. SAPs have long been shown to aid in perennial plant growth and establishment, and this study supports the idea that SAPs may also help in cheatgrass control. Granulated SAP can easily be applied through a drill seeder or combined into a pellet with seed, making SAP application a practical choice for managers.

COMPETITION 2 EXPERIMENT

Overview

- Goal: Test effectiveness of super-absorbent polymer at reducing the competitive ability of cheatgrass when applied with complex seed mix of desirable perennials. Use a larger plot size than that used in the Competition experiment so that edge effects are less likely to influence vegetation within plots. Use a higher seeding rate of cheatgrass than that used in the Competition experiment to test the effect of polymer under higher cheatgrass propagule pressure.

- Conducted at 2 sites: SGE and WRR (Figure 1, Table 1)
- Treatment:
    - Super-absorbent polymer (2 levels): super-absorbent polymer applied (SAP) or no polymer applied (no SAP)
- Design: completely randomized, with 3 replications per site
- Plot size: 6.4 X 8.1 m

METHODS

The vegetation which had grown on the well pad surface between 2009 and 2012 was characterized at each site using 6 systematically arrayed 12.8 m point-intercept transects per site, with hits every 20 cm, for a total of 384 hits per site.

Cheatgrass seed was collected using a lawnmower with a bagging attachment from monocultures or near-monocultures from two locations, one within 10 miles of the study sites, and another about 50 miles from the study sites. Collections were made in late June or early July 2012, 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 three 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. The collection from the location nearer the study sites was sufficient to supply about 2/3 of the number of seeds needed for the experiment. The remaining 1/3 of seeds were drawn from the collection from the further location, and this material was mixed thoroughly with that of the other collection. Next, a volume of seed sufficient to supply 600 seeds/m^2 was prepared for each plot.

Site preparation and seeding occurred in early to mid September, 2012. Existing vegetation was removed by ripping to 30 cm, then disking to 15 cm with a Plotmaster. Uprooted vegetation was then removed by hand or with rakes. Next, the plots were rolled with the Plotmaster to create a firm, level surface. Next, we simulated a drill seeding by creating furrows with the Plotmaster, then hand-sprinkling seed into these furrows and pressing soil over them. We chose this method because it allowed for the seeding and polymer application rates to be precisely known. The seed mix in Table 3 was applied to all plots. In plots randomly selected for the polymer treatment, Tramfloc® 1001 granulated polymer (a cross-linked copolymer of acrylamide and potassium acrylate; Tramfloc®, Inc, Tempe, AZ, USA) was applied at 45 g/m^2 to furrows, after seed application but before pressing soil over the seed. The Tramfloc® product was used because Luquasorb® 1280 RM (which was used in the Competition experiment) was no longer available.

Directly after desirable species were seeded, cheatgrass seed was hand-broadcast at 600 seeds/m^2 then lightly raked to incorporate it into the soil in all plots. In mid-November, 2012, locally-collected Wyoming big sagebrush was hand-broadcast over snow at 270 seeds/m^2.

Future work will include seedling counts (1 year post-treatment), cover of all plant functional groups (2 and 3 years post-treatment) and may also include biomass assessment.

GULLEY EXPERIMENT

Overview

- Goal*:* identify which potential sources of weeds are important to control: those that originate from within the soil seed bank of the reclamation area, those that 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 whole plot factor was fallowing, the subplot factor was seed barriers, and the sub-subplot factor was Plateau (Figure 4). Whole plots were completely randomized.
- 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 them 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, DirtGlue soil binding agent 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. 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. 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 that had been caught in the dispersal barriers in 2009 germinated and grew through the barrier. In order 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 seed rain traps (Appendix 1). 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 from each subsample.

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 was assessed by percent cover using five 1m^2 miniplots per sub-subplot. One miniplot was located in the center of the sub sub-plot, and the remaining miniplots were equidistant from the center miniplot and a sub sub-plot corner. A grid containing thirty-six intersections was held over each miniplot, and point-intercept hits were measured at each grid intersection using a laser point-intercept sampling device (Synergy Resource Solutions, Bozeman MT). All layers of vegetation were identified to species at each hit. When calculating percent cover of a given functional group, such as perennial grasses, overlapping hits of different species within a functional group (for instance, western wheatgrass overlying Sandberg bluegrass) were counted as a single instance of the functional group.

The cover of perennial grasses, perennial forbs, annual forbs, annual grasses, and shrubs in response to site, fallow treatment, Plateau treatment, and barrier treatment was analyzed using ANOVA in SAS PROC MIXED. All factors were considered fixed. Site and fallowing were considered between-subject effects for whole plots, and barriers and Plateau treatment (nested within barriers) were considered within-subject effects. Biennial forbs were lumped with annual forbs. Cover data was transformed by an arcsine [square root (x)] transformation to improve normality. Separate variance estimates by site and Plateau treatment were used in the models in addition to transformation, a choice justified by lower AIC values. A full model including all possible interactions was first considered, and a backwards model selection process was used to determine the final model. A significance level of $\alpha = 0.05$ was used to determine significantly different means, and a level of $\alpha = 0.10$ for interactions was used to determine which means to compare. The percentage of native versus non-native species was calculated for all functional groups.

RESULTS

Across sites and treatments, 99.0% of perennial grass cover was native, 99.8% of perennial forb cover was native, 100% of shrub cover was native, 1.9 % of annual forb cover was native, and 0% of annual grass cover was native.

Perennial grass cover was influenced by large main effects of site, fallowing treatment, and barriers ($p < 0.001$) as well as many interacting effects, including a 4-way interaction between site and all three treatments ($p = 0.02$). Averaged across sites and interactions, the fallow treatment reduced perennial grass cover from 19.4% to 6.4%, and barriers increased perennial grass cover from 9.8% to 16.1%. At

YC1 and YC2, only fallowing and barriers had significant effects, in patterns similar to the cross-site pattern. At RYG and SKH, significant 3-way interactions occurred between fallowing, barriers, and Plateau treatment. The effect of the interaction was such that a positive influence of barriers was only significant in certain combinations of fallowing and Plateau: barriers were effective in fallowed plots in the absence of Plateau at SKH ($p = 0.009$), and nearly significantly effective in unfallowed plots in the absence of Plateau at RYG ($p = 0.06$), but ineffective in other cases ($p > 0.16$).

Perennial forb cover was influenced by site, Plateau, fallowing, barriers, an interaction between site and Plateau, and an interaction between site and fallowing ($p < 0.02$). Across sites, barriers increased perennial forb cover from 3.4% to 6.2% (Figure 5). Plateau had an impact only at YC1 and YC2 ($p < 0.0001$), reducing perennial forb cover from 12.8% to 5.5% at YC1, and from 7.2% to 2.1% at YC2. Fallowing only had an impact at RYG and YC1 ($p < 0.005$), where it *increased* perennial forb cover from 0.2% to 7.5% at RYG, and from 5.7% to 12.7% at YC1.

Annual forb cover was influenced dramatically by the main effect of fallowing ($p < 0.0001$), and many interactions, including a 4-way interaction between site, fallowing treatment, barrier treatment, and Plateau treatment ($p = 0.03$). Across sites, other treatments, and interactions, fallowing increased annual forb cover from 0.6% to 16.0%. Other effects will be presented site-by-site. At RYG, Plateau treatment and fallowing treatment interacted ($p = 0.007$). Without fallowing, annual forb cover was very low (0.5%) and no effect of Plateau was evident. In fallowed plots, Plateau reduced annual forb cover from 12.0% to 2.2% ($p = 0.003$). A similar interaction occurred at SKH, whereby Plateau had no effect in unfallowed plots ($p = 0.47$), but reduced forb cover from 30.6% to 10.9% in fallowed plots ($p < 0.0001$). A possible interaction also occurred between fallowing and barrier treatment at SKH ($p = 0.08$), whereby barriers had no effect in unfallowed plots, but may have reduced annual forb cover from 24.3% to 17.3% in fallowed plots ($p = 0.07$). At YC1, there were also interactions between fallowing and both Plateau treatment and barrier treatment ($p < 0.03$). There was no annual forb cover in unfallowed plots. In fallowed plots, the effect of Plateau was opposite that seen at RYG and SKH: Plateau increased annual forb cover from 12.2% to 27.8% ($p = 0.003$). Barriers reduced annual forb cover from 28.0% to 11.9% in fallowed plots ($p = 0.01$). At YC2, there was a 3-way interaction between barriers, fallowing, and Plateau treatments ($p = 0.006$). Without fallowing, annual forb cover was near zero where Plateau had not been applied. Annual forb cover was higher where Plateau had been applied ($p = 0.002$), and this effect was moderated by an interaction between Plateau and barriers ($p = 0.01$), whereby barriers possibly reduced annual forb cover from 4.0% to 1.3% in plots where Plateau had been applied ($p = 0.08$). In fallowed plots at YC2, there was no main effect of Plateau, but there was a possible interaction between Plateau and barriers ($p = 0.08$), whereby barriers *increased* annual forb cover where Plateau had been applied ($p = 0.01$), from 6.3% to 23.3% ($p = 0.01$).

Annual grass cover was influenced by Plateau treatment, and an interaction between Plateau and fallow treatment ($p < 0.0007$). Annual grass cover averaged 9.6% in unfallowed, no-Plateau plots, 1.5% in plots with only the fallow treatment, 0.0% in plots with only the Plateau treatment, and 0.3% in plots with both the fallow and Plateau treatments.

Shrub cover was influenced by strong effects of fallowing, Plateau, and their interaction ($p < 0.0001$; Figure 6), and also by interactions between treatments and site, though these were smaller in magnitude. Across sites and other treatments, fallowing had a large negative effect, reducing shrub cover from 16.1% to 1.3%. Plateau increased shrubs, but only in the absence of fallowing. Plateau increased shrub cover from 9.7% to 22.6% in unfallowed plots ($p < 0.0001$). At RYG, SKH, and YC1, shrub cover was influenced by Plateau, fallowing and their interaction in the manner described above ($p < 0.003$ for main effects at these 3 sties, $p< 0.09$ for the interaction). At YC2, only the fallowing treatment had an effect ($p= 0.01$). Shrub cover was 1.3% in fallowed plots and 6.3% in unfallowed plots.

DISCUSSION

The fallowing treatment had detrimental effects on perennial grasses and shrubs (Figure 7), and caused a dramatic increase in annual forbs. Part of the difference in fallowed and unfallowed plots is due to the experimental design, because fallowed plots were seeded in fall 2010, while unfallowed plots were seeded in fall 2009. Even considering that the 1-year time lag between fallowed and unfallowed plots will likely decline with time, fallowing with Pendulum appears to have resulted in residual effects of the herbicide on the plant community. The fallowing treatment continued to provide good control of annual grasses 2 years post-seeding, and interestingly, caused an increase in forb cover at 2 of the 4 sites. Fallowing appears to have favored some forb species over others, as we detected more Western yarrow in unfallowed plots, but more Utah sweetvetch and Lewis flax in fallowed plots (Figure 5).

Plateau herbicide had some desirable and some undesirable effects. Forbs were reduced with Plateau at 2 of 4 sites, but shrubs, especially big sagebrush, increased with Plateau application (Figure 6). Plateau continued to provide good control of annual grasses 2 and 3 years post-application (recall that the timing of Plateau application depended on fallowing treatment in this experiment). Plateau either increased or decreased annual forbs, depending on site and fallowing treatment. Unlike results from 2011, we saw no negative effects of Plateau on perennial grasses. The negative effect on forbs corroborates earlier studies (Baker et al. 2007, Owen et al. 2011), and the positive effect on shrubs corroborates what was seen in the Pipeline experiment of this project (Johnston 2012). The combination of Plateau and fallowing appears to be too heavy-handed, with very little cover of any functional groups in plots where both treatments were applied.

Barriers had a positive effect on both grass and forb cover, an effect not seen in prior years, and had desirable or undesirable effects on annual forbs, depending on site and fallowing treatment. The effects on grasses and forbs may have been due to snow drifting, which may have increased soil moisture in some parts of the barrier plots. A noticeable increase in the stature of grasses was evident near the barriers. Barriers did not help control annual grasses, which was the objective of the treatment. The application of the barriers was imperfect. Wind and cow trampling compromised the barriers at RYG and SKH during a critical time of cheatgrass dispersal in 2009, and design modifications improved the barriers over time, as we learned how to prevent weeds from passing beneath the barriers or growing through them. Other types of seed dispersal barriers, such as trenches, brush piles, or strips of live competitive grasses, may be more effective.

The Gulley experiment will be monitored for 2 additional growing seasons.

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 8)
- Plot size: 9.1 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 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 four liters of topsoil from brush stockpiles was scattered over each brush plot.

Mountain big 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 was assessed in 2012 by percent cover using five $1m^2$ miniplots per plot. One miniplot was located in the center of the plot, and the remaining miniplots were equidistant from the center miniplot and a plot corner. A grid containing thirty-six intersections was held over each miniplot, and point-intercept hits were measured at each grid intersection using a laser point-intercept sampling device (Synergy Resource Solutions, Bozeman MT). All layers of vegetation were identified to species at each hit. When calculating percent cover of a given functional group, such as perennial grasses, overlapping hits of different species within a functional group (for instance, western wheatgrass overlying Sandberg bluegrass) were counted as a single instance of the functional group.

Analysis of variance in SAS PROC MIXED was used to analyze differences in responses to treatments. Site was included as a fixed effect. Cover data was analyzed separately by the following functional groups: perennial grasses, perennial forbs, annual grasses, annual forbs, and shrubs. Biennial forbs were lumped with annual forbs. Cover data for perennials was transformed by an arcsine [square root (x)] transformation to achieve normality, and cover data for annuals was transformed by square root(x). A full model including all possible interactions was first considered, and a backwards model selection process was used to determine the final model. A significance level of $\alpha = 0.05$ was used to determine significantly different means, and a level of $\alpha = 0.10$ for interactions was used to determine which means to compare.

RESULTS

Across sites and treatments, 96.3% of perennial grass cover was native, 99.1% of perennial forb cover was native, 100% of shrub cover was native, 58.4% of annual forb cover was native, and 0% of annual grass cover was native.

Perennial grass cover was influenced by site, the seeding treatment, and their interaction ($p < 0.0001$), as well as by brush treatment ($p = 0.02$). Seeding increased perennial grass cover from 16.0% to 43.7% at SCD, from 8.0% to 36.8% at SPG, from 11.0% to 20.3% at SQS, and from 9.3% to 30.0% at TGC ($p < 0.001$ for all sites; Figure 9a). Much of the grass cover in seeded plots was Mountain Brome

(*Bromus marginatus*), which accounted for 35-63% of seeded plot grass cover (Figure 9a). The brush treatment increased perennial grass cover from a mean of 20.2% to 23.5% (Figure 11).

Perennial forb cover was influenced by site, seeding treatment, surface treatment, a surface treatment by seeding interaction, a site by seeding treatment interaction, a site by surface treatment interaction, and a site by brush treatment interaction ($p < 0.040$). Across sites, surface treatment had an effect in seeded plots ($p = 0.002$) but not in unseeded plots ($p = 0.36$); forb cover averaged 9.4% in flat plots with seed and 14.1% in rough plots with seed. Seeding increased perennial forb cover from 2.6% to 8.4% at SCD, from 3.0% to 15.9% at SPG, and from 2.0% to 8.1% at SQS ($p < 0.0001$), but did not have a significant effect at TGC (Figure 9b). The rough surface increased forb cover at SCD and SPG ($p < 0.03$), had no discernable effect at SQS, and reduced forb cover at TGC ($p = 0.01$; Figure 10). Brush had an effect at SCD and at SQS ($p < 0.05$). At SCD, brush increased forb cover from 3.7% to 7.3%, and at SQS, brush increased forb cover from 4.0% to 6.1%. TGC was unique in two ways: the seeding did not affect total forb cover, and the rough surface reduced forb cover. Both of these anomalies can be attributed to white locoweed (*Oxytropis sericea*). This species, which was not seeded, was very prevalent (Figure 9b), especially in flat surface plots (Figure 10).

Annual forb cover was influenced by site, seed treatment, brush treatment, an interaction between site and seed treatment, and an interaction between seed and surface treatment ($p < 0.05$). Across sites, surface treatment had opposite effects in seeded versus unseeded plots. In seeded plots, the rough surface reduced annual forbs from 10.6% to 7.7% ($p = 0.01$). In unseeded plots, the rough surface increased annual forbs from 21.6% to 25.5% ($p = 0.05$). Across sites and other treatments, the brush treatment reduced annual forbs from 18.0% to 14.7% ($p = 0.05$; Figures 10 and 11). Seeding reduced annual forb cover from 23.5% to 0.7% at SCD, 16.0 to 0.7% at SPG, from 40.5% to 26.9% at SQS, and from 14.3 to 8.2% at TGC.

We detected no annual grass cover at SQS or TGC, and annual grass cover was only 0.2% at SPG and 0.6% at SCD. We present analysis here only for the SCD site. At SCD, seed treatment, surface treatment, and their interaction influenced annual grass cover ($p < 0.01$). In unseeded, flat surface plots, annual grass cover was 2.5%. In unseeded, rough surface plots, as well as all seeded plots, annual grass cover was 0%.

Shrub cover was influenced by site, seed treatment, brush treatment, and a 3-way interaction involving site, surface treatment, and seed treatment ($p < 0.01$). Averaged across sites, seeding reduced shrub cover from 6.3% to 4.1%, with significant differences at SPG and TGC (Figure 9c). Brush increased shrub cover from 4.4% to 5.9% (Figure 11). Although the 3-way interaction involving site, surface treatment, and seed treatment was significant, there were few strong patterns within a site-by-site analysis. The interaction may have been due to higher shrub cover with the flat surface when seeded at SQS ($p = 0.04$), while there was a trend for higher shrub cover with the rough surface when seeded at other sites.

DISCUSSION

Seeding increased perennial grass and forb cover, and reduced shrub, annual forb, and annual grass cover three years post treatment. Higher annual cover in unseeded plots was expected, as annual plants are typically prolific seed producers and tend to dominate following disturbances. However, annual forb cover in unseeded plots is declining. At all sites, annual forb cover was less than half of 2011 values in unseeded plots, and the percentage of annual cover which is native has increased (58% for 2012, 41% for 2011). The most prevalent annual was the native Douglas' knotweed (*Polygonum douglasii*). Seeding decreased shrub cover, even though shrubs were seeded. Higher shrub cover in unseeded plots was due to better establishment of Big Sagebrush, as well as to establishment of snowberry and yellow rabbitbrush (*Chrysothamnus vicidiflorus*; Figure 9c). The lessened competition in unseeded plots is promoting establishment of shrubs from naturally occurring seed.

The rough soil surface treatment increased perennial forb cover at SCD and SPG, reduced annual forbs across sites, and controlled annual grasses at the one site, SCD, with sufficient annual grasses for analysis. Perennial forb cover was higher with the flat surface at TGC, however, due to the unseeded native White Locoweed, which had 9% cover in flat surface plots but only 3% cover in rough surface plots. TGC was flatter than other sites, and required very little cut-and-fill to create a level surface during the well pad simulation. The topsoil layer was deep and was not completely disturbed. The year after the disturbance, mature White Locoweed plants were noted at the site. In rough surface treatment plots, the action of digging holes and mounding soil disturbed these plants, but in flat surface plots, this species appears to have survived treatment implementation. The reduction in annual forbs and in annual grasses (namely cheatgrass) with the rough soil surface is similar to that observed in the Strategy Choice experiment at the MTN site. As is explained in the following section, this may be due to reduced dispersal of weed seeds in rough surface treatment plots.

The brush treatment improved shrub and perennial grass cover, and reduced cover of annuals. The addition of brush may have added seed to the plots, and the brush may also improve the establishment of shrub and grass seedlings.

The Mountain Top experiment contrasts extreme treatments: seeding with a high density of perennial grasses, shrubs, and forbs, versus not seeding at all, in order to gauge the ecological resiliency of higher-elevation sites. The results occurring in unseeded plots, over time, will provide a baseline of expectations for these sites when topsoil is managed well, microcatchments providing higher moisture availability are provided, and when mulched with native brush. In 2012, 3 years post-seeding, the cover of native species in seeded plots remained much higher than that in unseeded plots, largely due to high cover of Mountain Brome, Rocky Mountain Penstemon, and Western Yarrow. Shrub cover, however, was higher in unseeded plots. Shrubs are also dominant in the undisturbed communities surrounding the 4 sites of this experiment, therefore it is possible that in the future the unseeded plots may more closely resemble the undisturbed landscape than will seeded plots.

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 four sites: WRR, SGE, GVM, MTN (Figure 1, Table 1)
- Treatments include:
  - Seed mix (two levels): seeded with a balanced seed mix (called ‘high competition’ or ‘HC’ in prior reports) or a high-forb seed mix (called ‘low competition’ or ‘LC’ in prior reports)
  - Soil surface/mulch type (two levels): flat with straw mulch (flat/straw) or rough surface with brush mulch (rough/brush)
  - Herbicide (two levels): Plateau applied (Plateau) or no Plateau applied (no Plateau)
- Completely randomized factorial (Figure 12)
- Plot size: 9 m x 6 m
- Three replications per site
- The four locations had 0-15% non-native cover prior to the start of the experiment

METHODS

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

Seed mixes for the balanced and high-forb plots are shown in Table 6. A key difference between the mixes is in the number and type of grass seeds used. In the balanced mix, 344 grass seeds/m^2 (32 seeds/ft^2) were used, and these were mostly rhizomatous wheatgrasses. In the high-forb mix, 156 grass seeds/m^2 (15 seeds/ft^2) were used, and these were mostly bunchgrasses. The high-forb mix had nearly 75% forb seeds (Figure 13).

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 two plots was mixed, and then that quantity was applied to the two 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 that 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.

Ambient cheatgrass propagule pressure was quantified at all four sites in 2009- 2011 using techniques outlined in Appendix 1. The seeds caught per square meter for the entire growing season were calculated for each site.

Vegetation was assessed in 2011 and 2012 by percent cover using five 1m^2 miniplots per plot. One miniplot was located in the center of the plot, and the remaining miniplots were equidistant from the center miniplot and a plot corner. A grid containing thirty-six intersections was held over each miniplot, and point-intercept hits were measured at each grid intersection using a laser point-intercept sampling device. All layers of vegetation were identified to species at each hit. When calculating percent cover of a given functional group, such as perennial grasses, overlapping hits of different species within a functional group (for instance, western wheatgrass overlying Sandberg bluegrass) were counted as a single instance of the functional group.

Standing crop of biomass was assessed in 2012 using a double-sampling technique (Ahmed et al. 1983). Sixteen 0.25 m^2 sampling frames were arrayed systematically within each plot; 42% of these were clipped as well as estimated ocularly and 58% were estimated only. Ocular estimates were corrected using regressions based on sub-life-form species groups with similar morphology (Ebrahimi et al. 2008). The average R^2 of these regressions was 0.84 (Appendix 2). Clipping and estimates included all standing aboveground biomass, live or dead, and the values therefore reflect a cumulative assessment of treatments on available wildlife forage.

Response variables cover (2011 and 2012) and standing crop biomass (2012) of perennial grasses, perennial forbs, annual forbs, annual grasses, and shrubs were analyzed using a four–factor (site, seed mix, soil surface, and Plateau treatment) model in SAS PROC MIXED, Version 9.3 (SAS Institute 2012). Biennial forbs were combined with annual forbs for analysis. All factors were considered fixed effects. Transformations of response variables were performed to achieve approximately homogeneous variance and normality when the need was indicated by residual plots. Annual grass cover and biomass varied so greatly with both site and Plateau treatment that variance was not homogeneous, even after transformation; therefore, separate variance estimates by site and Plateau were used in the models for these variables in addition to transformation, a choice justified by lower AIC values. No annual grass cover was detected at the SGE site in 2012; this site was excluded from that analysis. A full model including all main effects and interactions was first considered, and a backwards model selection process was used to simplify the model. A significance level of $\alpha = 0.1$ was used to retain interaction terms, and $\alpha = 0.05$ to retain main effects, subject to the restriction that a main effect was not a candidate for removal if it was involved in an interaction that was still in the model. Statistical comparisons of means associated with significant main effects and interactions were made in the transformed scale, but means are presented in graphs in the original scale. Where site by treatment interactions occurred, results are presented on a site-by-site basis. Because the Plateau treatment was only conducted at two of the four sites (GVM and MTN), separate backwards model selection processes were conducted for models with the Plateau treatment versus those without. Models excluding Plateau plots, but including all four sites, are summarized in the sections labeled “in the absence of herbicide”. Models including Plateau plots, but excluding the SGE and WRR sites, are summarized in sections labeled “interactions with herbicide treatment.” Significant effects not involving the herbicide treatment were not discussed for this latter set of models, as they are addressed more comprehensively by the analysis including all four sites.

RESULTS

Ambient cheatgrass propagule pressure in 2009- 2011 was 50- 300 times higher at GVM than at any of the other three sites (Figure 14). In 2011 the values were as follows: GVM, 1300 seeds/m^2; MTN, 1.3 seeds/m^2; SGE, 4.0 seeds/m^2; and WRR, 4.0 seeds/m^2.

Across sites and treatments, perennial vegetation cover was nearly synonymous with native cover, and annual cover was nearly synonymous with non-native cover. In 2011, 100% of perennial grass cover was native, 99% of perennial forb cover was native, and 100% of shrub cover was native. Annual forb cover was 97% non-native, and annual grass cover was 100% non-native and 98% cheatgrass.

Perennial grasses in absence of herbicide. Perennial grass cover and biomass were significantly affected by seed mix (Table 7). Across site averages for the high-forb vs. balanced mixes were: 29.9% vs. 41.9% (2011 cover); 26.6% vs. 39.4% (2012 cover); and 65.6 g/m^2 vs. 91.8 g/m^2 (2012 biomass; see Figure 15 for site-specific effects). The effect of soil surface on perennial grasses depended on site (Table 7). The rough/brush surface increased 2011 perennial grass cover from 23.7% to 41.3% at MTN [$t(39) = 3.77$, $p = 0.0005$] and from 31.8% to 41.5% at SGE [$t(39) = 2.06$, $p = 0.046$], but didn’t have significant effects at other sites ($p > 0.086$). In 2012, the rough/brush surface *reduced* perennial grass cover at WRR from 58.5% to 34.1% [$t(38) = 5.21$, $p < 0.0001$] but did not significantly affect other sites ($p > 0.1237$). In 2012, the rough/brush surface increased perennial grass biomass at MTN from 56.8 g/m^2 to 122.5 g/m^2 [$t(32) = 5.12$, $p < 0.0001$; Figure 16f, ‘no Plateau’ bars] and at SGE from 51.5 g/m^2 to 74.7 g/m^2 [$t(32) = 2.56$, $p = 0.015$], but reduced it at WRR from 166.3 g/m^2 to 79.4 g/m^2[$t(32) = 4.97$, $p < 0.0001$].

Perennial grass interactions with herbicide treatment. The effect of Plateau on perennial grasses depended on site for all responses measured (Table 8), with more detrimental effects at MTN than at GVM. In 2011, Plateau reduced perennial grass cover from 32.5% to 7.0% at MTN [$t(32) = 10.64$, $p < 0.0001$] and from 28.3% to 16.9% at GVM [$t(32) = 4.06$, $p = 0.0003$]. In 2012, Plateau did not detectably effect perennial grass cover or biomass at GVM, but at MTN, Plateau reduced cover from 37.6% to 9.8% [$t(40) = 11.63$, $p < 0.0001$] and reduced biomass from 89.6 g/m^2 to 44.3 g/m^2 [$t(40) = 4.75$, $p < 0.0001$]. For 2012 cover, a 2-way interaction also occurred between Plateau and surface treatment (Table 8). In the absence of Plateau, no effect of surface treatment was evident, but with Plateau, rough/brush surfaces increased grass cover from 10.0% to 14.6% [$t(40) = 2.79$, $p = 0.008$].

Perennial forbs in absence of herbicide. Perennial forb cover and biomass were significantly affected by seed mix (Table 7; see Figure 15 for site-specific effects). Across sites, the averages for the high-forb vs. balanced mixes were as follows: 25.7% vs. 15.9% (2011 cover); 16.5% vs. 10.7% (2012 cover); and 32.8 g/m^2 vs. 23.6 g/m^2 (2012 biomass). Rough/brush surfaces had an effect only on 2012 forb cover (Table 7), reducing it from 15.1% to 12.1%.

Perennial forb interactions with herbicide treatment. Perennial forb 2011 and 2012 cover values were influenced by Plateau, site, and their interaction (Table 8), but no significant effect of Plateau was found for 2012 perennial forb biomass (Figure 16b, g). In 2011, Plateau reduced perennial forb cover at MTN from 28.7% to 17.7% [$t(33) = 3.18$, $p = 0.0032$], but there was no detectible effect at GVM. Similarly, in 2012, Plateau reduced perennial forb cover at MTN from 24.0% to 14.8% [$t(42) = 4.09$, $p = 0.0002$], but there was no effect detected at GVM.

Shrubs in the absence of herbicide. Shrub cover in 2011 and 2012 was not affected by seed mix, but was affected by soil surface. Shrub cover averages for rough/brush surface and flat/straw plots were: 5.8% and 8.5% (2011), and 7.4% and 9.8% (2012). Shrub biomass in 2012 was affected by seed mix, but not soil surface (Table 7). Shrub biomass was 42.0 g/m^2 with the high-forb mix and 33.7 g/m^2 with the balanced mix (Table 7; see Figure 15 for site-specific effects).

Shrub interactions with herbicide treatment. Shrub cover and biomass were influenced by a strong main effect of Plateau, and this was modified by a 3-way interaction between site, Plateau, and soil surface for all responses (Table 8). At GVM, Plateau reduced all shrub responses, and did not interact with soil surface. In 2011, shrub cover was 2.9% in Plateau plots and 7.9% in no-Plateau plots [$t(32) = 4.25$, $p = 0.0002$]. In 2012, cover was 1.9% in Plateau plots and 8.5% in no-Plateau plots [$t(33) = 5.32$, $p < 0.0001$], and biomass was 33.54 g/m^2 in Plateau plots and 65.3 g/m^2 in no-Plateau plots [$t(40) = 2.63$, $p = 0.0121$; Figure 16c]. At MTN, Plateau and soil surface interacted for all three responses ($p < 0.006$). Without Plateau, soil surface had no significant effect ($p > 0.15$ for all 3 responses). In the presence of Plateau, 2011 shrub variables were higher in rough/brush surface plots: 2011 cover 8.0% in rough/brush surface plots and 1.7% in flat/straw plots [$t(17) = 2.90$, $p = 0.0099$], 2012 shrub cover was 10.4% in rough/brush surface plots and 1.3% in flat/straw plots [$t(20) = 4.56$, $p = 0.0002$], and biomass was 273.3 g/m^2 in rough/brush surface plots, and 27.5 g/m^2 in flat/straw plots [$t(20) = 4.56$, $p = 0.0002$; Figure 16h]. Shrub biomass was also influenced by an interaction between seed mix and Plateau (Table 8). Without Plateau, shrub biomass was influenced by seed mix as mentioned in the preceding paragraph; with Plateau, no effect of seed mix was evident.

Annual grasses in the absence of herbicide. We detected no effect of seed mix on annual grasses for any response variable (Table 7). The effect of soil surface on annual grass cover and biomass depended on site (Table 7), with significant effects being detected only at MTN. At MTN in 2011, annual grass cover was 5.9% in rough/brush surface plots and 44.1% in flat/straw plots [$t(40) = 7.29$, $p < 0.0001$; Figure 17]. At MTN in 2012, annual grass cover was 0% in rough/brush surface plots and 7.0% in flat/straw plots [$t(40)$

= 6.51, $p < 0.0001$], and annual grass biomass was 0.022 g/m^2 in rough/brush surface plots and 0.27 g/m^2 in flat/straw plots [$t(40) = 2.30$, $p = 0.027$; Figure 16i].

Annual grass interactions with herbicide treatment. In 2011, annual grass cover was significantly affected by Plateau (Table 8), with 4.8% cover in plots with Plateau, and 27.1% cover in plots without Plateau. In 2012, there was no main effect of Plateau on annual grass cover or biomass (Table 8). For all annual grass responses, a 3-way interaction occurred between site, Plateau, and surface treatment (Table 8). For 2011 and 2012 cover, this was due to a 2-way surface treatment*Plateau interaction which occurred only at MTN (p < 0.001). At MTN, in plots without Plateau, annual grass 2011 and 2012 cover were influenced by soil surface, as described in the prior paragraph, and there was no effect of soil surface in plots with Plateau (Figure 17). For 2012 biomass, a 2-way surface*Plateau interaction occurred only at GVM (p = 0.02). At GVM in 2012, there was no effect of soil surface in plots *without* Plateau, but in plots with Plateau, annual grass biomass was 0.20 g/m^2 with the rough/brush surface and 1.19 g/m^2 with the flat/straw surface [$t(18) = 2.15$, $p = 0.0456$].

Annual forbs. Annual forb cover in 2012 was so low that we did not detect any annual forb cover in 78% of plots. Due to the high proportion of zeros in the 2012 cover dataset, we chose to limit our analysis to 2011 cover and 2012 biomass. In the absence of herbicide, there were no effects of any treatments on 2011 cover (p > 0.13) or 2012 biomass (p > 0.27). Plateau increased 2011 annual forb cover from 11.4% to 27.5% at GVM [$t(37) = 3.76$, $p = 0.0006$] and from 7.0% to 14.1% at MTN [$t(37) = 2.05$, $p = 0.047$]. In 2012, Plateau increased annual forb biomass from 0.19 g/m^2 to 8.9 g/m^2 at GVM [$t(40) = 5.97$, $p < 0.0001$; Figure 16e]. At MTN, a 2-way interaction between Plateau treatment and soil surface occurred for 2012 annual forb biomass (p = 0.0052). Without Plateau, annual forb biomass averaged 0.15 g/m^2 and no effect of soil surface was evident. With Plateau, annual forb biomass was 21.3 g/m^2 in flat/straw surface plots and 0.21 g/m^2 in rough/brush surface plots $t(20) = 5.88$, $p < 0.0001$; Figure 16j].

DISCUSSION

The rough/brush surface treatment was successful at limiting cover and biomass of weedy annuals, and the effects were strongly dependent on site and Plateau treatment. One site, GVM, had much higher cheatgrass propagule pressure than the other three sites. At GVM, no effect of rough/brush surfaces was evident in the absence of Plateau, but with Plateau, 2012 annual grass biomass was 6-fold lower with the rough/brush surface. Of the 3 sites with very low cheatgrass propagule pressure, only one site, MTN, had annual grass cover exceeding 10% in any treatment. At MTN, the rough/brush surface was effective at controlling annual grasses in the absence of Plateau, lowering 2011 annual grass cover from 44% to 6%. The pattern of effectiveness suggests that rough/brush surfaces may be a useful complementary or alternative weed control technique for undesirable annuals. At sites where ambient weed propagule pressure is high, rough/brush surfaces may augment the effectiveness of selective herbicides. At sites where ambient weed propagule pressure is low, rough/brush surfaces may be sufficient to prevent the spread of weeds after a disturbance.

The effectiveness of rough/brush surfaces may be due to seed dispersal limitation and altered competitive dynamics. Prior work has shown that holes and shrubs are effective at entrapping seeds (Chambers 2000); at sites with only a few cheatgrass seeds, rough/brush surfaces may be sufficient to limit cheatgrass to a small portion of the restoration area. Roughened surfaces also increase soil moisture (Gupta et al. 1999, Li et al. 2006), and several studies have shown that cheatgrass is a more effective invader with lower or more variable soil moisture (Bradford and Lauenroth 2006, Chambers et al. 2007, Shinneman and Baker 2009). Rough/brush surfaces may control cheatgrass by trapping cheatgrass seeds in an environment in which they are less competitive.

The effect of rough/brush surfaces on desirable perennial vegetation depended on functional group. 2012 perennial forb cover, 2011 shrub cover, and 2012 shrub cover were approximately 1/4 lower with rough/brush surfaces across sites, but no effect was seen on forb or shrub biomass. In this study, soil surface type was coupled with practically compatible seeding techniques: in flat/straw plots, most grasses were drill seeded but most forbs and shrubs were broadcast seeded, while rough/brush surface plots were completely broadcast-seeded. There was some spatial separation of grass and forb/shrub seed in flat/straw plots which may have aided shrub and forb establishment. The effect of rough/brush surfaces on perennial grasses was site-dependent: 2012 biomass was higher with rough/brush surfaces at two of four sites, but lower at one site. The site with better grass establishment in flat/straw plots, WRR, was the highest elevation site with the least alkaline soils and highest average summer precipitation. At this site, rough/brush surfaces were likely not needed to aid in perennial grass establishment, and a lack of establishment on the mounds between rough/brush surfaces led to less cover of perennial grasses in rough/brush surface plots.

The effect of seed mix was consistent across sites; the high-forb mix resulted in higher 2011 and 2012 forb cover, higher 2012 forb biomass, and higher 2012 shrub biomass than the balanced seed mix. Two years post-seeding, forb cover was 22% with the high-forb mix but only 14% with the balanced mix. We detected no effect of seed mix on 2011 or 2012 annual forb cover, 2012 annual forb biomass, 2011 annual grass cover, or 2012 annual grass cover. The high-forb mix differed from the balanced mix in having a much lower density of rhizomatous grass (Table 6, Figure 13) and by including 3 additional species of perennial forbs: *Heterotheca villosa* (hairy golden aster), *Packera multilobata* (multi-lobed groundsel) and *Erigeron speciosus* (showy fleabane). Hairy golden aster and multi-lobed groundsel established successfully; in high-forb plots in 2011, hairy golden aster cover was 1.0% and multi-lobed groundsel cover was 2.6%. This accounts for less than half of the difference in forb cover between the seed mixes. The rest of the difference is due to better establishment of forbs included in both mixes, which were seeded at the same rate (Table 6). This is likely because the high-forb mix had very little rhizomatous grass seed. The idea that seed mixes should limit the proportion of rhizomatous grasses in order to promote a mixed plant stand was proposed nearly 30 years ago (Redente et al. 1984). However, seed mixes commonly used in reclamation continue to have a large proportion of rhizomatous grasses (Figure 13). This may occur because rhizomatous grasses are useful for erosion control, because appropriate forb seeds are expensive or unavailable, or out of a fear of weed invasion. Studies in the North American tallgrass prairie have shown that high-forb seed mixes can inhibit weeds (Dickson and Busby 2009, Carter and Blair 2012), and our study shows a similar result for sites in the Colorado Plateau. Because forbs are critical for wildlife, high-forb seed mixes should be considered for areas where erosion is not a concern.

The Plateau treatment successfully controlled cheatgrass, but caused an increase in annual forbs 2 and 3 years post treatment, and had either neutral or negative effects on perennials. A recent study has shown that increasing the plant-back interval may avoid negative effects of Plateau on perennial grasses (Sbatella et al. 2011). In this study, except for big sagebrush, species were seeded shortly after Plateau was applied. More favorable results may have been found if desirable plants had been seeded several months after Plateau application. Several studies have suggested that one-time Plateau treatment alone is not sufficient to restore Wyoming big sagebrush communities dominated by cheatgrass (Morris et al. 2009, Elseroad and Rudd 2011, Owen et al. 2011). Combining Plateau with other control measures such as prescribed fire has been more effective (Barnes 2004, Davies and Sheley 2011). In this study, we found that combining Plateau with a rough/brush surface led to better results. Rough/brush surfaces plus Plateau caused a 10-fold decrease in weedy annual forb biomass at MTN, increased shrub cover and biomass at MTN, and lessened annual grass biomass 3 years post-treatment at GVM.

CONCLUSION

Treatments which appear promising in improving the quality of reclaimed wildlife habitat include applying Plateau herbicide (with extreme caution), timing disturbances to maximize weed seed burial, creating a rough/brush soil surface composed of mounds and holes, utilizing obstructions to prevent weed seed dispersal, treating soil with granulated super-absorbent polymer, and using a seed mix focused on perennial forbs.

This report contains results of three experiments in which Plateau herbicide was applied. Of these, one experiment demonstrated only positive effects of the herbicide, one demonstrated both positive and negative effects, and one demonstrated mainly negative effects. In all 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) to low and mid-elevation sites, and results after three years are very favorable. The herbicide was neutral with respect to grasses and forbs, but greatly improved shrub cover and reduced annual grass cover. In the Gulley experiment, Plateau was applied with a backpack sprayer at 140 g ai/ha (8 oz/ac) to low-elevation, weedy sites, and results after 3 years are mixed. Shrubs increased with Plateau application, and Plateau successfully controlled annual grasses, but Plateau decreased perennial forbs at two sites, and in certain cases caused an increase in annual forbs. In the Strategy Choice experiment, Plateau was applied with a backpack sprayer at 140 g ai/ha (8 oz/ac) to mid-elevation sites, and results after three years are unfavorable: perennial grass and shrub cover were greatly reduced, and annual forb cover increased where Plateau was applied. The differences cannot be entirely attributable to time since treatment, because the Pipeline experiment showed favorable responses to Plateau application after only two years (Johnston 2011b). The lower application rate used in the Pipeline experiment partially explains these results. The difference between the Gulley experiment and the Strategy Choice experiment may be due to the difference in initial weediness of the treated sites. At the Gulley sites, cheatgrass was a major component of the plant community prior to disturbance, and the positive effects of cheatgrass control may have counteracted the direct negative effect of the herbicide. At the Strategy Choice sites, the application rate was too high for the conditions. Using lower rates, matching the rate to the site, and increasing time between application and seeding are recommended. A rate of 105 g ai/ha (6 oz./acre) may be a good maximum for very weedy sites, with lower rates to be used at less weedy sites. Note that the 105 g ai/ha rate was shown to provide only fleeting and ultimately insufficient cheatgrass control in Wyoming sagebrush communities in a prior study (Morris et al. 2009). It appears that while a light rate of Plateau application may be beneficial in restoration, it cases of severe infestation, it should be coupled with other measures to control cheatgrass.

One such other measure is the judiciously-timed application of disturbance. Auxiliary data taken for the Pipeline and Gulley experiments shows the time course of cheatgrass seed dispersal in northwestern Colorado, with a peak in late June, and continued dispersal until mid-September (Appendix 1). At the weediest site measured, cheatgrass seed production peaks at 160 seeds/m^2 per day. Since 40 cheatgrass seeds/m^2 is sufficient to hinder the growth of even the most competitive perennial grasses (Evans 1961), many times more cheatgrass seed is produced *in a single day* than is acceptable for establishing native plants on restoration sites. Furthermore, these will readily spread from the edge of disturbances into bare soil areas (Johnston 2011a). Given the timing of cheatgrass seed dispersal, the worst possible scenario is if a disturbance occurs before spring, and is left bare over the summer. If the disturbance occurs in the fall, however, and is planted immediately, then there is little opportunity for cheatgrass seeds to disperse before seeded species germinate. Because cheatgrass seeds are sensitive to burial (Wicks 1997), then a fall disturbance will partially control cheatgrass. This was the case in the Pipeline experiment, where cheatgrass density was 5 times lower in the disturbed area than in the adjacent undisturbed area the spring following disturbance.

There were two experiments where a roughened 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 both experiments the rough soil surface outperformed the flat soil surface in most respects. The rough soil surface produced higher perennial forb cover at two sites in the Mountain Top experiment, higher perennial grass cover and biomass at two of the Strategy Choice sites, and lower annual grass cover at one site in each experiment. In both experiments, the seed was applied at the same rate in the rough surface plots, which were broadcast, as the flat surface plots, which were drill seeded. These results bring into question the common practice of doubling the seeding rate for broadcast seeding. If the seedbed is well-prepared, doubling the seeding rate may be wasteful. The machinery and mobilization costs for the two methods are comparable, therefore broadcast seeding over a rough soil surface appears to be a cost-effective alternative. These results confirm and extend those of Eldridge (2011) who found that a rough soil surface treatment improved the cover of native plants at low elevation sites in the Colorado River Valley (Eldridge et al. 2011). In the future restoration practitioners will face challenges not only from disturbances and invasive species, but also from climate change and increased drought, which can exacerbate problems with invasive species (Carter & Blair, 2012). Additional tools are needed to make plant communities resistant to invasive species under climate change (Carter and Blair 2012). Because rough/brush surfaces may help control invasives without damaging perennials, and may help their persistence by increasing soil moisture (Li et al., 2006), rough/brush surface planting should be considered as a technique which may make plant communities more resilient under increased drought conditions.

The reduction in annual grass shown at two sites with a rough soil surface treatment, the SCD site in the Mountain Top experiment, and the MTN site in the Strategy Choice experiment, suggests that a rough soil surface may aid in cheatgrass control under certain conditions. Altered competitive dynamics is one explanation for these results, but altered seed dispersal is probably also important. In a study of many kinds of seeds, Chambers (2000) found that large holes capture more seeds than flat surfaces (Chambers 2000). Recent work done as part of this project has shown that cheatgrass seeds move farther in the absence of obstructions that they do in intact ecosystems (Johnston 2011a). At both the SCD and MTN sites, cheatgrass was not prevalent prior to disturbance. The rough soil surface probably prevented a few cheatgrass seeds introduced during disturbance from spreading, concentrating them in a higher-moisture microclimate, where they may have been less competitive. Another experiment, the Gulley experiment, looked explicitly at creating obstructions to seed dispersal, in the form of windowscreen barriers placed around plots. These barriers had opposite effects on weedy annuals, sometimes increasing them, sometimes decreasing them, depending on site and fallowing treatment. One explanation for this result is that weed seeds could as easily be retained by the barriers as they might be excluded by them. This experiment demonstrates that manipulating seed dispersal can influence plant communities, although the methods need to be further refined.

In the Competition experiment, we tested the effect of granulated super-absorbent polymer (SAP) on the competitive balance between perennial wheatgrasses and cheatgrass. Three years post-treatment, cheatgrass cover remains lower in plots where SAP was applied than in no-SAP plots. Unlike prior years, this effect was evident at both research sites. To test for repeatability, 2 new experiments were initiated in 2012. One of these, the Competition 2 experiment, tests SAP in the same locations as the Competition experiment, but with different conditions: higher cheatgrass propagule pressure, a different SAP manufacturer, and a more complex seed mix. Another new experiment, conducted at Horsetheif State Wildlife Area near Fruita, CO, tests the effect of SAP when applied in conjunction with a rough soil surface, similar to that used in the Strategy Choice experiment. For details on this experiment, please see the CPW annual report "Rangeland restoration with super-absorbent polymer and potholed surface at Horsethief State Wildlife Area," available on the CPW website.

Two experiments examined the consequences of seed mix choices. In the Strategy Choice experiment, we compared a seed mix with almost 75% forbs by seed number and virtually no rhizomatous grass (the high-forb mix) to a seed mix with fewer forbs and a typical, 4.4 kg/ha (3.9 PLS/acre) rate of rhizomatous grass (the balanced mix). In the Mountain Top experiment, we compared a seed mix with 4.4 kg/ha rhizomatous grass to the extreme of not seeding at all. The high-forb mix produced higher forb cover with similar weed cover to the balanced mix. The unseeded plots in the Mountain Top experiment had more weeds than the seeded plots, but the weeds were not species thought to persist over time, and they also had higher shrub cover. Collectively, these studies suggest that post-reclamation wildlife habitat could be improved by altering the composition of seed mixes to focus on forbs, bunchgrasses, and shrubs. The idea that seed mixes should limit the proportion of 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 competitive 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. This study made use of several forb species provided by the Uncompagre Partnership (http://www.upartnership.org/) that 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, hairy golden aster, sulfur flower buckwheat, bluestem penstemon (*Penstemon cyanocaulis*), and Western yarrow. The results of this study highlight the importance of making species such as these available at a reasonable cost.

Treatments which do not appear promising include surface compaction, fallowing with Pendulum herbicide, and addition of a soil binding agent to the soil. Rolling to create slight soil surface compaction was attempted in two 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. In no case was cheatgrass emergence affected, and a negative effect on shrubs was found in the Pipeline experiment. Fallowing with Pendulum herbicide was attempted in the Gulley experiment, and the results were detrimental to perennial grasses and forbs. Soil binding agent was tested in the Competition experiment, and had mixed results, at times causing increased cheatgrass cover, and at times limiting it. Because of these inconsistencies and the cost of the treatment, it is unlikely to be recommended.

In summary, excellent restoration of wildlife habitat following oil and gas disturbances is possible over a wide range of elevations in northwestern Colorado. At lower elevations and in places with some cheatgrass cover prior to disturbance, then a combination of approaches to control cheatgrass and promote native plants should be used. This may include a light herbicide application, using roughened soil surface, and amending soil with a super-absorbent polymer. At middle and higher elevations, using a roughened soil surface and using a seed mix primarily of forbs is recommended. Note that these results apply to slopes of less that 5% and areas protected from grazing. Steeper slopes and grazed areas may require using rhizomatous grasses to protect soil resources.

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Table 1. Study site information. Pie charts are baseline relative cover from undisturbed areas.

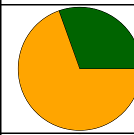
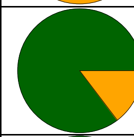
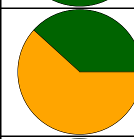
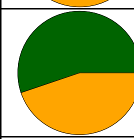
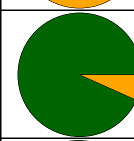
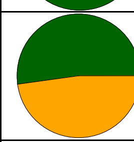
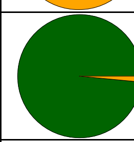
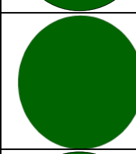
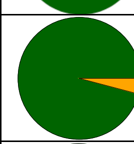
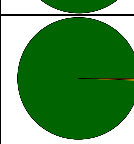
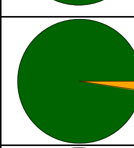
code	Name	landowner	elev. m (ft)	experiment(s) conducted	cover (NonNative / Native)
SKH	SK Holdings	WPX Energy	1561 (5120)	Pipeline Gulley	
GVM	Grand Valley Mesa	WPX Energy	1662 (5451)	Pipeline Strategy Choice	
YC2	Yellow Creek 2	CPW	1829 (5999)	Pipeline Gulley	
YC1	Yellow Creek 1	CPW	1905 (6248)	Pipeline Gulley	
SGE	Sagebrush	BLM	2004 (6573)	Strategy Choice Competition/ Comp. 2 Seed Dispersal	
RYG	Ryan Gulch	WPX Energy	2084 (6835)	Pipeline Gulley	
MTN	Mountain Shrub	BLM	2183 (7160)	Strategy Choice	
WRR	Wagon Road Ridge	WPX Energy	2216 (7268)	Pipeline Strategy Choice Competition / Comp.2 Seed Dispersal	
SCD	Scandard	BLM	2342 (7681)	Mountain Top	
SPG	Sprague (formerly called Snowpile)	Conoco	2445 (8019)	Mountain Top	
TGC	The Girls' Claims	Encana Oil and Gas, Inc.	2527 (8288)	Mountain Top	
SQS	Square S	CPW	2676 (8777)	Mountain Top	

Table 2. 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 3. Seed mix used in the Competition 2 experiment. Cheatgrass (*Bromus tectorum)* was also seeded at 600 seeds/m^2.

Scientific Name	Common Name	Variety	Seeds/ m^2	PLS (kg/ha)	Seeds/ ft^2	PLS (lbs/ ac)
forbs						
Eriogonum umbellatum	sulphur flower buckwheat	VNS	130	3.5	12.1	3.1
Hedysarum boreale	Utah sweetvetch	Timp	26	3.5	2.4	3.1
Linum lewisii	Lewis flax	Maple Grove	91	1.4	8.5	1.2
Penstemon palmeri	Palmer penstemon	Cedar	104	0.8	9.7	0.7
grasses						
Pascopyrum smithii	western wheatgrass	Arriba	39	1.6	3.6	1.4
Achnatherum hymenoides	Indian ricegrass	Nezpar	130	4.1	12.1	3.6
Bouteloua gracilis	blue gramma	Hachita	65	0.4	6.0	0.4
Elymus elymoides	bottlebrush squirreltail	Toe Jam Creek	65	1.5	6.0	1.4
Elymus trachycaulus	slender wheatgrass	San Luis	52	1.8	4.8	1.6
Poa sandbergii	Sandberg bluegrass	Cedar	182	0.9	16.9	0.8
Pseudoroegneria spicata	bluebunch wheatgrass	Anatone	104	3.4	9.7	3.0
shrubs						
Atriplex canescens	fourwing saltbush	Colorado source	195	32.2	18.1	28.7
Artemisia tridentata	big sagebrush	local collection	150	0.6	13.9	0.5

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						
Artemisia 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
Krascheninnikovia 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/straw surface. In plots with a rough/brush surface, all seed was broadcast.

	Scientific Name	Common Name	Variety	high comp.mix seeds/ m^2	high comp.mix PLS (kg/ha)	low comp.mix seeds / m^2	low comp.mix PLS (kg/ha)
drill seeded	***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
	Artemisia 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**

Table 7. F-values and significance of the linear model for soil surface and seed mix treatments in the Strategy Choice experiment at all 4 sites.

	perennial grass[1]	perennial forb[1]	shrub[1]	annual grass[2]	annual forb[2]
2011 Cover					
soil_surface	6.23*	0.12	4.29*	5.78*	0.04
seed mix	26.20***	28.79***	2.75	1.06	0.04
site	10.46***	33.83***	4.31*	60.46***	13.34***
soil_surface X *seed mix*	1.97	0.69	1.15	0.09	2.49
site X *soil_surface*	5.45**	1.23	1.58	15.35***	0.45
site X *seed mix*	0.36	0.51	1.87	0.65	0.91
site X *soil_surface* X *seed mix*	1.43	2.17	2.22	0.56	0.32
2012 Cover					
soil_surface	6.25*	9.52**	4.01*	1.59	-
seed mix	35.11***	33.89***	0.90	0.19	-
site	30.73***	113.36***	1.59	1.91	-
soil_surface X *seed mix*	2.91	0.06	1.35	0.79	-
site X *soil_surface*	8.28***	1.04	1.70	4.30*	-
site X *seed mix*	0.70	3.21*	0.78	1.85	-
site X *soil_surface* X *seed mix*	1.32	6.95**†	9.49***†	0.86	-
2012 Standing Crop Biomass					
soil_surface	0.55	1.09	2.37	1.14	1.22
seed mix	14.48***	6.09*	4.60*	0.71	0.01
site	38.19***	56.93***	3.76*	11.32***	1.03
soil_surface X *seed mix*	1.09	2.20	0.01	1.15	0.00
site X *soil_surface*	19.49***	2.17	0.26	3.12	0.73
site X *seed mix*	0.89	0.37	1.03	1.09	0.05
site X *soil_surface* X *seed mix*	6.95**†	1.01	2.98*†	0.56	0.16

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

[1] Transformations: arcsin[sqrt(*cover*)] or log (*biomass*+15).

[2] Transformations: sqrt(*cover*) or log (*biomass*+0.01).

† These interactions are discussed in Appendix 3.

Table 8. F-values and significance for the Strategy Choice analysis with herbicide effects.

2011 Cover	**perennial grass[1]**	**perennial forb[1]**	**shrub[1]**	**annual grass[2]**	**annual forb[2]**
imazapic	107.97***	6.46*	30.17***	52.52***	15.84***
soil_surface	21.98***	0.00	0.27	6.77*	2.38
seed mix	18.71***	9.19**	5.12*	0.80	0.30
site	8.35**	42.64***	10.46**	2.51	9.19**
seed mix X imazapic	0.00	0.16	0.61	0.48	0.16
soil_surface X imazapic	0.00	0.38	8.14**	1.82	3.32
soil_surface X seed mix	0.50	1.19	0.47	1.31	0.10
soil_surface X seed mix X imazapic	0.25	0.28	0.21	2.64	3.51
site X imazapic	21.64***	3.92	0.27	0.10	1.37
site X soil_surface	19.89***	9.32**	4.60*	3.98*	0.08
site X seed mix	0.04	0.04	0.56	3.42	3.82
site X seed mix X imazapic	0.00	1.69	0.00	4.44*	0.00
site X soil_surface X imazapic	2.48	1.73	5.93*	16.89***	0.72
site X soil_surface X seed mix	1.02	2.90	2.87	0.03	1.81
site X soil_surface X seed mix X imazapic	6.85*†	1.28	4.40*	1.12	0.05
2012 Cover					
imazapic	81.82***	2.97	36.69***	2.58	-
soil_surface	1.43	3.98*	0.80	2.63	-
seed mix	48.06***	12.92**	2.50	0.00	-
site	10.68**	188.97***	6.13*	3.67	-
seed mix X imazapic	0.08	0.50	0.00	2.38	-
soil_surface X imazapic	7.24*	0.87	9.39**	0.00	-
soil_surface X seed mix	0.98	1.83	3.78	0.02	-
soil_surface X seed mix X imazapic	0.49	0.15	0.45	2.92	-
site X imazapic	51.10***	15.69***	3.22	1.71	-
site X soil_surface	4.40*	0.75	4.29*	2.05	-
site X seed mix	0.66	0.31	0.10	4.91*	-
site X seed mix X imazapic	0.24	0.24	0.01	2.59	-
site X soil_surface X imazapic	1.06	1.08	8.79**	6.77*	-
site X soil_surface X seed mix	1.75	2.11	4.14*	0.12	-
site X soil_surface X seed mix X imazapic	1.48	0.76	3.95	0.01	-
2012 Standing Crop Biomass					
imazapic	11.88**	2.81	4.40*	0.04	56.36***
soil_surface	8.69**	0.12	1.41	1.52	9.96**
seed mix	9.38**	2.63	0.05	0.24	0.05
site	5.89*	224.85***	11.89**	4.76*	3.62
seed mix X imazapic	3.34	0.66	4.63*	4.43*†	0.01
soil_surface X imazapic	0.72	0.00	0.04	0.50	1.26
soil_surface X seed mix	2.58	0.22	2.56	0.24	0.34
soil_surface X seed mix X imazapic	1.15	0.03	0.40	2.31	1.69

site X imazapic	10.27**	0.17	2.99	8.15**	0.15
site X soil_surface	12.06**	2.63	16.06***	0.32	13.08**
site X seed mix	0.98	0.03	1.60	8.56**	0.45
site X seed mix X imazapic	0.34	0.31	0.02	2.46	0.30
site X soil_surface X imazapic	0.00	0.46	23.93***	8.76**	8.93**
site X soil_surface X seed mix	0.13	0.93	0.95	0.02	0.13
site X soil_surface X seed mix X imazapic	1.27	0.18	0.21	0.01	0.07

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

† These interactions are discussed in Appendix 3.

[1] Transformations: arcsin[sqrt(*cover*)] or log (*biomass*+15).

[2] Transformations: sqrt(*cover*) or log (*biomass*+0.01).

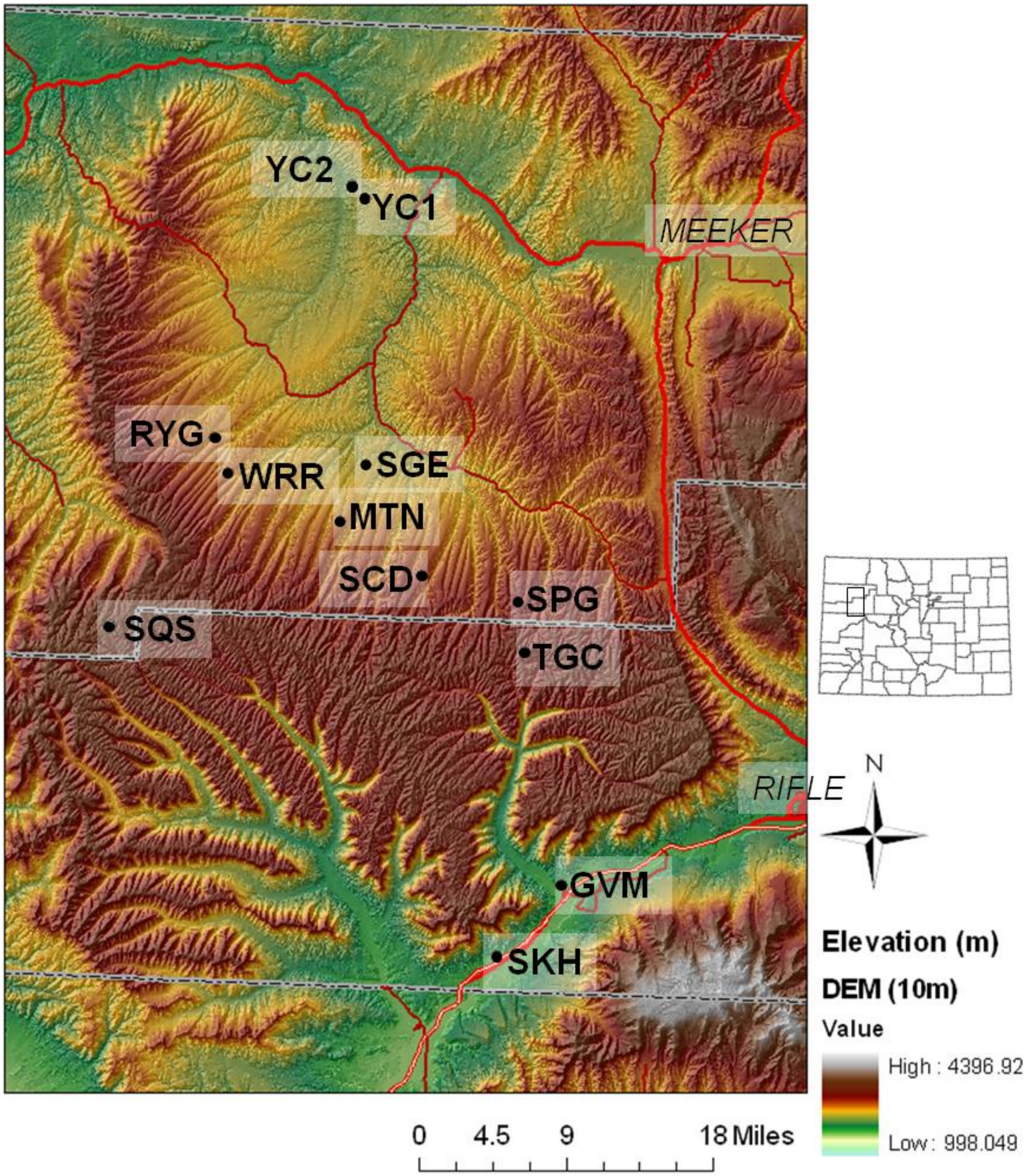


Figure 1. Locations of the 12 research sites in Rio Blanco and Garfield counties, Colorado.

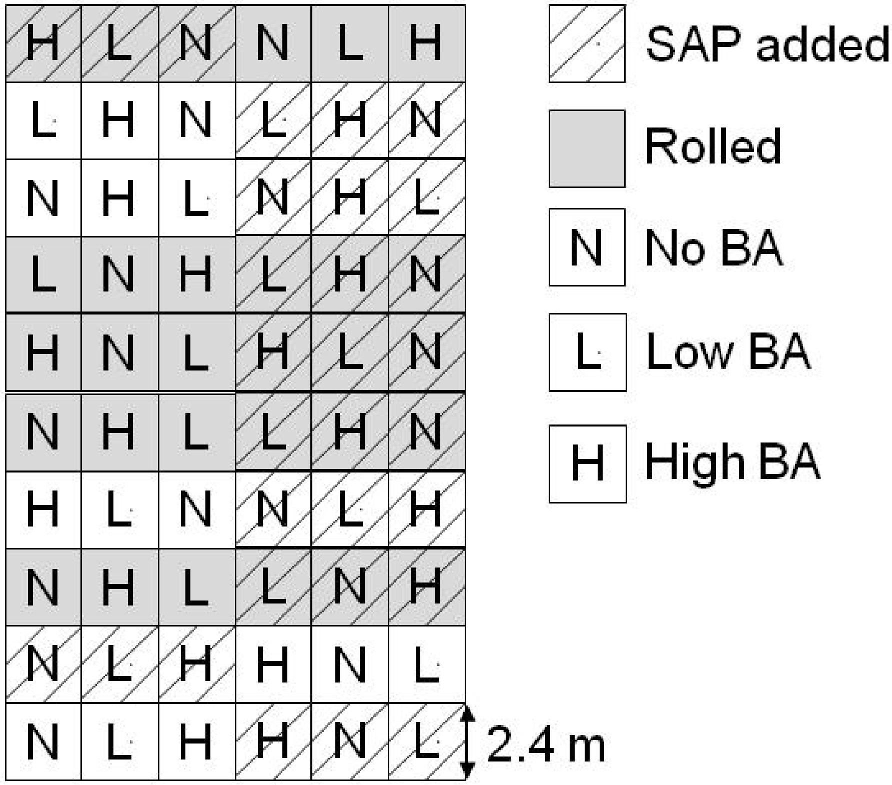


Figure 2. Layout of the Competition experiment at one of 2 research sites. SAP = super- absorbent polymer. BA = soil binding agent.

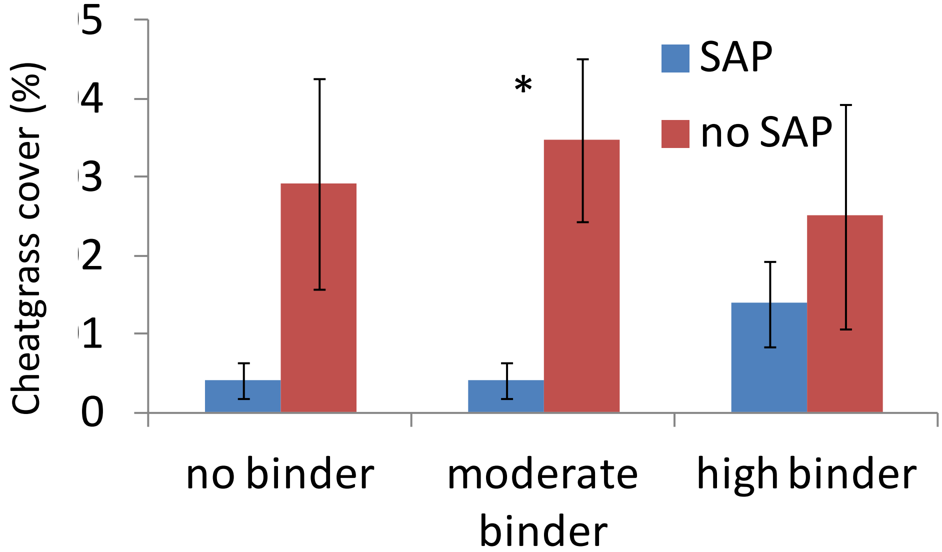


Figure 3. Effect of super-absorbent polymer (SAP) on cheatgrass cover at 3 levels of binding agent in the Competition experiment, 3 years post-treatment. Error bars = standard error of data in original scale. Asterisks denote significantly different (p < 0.05) means of data based on analysis in transformed scale.

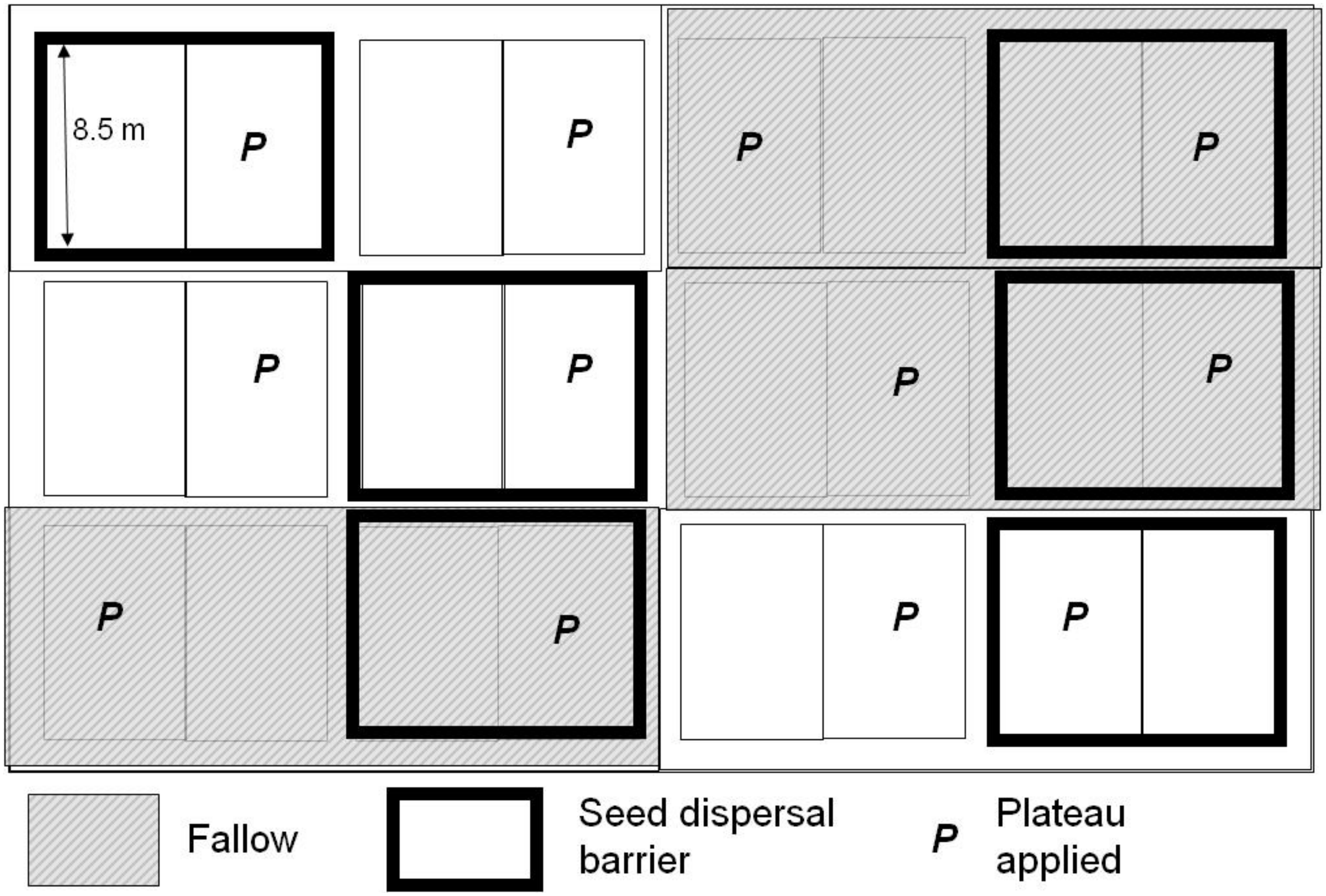


Figure 4. Layout of the Gulley experiment at one of 4 research sites.

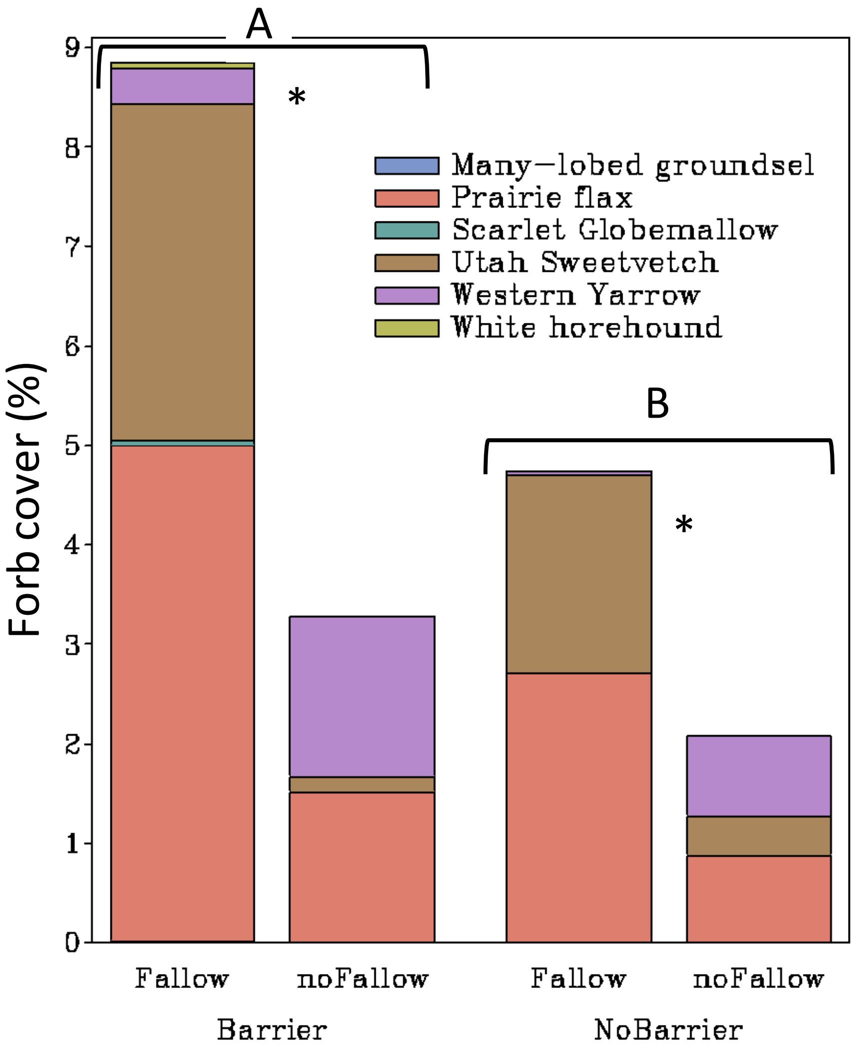


Figure 5. Effect of fallowing and barriers on forb cover in the Gulley experiment. Letters denote significant differences between barrier treatment groups. Stars denote significant differences between fallowing treatment groups (α = 0.05). Data are averaged over 4 sites.

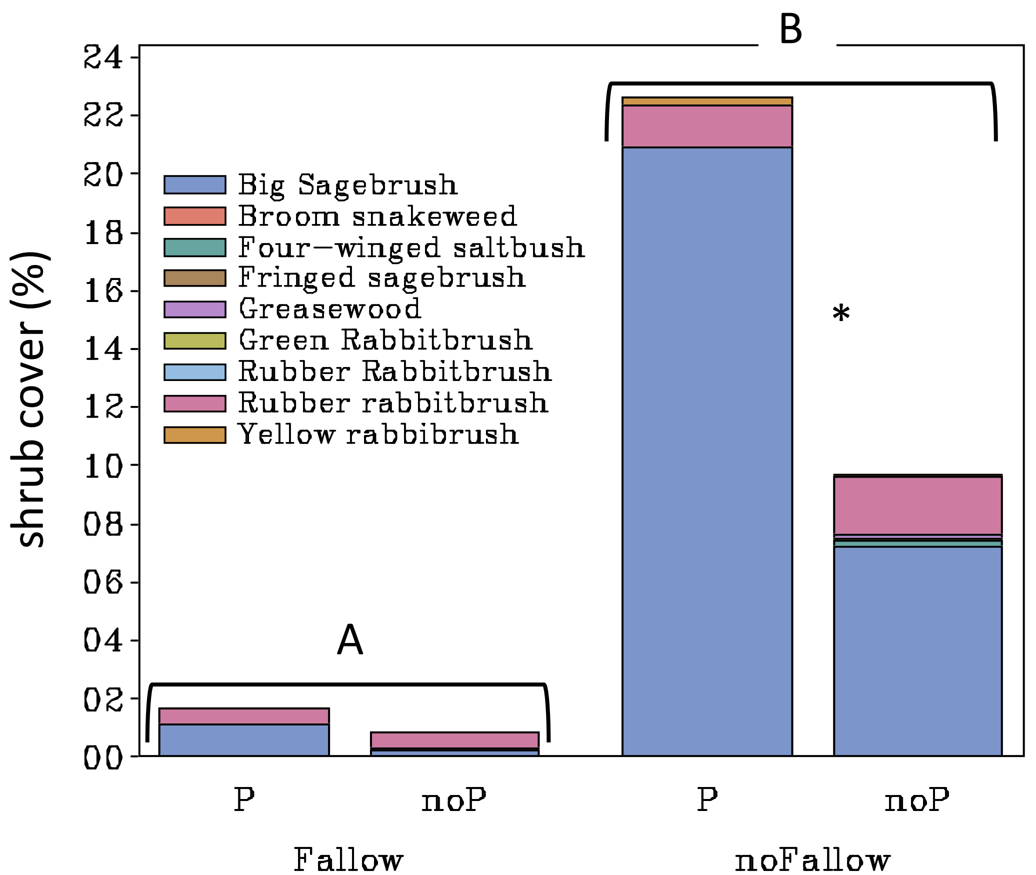


Figure 6. Effect of fallowing and Plateau (P) on shrub cover in the Gulley experiment. Letters denote significant differences between fallow treatment groups. Stars denote significant differences between Plateau treatment groups (α = 0.05). Data are averaged over 4 sites.

Figure 7. Overview of the Gulley experiment at the Ryan Gulch site. Plots right of the white line received the fallow treatment.

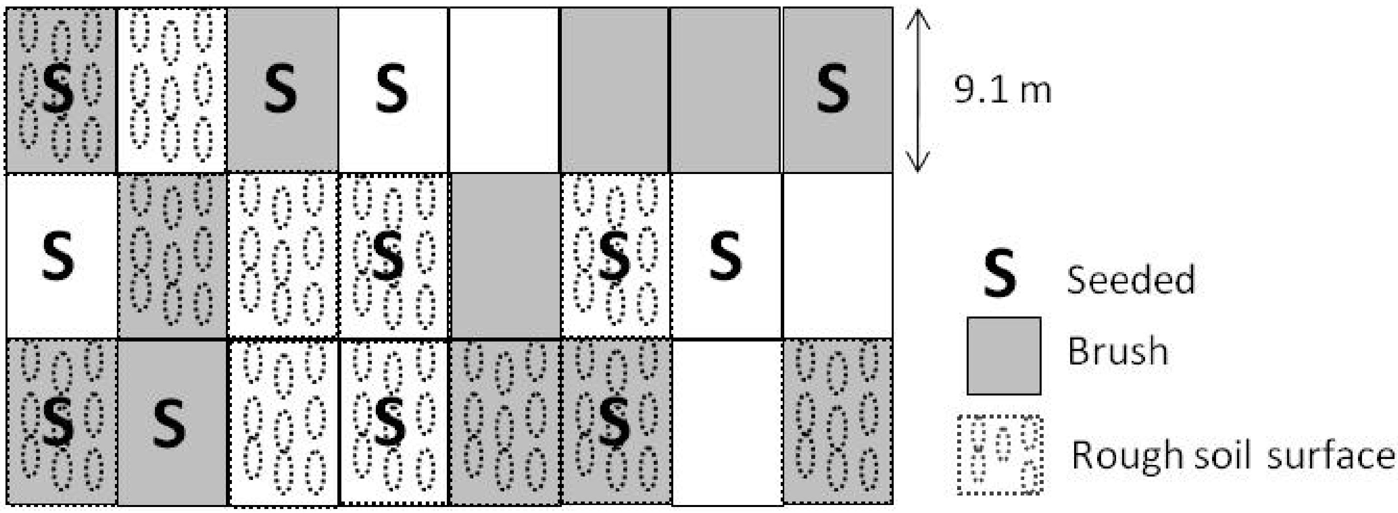


Figure 8. Layout of the Mountain Top experiment at one of 4 research sites.

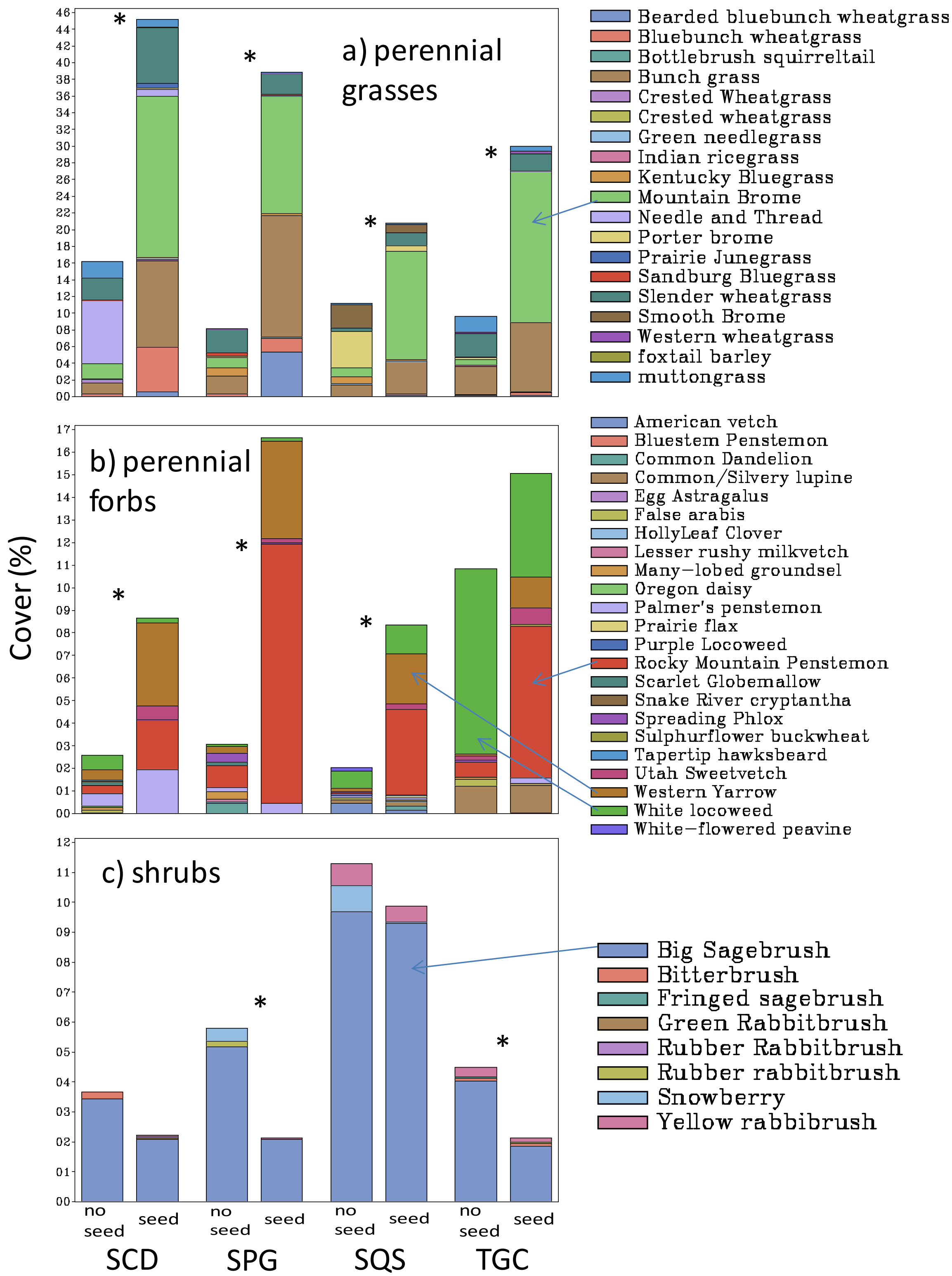


Figure 9. Effect of seeding on cover of a) perennial grasses, b) perennial forbs, and c) shrubs at 4 sites in the Mountain Top experiment: Scandard (SCD), Sprague (SPG), Square S (SQS), and The Girls' Claims (TGC). Stars denote significant differences at α = 0.05.

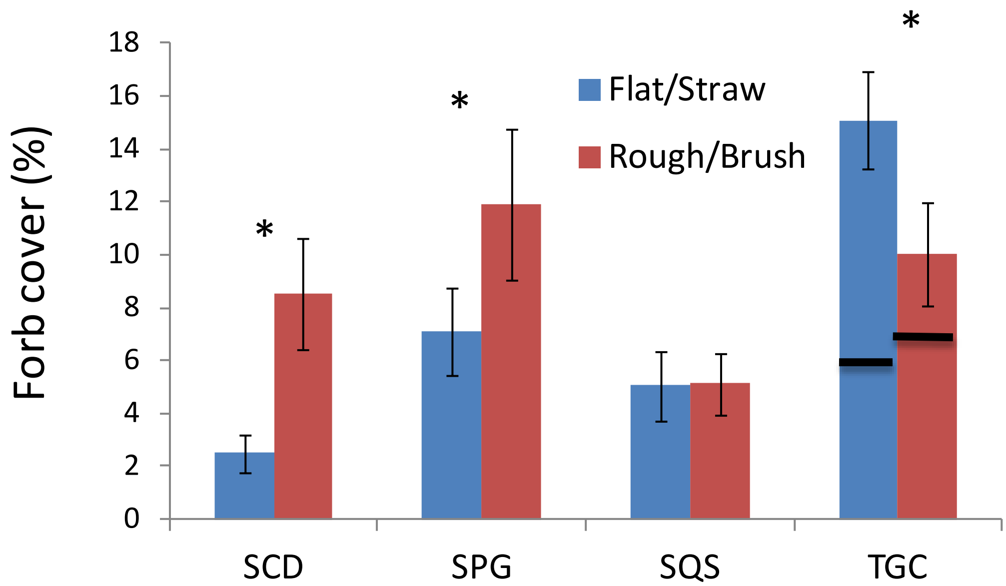


Figure 10. Effect of soil surface treatment on perennial forb cover at 4 sites in the Mountain Top experiment: Scandard (SCD), Sprague (SPG), Square S (SQS), and The Girls' Claims (TGC). Error bars = SE. Stars denote significant differences at $\alpha = 0.05$. The lines within the bars for the TGC site indicate forb cover of species other than *Oxytropis sericea* (White locoweed).

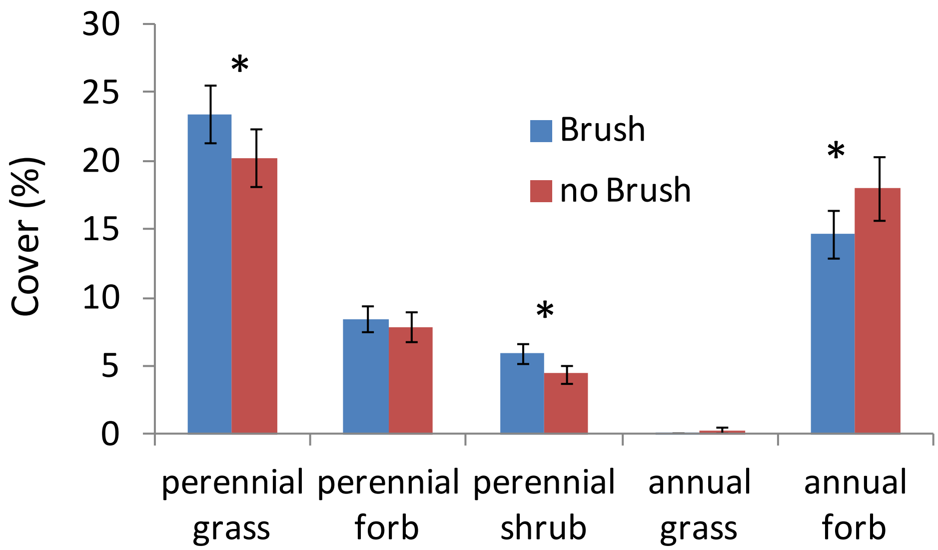


Figure 11. Effect of brush mulching on cover of all functional groups in the Mountain Top experiment. Data are averaged over 4 sites. Error bars = standard error of data in original scale. Asterisks denote significantly different (p < 0.05) means of data based on analysis in transformed scale.

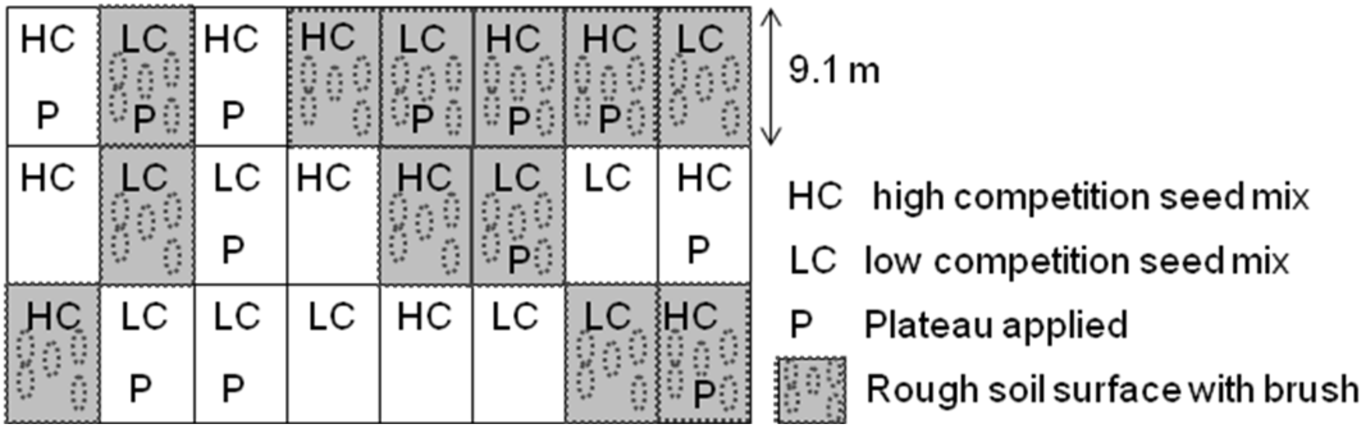


Figure 12. Layout of the Strategy Choice experiments at one of 2 sites where the full experiment was implemented. At 2 additional sites, a reduced form of the experiment lacking the Plateau treatment was implemented.

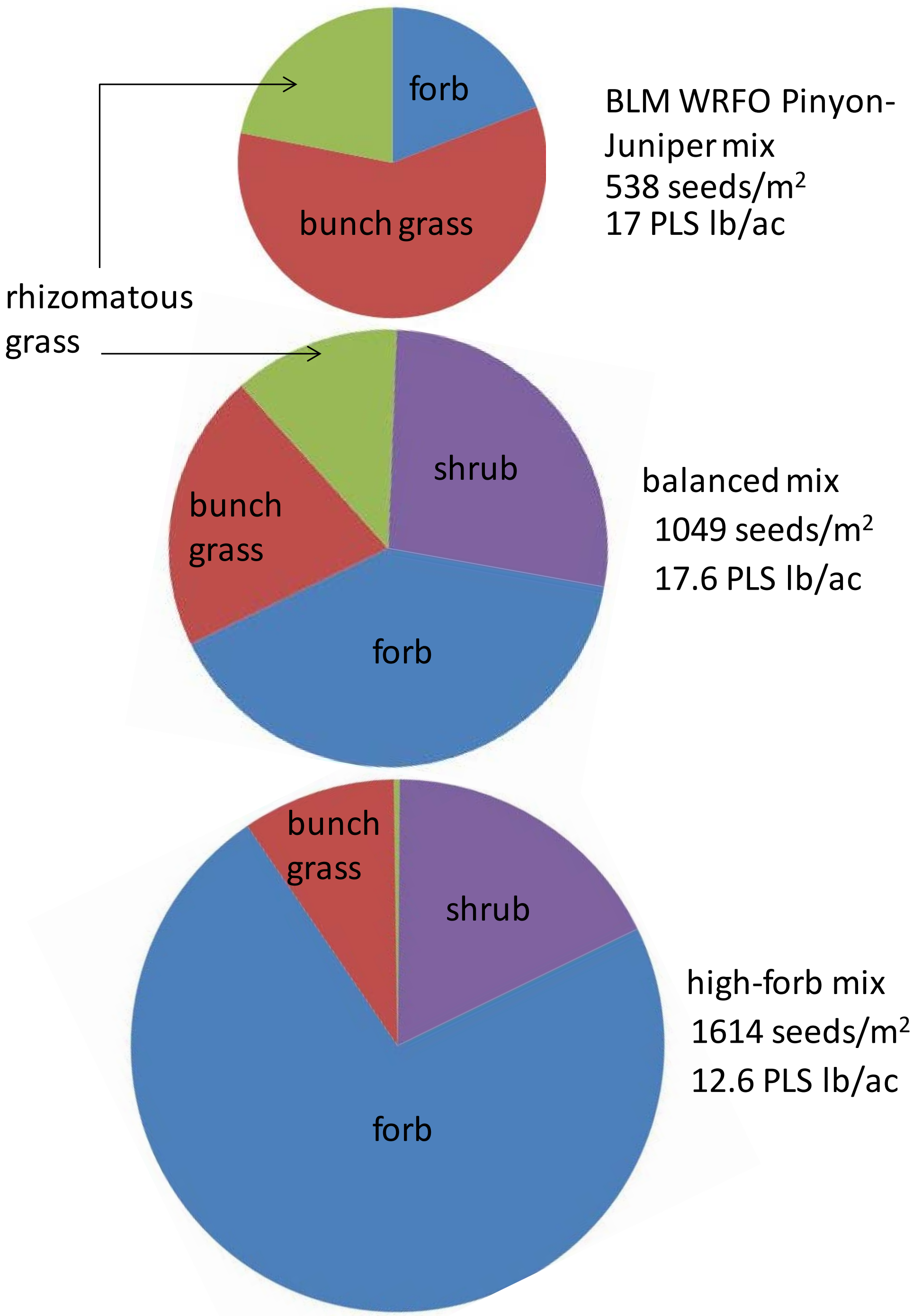


Figure 13. Comparison of the seed mixes used in the Strategy Choice experiment, with a commonly used Bureau of Land Management (BLM) mix for reference. The size of the pie charts is proportional to the number of seeds in the mix.

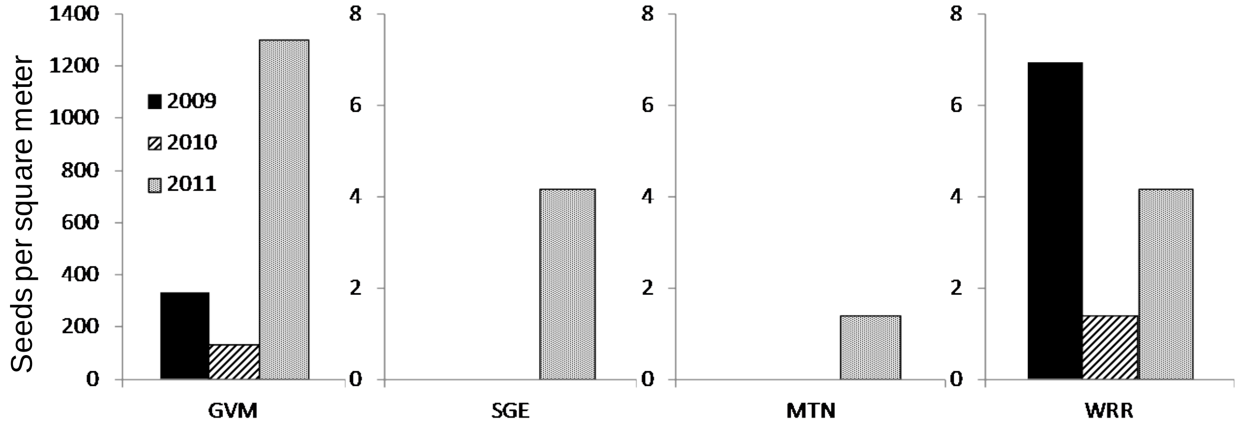


Figure 14. Ambient cheatgrass propagule pressure near each of the four study sites in the Strategy Choice experiment, 2009-11: Grand Valley Mesa (GVM); Mountain Shrub (MTN); Sage (SGE); and Wagon Road Ridge (WRR). Note differing y-axis scales.

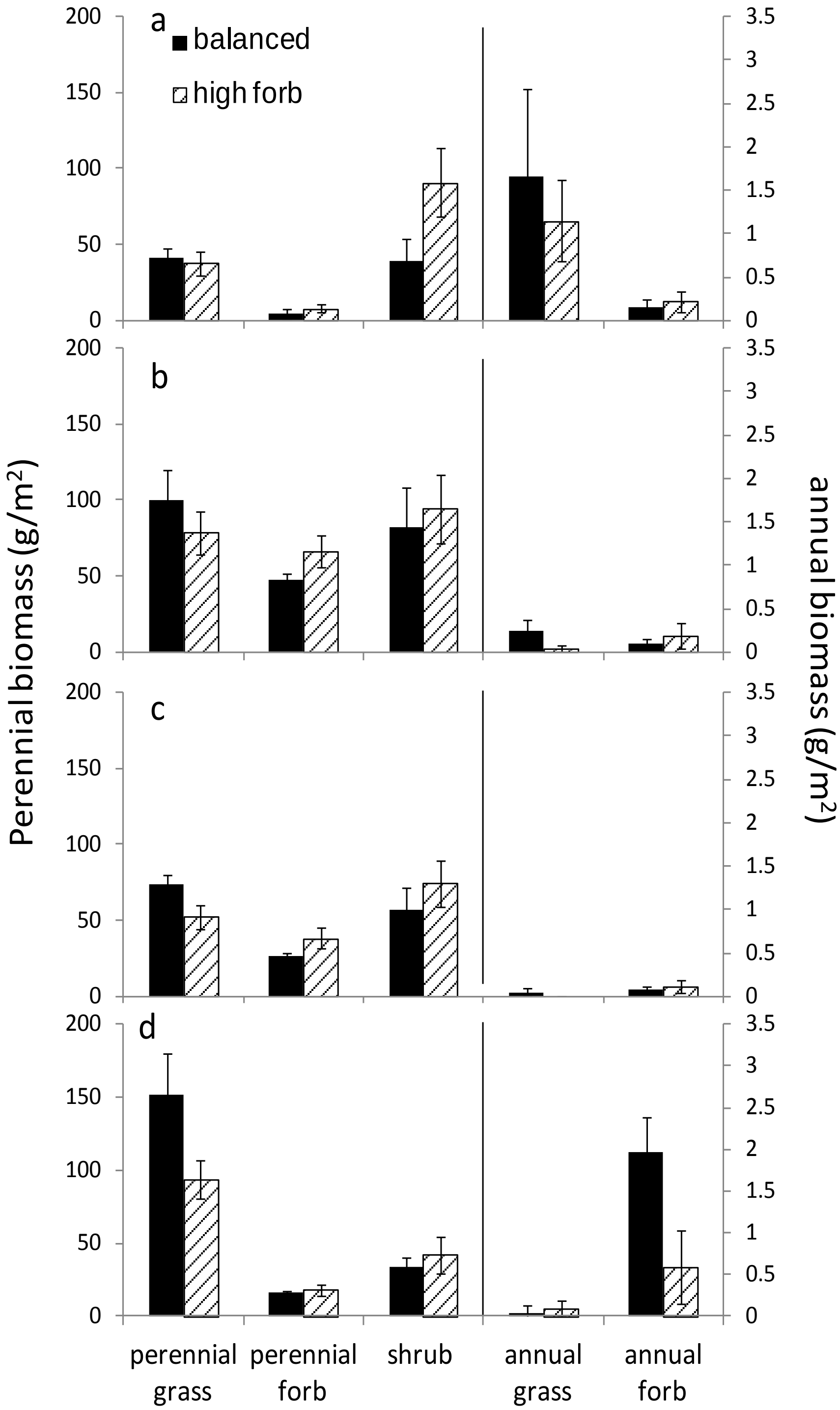


Figure 15. 2012 biomass of perennial grasses, perennial forbs, and shrubs (left axis) as well as annual grasses and annual forbs (right axis) in the absence of Plateau for plots with the balanced vs. high-forb seed mixes at 4 sites: a) Grand Valley Mesa; b) Mountain Shrub; c) Sage; and d) Wagon Road Ridge. Error bars = standard error.

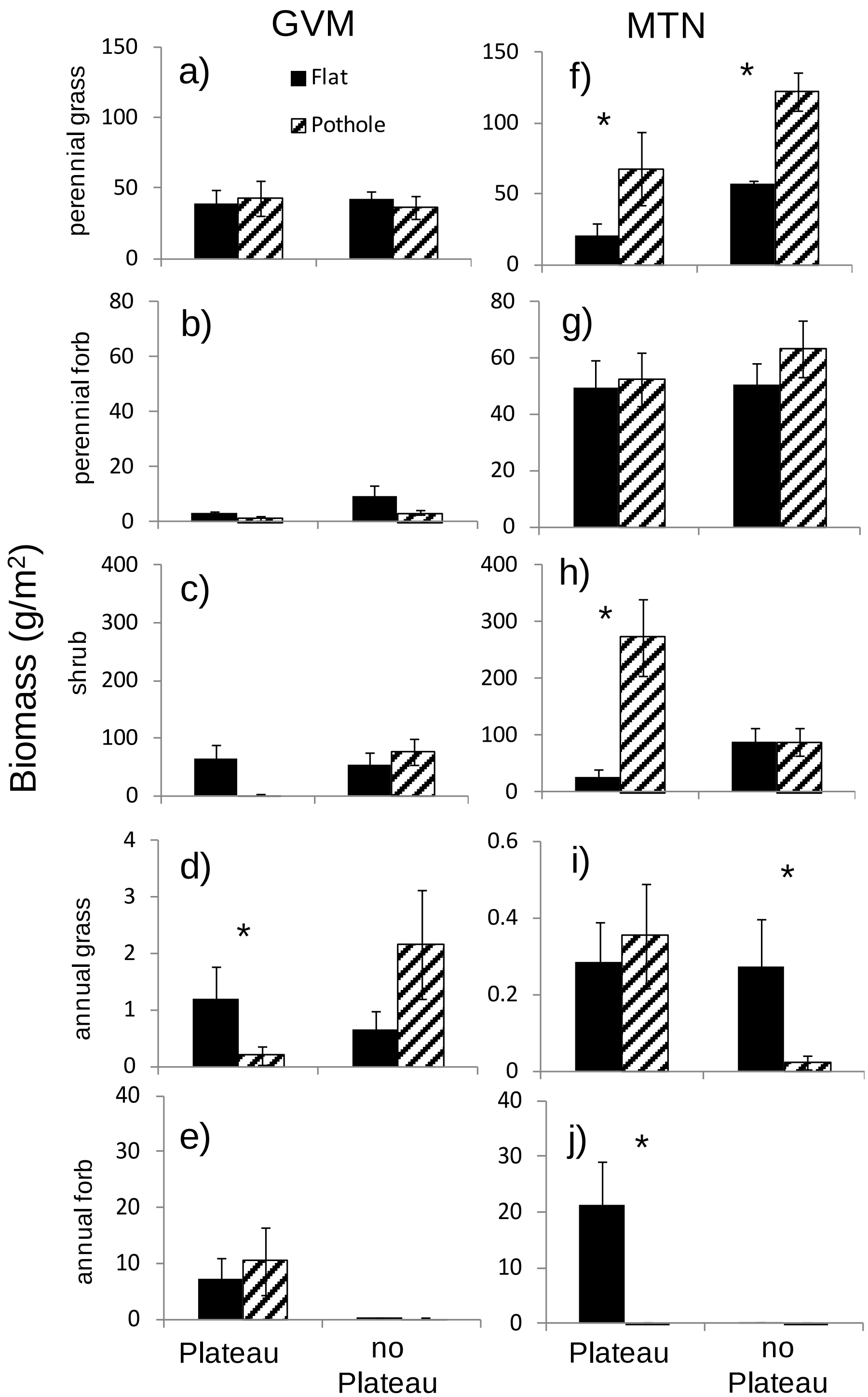


Figure 16. 2012 biomass of perennial grasses (a, f), perennial forbs (b, g), shrubs (c, h), annual grasses (d, i), and annual forbs (e, j) in response to Plateau and soil surface treatment at Grand Valley Mesa (GVM; a-e) and Mountain Shrub (MTN; f-j) sites. Data are averaged over seed mix treatment. Error bars = standard error of data in original scale. Asterisks denote significantly different (*p* < 0.05) means of data based on analysis in transformed scale.

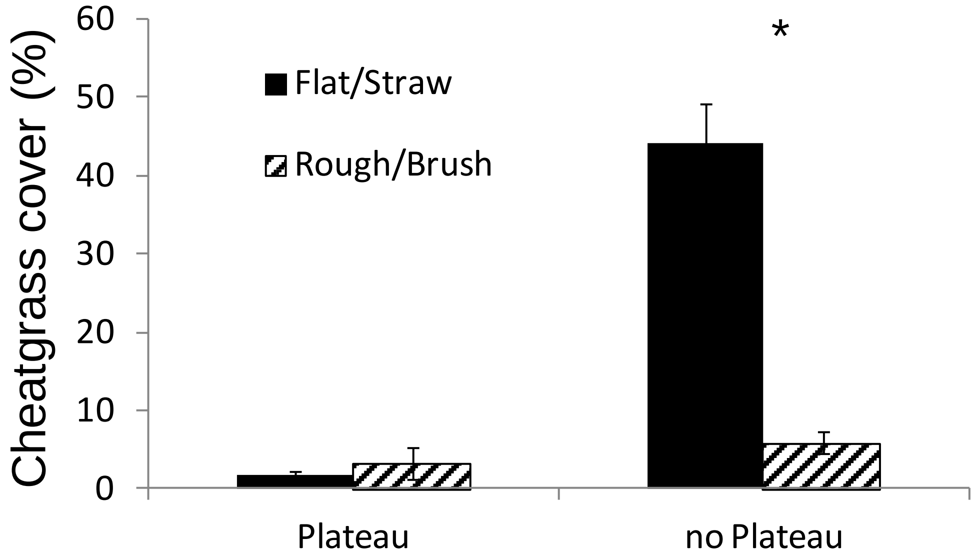


Figure 17. 2011 annual grass cover at the Mountain Shrub site in response to Plateau and soil surface treatment. Error bars = standard error of data in original scale. Asterisks denote significantly different (p < 0.05) means of data based on analysis in transformed scale.

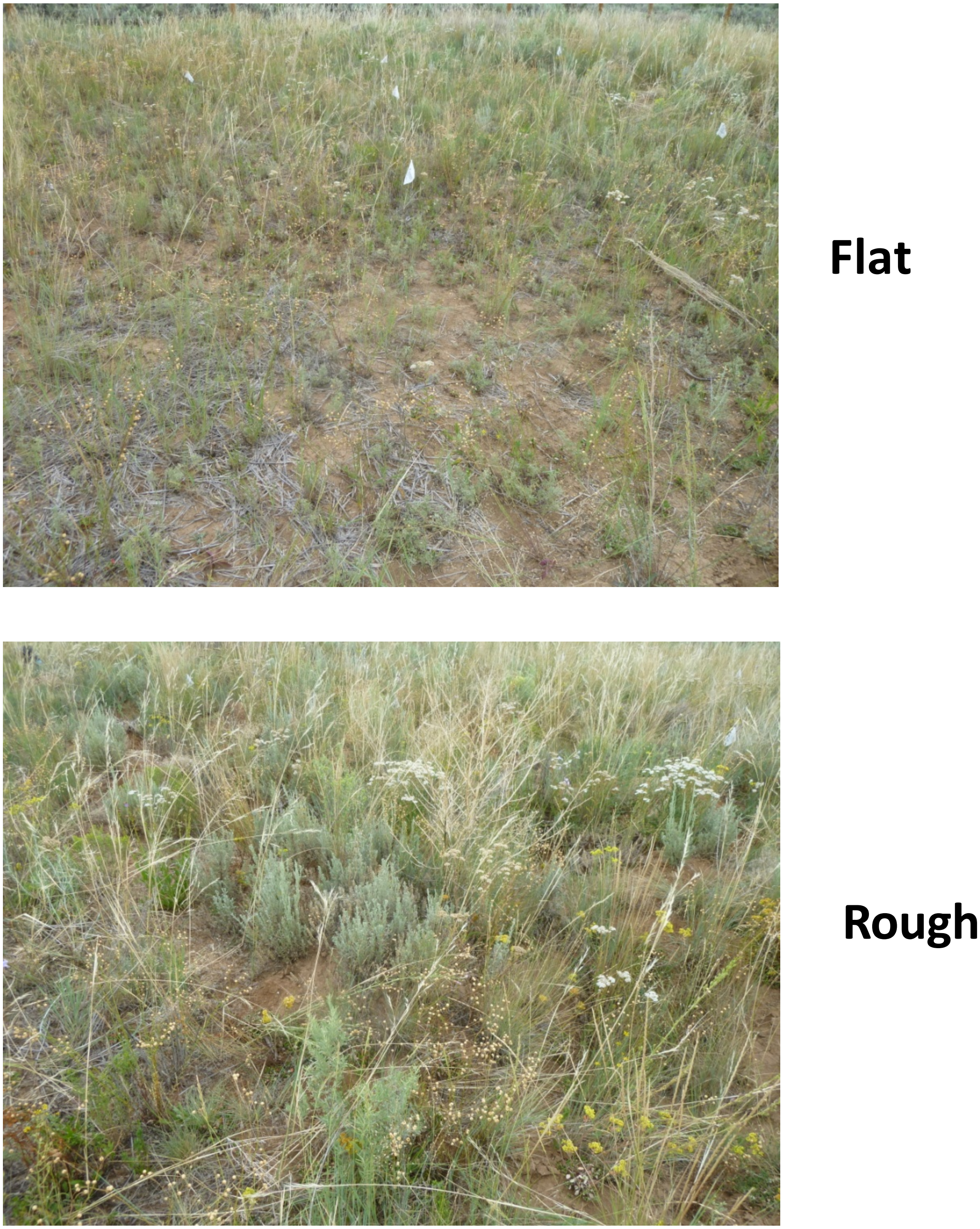


Figure 18. Visual comparison of flat/straw surface versus rough/brush surface plots in the Strategy Choice experiment at the MTN site. Both plots received the high-forb seed mix and did not receive Plateau herbicide.

APPENDIX 1

CHEATGRASS PROPAGULE PRESSURE METHODS

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.
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 A1-1). Eight traps were set in systematically chosen locations in undisturbed vegetation surrounding each site. Cheatgrass seeds were counted and removed from traps a mean of every 12 days from mid-May to late September, 2009- 2011. 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. The time course of cheatgrass propagule pressure over the course of the season (Figure A1-2) was calculated by finding the average number of seeds caught per Julian date, averaging this data over three years, and then applying a cubic spline smoothing function with an nn value of 15 (Reinsch 1967).

Figure A1-1. A seed trap.

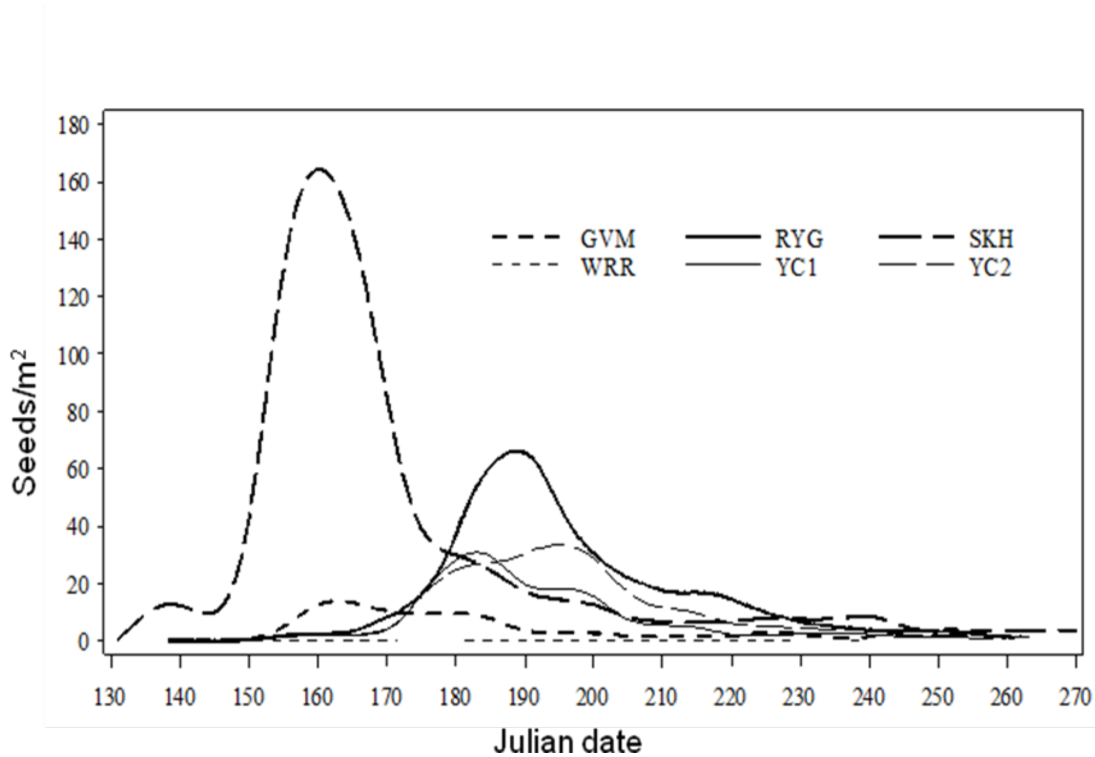


Figure A1-2. Prevalence of cheatgrass seeds between May and September in undisturbed locations near the 6 study sites. Data are averages over 3 years, 2009-11.

APPENDIX 2

REGRESSIONS USED TO CORRECT OCULAR ESTIMATES IN DOUBLE SAMPLING FOR BIOMASS IN THE STRATEGY CHOICE EXPERIMENT

Similar to prior work (Ahmed et al. 1983), we found that including an intercept made little difference in the correction factor. We chose to apply the regression without an intercept in order to avoid negative or inflated corrected estimates for very small values. However, the regression results with an intercept are included here along with the corresponding R^2 values, as R^2 values in the absence of an intercept are not easily interpretable.

Species Group	Species Included	n	Regression with intercept: Intercept	slope	R^2	Regression slope without intercept
ACMI	*Achillea millefolium*	14	0.11	1.51	0.99	1.51
ARTR	*Artemisia tridentata*	68	1.41	1.33	0.96	1.33
BG	*native perennial grasses*	111	2.79	1.47	0.70	1.61
ERUM	*Eriogonum umbellatum*	79	0.54	1.49	0.73	1.59
HEBO	*Hedysarum boreale*	23	0.16	1.00	0.98	1.00
LILE	*Linum lewisii*	42	0.20	1.73	0.80	1.79
annuals	*Bromus tectorum, Salsola tragus*	41	-0.01	0.97	0.82	0.96
rosette forbs	*Penstemon* sp.*, Packera multilobata, other forbs*	89	0.04	1.54	0.63	1.55
Non-ARTR shrubs	*Chrysothamnus* sp.*, Atriplex* sp*, Krashenninikovia lanata*	23	0.09	0.91	0.99	0.91

APPENDIX 3

DISCUSSION OF SIGNIFICANT INTERACTIONS IN TABLES 7 AND 8 OF THE STRATEGY CHOICE EXPERIMENT WHICH WERE OMITTED FROM THE GENERAL TEXT

Table 7

- 3 way interaction between site, surface treatment, and seed mix for 2012 perennial grass biomass: At GVM, the effect of potholes on biomass depended on seed mix; potholes reduced biomass from 53.1 g/m^2 to 21.8 g/m^2 in plots with the high-forb mix [$t(8) = 3.44$, $p = 0.0089$], but didn't have a detectible effect in plots with the balanced mix. This 2-way interaction did not occur at other sites.
- 3 way interaction between site, surface treatment, and seed mix for 2012 perennial forb cover: This interaction was likely to due to a 2-way interaction between soil surface and seed mix at WRR (p = 0.0037). In pothole plots at WRR, perennial forb cover was 13.5% with the balanced mix and 8.3% with the high-forb mix [$t(8) = 3.37$, $p = 0.045$]. For other combinations of sites and soil surfaces, perennial forb cover was either higher with the high-forb mix, or similar between the seed mixes.
- 3 way interaction between site, surface treatment, and seed mix for 2012 shrub cover: This was likely due to a 2-way interaction between soil surface and seed mix which occurred at WRR (p = 0.0009) but was not evident at other sites. In flat plots at WRR, shrub cover was 11.3% with the balanced mix and 2.4% with the high-forb mix [$t(8) = 4.28$, $p = 0.0027$]. In other combinations of site and soil surface, shrub cover was higher with the high-forb mix, or similar between the two mixes.
- 3 way interaction between site, surface treatment, and seed mix for 2012 shrub biomass: When broken down by site, the 2-way interaction between soil surface and seed mix was not significant for any individual site ($p > 0.1189$). The interaction may have been caused by a trend for higher shrub biomass with flat/balanced and pothole/high-forb combinations at both WRR and SGE, while the opposite treatment combinations had higher shrub biomass at MTN.

Table 8

- 4-way interaction between site, imazapic, surface, and seed mix for 2011 perennial grass cover: The magnitude of the effect of this interaction was small in comparison to the main effects. It likely occurred because in plots with both imazapic and the high-forb mix, potholes had different effects at GVM and MTN. At GVM, potholes may have reduced cover from 18.7% to 7.8% [$t(8) = 1.87$, $p = 0.098$], while at MTN, potholes increased it from 0% to 10.6% [$t(8) = 7.64$, $p < 0.0001$].
- 2-way interaction between imazapic and seed mix for 2012 annual grass biomass: When broken down into the 4 possible component comparisons (e.g. imazapic vs. no imazapic in high-forb plots), no comparisons were significant at the a= 0.05 level.

Colorado Division of Parks and Wildlife
January 2012 – August 2013

WILDLIFE RESEARCH REPORT

State of:	Colorado	: Division of Parks and Wildlife
Cost Center:	3420	: Avian Research
Work Package:	0663	: Terrestrial Species Conservation
Task No.:	N/A	: Rangeland restoration with super-absorbent polymer and potholed surface at Horsethief State Wildlife Area
Federal Aid Project No.	N/A	

Period Covered: January 16, 2012 – August 31, 2013
Author: D. B. Johnston

Personnel: T. Stroh, Bureau of Reclamation; R. Velarde, J.T. Romatzke, I. Archer, CPW

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ABSTRACT

Rangeland restoration often fails due to inadequate moisture to support germination, overwhelming competition from non-native annuals, or both. Two techniques which have helped ameliorate these difficulties in a prior CPW study are the use of a roughened, or pothole, surface, and addition of super-absorbent polymer (SAP) to the soil. Both of these techniques have been helpful, when used alone, in restoring well pad disturbances in northwestern Colorado under pressure from the non-native cheatgrass (*Bromus tectorum* L.). In this study, these two techniques are combined in the restoration of previously undisturbed rangeland which is heavily invaded by cheatgrass. The study site is within Horsethief State Wildlife Area near Fruita, Colorado. A new implement, called a pothole seeder, was developed in order to make the creation of the potholed surface more efficient. Four polygons, totaling 6.7 acres, were treated with the pothole seeder in November, 2012. Two of these polygons received granulated SAP, which was applied at 300 lbs/ac by mixing the granules with the seed and broadcasting over the potholed surface. A custom-built chain drag trailer was used to cover the seed and polymer. In 2013, seedling counts and density of SAP crystals within potholes were conducted. In 2014 and beyond, seedling count or cover data will be assessed annually.

WILDLIFE RESEARCH REPORT
RANGELAND RESTORATION WITH SUPER-ABSORBENT POLYMER AND POTHOLE SURFACE AT HORSETHIEF STATE WILDLIFE AREA

DANIELLE B. JOHNSTON

PROJECT OBJECTIVES

1. Develop an implement (called a ‘pothole seeder’) which can quickly and efficiently create a roughened soil surface of large mounds and holes.
2. Using the pothole seeder, treat a several-acre area which can be conveniently viewed by those interested seeing results of the technique.
3. Examine the effectiveness of pothole seeding in combination with a light herbicide application for restoration of a degraded, cheatgrass-invaded rangeland.
4. Compare the results of restoration when pothole seeding is done with vs. without application of granulated super-absorbent polymer (SAP).

SEGMENT OBJECTIVES

1. Select study locations and obtain necessary permits for ground-disturbing activities.
2. Develop, test, and refine pothole seeder implement.
3. Treat 6.7 acre-area at Horsethief State Wildlife Area. Apply SAP in half of treated polygons.
4. Monitor soil moisture and seedling counts in the project area.

INTRODUCTION

In the CPW study ‘Restoring Energy Fields for Wildlife’, two techniques which improved restoration were the creation of a rough, or potholed soil surface, and addition of super-absorbent polymer (SAP) to the soil (Johnston 2012). Both of these techniques were helpful in establishing desirable perennial vegetation while under competition from cheatgrass (*Bromus tectorum* L.). The potholed soil surface reduced cheatgrass cover about 7-fold at a site with low cheatgrass propagule pressure, and also reduced cheatgrass biomass, when in combination with imazapic herbicide (Plateau ®, BASF corporation), at a site with high cheatgrass propagule pressure. The mechanism is not entirely known, but it is possible that potholes trap seeds in areas where soil moisture is concentrated, and that cheatgrass seeds are less competitive in that environment. SAP reduced cheatgrass cover 2-4 fold at two different sites over a two year time span. It is thought that SAPs reduce the competitive ability of cheatgrass by extending the period of time soils are moist, as cheatgrass is more competitive when soil moisture is more variable (Johnston 2012).

In the prior study, these techniques were explored in independent experiments, on simulated well pad disturbances, and in the absence of herbivory from livestock or wildlife. The focus of this study is to explore how these techniques perform when combined with one another, when applied to a previously undisturbed rangeland, and when exposed to herbivory by wildlife. This study also focuses on how to apply these techniques at a scale more meaningful to rangeland restoration than the prior study, which utilized small research plots.

STUDY AREA

The study was implemented on four polygons totaling 6.7 acres (2.7 ha) at Horsethief State Wildlife Area (SWA) near Fruita, CO (Figure 1). The area was ideal for this study because it possessed several acres of level ground with complete or near-complete domination by cheatgrass, and easy access for equipment and for those who might wish to view the project in the future. The region is arid, receiving about 9 inches (230 mm) of precipitation per year, with about half falling during the growing season of

April through September (NOAA Fruita CO US weather station records, 1990-2011). Common vegetation includes cheatgrass, Sandberg's bluegrass (*Poa secunda*), needle-and-thread (*Hesperostipa comata*), greasewood (*Sarcobatus vermiculatus*), Wyoming big sagebrush (*Artemisia tridentata* spp. *Wyomingensis*), Russian thistle (*Salsola tragus*), halogeton (*Halogeton glomeratus*), plains pricklypear (*Opuntia polycantha*), sego lily (*Calochortus nuttalli*), and yellow rabbitbrush (*Chrysothamnus viscidiflorus*). Soils are sandy, derived from Wingate sandstone.

METHODS

Equipment development. In the prior study, the 'rough' soil surface was created with a mini-excavator. Each hole was dug individually with the backhoe, and the process was expensive and time-consuming. To apply a similar treatment on a larger scale, a more efficient process was needed. This required building a new piece of machinery, which was done through a collaborative effort between Colorado Parks and Wildlife and WPX Energy. The 'pothole seeder' was constructed of a Land Pride DH2596 disk harrow (Land Pride, Salina, KS, USA) with custom 28-inch (71 cm) disks, a Herd 2440 broadcast seeder (Kasco manufacturing Co, Inc., Shelbyville, IN) and a custom-built chain drag trailer (Figure 2). The front gang of disks was removed from the cultivator, and every other disk was removed from the rear gang. The remaining disks were deeply notched with two large notches. Notches of adjacent disks were offset by 90 degrees, so that when an un-notched portion of one disk contacted the ground, and thereby would dig, the adjacent disk's notched portion would contact the ground, and thereby would not dig (Figure 3). As a result, the machine produced a checkerboard pattern of mounds and holes when dragged over the ground (Figure 4). The holes were approximately 30 cm deep, as measured from the bottom of a hole to the top of an adjacent mound. The broadcast seeder was mounted to the rear portion of the cultivator, and a shroud was built to help contain the broadcast seed to within the strip of ground prepared by the notched disks. The chain drag trailer helped to incorporate seed over the potholed surface. Welding and structural engineering were completed by Roustabout Specialties of Grand Junction, Colorado. Funding was provided by WPX Energy, and Rob Raley of WPX Energy contributed to the design. The machine requires at least a 75 HP tractor with 4WD.

Site preparation. Scattered sparse greasewood plants were cut with a brush hog prior to treatment implementation. All four polygons were sprayed with 70 g ai/ha (4 oz/acre) of Plateau ™ (ammonium salt of Plateau, BASF Corporation, Research Triangle Park, NC, *hereafter* Plateau) and 50 gal/acre of water using a 7-nozzle boom tow sprayer on 8/28, or 8/29, 2012. At the time of application, no emerging cheatgrass was visible.

Treatment. Polygons were potholed and seeded in a single pass of the pothole seeder on 11/5, and 11/6, 2012. The seed mix in Table 1 was used. Potholing and seeding was done at a rate of 3 mph (5 kph), and about 2 acres (0.8 ha) could be treated per hour.

Two of the four polygons were randomly selected to receive SAP. In these polygons, Tramfloc® 1004 granulated polymer (a cross-linked copolymer of acrylamide and potassium acrylate; Tramfloc®, Inc, Tempe, AZ, USA) was added at 300 lbs/acre (270 kg/ha). The product was mixed directly into the broadcast seeder along with the seed, and the seeder was recalibrated to accommodate the SAP's additional volume. Tramfloc 1004 has an average 4 mm grain size, and this large grain size allowed the dense polymer to remain in suspension with the seed. Periodic checks of the hopper during seeding showed that the polymer remained in suspension well. However, the flow rate of both seed and SAP declined as the hopper emptied, which resulted in some variation in both seeding rate and SAP application rate.

Responses measured. We set up subplots in spatially balanced, random locations within each polygon for assessment of responses. Most polygons received five subplots, but the small size of polygon 4 would only accommodate three subplots. In addition, three subplots were chosen in each of two untreated areas in order to gather reference data. Subplots are circular with a radius of 8m.

At each subplot, we measured soil moisture monthly from March-September, 2013. Soil moisture measurements were stratified by mounds vs. holes, with five measurements taken in each category in each subplot. Soil moisture readings were taken to 12 cm using a Hydro Sense® Soil Water Measurement System (Campbell Scientific, Inc, Logan, Utah).

Seedling counts were also conducted at each subplot, in June and September, 2013, on eight 0.5 m by 1.0 m miniplots per subplot. These were arrayed along the cardinal axes of each subplot, with two miniplots per axis, with one 3 m and one 6 m from the plot center. The placement of miniplots was random with respect to the presence of mounds and holes. Seedlings were identified to species where possible. Plants which were obviously survivors of the treatment implementation were not counted as seedlings.

On May 21, 2013, counts of SAP crystals were made for five randomly chosen holes per subplot in the two polygons which received SAP. This was data was collected because some SAP had extruded from the soil surface, and it was apparent that the SAP application was not even across the polygons. The data may be used as a covariate in future analysis.

RESULTS AND FUTURE WORK

The pothole seeder was effective at producing a similar soil surface to that previously achieved with a mini-excavator, and the process was much more efficient. The broadcast seeder worked well, although about 30% of seed was not broadcast over the potholed surface, as the shroud which was designed to constrain the seed was not completely effective. Making the shroud larger is not practical, as that would interfere with the turning of the machine. Most of the seed which missed the shroud was cast to the left-hand side. Applying the treatment in a clockwise fashion within a polygon is a practical solution, since this would allow the seed which missed the shroud to be covered over in the next pass of the machine.

The SAP used had a 4mm granule size, and when it absorbed water, the particles swelled to about 2 cm in size. This large size caused much of the product to extrude from the soil surface, indicating that the degree of soil covering provided by the chain drag was inadequate to keep the product incorporated into the soil. SAPs degrade when exposed to light, so the effectiveness of the SAP application may be compromised. Even so, in late August, 2013, nearly a year after application, the product was still evident within potholes.

In 2014, seedling count data will be repeated in early September, and soil moisture measurements will be made monthly from May to September. Very little seedling recruitment was noted in 2013, therefore it is unlikely that enough vegetation will exist in 2014 to warrant collecting cover data. The experiment will be monitored for three growing seasons, and data will be synthesized and presented in future reports.

The pothole seeder will be used for oil field disturbance reclamation near Parachute, CO by WPX Energy in October 2013.

LITERATURE CITED

Johnston, D. B. 2012. Restoring energy fields for wildlife. Colorado Parks and Wildlife annual research report, Avian research program. http://wildlife.state.co.us/SiteCollectionDocuments/DOW/Research/Habitat/RestoringEnergyFieldsforWildlife2011AnnualReport.pdf.

Table 1. Seed mix.

Type	**common name**	**Genus**	**Species**	**Seeds/ m^2**	**PLS/ acre**
forb	Western yarrow	*Achillea*	*millefolium*	30	0.04
bunchgrass	Indian ricegrass	*Achnatherum*	*hymenoides*	60	1.67
shrub	Wyoming Sagebrush	*Artemisia*	*tridentata*	120	0.32
shrub	Fourwing saltbush	*Atriplex*	*canescens*	40	5.89
bunchgrass	Blue Gramma	*Bouteloua*	*gracilis*	100	0.56
shrub	yellow rabbitbrush	*Chrysothamnus*	*viscidiflorus*	50	0.31
bunchgrass	bottlebrush squirreltail	*Elymus*	*elymoides*	60	1.26
bunchgrass	Streambank wheatgrass	*Elymus*	*lanceolatus ssp. psammophilus*	40	0.95
bunchgrass	slender wheatgrass	*Elymus*	*trachycalus*	40	1.22
rhizomatous grass	Thickspike wheatgrass	*Elymus*	*lanceolatus ssp. lanceolatus*	50	1.30
shrub	rubber rabbitbrush	*Ericameria*	*nauseosa*	60	0.40
forb	Aspen fleabane	*Erigeron*	*speciosus*	50	0.13
forb	Sulfur-flower buckwheat	*Eriogonum*	*umbellatum*	23	0.45
forb	Utah sweetvetch	*Hedysarum*	*boreale*	15	1.81
bunchgrass	needle and thread	*Hesperostipa*	*commata*	30	1.06
shrub	winterfat	*Krascheninnikovia*	*lanata*	10	0.36
forb	Lewis flax	*Linum*	*lewsii*	40	0.54
rhizomatous grass	western wheatgrass	*Pascopyrum*	*smithii*	30	1.07
forb	Dusty Penstemon	*Penstemon*	*comarrhenus*	90	0.61
forb	Palmer penstemon	*pestemon*	*palmeri*	60	0.40
bunchgrass	Sandberg Bluegrass	*Poa*	*sandbergii*	60	0.26
bunchgrass	bluebunch wheatgrass	*Pseudoroegneria*	*spicata*	60	1.73

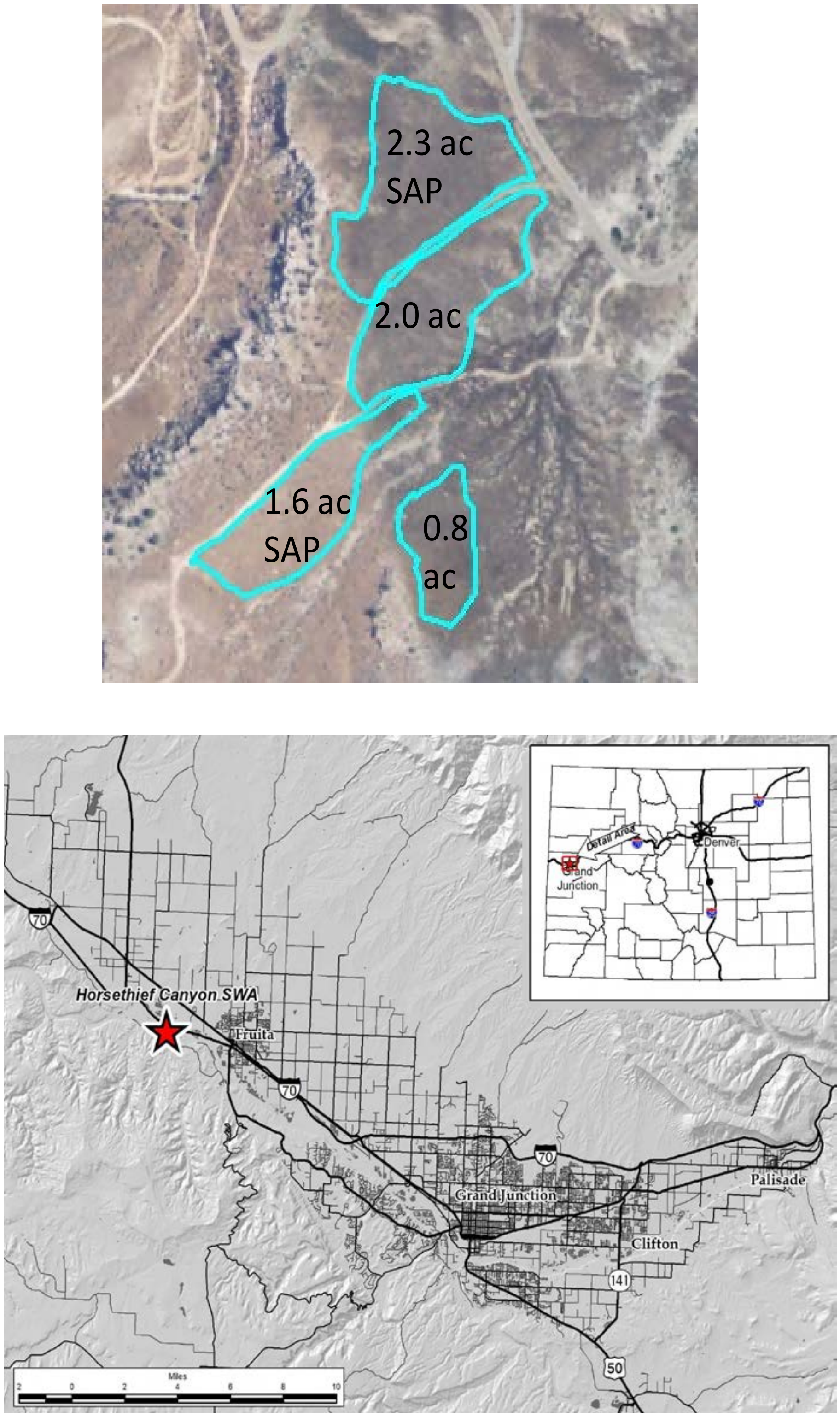

Figure 1. Study site layout and location. Two of four polygons received super-absorbent polymer (SAP).

Figure 2. The pothole seeder.

Figure 3. Disks were deeply notched on the pothole seeder, and the notches were offset on adjacent disks.

Figure 4. Alternating pattern of mounds and holes created by the pothole seeder. Orange notebook provided for scale.

Colorado Division of Parks and Wildlife
January 2012 – August 2013

WILDLIFE RESEARCH REPORT

State of:	Colorado	:	Division of Parks and Wildlife
Cost Center:	3420	:	Avian Research
Work Package:	0663	:	Terrestrial Species Conservation
Task No.:	N/A	:	Examining the effectiveness of mechanical treatments as a restoration technique for mule deer habitat

Federal Aid
Project No. N/A

Period Covered: January 16, 2012 – August 31, 2013

Author: D. B. Johnston

Personnel: M. Paschke and G. Stephens, Colorado State University; L. Belmonte, Bureau of Land Management; B. deVergie and J.C. Rivale, CPW

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ABSTRACT

The pinyon-juniper (PJ) habitat type has been expanding in the western United States and managers often seek methods of thinning or removing pinyon pine (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*) trees in order to improve habitat for big game. Because prescribed fire is difficult or impossible to implement in many areas, mechanical tree removal has become common. Several methods of mechanical removal are available, including ship anchor chaining, roller-chopping, and hydro-axing. These differ in cost as well as in the type of woody debris and soil disturbance produced. In order to compare the effectiveness of these three removal methods in PJ forests, a replicated field study was implemented in the Magnolia region of the Piceance Basin, Rio Blanco County, Colorado. Replicates included a 0.8 ha parcel treated with each of the three treatment types, as well as a control (untreated) parcel. Half of each treated parcel was seeded with a native seed mixture emphasizing palatable shrubs. Four replicates occurred in North Magnolia, which had higher initial tree density and lower basal area than South Magnolia, where three additional replicates were implemented. Mechanical treatments were completed in the fall of 2011, and understory cover and biomass were assessed in 2012. In the first year post-treatment, chained plots had higher grass biomass than rollerchopped or hydro-axed plots, likely due to greater survival of existing plants. An effect of seeding was only evident for seeded annuals, which had 10-fold higher biomass in seeded subplots at the North Magnolia site, and 20-fold higher biomass in seeded subplots at South Magnolia. Cover and biomass were also assessed in 2013, and synthesized results will be presented in next year's report.

WILDLIFE RESEARCH REPORT

EXAMINING THE EFFECTIVENESS OF MECHANICAL TREATMENTS AS A RESTORATION TECHNIQUE FOR MULE DEER HABITAT

DANIELLE B. JOHNSTON

PROJECT OBJECTIVES

5. Assess vegetation response to removal of pinyon and juniper trees via three different mechanical treatments: ship anchor chaining (with two passes), hydro-axing, and roller chopping.
6. Assess response of desired shrubs to seeding within each mechanical treatment. Focal shrubs include chokecherry (*Prunus virginiana*), Saskatoon serviceberry (*Amelanchier alnifolia*), Utah serviceberry (*Amelanchier utahensis*), mountain mahogany (*Cercocarpus montanus*), bitterbrush (*Purshia tridentata*), and winterfat (*Kraschenninnikovia lanata*).
7. Compare cost-effectiveness of the three mechanical treatments.
8. Examine cost-effectiveness of seeding shrubs in the three mechanical treatments.

SEGMENT OBJECTIVES

1. Assess cover and biomass in treated and control plots one and two years post-treatment.
2. Characterize the study locations by analyzing the contents of the seed bank.
3. Characterize the study locations by assessing stand density and basal area in control plots.
4. For the first post-treatment year, analyze differences in shrub, grass, and forb cover and biomass due to seeding and due to type of mechanical treatment.

INTRODUCTION

Pinyon-juniper (PJ) woodlands play an important role in mule deer ecology. Pinyon pine (*Pinus edulis*), Utah juniper (*Juniperus osteosperma*) and the associated understory shrub species such as mountain mahogany (*Cercocarpus montanus*), antelope bitterbrush (*Purshia tridentata*) and big sagebrush (*Artemisia tridentata*) are key to winter survival (Hansen and Dearden 1975, Heffelfinger 2006). Deer strongly select for this habitat type because of the escape and thermal cover provided by pinyon and juniper trees (Anderson et al. 2013). However, pinyon-juniper habitats occasionally lack understory and may provide very little forage (Bender et al. 2007). It has been shown that increasing nutrition in poor quality pinyon-juniper winter range can increase deer populations in western Colorado (Bishop et al. 2009). Therefore, creating patches of habitat types with higher nutritional value within pinyon-juniper stands is a desirable management objective for mule deer.

The pinyon-juniper habitat type has increased in many parts of western North America over the past 100 years (Miller and Rose 1999, Schaffer et al. 2003, Bradley and Fleishman 2008). Disruption of natural fire regimes, overgrazing, and invasion by weedy species have led to a wide array of management problems. Of particular concern are overgrown stands of PJ that have allowed the overstory to shade out understory plant species. Because of the proximity to infrastructure and human activity, as well as the lack of continuous understory fuels, prescribed fire is often eliminated from consideration as a management tool. Alternatives to natural restoration do exist in the form of mechanically created disturbances, which can open up the canopy and reduce competition (Fairchild 1999). Over the past 50 years, it has been demonstrated in Utah that the mechanical modification of PJ, together with subsequent seeding of selected species, can be an effective restoration technique (Fairchild 1999). However, several mechanical removal methods exist, and little information is available to determine which method is most cost-effective.

Determining the most-effective approach to mechanical pinyon-juniper removal is imperative due to the current need for habitat improvements which may offset some of the impacts of oil and gas development. Recent studies have shown that oil and gas activities can influence deer populations due to both direct habitat loss and to indirect effects due to disturbance (Sawyer et al. 2006). In western North America, oil and gas development commonly coincides with pinyon-juniper habitats. A Colorado Parks and Wildlife research project is currently examining the degree to which oil and gas impacts on deer populations may be mitigated by removing pinyon and juniper trees (Anderson 2011). If mitigation proves successful, then removal of pinyon-juniper trees may be widely prescribed as a mitigation treatment for oil and gas impacts.

Mechanical treatments in PJ forests differ in the size of woody litter produced and in the degree of soil disturbance created. Chaining is a technique by which trees are removed by dragging a ship anchor chain between two bulldozers. Trees are uprooted and left intact and the action of uprooting creates a great degree of soil disturbance (Cain 1972). Roller chopping is a technique where a heavy rotating drum with protruding steel plates is pulled behind a bulldozer. The bulldozer knocks the trees over and the drum chops them into large pieces. The action of the roller chopper creates soil disturbance, though to a lesser degree than does chaining. Hydro-axing is a technique by which a rubber-tired tractor with a front-end mounted high powered blade mulches trees. Fine woody debris is produced, and there is little ground disturbance. Hydro-axing is a relatively new method which has gained favor because of the lower degree of ground disturbance, but only recently has any research been done to understand the effect of hydro-axing on plant communities (Battaglia et al. 2010). No studies have made head-to-head comparisons of older mechanical removal methods with hydro-axing.

Differences in the size of woody litter produced and the degree of soil disturbance may influence the germination and establishment of desirable understory species. For instance, the mulch layer produced by a hydro-axe treatment may have positive or negative effects on germination; germination may be inhibited by lower light availability at the soil surface, or it may be enhanced by higher soil moisture. In chaining and roller chopping, the higher degree of soil disturbance may provide an opportunity for seeded species to establish, or it may become a liability by allowing invasion by weedy species. Finally, in a chaining treatment, the tree skeletons may offer a few years of protection from herbivory, which could play an important role in allowing shrubs to establish. These differences may affect the success of seeding attempts following mechanical tree removal, but such differences have yet to be examined. Finally, characteristics of the PJ forest stand, such as density, basal area, and understory seed bank, may influence which treatment produces the most desirable results.

Our study has three goals: to compare the desirability of vegetation produced by three types of mechanical treatment (ship anchor chaining, roller chopping, and hydro-axing), to determine the usefulness of seeding within each of these three treatments, and to determine if these results differ between two PJ stands with differing basal areas and densities. Desirable vegetation in this context is native vegetation with a high proportion of ground cover consisting of broadleaf forbs and palatable shrubs.

STUDY AREA

The Piceance Creek Basin, located in northwestern Colorado, serves as winter range for one of North America's largest migratory mule deer (*Odocoileus hemionus*) populations (Lee 1984). The area, which spans across both Rio Blanco and Garfield counties, is also rich in oil shale and natural gas (Taylor 1987). Development of the basin for the extraction of these resources has gone on for decades and continues to grow. The Piceance Creek Basin ranges in elevation from 1706 meters to 2743 meters with the highest points near the edges (Tiedeman 1978). This basin encompasses nearly 4143 square kilometers and is bordered from the north by the White River, from the south by the Roan Plateau, from the east by the Grand Hogback and from the west by the Cathedral Bluffs (Taylor 1987). Terrain varies from rugged badlands, abrupt cliffs and sharp ridges to open valleys, parks and basins (Baker 1970). Its semiarid climate receives between 27 and 63 centimeters of annual precipitation, half coming in the form of snow during winter months (Tiedeman 1978). The basin is part of the Green River Geologic Formation, consisting of primarily sandstone, siltstone, mudstone, limestone, and shale (Campbell 1974). Soils range from deep sandy alluvial soils and heavy clay soils to entisols and dark mollisols, above 2346 meters (Campbell 1974, Tiedeman 1978). Bottomland sagebrush and desert shrub dominate lower elevations (Tiedeman 1978). Middle elevations are dominated by upland sagebrush, mixed mountain shrub, and pinyon-juniper woodlands (Tiedeman 1978). Grasslands, aspen (*Populus tremuloides*) and douglas-fir (*Pseudotsuga menziesii*) forests can be found at the highest elevations (Tiedeman 1978). The Magnolia area of Piceance occupies the northeastern corner of the basin, and is bounded by Piceance Creek on the south and west, the White River on the north, and the Grand Hogback on the east. It is dominated by pinyon-juniper woodlands.

Historically, the land was sparsely populated and used primarily for agricultural and recreational purposes (Tiedeman 1978). In recent decades, natural resource extraction has dramatically altered the landscape. Today the oil and gas industry plays a prominent role in the basin with Rio Blanco and Garfield counties producing vast quantities of oil and natural gas (Colorado Oil and Gas Conservation Commission 2011). Through the construction of well pads, roads and compressor stations, development of this infrastructure has and continues to fragment suitable mule deer habitat (Anderson 2011). Traffic, noise and increased human presence also contribute to adversely affect this important winter range (Anderson 2011).

METHODS

Site Selection

Study area selection was done in conjunction with Dr. Charles Anderson's larger-scale project to examine deer responses to PJ removal (Anderson 2011). First, several hundred PJ stands were delineated within the Magnolia area of Piceance Basin using aerial photography, excluding areas with slopes greater than 30%. Next, stands were visited and scored for suitability of treatment based on a scale of 1 to 3:

<u>Score 1 – most suitable acreage.</u> These parcels contained abundant younger trees growing in dense stands. Simultaneously, the understory of desired shrubs, grasses, and forbs appeared to be robust. Treatment of these areas should yield a strong growth response from that desired understory.

<u>Score 2 – highly suitable acreage.</u> These parcels contained a mix of younger and older trees that grew in less dense patches. The understory of desired shrubs was also less robust than a Score 1 site. Score 2 parcels were highly suitable for treatment, but will likely yield a lesser initial growth response from the desired understory than a Score 1 site.

<u>Score 3 – suitable acreage</u>. These parcels contained more mature PJ,that possessed larger individual tree canopies, growing in less dense stands. Diameter of tree trunks was larger than trees in Score 1 or 2 sites. The understory of desired shrubs, grasses, and forbs was often lacking, and more bare ground was found here than Score 1 or 2 tracts.

Delineations and suitability scores were assigned by Todd Graham of Ranch Advisory Partners. A total of 203 tracts comprising 1,445 acres were deemed suitable for treatment. Next, two focal areas were selected based on the following criteria: at least 40 acres with the same suitability score were available, access routes for ground-disturbing equipment were available, and the cover of PJ trees within each area was as uniform as possible. These two focal areas, called North Magnolia (elevation 2194 m) and South Magnolia (elevation 1828 m), are shown in Figure 1. At the North Magnolia site, a contiguous parcel met the needed criteria. At South Magnolia, the study area was fragmented by gullies which were unsuitable for treatment.

Experimental Design and Setup

We implemented a split-plot design with four blocks at the North Magnolia location, and three blocks at the South Magnolia location (Figure 1). Block divisions were designed to minimize variation within each block in PJ density, based on visual inspection of the aerial photography. Mechanical treatments were randomly assigned to whole plots within blocks. Each treated was further subdivided into two subplots, with seeding treatments (seeded or unseeded) randomly assigned to subplots within plots. Control plots were not seeded. Subplots were 0.40 ha (1 acre) in size and about three times as long as wide. The long axis of each subplot was arranged perpendicular to the slope. This is because mechanical treatments are typically applied across slopes, rather than up and down them, because it is safer and saves fuel to drive heavy machinery across the slope.

Mechanical Treatments

Mechanical treatments were applied between Oct. 23, 2011 and Nov. 28, 2011. Ship anchor chaining was done using two D8 bulldozers (Caterpiller, Inc., USA), each attached to one end of an 18 m (60-ft.) ship anchor chain with links weighing 40.8 kg (90 lbs.) each. Trees were pulled over by running the chain in one direction, and then killed more completely by running the chain back over the plots in the opposite direction (2-way chaining; Figure 2a-b). Roller chopping was accomplished by attaching a 3.7 m (12-ft.) long, 0.6 m (1.9-ft.) diameter roller chopper to a D8 dozer (Figure 2c). The drum weighed approximately 1100 kg (2,500 lbs.) when empty and held 8338 li (2,200 gal) of water. The drum was filled during operation for a total weight of approximately 9100 kg (20,000 lbs.). Roller chopper plates acted as blades to chop downed trees into pieces approximately 30 cm long (Figure 2c-d). Hydro-axing was accomplished used a 930 Barko industrial tractor with a drum-style FAE flail head, which produced fine masticated material ranging in size from 2 – 20 cm and a few larger sections of tree boles (Figure 2e-f). All vegetation was masticated to ground level (or as close as the equipment will allow; less than 30 cm). In the vicinity of former trees, masticated material was up to 40 cm deep. Equipment operators used handheld GPS units to ensure the correct areas were being thinned. Every plot was completely treated and no “leave” areas, or refugia, strips were left in the plots. More detailed descriptions of chaining (Vallentine 1989), rollerchopping (Vallentine 1989), and hydro-axing (Hunter et al. 2007) may be found elsewhere.

Although the area of the seeded and unseeded subplots was only 0.4 ha, an area larger than this was mechanically treated in some cases. The estimated total area treated across all 21 thinned plots was 16.8 ha.

Seeding

All seeded plots received the same diverse native seed mix comprised of 10 shrub species, 14 forb species and 10 grass species. The mix emphasizes shrubs while incorporating light rates of forbs and grasses in order to fill resource niches and thereby reduce the likelihood of weed invasion (Table 1).

The method of seeding differed for each mechanical treatment. In seeded, hydro-axed subplots, all seed was broadcast using EarthWay® hand crank spreaders prior to treatment implementation. Because the seed mix contained seeds of varying sizes, seeds had to be grouped based on size (Table 1) in order for uniform seed dispersal to occur using the spreaders. Five evenly spaced passes, parallel to the long axis of the plot, were made through each seeded subplot using the hand spreaders. Two seeders followed one navigator using a handheld GPS unit to ensure dispersal occurred in the seeded subplot only. In seeded, roller chopped subplots, the majority of species were hand-broadcast prior to treatment implementation, but several large-seeded shrub species that benefit from deeper planting (group 5 in Table 1) were seeded using Hansen seed dribblers mounted to the tracks of the bulldozer (Figure 3). The linear seeding rate for dribbled seed was 3.5 g/m. Chained subplots were seeded in the same manner as roller chopped plots.

Grazing Cage Installation

In order to test whether or not grazing had an effect on shrub density in seeded subplots, grazing cages were installed in May 2012. Three pyramid shaped grazing cages (1 m^2 at the base and 1 m tall, constructed of a rebar frame covered in woven wire) were placed in each seeded subplot. Cage locations were placed systematically along the centerline of the long axis of each subplot, with one cage directly in the middle of the subplot, and the other two cages two-thirds of the distance between this cage and the end of the plot. In some cases, downed trees, slash, shrubs, or rock made the systematic location unsuitable to accept the placement of a cage. The nearest suitable point was chosen in these cases. Cage locations contained space for both the cage and an adjacent point of visually comparable cover to serve as a reference location. A coin flip was used to determine which of the two points received the cage, and which was chosen as a reference point. The reference point was marked with a nail.

PJ Stand Analysis

Tree basal area and density in control plots was measured in spring 2013. Five evenly spaced belt transects per control plot were used for density counts and basal diameter measurements of live trees ≥ 2m tall. Width of belt transects varied from 2 to 18 m to allow roughly 20 trees to be sampled per belt. Single juniper trees were often multi-stemmed or elliptical in shape at the base. Multi-stemmed trees at the ground level were measured separately for diameter and added together to determine basal area for that single tree. For elliptical junipers, diameter measurements taken along the wide and the narrow axes were averaged and that average was used as the diameter. Original control plots in block E and G could not be used for these measurements due to logistical issues; similar areas adjacent to the original controls were chosen and also used for subsequent summer 2013 biomass and cover sampling.

Seedbank Study

In May 2012, following treatments and seeding, 3.7 L of soil were collected from each of the 49 subplots. Soil samples were sieved (5.6-mm wire mesh) to remove rocks and debris; sieved soil was then layered 1 cm deep atop bio fungicide potting soil in 20-cm diameter growth pots. Field soil samples for each subplot were distributed between ten growth pots and soaked with water in a greenhouse 2-3 times per week (or when soil surfaces appeared dry). As plants germinated they were identified and removed from the pot. The soil seedbank growth period continued until mid-February 2013.

Plant Cover and Biomass

Percent cover, biomass, and shrub density data was gathered along 20 systematically placed transects in each subplot. These were arrayed perpendicular to the long axis of the plot, equidistant from one another. Percent cover, by species, was estimated using the first-hit point-intercept method at every meter along each transect. For biomass, sampling frames (0.25-m x 0.75-m) were placed at a randomly selected point on each transect, and all current year's aboveground plant growth was clipped (up to 1.4-m tall) and bagged by species. Herbaceous species were clipped only if they were rooted inside the frame. For woody species, any current year's growth hanging inside the frame (whether it was rooted in or out) was clipped. All biomass was composited by species for each subplot. Plant biomass was oven-dried to constant mass at 65°C and subsequently weighed to estimate total aboveground production per subplot. Shrubs rooted within biomass frames were counted for density prior to being clipped.

Statistical Analysis

Statistical analyses were run using SAS 9.3 (SAS Institute, Cary, NC, USA). Analyses were run by the response variables of percent cover and biomass; and within those variables, vegetation was grouped to analyze treatment differences. The groupings were life-form (grass, forb, shrub, tree), nativity, and growth habit (annual, perennial). Due to extreme climatic differences between years, analyses for year 1 and 2 were done separately. Data were transformed as necessary to achieve normality prior to parametric analyses (see Appendix 1 for specific transformations used). For response variables in which transformations were not sufficient (typically due to zero-inflation), analyses were conducted using non-parametric Friedman's tests. Significance was determined at $\alpha = 0.05$.

Parametric analyses were conducted using a nested randomized complete block split-plot mixed effects model where site, and mechanical and seed treatments were fixed effects and block within site and mechanical treatment within block were random effects; the Kenward-Rogers denominator degrees of freedom method was used to account for unequal variances. Because there were significant site by treatment (mechanical, seed, or both) interactions, further analyses were conducted for each site separately. For significant effects, pairwise comparisons were made using Tukey's adjustment.

In addition to mechanical treatment plots, there was one control plot (no mechanical or seed treatment) within each block. Treatments were compared to control in a separate analysis for each site using the mechanical treatment by seed treatment interaction as a fixed effect, block as a random effect, and Dunnett's adjustment to assess the effect of mechanical by seed treatment combinations relative to control.

RESULTS

Our stand analysis revealed differences in site composition and structure between North Magnolia and South Magnolia. Mean total tree basal area (Figure 4a) in control plots was greater at South compared to North. Mean basal area of *J. ostersperma* was also greater at South while *P. edulis* was not. Density (Figure 4b) only differed when looking at *P. edulis* alone; North had far more trees/ha than South. The soil seedbank study also indicated possible differences between North and South Magnolia. Pots from North Magnolia and South Magnolia in total germinated 723 and 415 plants, respectively. Twenty-five plants, about 2% of the total, were seeded species.

First year results indicated an effect of mechanical and seeding treatments. An effect of mechanical treatment was seen with grass biomass; chain plots had greater grass biomass ($3.46\ g/m^2 \pm 1.17$) than either hydro-ax ($2.08\ g/m^2 \pm 0.58$) or rollerchop ($1.75\ g/m^2 \pm 0.46$) plots ($p = 0.01$). Analysis by site, which looked at response variables in North Magnolia and South Magnolia separately, revealed an effect of seeding on seeded annual forb species; biomass of those species was $0.09\ g/m^2$ greater in seeded subplots than in unseeded subplots at north Magnolia ($P = 0.014$) and $0.2\ g/m^2$ greater at South Magnolia ($p = 0.003$; Figure 5). A site effect was evident for understory biomass in treated plots, with North Magnolia averaging $13.07\ g/m^2 \pm 1.35$ and South Magnolia averaging $6.1\ g/m^2 \pm 1.09$ ($p = 0.04$). Average understory biomass over all mechanically treated plots was $10.08\ g/m^2 \pm 1.04$ and there were no statistically significant difference between treatments.

Cover analysis yielded no significant differences between treatments in all categories except bare ground (Figure 6). There was a higher percentage of bare ground in rollerchop plots (20%) versus chain (16%) and hydro-ax (12%, $p = 0.002$).

DISCUSSION

Although the impacts of tree removal and seeding may require several years to realize (Tausch and Tueller 1977, Bates et al. 2000), some interesting results did occur in our first post-treatment year. Grass biomass was highest in the chained plots, and this was not influenced by whether or not the subplot was seeded. It appears that the highest survival of existing understory grasses occurred in chained plots. Even though chaining has often been thought to cause a great degree of soil disturbance, in this study rollerchopping produced this greatest percentage of bare ground, and chaining was not significantly different from hydro-axing. We noted that chaining had a much more variable impact to the soil surface than the other treatments. Bulldozer attachment points for the chain are often elevated from the ground up to a meter or more, which directly affects how much of the chain is actually in contact with the soil surface. In addition, when the chain is being dragged it may ride above the ground entirely if it is caught in a pile of slash. The higher grass biomass in chain plots suggests that chaining may have left more of the soil surface undisturbed. This could be important for ensuring surviving ground cover, which would reduce soil erosion and provide forage. In hydro-axed plots, it is reasonable to assume that much of the grass layer was entirely buried by masticated wood. In rollerchopped plots, the action of a large bladed drum being dragged and rolled over the ground may have buried grass or even scraped it off the soil surface.

Total plant biomass and cover were not influenced by seeding, but the biomass of seeded annual species was greater in seeded than unseeded subplots. This suggests that the native seedbank may be lacking in those types of species that are well adapted to early, post-disturbance communities and can provide quick cover and competition against invasives. The effect was larger at South Magnolia, which was also the site with higher basal area and lower tree density, indicating that it was a more mature stand. Although these results are preliminary, they suggest that seeding may be beneficial, and that the degree of benefit may vary with stand type.

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Table 2. Native seed mix. Functional Group: G - grass, F - forb, S - shrub. Lifespan: P - perennial, A - annual. Seeding groups 1 - 4 were hand broadcast while group 5 was seeded using bulldozer mounted seed dribblers in the chain and rollerchop plots. Group 5 was hand broadcast in hydro-ax plots.

Functional Group	Type	Seeding Group	Latin Name	Common Name	Pure Live Seeds/m^2
G	P	1	*Achnatherum hymenoides* (Roem. & Schult.) Barkworth	Indian Ricegrass	18
F	A	2	*Amaranthus retroflexus* L.	Redroot Amaranth	12
S	P	5	*Amelanchier alnifolia* (Nutt.) Nutt. ex M. Roem.	Saskatoon Serviceberry	30
S	P	5	*Amelanchier utahensis* Koehne	Utah Serviceberry	12
F	P	2	*Artemisia frigida* Willd.	Fringed Sagebrush	36
F	P	2	*Artemisia ludoviciana* Nutt.	White Sagebrush	24
S	P	2	*Artemisia tridentata* Nutt.	Wyoming Sagebrush	24
F	P	1	*Balsamorhiza sagittata* (Pursh) Nutt.	Arrowleaf Balsamroot	12
S	P	5	*Cercocarpus montanus* Raf.	Mountain Mahogany	24
S	P	2	*Ericameria nauseosa* (Pall. ex Pursh) G.L. Nesom & Baird	Rubber Rabbitbrush	18
S	P	2	*Chrysothamnus viscidiflorus* (Hook.) Nutt.	Yellow Rabbitbrush	18
F	A	1	*Cleome serrulata* Pursh	Rocky Mountain Beeplant	24
F	P	2	*Crepis acuminata* Nutt.	Tufted Hawksbeard	1
G	P	1	*Elymus elymoides* (Raf.) Swezey	Bottlebrush Squirreltail	18
G	P	1	*Elymus trachycaulus* (Link) Gould ex Shinners	Slender Wheatgrass	12
F	P	3	*Eriogonum umbellatum* Torr.	Sulfur-Flower Buckwheat	10
F	P	5	*Hedysarum boreale* Nutt.	Utah Sweetvetch	12
F	A	1	*Helianthus annuus* L.	Common Sunflower	30
G	P	1	*Hesperostipa comata* (Trin. & Rupr.) Barkworth	Needle And Thread	12
G	P	2	*Koeleria macrantha* (Ledeb.) Schult.	Prairie Junegrass	24
S	P	3	*Krascheninnikovia lanata* (Pursh) A. Meeuse & Smit	Winterfat	18
F	P	1	*Linum lewisii* Pursh	Lewis Flax	24
F	P	5	*Lupinus argenteus* Pursh	Silvery Lupine	12
F	P	1	*Oenothera caespitosa* Nutt.	Tufted Evening Primrose	12
F	P	1	*Oenothera pallida* Lindl.	Pale Evening Primrose	24
G	P	1	*Pascopyrum smithii* (Rydb.) Á. Löve	Western Wheatgrass	6
F	P	1	*Penstemon strictus* Benth.	Rocky Mountain Penstemon	36
G	P	2	*Poa fendleriana* (Steud.) Vasey	Muttongrass	
G	P	2	*Poa secunda* J. Presl	Sandberg Bluegrass	12

S	P	4	*Prunus virginiana* L.	Chokecherry	6
S	P	5	*Purshia tridentata* (Pursh) DC.	Bitterbrush	30
S	P	5	*Rhus trilobata* Nutt.	Skunkbush Sumac	6
G	A	4	*Triticum aestivum* L.	Quick Guard	
			x *Secale cereale* L.		12
G	A	2	*Vulpia octoflora* (Walter) Rydb.	Six-Weeks Fescue	18

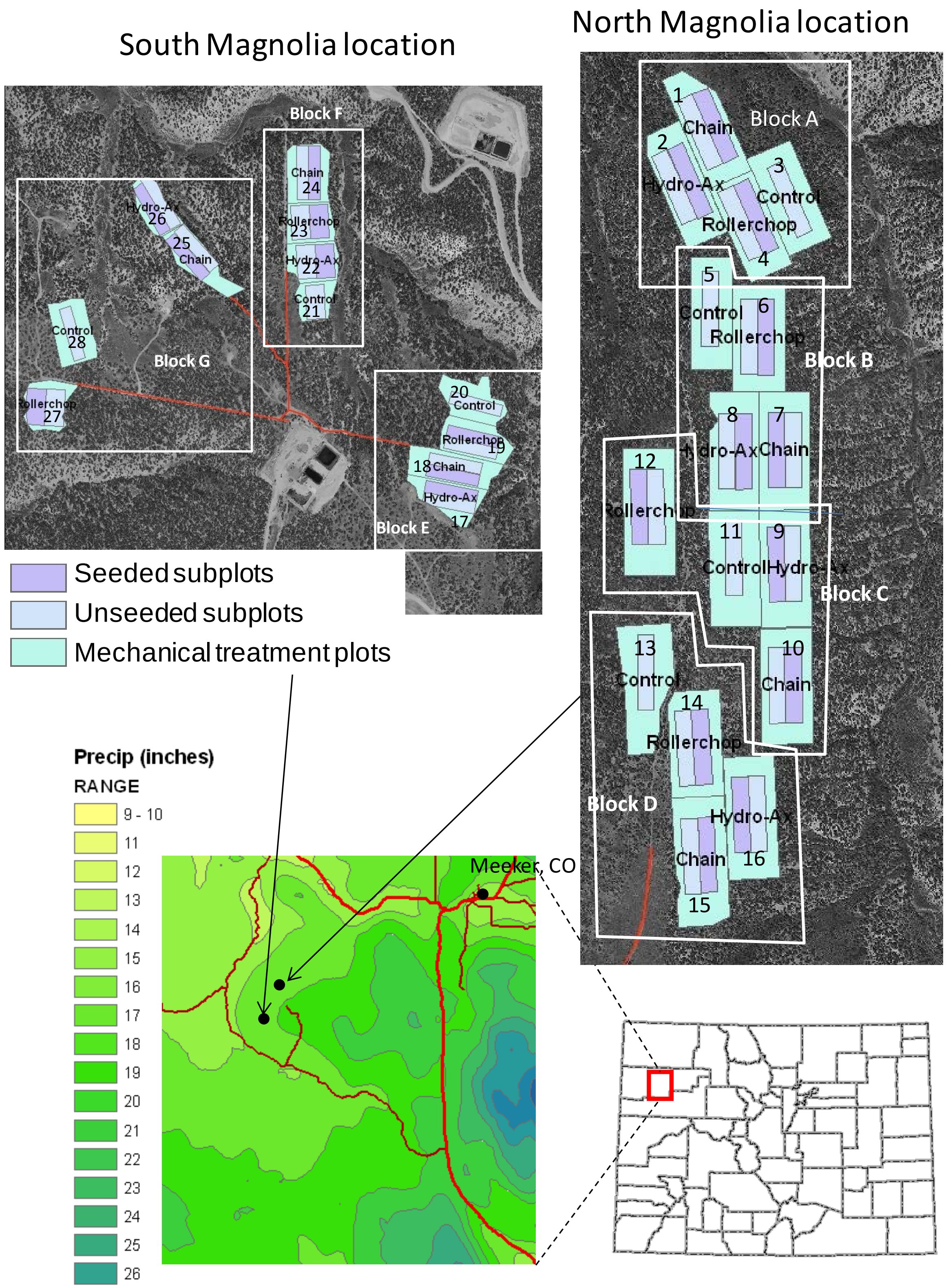

Figure 1. Layout of experiment within North and South Magnolia locations, Rio Blanco County, Colorado.

Figure 2. Types of machinery used and woody debris produced: Ship anchor chaining (a) and tree skeletons left behind by chaining (b); roller chopper (c) and coarse debris left by roller-chopping (d); drum-style hydro-axe (e) with fine debris left behind by hydro-axing (f).

Figure 3. Hansen-style seed dribbler mounted to the track of bulldozer. Two such dribblers were mounted on each bulldozer.

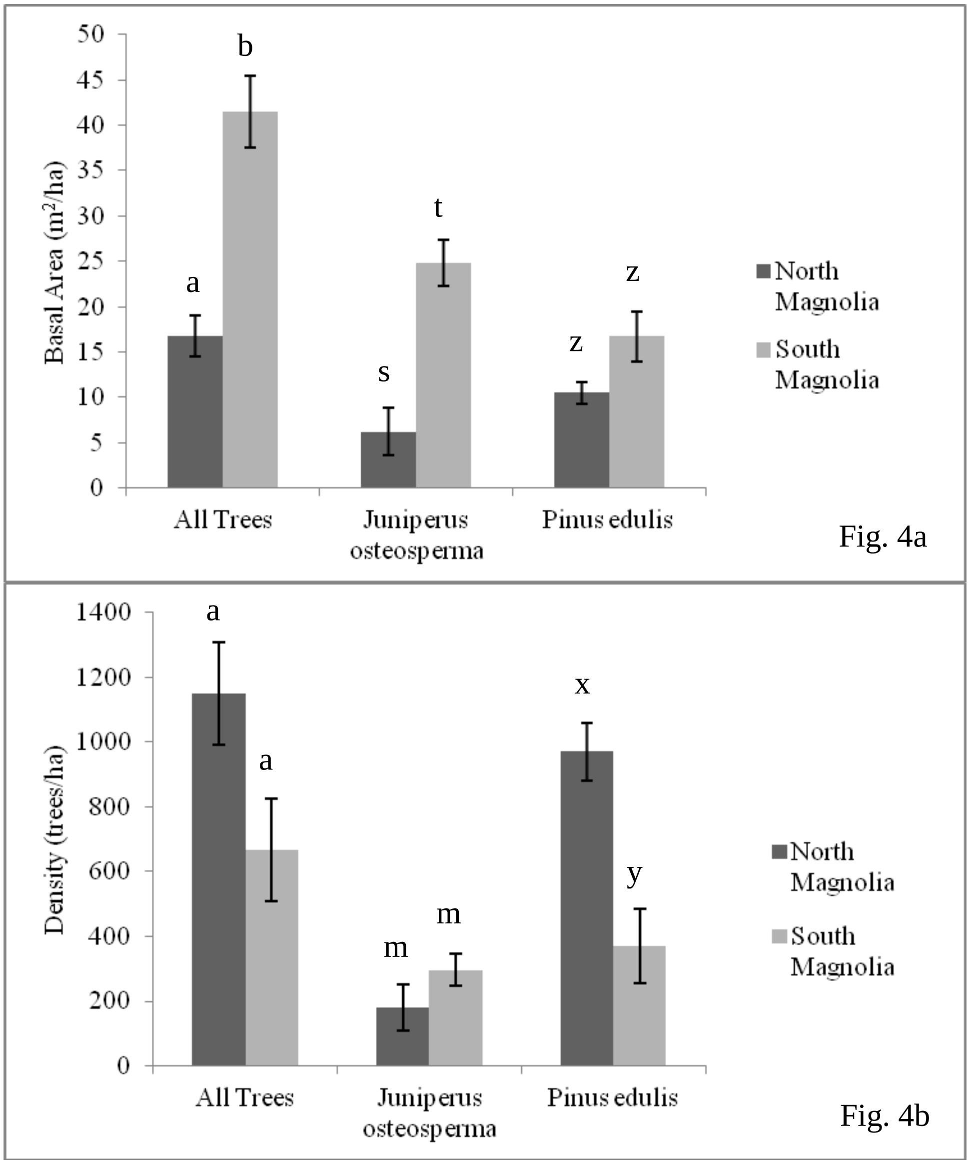

Figure 4. Mean basal area (Fig. 4a) and density (Fig. 4b) for all trees together, just *J. ostersperma*, and just *P. edulis* for North Magnolia and South Magnolia. Raw data was graphed and analyzed. For each comparison, bars with different letters differ significantly at $\alpha = 0.05$.

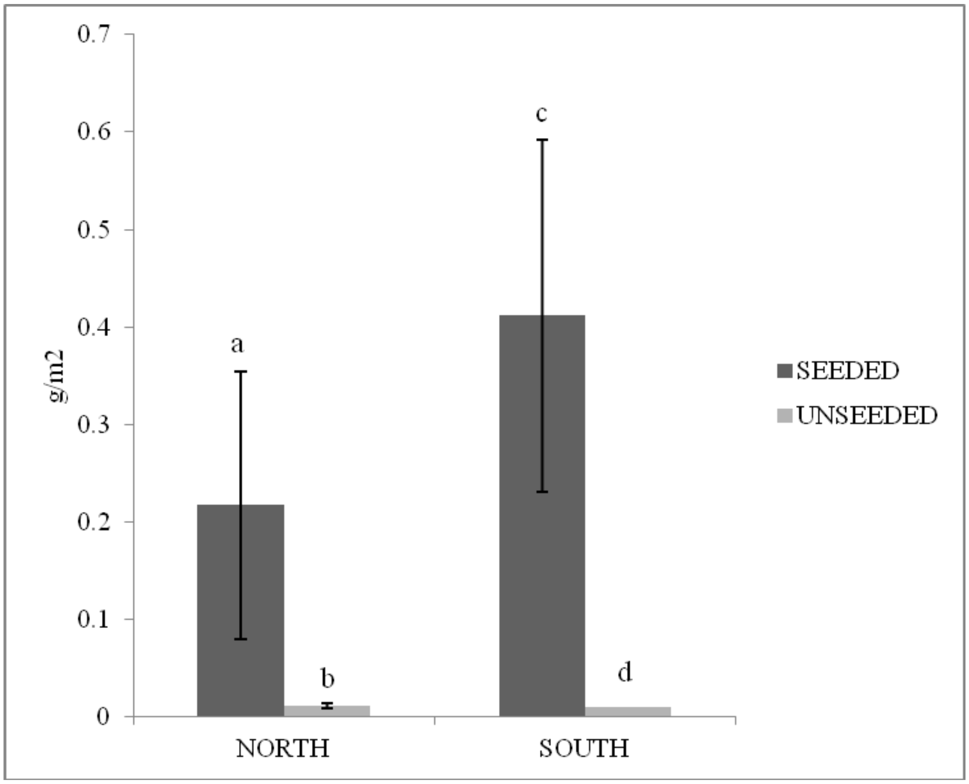

Figure 5. Biomass, with standard error bars, of seeded annual species by site and by seeding treatment. In both sites, seeded annual biomass was higher in seeded versus unseeded subplots. For each comparison, bars with different letters differ significantly at α = 0.05.

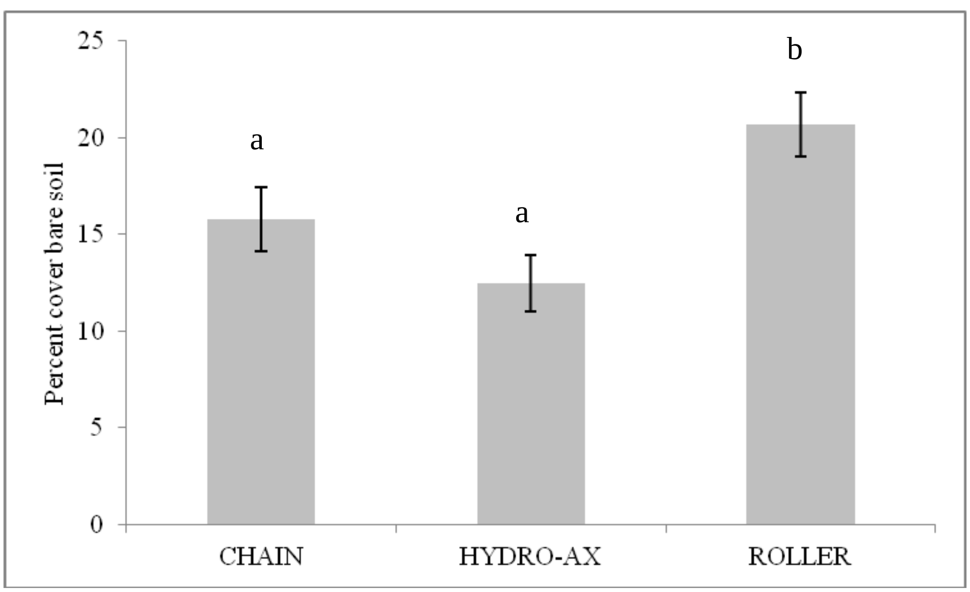

Figure 6. Percent cover of bare soil for each treatment. Rollerchop plots had a higher percentage of bare ground compared to chain and hydro-ax. Raw data was graphed and analyzed. For each comparison, bars with different letters differ significantly at α = 0.05.

Appendix 1.

Table 1: Transformations used for statistical analysis of biomass (Table 1a) and cover (Table 1b). Different transformations were used for the various groupings of vegetation.

Table 1a

TRANSFORMATION	BIOMASS
Log +1	All understory species
Log +1	Grasses
Log +1	Shrubs
Log +1	Forbs
Log +1	High palatability species
Quarter Root	Annuals
Log +1	Perennials
Log +1	Native species
Non-parametric Friedman test	Invasive species
Log +1	All seeded species
Log +1	Seeded shrub species
Square Root	Seeded grass species

Table 1b

TRANSFORMATION	COVER
Arcsine square-root	Total Cover
Arcsine square-root	Grasses
Arcsine square-root	Shrubs
Arcsine square-root	Forbs
Arcsine square-root	All plant species
Square root	Rock
Cube root	Masticated wood
No transformation	Bare soil
No transformation	Litter
Arcsine square-root	Perennial species
Arcsine square-root	Native species