BIG HORN BASIN GREATER SAGE-GROUSE HABITAT EFFECTIVENESS MODELING

Completion Report

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Prepared By:

Wyoming Wildlife Consultants, LLC
Matt Holloran, Principal Author
Post Office Box 893
Pinedale, Wyoming 82941

Kate Belinda
GIS Support
Post Office Box 295
Boulder, Wyoming 82923

Prepared For:

Biodiversity Conservation Alliance
Post Office Box 1512
Laramie, Wyoming 82073

Critical reviews of report drafts were incorporated into this completion report; these reviews were provided by:

Jeffrey L. Beck, PhD, Department of Renewable Resources, University of Wyoming, Laramie, Wyoming 82071.

Kevin E. Doherty, PhD, Senior Ecologist, Audubon Wyoming, Laramie, Wyoming 82072.

Tom Easterly, Wildlife Biologist, Wyoming Game and Fish Department, Greybull, Wyoming 82426.

Rory Karhu, Wildlife Biologist, Natural Resources Conservation Service, Worland, Wyoming 82401.

Erik Molvar, Wildlife Biologist, Biodiversity Conservation Alliance, Laramie, Wyoming 82073.

Tim Stevens, Wildlife Biologist, Bureau of Land Management, Worland, Wyoming 82401.

INTRODUCTION

Sagebrush (*Artemisia* spp.)-dominated landscapes throughout western North America are experiencing unprecedented levels of anthropogenic and natural disturbances resulting in widespread and rapid changes to habitats required to sustain greater sage-grouse (*Centrocercus urophasianus*) populations (Knick et al. 2003). As a result, populations of greater sage-grouse (hereafter sage-grouse) in 2003 were 33-50% as large as those during the 1960s (Connelly et al. 2004) and occupied appoximately 56% of the species' pre-European settlement distribution (Schroeder et al. 2004).

Declines in sage-grouse population size and distribution have led land managers, wildlife managers and users of federal lands to propose habitat enhancements as the primary means of generally mitigating these declines. Enhancing sagebrush habitats typically entails treatment of the shrub overstory (e.g., prescribed fire, herbicide applications, mowing, aeration) in an attempt to enhance the herbaceous understory and regenerate sagebrush. However, sage-grouse population and sagebrush habitat responses to habitat treatments are not consistent. Several researchers have documented no adverse responses of populations to treatment (Wallestad 1975, Martin 1990), whereas others have documented population declines in response to treatment (Benson et al. 1991, Connelly et al. 1994). Treatments do not consistently result in increased forb or insect diversity or abundance in the long-term (e.g., >3 to 5 years; Fischer et al. 1996, Nelle et al. 2000, Slater 2003), suggesting limited utility for enhancing brood-rearing habitats. Manipulating relatively large proportions of available sagebrush habitats, or manipulating wintering or nesting habitats is believed to have the greatest potential to result in sage-grouse population declines (Wallestad 1975, Swenson et al. 1987, Connelly and Braun 1997, Connelly et al. 2000*a*).

One of the factors implicated in range-wide sage-grouse population declines during the early 1900s (Girard 1937) was conversion of sagebrush habitats for agriculture (Griner 1939, Patterson 1952). More recent investigations have reported that inactive (abandoned) sage-grouse leks had a higher percentage of tilled lands within 4-km compared to active leks in North Dakota (Smith 2003), and sage-grouse lek persistence in the Powder River Basin, Wyoming was related positively to the proportion of sagebrush habitat and negatively to the proportion tillage agriculture within 6.4 km (Walker et al. 2007).

Generally, the distance from a road at which decreases in wildlife population density are detected are positively correlated with increased traffic and speed (Forman and Alexander 1998). The upgrade of coal mine haul roads in Colorado resulted in a lek 50 m from the road becoming inactive, and an 83% reduction in the number of males on a lek within 500 m of the road within 3 years post-upgrade (Braun 1986, Remington and Braun 1991). Holloran (2005) reported that haul roads associated with natural gas development activities in Wyoming negatively influenced male lek attendance within 3 km, and declines in the number of males were positively associated with increased traffic levels and vehicle activity during the daily strutting period (i.e., early morning). Additionally, patch occupancy probabilities of Gunnison sage-grouse (*Centrocercus minimus*) were positively correlated with distance to roads (Oyler-McCance 1999).

We investigated relationships between sage-grouse population trends as estimated from lek surveys and amounts of surface disturbance on landscapes surrounding leks over a 25-year period. The surface disturbance parameters investigated included acreage converted to agriculture or bare ground (e.g., well pads, home sites), acreage experiencing sagebrush perturbation, and mileage of road evident on aerial-based imagery. Disturbance variables were developed at the scale of habitats surrounding lek complexes. Our objective was to investigate potential relationships between sage-grouse population trends and the extent of landscape manipulation.

In the following analyses, sage-grouse population trends through time were established from lek survey data. Concern over the usefulness of lek surveys has been expressed (Beck and Braun 1980, Walsh et al. 2004); however lek surveys comprise the long-term data available on sage-grouse populations and according to Connelly et al. (2004), generally appear to provide reliable population trend data at relatively broad spatial scales. To counteract some potential shortcomings associated with these data, we estimated population trends at the lek complex spatial scale and modeled differences in population trend slopes as opposed to absolute change in populations. These analyses were conducted over a relatively small geographic region and the variability associated with predictor variables was not inclusive. Readers are cautioned to recognize the data used in the following investigations. This investigation should be interpreted as a pilot study.

STUDY AREA

The study was conducted in the southeast portion of the Big Horn Basin (BHB) in Washakie and eastern Hot Springs counties, Wyoming (Figure 1). We used aerial imagery from 1981 to 2006 and the Wyoming Game and Fish Department (WGFD; Cheyenne, WY) sage-grouse database to compile the analyzed dataset. Elevations ranged from approximately 1280 to 1830 m. Western portions of the area were in a 14 to 28-cm precipitation zone while eastern portions entered a 28 to 37-cm precipitation zone (Wyoming Geographic Information Science Center [WyGISC]; University of Wyoming, Laramie, WY; 2002). Judging from aerial imagery, vegetation was predominantly shrub-dominated. Conifer stands occurred in eastern portions of the area, and deciduous stands occurred along many riparian corridors.

METHODS

DATA ACQUISITION:--Sage-grouse lek location data were obtained from the WGFD sage-grouse database. We visually examined the distribution of leks situated in the BHB and identified a region with relatively high lek densities. Following discussions with Bureau of Land Management (BLM), WGFD, and Natural Resources Conservation Service (NRCS) wildlife biologists, we selected the southeastern region of the BHB (Figure 1) to conduct our analyses. Known leks in the southeast region were grouped into unique complexes based on a visual assessment of spatial orientation and availability of lek survey data between the early 1980s and 2006 (Table 1). We designated complexes based solely on spatial orientation of leks; levels of sage-grouse interaction between leks in designated complexes were unknown. We buffered leks by 5 km to encompass the area where a majority of the females being bred on the leks would nest (Holloran and Anderson 2005) and raise their broods during early brooding. Buffers were dissolved by complex to establish lek complex sample units (Figure 2).

Hardcopy aerial photographs of selected regions were compiled from BLM (1981) stockpiles, scanned, and geo-referenced into a digital raster using ArcGIS (ESRI, Redlands, CA). USGS Digital Orthophoto Quarter Quadrangles (DOQQs) were compiled from the Wyoming Spatial Data Clearinghouse (1994), and County Mosaics were acquired from the WGFD (2002) and the NRCS GIS online servers (2006). Surface disturbing features visually discernable in the imagery were manually digitized into GIS shapefiles; we referenced BLM records during this process but did not include any spatial information in shapefiles that was not generated from imagery. Surface disturbances attributed to agricultural operations were established based on land ownership, land-use patterns, and moisture levels evident in color infrared (CIR) imagery taken in 2002. Areas maintaining vegetation with high moisture content as discerned by the presence of red tones in CIRs were considered agricultural areas. Disturbed areas maintaining vegetation but not exhibiting red tones in CIRs or traditional agricultural land-use patterns were considered perturbations; naturally occurring perturbations (e.g., wildfire) and anthropogenic treatments of different types (e.g., prescribed fire, herbicide application) were grouped into this disturbance category. Disturbed areas with no vegetation (e.g., well pads, home sites) were grouped into a single surface disturbance category. Linear disturbances discernible at a 1:12,000 scale were considered roads; digitizing at this scale resulted in smaller 2-track roads not being digitized. We did not attempt to truth or add attributes not readily discernible from imagery (e.g., treatment type, road surface) to shapefiles.

PREDICTOR VARIABLES:--Digitizing resulted in 4 temporally distinct layers (1981, 1994, 2002, and 2006) outlining disturbances into categories: (1) agricultural fields, (2) perturbations, (3) areas where vegetation had been removed (converted areas), and (4) roads. For each layer, we calculated acres of disturbed habitat by category and miles of road within complex buffer regions (Figures 3-10). Disturbances spatially situated where buffers overlapped were included in disturbance category totals for each sample unit. Areas identified as disturbed in a given year's layer were included in category totals in subsequent layers.

We considered 1981 the base year. The amount of acreage disturbed and miles of road added were calculated for each distinct time period between available imagery. For example, the amount of land converted to agriculture within the time period between 1981 and 1994 was calculated as the total converted acres estimated in 1981 subtracted from total acres estimated in 1994; this calculation resulted in an estimate of the amount of ground converted during the 13-year period between 1981 and 1994. In addition to calculating estimates for each category independently, we combined perturbation and agricultural conversion estimates to establish a sagebrush manipulation variable (i.e., potential sage-grouse habitat existed following disturbance). Acreage of surface disturbed by roads was estimated as the area within a 33.3-foot buffer of the center line of all roads. To establish this buffer distance, we used improved surface road layers available through the Wyoming Spatial Data Clearinghouse, and estimated the proportion of roads digitized from 2006 imagery that were improved surface. We assumed a 100-foot buffer around improved surface roads and a 15-foot buffer around unimproved roads. We combined agricultural, perturbation, conversion and road disturbance acreage estimates to establish a total acres disturbed variable. To standardize across different sized sample units, we converted acreage and distance estimates to proportions by dividing acres disturbed or miles of road by the total acreage of the buffered region; these estimates were calculated for each time period imagery was available.

We additionally calculated the cumulative proportion of area where sagebrush was manipulated (e.g., converted to agriculture and where perturbations had occurred, combined) and total acreage disturbed. For example, as the estimated acreage converted to agriculture and experiencing perturbation by 1994 included the area disturbed evident in 1981 imagery plus the area disturbed between 1981 and 1994, we divided the 1994 estimate by the total acreage of the lek complex sample unit to establish the cumulative proportion of that sample unit converted to agriculture and where perturbation had occurred by the year 1994.

Inclusively for each sample unit, we calculated the following predictor variables:

- Proportion of area converted to agriculture by time period (Prop_Ag);
- Proportion of area perturbed by time period (Prop_Pert);

- Proportion of area converted to bare ground by time period (Prop_Convert);
- Proportional change in miles of road added by time period (Prop_Road);
- Proportion of area where sagebrush was manipulated by time period (Prop_AgPert);
- Proportion of area disturbed by time period (Prop_Total);
- Cumulative proportion of total acres of sagebrush manipulated for each time period (CumProp_AgPert); and
- Cumulative proportion of total acres disturbed for each time period (CumProp_Total).

Roughness (i.e., the ratio of actual surface area to planimetric area) of perturbed habitats was calculated using nearest neighbor analysis in ArcGIS Spatial Analyst from 30-m digital elevation models (DEMs); proportional aspect of perturbed habitats was also calculated using DEMs (WyGISC).

LEK SURVEYS (RESPONSE VARIABLE):--Sage-grouse lek data were obtained from the WGFD sage-grouse database. We used survey data to estimate annual average lek size per complex; to ensure relatively accurate estimates, we only established average lek size for years when >33% of the leks within a complex were surveyed. During years when multiple surveys were conducted on a single lek, we randomly selected the number of males documented during one of those visits. For each complex and known time period as dictated by available imagery, we plotted average lek size by year and established trends as the straight-line slope of the line generated through the plotted points (SigmaPlot; Systat Software Inc., San Jose, CA). We additionally considered a lek where no males were surveyed for ≥3 years within a given time period, or leks designated as inactive in the sage-grouse database to have become inactive during that time period. Complex response variables were established as: (1) the slope of average lek size through time by complex (Trend_Slope), and the proportion of leks within a complex that became inactive (Prop_Inactive).

STATISTICAL ANALYSES:--We used stepwise linear regression (Neter et al. 1996) to model relationships between lek complex response variables and landscape disturbance predictor variables; F to enter was established at 0.05 and F to remove at 0.10 (SPSS Inc., Chicago, IL). Stepwise regression can validly be used to identify potentially influential variables for subsequent analysis on a different data set, and is helpful when numerous explanatory variables are being investigated in an exploratory analysis. All subsets of non-correlated (Pearson's correlation coefficient ≤|0.75|) predictor variables were modeled. Potentially influential data points were identified through fitted line plots (Minitab Inc., State College, PA, USA) and removed from modeling. When an outlier is present, the fitted regression line may be pulled disproportionately towards the outlying observation; this may be especially problematic when a linear regression model is fitted to a data set with relatively small numbers of cases (Neter et al. 1996). If ≥2 points were considered influential subsequent to removal of initial influential point, we considered the data insufficient to determine a potential relationship. We additionally compared overall trend slopes (1981-2006) by weighted average roughness and weighted proportional aspect of perturbed habitats within complex buffers using stepwise linear regression; weights were calculated by acres of perturbations. We evaluated multivariate models by adjusted R^2 values; univariate relationships are presented and compared using R^2 values.

RESULTS

All the multivariate models produced statistically fit the data. Sage-grouse lek trends were negatively related to the proportion of habitat experiencing perturbation or combinations of this variable with other surface disturbances (i.e., Prop_AgPert and Prop_Total). These 3 variables were highly correlated

(Pearson's correlation coefficient >|0.93|). Adjusted R^2 values suggest that, of the variables examined, changes in the amount of surface experiencing perturbation best predicted sage-grouse population trends (Adjusted R^2 = 36.3; Table 2).

The proportion of leks within a complex that became inactive was positively related to proportions of the surface converted to agriculture and experiencing perturbation combined (i.e., Prop_AgPert) or proportions of area disturbance (i.e., Prop_Total).

Roughness of habitats experiencing perturbation was negatively related to sage-grouse lek trends. Aspects of habitats experiencing perturbation did not consistently influence sage-grouse lek trends or proportions of leks becoming inactive (Table 3).

Univariate linear regression relationships and the data used in analyses are provided in the results for reference (Tables 3 and 4).

DISCUSSION

The modeling efforts undertaken herein suggest the existence of a landscape-scale relationship between numbers of breeding sage-grouse and acres of habitat disturbed. Sage-grouse populations are influenced by numerous habitat management and naturally occurring events not investigated in these analyses (e.g., livestock grazing, weather, predator assemblages; Connelly et al. 2000*b*). Therefore, surface disturbance variable combinations explaining up to 36% of the variation in lek survey indices imply biologically meaningful relationships (Neter et al. 1996). It is important to reiterate the focus of this study as a pilot; in general the relationships establish the need to further investigate potential relationships between sage-grouse population trends and amounts of habitat manipulated at larger spatial scales.

Big Horn Basin sage-grouse populations as measured by rates of change in the number of males occupying leks and the proportion of leks becoming inactive in a lek complex were negatively influenced by the acreage of landscape disturbed within 5 km of leks. Disturbances influencing populations included agricultural conversion, sagebrush perturbations, and combinations of these factors plus other anthropogenic surface disturbing activities. The population trend results suggest a positive and linear relationship; the rate of lek occupancy decline increased (e.g., lek trends became more negative) as the proportion of the landscape disturbed increased. Likewise, the proportion of inactive leks in a complex increased (e.g., an increase in the number of inactive leks) as the proportion of the landscape disturbed increased. The disturbance types identified will either temporarily or permanently alter potential habitat. Research suggests that 35 to >100 years (Colket 2003, Baker 2006) may be required for Wyoming big sagebrush (*A. tridentata wyomingensis*)-dominated landscapes experiencing perturbation to again provide sage-grouse habitat (Harniss and Murray 1973, Wright and Bailey 1982, Watts and Wambolt 1996).

Landscapes within 5 km of leks represent where most females breeding on leks within a complex will nest (Holloran and Anderson 2005), and anecdotal evidence suggests the areas investigated are used during the winter. Research suggests that manipulation of large amounts of available winter or nesting habitat is likely to restrict the amount of area with suitable structural conditions, which may negatively influence winter survival or nesting success within, and also near manipulated areas (Connelly et al. 1991, Niemuth and Boyce 1995, Connelly et al. 2000a, Slater 2003).

We investigated relationships between sage-grouse trends and aspect and roughness of habitats experiencing perturbation with 2 thoughts: (1) moisture availability as dictated by snow drifting driven by prevailing winds and aspect may influence sage-grouse population response to perturbation due to potential vegetative responses; and (2) roughness represents a landscape variable distinguishing sage-grouse nests from available habitats in Wyoming (Jensen 2006), thus roughness of areas experiencing perturbation may influence sage-grouse population response. The roughness results suggested that perturbations in rougher terrain negatively influenced lek count indices. Jensen (2006) reported that sage-grouse populations residing in lower elevation areas (1850-2100 m) in southwest Wyoming selected rougher terrain for nesting, while populations in higher elevation areas (2150-2300 m) selected less rough terrain. Elevations in the BHB study area ranged from approximately 1280 to 1830 m, thus rougher terrain may be selected by nesting females. We emphasize that these results are merely suggestive; using these suggestions to formulate management decisions requires more in-depth research on sage-grouse habitat selection and range response to perturbation in the BHB.

MANAGEMENT IMPLICATIONS

Results of this research suggest that relationships exist between sage-grouse populations and acreage of habitats disturbed at the landscape scale. The temporal extent of data analyzed (25 years) is generally less than the time required for Wyoming big sagebrush to fully reoccupy a site experiencing perturbation, and populations may yet respond positively in these habitats.

We believe these analyses establish the need for a larger scale study incorporating spatial replication into the data. We were unable to estimate an area of treatment threshold as the variability in the data analyzed was not sufficient to generate relationships needed to establish threshold levels (the proportion of area disturbed in the analyzed dataset ranged from <0.1 to 3.4%; Table 4). By expanding the variation associated with the proportion of habitat disturbed estimates, a larger-scale study may be able to establish thresholds to the amount of habitat that can be disturbed without eliminating sage-grouse during habitat recovery periods. Quantification of these thresholds may be important to manage sage-grouse as habitat manipulations focused on enhancing populations to mitigate population declines resulting from anthropogenic uses of sagebrush-dominated landscapes (e.g., energy development) become more prevalent.

Swenson et al. (1987), comparing habitat treatment studies conducted in Wyoming, Montana and Colorado, reported that manipulating ≥16% of the sagebrush in an area was correlated with a 50 to 100% reduction in sage-grouse populations; conversely, manipulation of ≤11% of the sagebrush was correlated with stable to increasing populations. Additionally, Connelly et al. (2000*a*) reported that the effects of removing 57% of big sagebrush-dominated habitats within a 12,655-acre area on the sage-grouse breeding population in Idaho included increased loss of leks relative to a control area.

LITERATURE CITED

Beck, T. D., and C. E. Braun. 1980. The strutting ground count: variation, traditionalism, management needs. Proceedings of the Western Association of Fish and Wildlife Agencies 60:558-566.

Benson, L. A., C. E. Braun, and W. C. Leininger. 1991. Sage grouse response to burning in the big sagebrush type. Proceedings: Issues and Technology in the Management of Impacted Western Wildlife, Thorne Ecological Institute 5:97-104.

Braun, C. E. 1986. Changes in sage grouse lek counts with advent of surface coal mining. Proceedings: Issues and Technology in the Management of Impacted Western Wildlife, Thorne Ecological Institute 2:227-231.

Connelly, J. W., and C. E. Braun. 1997. Long-term changes in sage grouse (*Centrocercus urophasianus*) populations in western North America. Wildlife Biology 3:229-234.

Connelly, J. W., S. T. Knick, M. A. Schroeder, and S. J. Stiver. 2004. Conservation assessment of greater sage-grouse and sagebrush habitats. Western Association of Fish and Wildlife Agencies. Unpublished Report. Cheyenne, WY, USA.

Connelly, J. W., K. P. Reese, R. A. Fischer, and W. L. Wakkinen. 2000*a*. Response of sage grouse breeding population to fire in southeastern Idaho. Wildlife Society Bulletin 28:90-96.

Connelly, J. W., K. P. Reese, W. L. Wakkinen, M. D. Robertson, and J. W. Fischer. 1994. Sage grouse ecology report. Job Completion Report W-160-R-19 Subproject 9, Idaho Department of Fish and Game, Boise, ID, USA.

Connelly, J. W., M. A. Schroeder, A. R. Sands, and C. E. Braun. 2000*b*. Guidelines to manage sage grouse populations and their habitats. Wildlife Society Bulletin 28:1-19.

Connelly, J. W., W. L. Wakkinen, A. D. Apa, and K. P. Reese. 1991. Sage grouse use of nest sites in southeastern Idaho. Journal Wildlife Management 55:521-524.

Fischer, R. A., K. P. Reese, and J. W. Connelly. 1996. An investigation of fire effects within xeric sage grouse brood habitat. Journal Range Management 49:194-198.

Forman, R. T. T., and L. E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecological Systems 29:207-231.

Girard, G. L. 1937. Life history, habits, and food of the sage grouse *Centrocercus urophasianus* Bonapart. University of Wyoming Publication 3. University of Wyoming, Laramie, WY, USA.

Griner, L. A. 1939. A study of the sage grouse (Centrocercus urophasianus), with special reference to the life history, habitat requirements, and numbers and distributions. MS Thesis, Utah State Agricultural College, Logan, UT, USA.

Harniss, R. O. and R. B. Murray. 1973. 30 years of vegetal change following burning of sagebrush-grass range. Journal Range Management 26:322-325.

Holloran, M. J. 2005. Greater sage-grouse (*Centrocercus urophasianus*) population response to natural gas field development in western Wyoming. PhD Dissertation, University of Wyoming, Laramie, WY, USA.

Holloran, M. J., and S. H. Anderson. 2005. Spatial distribution of greater sage-grouse nests in relatively contiguous sagebrush habitats. Condor 107:742-752.

Jensen, B. M. 2006. Migration, transition range and landscape use by greater sage-grouse (*Centrocercus urophasianus*). MS Thesis, University of Wyoming, Laramie, WY, USA.

Knick, S. T., D. S. Dobkin, J. T. Rotenberry, M. A. Schroeder, W. M. Vander Haegen, and C. van Riper III. 2003. Teetering on the edge or too late? Conservation and research issues for avifauna of sagebrush habitats. Condor 105:611-634.

Martin, R. C. 1990. Sage grouse responses to wildfires in spring and summer habitats. MS Thesis, University of Idaho, Moscow, ID, USA.

Nelle, P. J., K. P. Reese, and J. W. Connelly. 2000. Long-term effect of fire on sage grouse nesting and brood-rearing habitats in the Upper Snake River Plain. Journal Range Management 53:586-591.

Neter, J., M. H. Kutner, C. J. Nachtsheim, and W. Wasserman. 1996. Applied Linear Regression Models: Third Edition. Richard D. Irwin, Inc. Chicago, IL, USA.

Niemuth, N. D., and M. S. Boyce. 1995. Spatial and temporal patterns of predation of simulated sage grouse nests at high and low nest densities: an experimental study. Canadian Journal Zoology 73:819-825.

Oyler-McCance, S. J. 1999. Genetic and habitat factors underlying conservation strategies for Gunnison sage-grouse. PhD Dissertation, Colorado State University, Fort Collins, CO, USA.

Patterson, R. L. 1952. The sage grouse in Wyoming. Wyoming Game and Fish Commission and Sage Books. Denver, CO, USA.

Ramsey, F. L., and D. W. Schafer. 2002. The Statistical Sleuth: A Course in Methods of Data Analysis Second Edition. Duxbury, Pacific Grove, CA, USA.

Remington, T. E. and C. E. Braun. 1991. How surface coal mining affects sage grouse, North Park, Colorado. Proceedings, Issues and Technology in the Management of Impacted Western Wildlife. Thorne Ecological Institute 5:128-132.

Schroeder, M. A., C. L. Aldridge, A. D. Apa, J. R. Bohne, C. E. Braun, S. D. Bunnell, J. W. Connelly, P. A. Deibert, S. C. Gardner, M. A. Hilliard, G. D. Kobriger, S. M. McAdam, C. W. McCarthy, J. J. McCarthy, D. L. Mitchell, E. V. Rickerson, and S. J. Stiver. 2004. Distribution of Sage-grouse in North America. Condor 106:363-376.

Slater, S. J. 2003. Sage-grouse (*Centrocercus urophasianus*) use of different-aged burns and the effects of coyote control in southwestern Wyoming. MS Thesis, University of Wyoming, Laramie, WY, USA.

Smith, J. T. 2003. Greater sage grouse on the edge of their range: leks and surrounding landscapes in the Dakotas. Thesis, South Dakota State University, Brookings, USA.

Swenson, J. E., C. A. Simmons, and C. D. Eustace. 1987. Decrease of sage grouse *Centrocercus urophasianus* after ploughing of sagebrush steppe. Biological Conservation 41:125-132.

Walker, B. L., D. E. Naugle, and K. E. Doherty. 2007. Greater sage-grouse population response to energy development and habitat loss. Journal of Wildlife Management 71:2644-2654.

Wallestad, R. O. 1975. Life history and habitat requirements of sage grouse in central Montana. Montana Fish and Game Department Technical Bulletin, Helena, MT, USA.

Walsh, D. P., G. C. White, T. E. Remington, and D. C. Bowden. 2004. Evaluation of the lek-count index for greater sage-grouse. Wildlife Society Bulletin 32:56-68.

Watts, M. J., and C. L. Wambolt. 1996. Long-term recovery of Wyoming big sagebrush after four treatments. Journal Environmental Management 46:95-102.

Wright, H. A., and A. W. Bailey. 1982. Fire ecology: United States and southern Canada. Wiley and Sons, New York, NY, USA.

Table 1. Individual sage-grouse leks used to create lek complex sample units, southeast Big Horn Basin, Wyoming, 1981-2006. Lek complex sample units were established by dissolving 5-km buffers around leks in complex (Figure 1).

Lek Complex	Leks Included in Complex Sample Unit[a]
Sample Unit 1	Bruner Draw 1; Bruner Draw 2; Weeter State; Buffalo Creek; Buffalo Creek 4; Buffalo Indian; Buffalo Creek 3; Mahogany Butte 1.
Sample Unit 2	Blue bank draw 56; Blue bank pens (satellite); Blue Bank shearing pens; Chalk Butte 1; Chalk Butte 2; Blue Bank 1; Deadline 1; Deadline 2; Deadline Draw; Deadline Draw 2; Deadline Draw 3; South Butte; South Butte 2; South Butte Cabin.
Sample Unit 3	Mahogany Butte 2; Mahogany Butte 3; Nowood 1 (Tolman pens); Nowood 2; Mahogany Butte 6
Sample Unit 4	Bud Kimball 4; Bud Kimball Corrals; West Bud Kimball Res.; Bud Kimball 2; Bud Kimball 3; Bud Kimball 6; Bud Kimball 7; White barn; North Butte.
Sample Unit 5	Demer Cabin; Denver Jake Draw; Lil' Denver Jake Draw (satellite); Little Denver Jake Draw; Little Sand Draw; Little Sand Draw (satellite).
Sample Unit 6	Zimmerman Buttes 1; Zimmerman Buttes 2; Zimmerman Buttes 3; Pinky Reservoir; Potter Butte; Zimmerman Draw.
Sample Unit 7	Black Mountain; Nowater Hill; Devils Slide Road; Minnick Basin 1; Minnick Basin 2; Minnick Basin 3; Sand Point.
Sample Unit 8	Mud Ck Rd South; Mud Creek; Mud Ck Rd North; Nowater Stockdrive; Nowater Stockdrive NW; Nowater Stockdrive SE; Lake Creek Divide.

[a] Lek names taken from the WGFD sage-grouse database.

The following list of variable combinations was examined for each response variable; Trend_Slope, and Prop_Inactive. High correlation values precluded inclusion of all variables in combination for modeling effort.

1. Prop_Pert, Prop_Road, and CumProp_AgPert;
2. Prop_Pert, Prop_Road, and CumProp_Total;
3. Prop_AgPert, Prop_Road, and CumProp_AgPert;
4. Prop_AgPert, Prop_Road, and CumProp_Total;
5. Prop_Total, Prop_Road, and CumProp_AgPert; and
6. Prop_Total, Prop_Road, and CumProp_Total.

Table 2. Multivariate regression results comparing sage-grouse lek survey derived response variables to landscape disturbance predictor variables within 5 km of leks in complex (lek complex sample unit; *n*=23), southeast Big Horn Basin, Wyoming, 1981-2006. Variable combination numbers correspond to the list provided above; variables are described in text.

Response Variable	Variable Combination	Identified Coefficients	Coefficient Values	Coefficient Significance	Adjusted R^2	Model F-value (df)	Model Significance
TREND_SLOPE							
	1 and 2	Constant	0.386	0.142	36.3	13.55	0.001
		Prop_Pert	-0.606	0.001			
	3 and 4	Constant	0.435	0.111	31.0	10.44	0.004
		Prop_AgPert	-0.724	0.004			
	5 and 6	Constant	0.528	0.097	23.9	7.59	0.012
		Prop_Total	-0.650	0.012			
PROP_INACTIVE							
	1 and 2	No Variables Entered Model at *alpha* = 0.05					
	3 and 4	Constant	0.177	0.005	29.4	9.74	0.005
		Prop_AgPert	0.152	0.005			
	5 and 6	Constant	0.156	0.027	22.9	7.25	0.014
		Prop_Total	0.137	0.014			

Table 3. Univariate regression results comparing sage-grouse lek count derived response variables to landscape disturbance predictor variables within 5 km of leks in complex (lek complex sample unit; *n*=23), southeast Big Horn Basin, Wyoming, 1981-2006. Variables are described in text. NOTE that variables designated by "*a*" or "*b*" in *Predictor Variable* column are included here for reference; these relationships include outliers (see Table 4) which may disproportionately influence linear association (i.e., R^2) or direction of relationships.

Predictor	Trend_Slope			Prop_Inactive		
Variable	*P*-value	R^2	Relationship	*P*-value	R^2	Relationship
Prop_Ag[a]	0.094	12.8	Negative	0.764	0.4	Negative
Prop_Ag[b]	0.014	26.5	Negative	0.284	5.7	Positive
Prop_Pert	0.001	39.2	Negative	0.089	13.2	Positive
Prop_AgPert[a]	0.003	35.7	Negative	0.195	7.9	Positive
Prop_AgPert	0.004	34.3	Negative	0.005	32.7	Positive
Prop_Convert[a]	0.224	7.0	Positive	0.722	0.6	Negative
Prop_Convert[b]	0.598	1.4	Positive	0.418	3.3	Negative
Prop_Road	0.064	15.4	Negative	0.136	10.2	Negative
Prop_Total[a]	0.005	31.7	Negative	0.257	6.1	Positive
Prop_Total	0.012	27.5	Negative	0.014	26.6	Positive
CumProp_AgPert	0.088	13.2	Negative	0.192	8.0	Positive
CumProp_Total	0.132	10.5	Negative	0.221	7.0	Positive
Perturbation Aspect						
North	0.297	26.4	Negative	0.446	15.1	Positive
East	0.392	18.7	Positive	0.288	27.3	Negative
South	0.638	6.1	Positive	0.666	5.1	Negative
West	0.574	8.5	Negative	0.450	14.9	Positive
Perturbation Roughness	0.228	43.2	Negative	0.417	22.7	Positive

[a] Relationship including 2 identified outliers; outlier removed and relationship established univariately (results in following row).

[b] Relationship including 1 identified outlier; these variables were not included in multivariate analyses due to multiple outliers.

Table 4. Sage-grouse lek count and landscape disturbance variable values by lek complex sample unit, southeast Big Horn Basin, Wyoming, 1981-2006. Variable values were calculated from the WGFD sage-grouse database and aerial photographs taken 1981 (base year), 1994, 2002, 2006.

	Dependent Variables[a]		Independent Variables[a]							
Lek Complex (Year)[b]	Trend Slope	Proportion Inactive	Prop Ag	Prop Treat	Prop AgTreat	Prop Convert	Prop Road	Prop Total	CumProp AgTreat	CumProp Total
Sample Unit 1 (94)	-2.076	0.167	1.919[c]	5.012	6.931[c]	0.000	0.049	7.130[c]	11.775	13.079
Sample Unit 1 (02)	-0.128	0.250	0.000	2.159	2.159	0.005	0.006	2.189	13.934	15.268
Sample Unit 1 (06)	0.209	0.000	0.037	0.000	0.037	0.000	0.009	0.074	13.971	15.342
Sample Unit 2 (94)	-0.520	0.125	0.000	0.764	0.764	0.221	0.050	1.188	0.764	2.274
Sample Unit 2 (02)	-0.842	0.500	0.000	0.000	0.000	0.006	0.019	0.084	0.764	2.357
Sample Unit 2 (06)	2.453	0.000	0.000	0.098	0.098	0.000	0.002	0.105	0.861	2.463
Sample Unit 3 (94)	-3.120	0.667	0.101[c]	2.925	3.027	0.050	0.026	3.180	10.002	11.036
Sample Unit 3 (02)	-0.564	1.000	0.000	3.386	3.387	0.000	0.000	3.387	13.389	14.423
Sample Unit 4 (94)	-0.632	0.000	0.000	0.932	0.932	0.000	0.088	1.287	4.042	5.444
Sample Unit 4 (02)	-0.069	0.400	0.000	0.409	0.409	0.000	0.008	0.441	4.451	5.885
Sample Unit 4 (06)	0.940	0.333	0.000	0.000	0.000	0.000	0.001	0.006	4.451	5.891
Sample Unit 5 (94)	-0.778	0.333	0.000	0.000	0.000	0.012	0.054	0.229	0.000	1.818
Sample Unit 5 (02)	1.112	0.000	0.000	0.000	0.000	0.025	0.036	0.169	0.000	1.987
Sample Unit 5 (06)	1.839	0.200	0.000	0.000	0.000	0.040	0.015	0.103	0.000	2.090
Sample Unit 6 (94)	-0.602	0.333	0.000	0.000	0.000	0.000	0.013	0.053	0.000	1.150
Sample Unit 6 (02)	0.637	0.000	0.000	0.000	0.000	0.001	0.020	0.080	0.000	1.230
Sample Unit 6 (06)	0.485	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.230
Sample Unit 7 (94)	-2.046	0.000	0.000	1.079	1.079	0.005	0.032	1.212	1.079	2.036
Sample Unit 7 (02)	0.932	0.000	0.000	0.000	0.000	0.030	0.033	0.162	1.079	2.199
Sample Unit 7 (06)	1.336	0.250	0.000	0.000	0.000	1.650[c]	0.003	1.663	1.079	3.862
Sample Unit 8 (94)	-0.950	0.500	0.000	1.303	1.303	0.003	0.009	1.340	1.303	2.298
Sample Unit 8 (02)	-0.566	0.500	0.000	0.000	0.000	0.190	0.026	0.295	1.303	2.593
Sample Unit 8 (06)	0.878	0.000	0.000	0.000	0.000	0.612[c]	0.000	0.612	1.303	3.205

[a] Variables described in text.

[b] See Figure1; Table 1.

[c] Data points identified as outliers; if >1 identified as outliers, variable was not included in multivariate analyses.

Figure 1. Big Horn Basin, Wyoming. Detail focuses on the area investigated for the efforts described in this document. Map base established from 90-m DEM and landownership layers (WyGISC).

Figure 2. Southeast Big Horn Basin, Wyoming (see detail Figure 1). Sample units were designated by 5-km lek buffers and dissolved by leks in a complex; complexes were established through a visual assessment of the spatial orientation of leks and do not reflect WGFD established complexes (see Table 1). Map base established from 2002 aerial imagery (WGFD).

Figures 3-10. Aerial imagery by complex with digitized predictor variables, southeast Big Horn Basin, Wyoming 1981-2006. Figures are presented from Sample Unit 1 through Sample Unit 8 (reference Figure 2 and Table 1).