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Reproductive Ecology of Greater Sage-Grouse in Strawberry Valley, Utah

Jared Jeffrey Baxter
Brigham Young University

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Jared Jeffrey Baxter

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Master of Science

Randy T. Larsen, Chair
Steven L. Petersen
David K. Dahlgren

Department of Plant and Wildlife Sciences
Brigham Young University

ABSTRACT

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Jared Jeffrey Baxter
Department of Plant and Wildlife Sciences, BYU
Master of Science

Greater sage-grouse (*Centrocercus urophasianus*; hereafter, sage-grouse) are a species of conservation concern in the rangelands of western North America due to their dramatic decline over the last half century. Effective conservation and management of sensitive species requires an understanding of how species respond to management actions. We examined two aspects of the reproductive phases of sage-grouse: nest predation, and habitat selection by female sage-grouse with chicks. In Chapter 1, we developed resource selection functions to assess the influence of mechanical treatments of mountain big sagebrush (*Artemisia tridentata vaseyana*) on habitat selection by greater sage-grouse with chicks. Post-treatment sage-grouse showed stronger selection for treatments and treatment edges than did pre-treatment sage-grouse. This altered pattern of selection by sage-grouse with broods suggests mechanical treatments may be a suitable way to increase use of mountain big sagebrush during the brooding period. In Chapter 2, we assessed the effect of habitat edges on nest predation of sage-grouse. The "edge effect" hypothesis states that habitat edges are associated with reduced nest success for birds. We tested the edge effect hypothesis using 155 nest locations from 114 sage-grouse. We derived edge metrics for 11 habitat cover types to determine which variables may have affected nest predation. We found support for the edge effect hypothesis in that nest predation increased with increasing edge density of paved roads. We provide evidence that the edge effect hypothesis may apply to greater sage-grouse and their habitats. Based on our results, we recommend minimizing disturbances that fragment critical nesting habitat of greater sage-grouse.

Keywords: resource selection, mechanical treatment, mountain big sagebrush, Strawberry Valley, edge effect, nest predation, greater sage-grouse

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CHAPTER 1

Resource Selection by Greater Sage-Grouse Reveals Preference for Mechanically-Altered Habitats

Jared J. Baxter[a], Rick J. Baxter[a], David K. Dahlgren[b], and Randy T. Larsen[a]
[a]Department of Plant and Wildlife Sciences, Brigham Young University, Provo, UT
[b]Wildland Resources Department, Utah State University, Logan, UT

ABSTRACT

Effective conservation requires an understanding of how species respond to management actions. For species of conservation concern such as greater sage-grouse (*Centrocercus urophasianus*), this understanding is urgently needed. We developed resource selection functions to assess the influence of mechanical treatments of mountain big sagebrush (*Artemisia tridentata vaseyana*) on habitat selection by greater sage-grouse during the critical brooding period. We measured multiple vegetation components, including shrub, grass, and forb cover, at random locations before and after sagebrush treatments. We used model selection and a 19-year telemetry data set (1998-2016) to evaluate response of greater sage-grouse to treatments. Statistical models were built using 418 locations from 72 females with broods (333 locations, 61 females pre-treatment; 85 locations, 11 females post-treatment). Using a difference in means comparison, we found shrub canopy cover decreased (mean ± SE) from 31.81 ± 0.70% to 16.16 ± 0.89% following mechanical treatment. Grass cover increased from 12.02 ± 0.51% to 31.33 ± 1.52% after treatment. Post-treatment forb cover (12.58 ± 1.23%) did not differ from pre-treatment estimates (12.39 ± 0.61%). Overall, greater sage-grouse selected areas that were 1) distant from trees, paved roads, and powerlines, 2) high in elevation, 3) near treatment edges, and

4) consisting of gentle slopes. Post-treatment sage-grouse showed stronger selection for treatments and treatment edges than did pre-treatment sage-grouse. Maps predicting probability of selection by brood-rearing sage-grouse showed increased use in and around mechanically-treated areas. This altered pattern of selection by sage-grouse with broods suggests mechanical treatments may be a suitable way to increase use of mountain big sagebrush during the brooding period.

INTRODUCTION

Loss and degradation of habitat threatens species across the globe (Dirzo and Raven 2003; Foley et al. 2005; Pimm and Raven 2000). The quantity and quality of habitats available to wildlife, including the rangelands of western North America, continue to decline due to the impacts of anthropogenic development, wildfires, climate change, and invasive species (Bradley 2010; Wisdom et al. 2005). Obligate species are more sensitive to habitat alterations, and are at increased risk of extinction compared to generalist species, especially when habitats are lost or degraded (Colles et al. 2009; Julliard et al. 2003; Saab and Rich 1997). Obligate species often have low adaptive ability and require effective, species-based management actions to mitigate impacts of habitat fragmentation and loss (Goble et al. 2012). Examining how species respond to management actions, whether through experimental or observational studies, is essential to guide effective conservation of vulnerable and imperiled species and their habitats.

The distribution of sagebrush (*Artemisia* spp.) has dramatically decreased across western North American rangelands in recent decades creating one of North America's most pressing conservation challenges (Connelly et al. 2004; Knick 1999). Big sagebrush (*A. tridentata* ssp.) once dominated between 400 000 - 600 000 km^2 in western North America (Beetle 1960;

McArthur and Stevens 2004). Recent estimates suggest there has been a 50 - 60% reduction in sagebrush since the beginning of the 19th century (Schroeder et al. 2004). Anthropogenic impacts are recognized as having the greatest influence on this decline in sagebrush (Leu and Hanser 2011; Walker et al. 2007; Wisdom et al. 2011). Additionally, encroachment by juniper (*Juniperus* spp.) woodlands and invasion by species such as cheatgrass (*Bromus tectorum*) have further impacted sagebrush ecosystems (Knick et al. 2013; Miller et al. 2011). Such a significant reduction and alteration in sagebrush systems has had profound effects on the distribution and abundance of sagebrush-obligate or near-obligate species, such as greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) (Connelly et al. 2004; Crawford et al. 2004; Wisdom et al. 2011). Sage-grouse have become a species of great conservation concern following their range-wide decline over recent decades. Loss of quality brood-rearing habitat, in particular, has been implicated as a major factor in the range-wide decline (Aldridge and Brigham 2002; Connelly et al. 2004; Crawford et al. 2004). Due to the decline in the amount and contiguity of sagebrush in North America, conservation and restoration of remaining suitable habitat has become increasingly important for sage-grouse.

Sage-grouse require sagebrush throughout all phases of their life cycle, but specific needs vary by season. Nesting and winter habitats are predominantly characterized by tall, dense stands of sagebrush (Connelly et al. 2000). In contrast, a productive and diverse understory of grasses and forbs with relatively sparse sagebrush cover is more typical of brood-rearing habitat (Drut et al. 1994; Klebenow 1969; Wallestad 1971). In some areas where brood-rearing habitat may be limiting, managers have reduced sagebrush cover using chemical, mechanical, or other (e.g., fire or grazing) means in an attempt to improve quality of brood-rearing habitat (BLM 2015; Utah DWR 2013). Plant community response to these sagebrush treatments, however, is highly variable and often dependent on the method used, subspecies of big sagebrush, and environmental conditions (e.g., precipitation, soil moisture, etc.) following treatment. Prescribed fire and mechanical treatments in Wyoming big sagebrush (*A. t. wyomingensis*) generally produced either neutral or negative (e.g., invasion of exotic annual grasses) responses in herbaceous cover and understory (Beck et al. 2012; Davies et al. 2011a; Davies et al. 2012b; Hess and Beck 2012). Annual grass cover, for example, increased 7-fold by the third year following mowed treatments in Oregon (Davies et al. 2011a). In Wyoming, perennial grass cover and height in mowed treatments did not differ from reference sites (Hess and Beck 2012). In contrast, production of forbs and grasses favored by sage-grouse increased in the immediate years following mechanical treatment in mountain big sagebrush (*A. t. vaseyana*) (Dahlgren et al. 2006; Davies et al. 2012c).

These studies produced data on the response of vegetation following treatments in sagebrush, yet little is known about how sage-grouse respond to these changes. Some evidence suggests that females with broods use areas where sagebrush cover is reduced (40% down to 10-15%), particularly within 30 - 90 m of treatment edges (Dahlgren et al. 2006; Dahlgren et al. 2015; Klebenow 1970; Thacker 2010). Female sage-grouse with broods favored treated areas if they contained increased availability of herbaceous plants (e.g., forbs) and associated arthropods which are linked to improved nutrition for sage-grouse (Dahlgren et al. 2015; Gregg et al. 2008). If these nutritional components were not present following treatment of sagebrush, sage-grouse avoided treated areas (Martin 1970). To our knowledge, however, there are no published reports examining habitat selection both before and after sagebrush removal, including using a geographic information system (GIS) to account for other features that may influence habitat selection. We took advantage of a 19-yr telemetry data set that spanned periods before and after mechanical treatment of sagebrush to assess response of sage-grouse to these actions.

The objectives of our study were to assess the effectiveness of mechanical treatments by 1) measuring shrub and herbaceous cover in treated and untreated sagebrush communities and 2) evaluating the influence of mechanical treatments on habitat selection by female sage-grouse with chicks during the brooding period (June - August) in a high-elevation (2 300 - 2 600 m) system dominated by mountain big sagebrush. We predicted that 1) herbaceous understory cover would increase with decreasing shrub cover resulting from mechanical treatment and 2) sage-grouse would demonstrate increased use of areas in and near treatments during the brood-rearing period following mechanical treatments. Our results present important findings with implications for the management of sagebrush throughout the West and for the conservation of greater sage-grouse.

METHODS

Study Area

Strawberry Valley was located in Wasatch County, Utah, south and east of the Uinta and Wasatch mountain ranges, respectively. Strawberry Reservoir was the dominant feature in the valley comprising nearly 7 000 surface ha at full pool. At elevations ranging from 2 300 - 2 600 m, the climate was characterized by cool summers (13.5°C mean air temperature) and cold winters (-8.7°C mean air temperature) with annual precipitation of 77.5 cm (NRCS National Water and Climate Center 2015). The majority of precipitation fell as snow from December to March, with snowpack often lasting into the early brood-rearing period (late May). No severe droughts or fires occurred in Strawberry Valley during our study years. No grazing by domestic livestock occurred in the study area, and the population of sage-grouse was not subject to hunting pressure by humans.

Mountain big sagebrush and silver sagebrush (*A. cana*) were the dominant shrubs in the area, typical of mesic sagebrush ecosystems. Common forbs found in our study area included silvery lupine (*Lupinus argenteus*), sticky purple geranium (*Geranium viscosissimum*), and sulphur-flower buckwheat (*Eriogonum umbellatum*). Common grasses included needle-and-thread (*Stipa comata*), Kentucky bluegrass (*Poa pratensis*), and prairie Junegrass (*Koeleria cristata*).

Defining availability of habitats to animals has the potential to influence resource selection functions (RSF). Thus, it is important to delineate an area that is biologically relevant to the species of interest and appropriate for the question asked. We limited our study area for the RSF to a 50% minimum convex polygon (MPC; Worton 1989) derived from 19 years of brood locations, centered on the lek nearest to the treated areas (Fig. 1). We then added a 1-km buffer (Aldridge and Boyce 2007; Carpenter et al. 2010; Sovern et al. 2015) to the MCP, which represented the approximate upper end of daily brood movements (Wallestad 1971). This buffer allowed us to capture additional areas likely associated with those broods found on the MCP boundary. We created the MCP using Home Range Tools 2.0 (Rodgers et al. 2012) in ArcMap 10.3 (ESRI®, Redlands, CA). With this process, we delineated a total study area of 10 080 ha that was then reduced by 33.7% to 6 680 ha after subtracting unavailable areas (i.e., Strawberry Reservoir).

Our objective with this delineation was not to estimate home range size, nor to assess habitat selection across the broad area used by semi-migratory sage-grouse in this population. Instead, our goal was to delineate an area available to brooding female sage-grouse in and around the areas mechanically altered and subsequently to determine if grouse with broods in this area selected for or against mechanical treatments (Gillies et al. 2006; Losier et al. 2015; Tardy et al. 2014). With this approach, we achieved a study area that was biologically relevant to sage-grouse with broods and appropriate for our particular study objectives, while avoiding overestimations that can occur with 95% MCPs (Burgman and Fox 2003).

Mechanical Treatments

The Utah Division of Wildlife Resources (UDWR) and United States Forest Service (USFS) mechanically treated sagebrush using either a chain harrow (chain with sections of railroad tracks welded to it) or a brushhog (mower). Approximately 165.7 ha of mountain big sagebrush were treated in 2009, 177.6 ha in 2011, and 91.9 ha in 2014, totaling 435.2 ha (6.5% of study area). Individual treatment plots (polygons) ranged in size from 0.4 ha to 14.9 ha, with an overall mean (± SE) of 3.6 ± 0.2 ha (Fig. 1). Treatments were implemented in September of each year, avoiding the critical period of brood-rearing and in association with seed set by sagebrush. These treatments were designed to increase productivity of the herbaceous understory by reducing sagebrush canopy cover in dense (> 40% sagebrush canopy cover) stands of sagebrush (Utah Watershed Restoration Initiative projects #1360 and #1816). Treatments followed a mosaic pattern, focusing on areas of high sagebrush canopy cover while avoiding rocky outcrops, riparian areas, and crucial winter habitat (thick cover on south and west slopes).

Sage-Grouse Capture and Monitoring

From 1998-2016 we captured female sage-grouse during March-May using a spotlight method (Wakkinen et al. 1992) and ATV or backpack generator. After capture, we identified age of females (adult or yearling) based on feather characteristics (Bihrle 1993; Crunden 1963). We then placed a 22-g necklace radio-transmitter (Advanced Telemetry Systems, Inc., Isanti, MN and Sirtrack, New Zealand) on each female and released them at the point of capture. Following capture and release, we attempted to locate radio-marked females twice per week using a 4-element Yagi antenna and TR-2 receiver (Telonics Incorporated®, Mesa, AZ) or R-1000 digital radio receiver (Communication Specialists Incorporated®, Orange, CA). We did not use triangulation to estimate locations of sage-grouse broods. We flushed females after locating them using radio-telemetry, searched the immediate vicinity (20 m) for chicks, then recorded the location using a handheld global position system (GPS) in the NAD83 datum. Brood locations were collected from June-August during daylight hours (0700 h - 2000 h) up until 7 weeks post-hatch. Broods were not checked on specific days post-hatch (e.g., day 7, 14). Trapping and handling of sage-grouse was permitted and approved by the Utah Division of Wildlife Resources (Certificate of Registration numbers 1COLL6817 and 4BAND9604) and by the Institutional Animal Care and Use Committee at Brigham Young University (most recent protocol number 16-0404).

Vegetation Measurements and Analysis

We quantified changes in vegetation within treatment polygons using data collected at random locations before (PRET, 1998-2009) and after (POST, 2010-2016) implementation of mechanical treatments. Prior to implementation of the 2009 treatment, we measured multiple vegetative components at random locations (*N*=175) in and around polygons to be treated in 2009 and 2011 (Baxter et al. 2009; Bunnell et al. 2004). We collected post-treatment habitat data during the summers of 2013 and 2014 at random locations throughout both the 2009 and

2011 treatment polygons. We generated 40 random locations each year (80 total) using the random points tool in ArcMap 10.2 (ESRI®, Redlands, CA). We used T^2 analysis (Bonham 1989), and the line intercept method (Ludwig and Reynolds 1988) to measure shrub overstory components, including shrub crown area (Bunnell et al. 2004), shrub height, horizontal obscurity, and shrub decadence. We used a modified 0.25 m^2 quadrat (Daubenmire 1959) and ocular estimation (Baxter et al. 2009; Bunnell et al. 2004) to measure percent cover and species richness of grasses and forbs in the understory.

Before making an overall comparison between PRET and POST vegetation components, we first compared PRET habitat data collected in the 2009 treatment with that collected in the 2011 treatment. We used a difference in means comparison with 95% confidence intervals for each vegetation component. Differences were considered significant if the confidence interval did not overlap zero. We followed the same procedure and compared POST habitat data collected in the 2009 treatment and 2011 treatment. No differences were found in either case. Therefore, we pooled PRET vegetation data for the 2009 and 2011 treatments, doing the same for POST vegetation data. We then made the overall comparison between PRET and POST vegetation data using the same difference in means comparison.

Resource Selection Functions

We evaluated brood habitat selection by sage-grouse at the population level (i.e. Johnson's second order; Johnson 1980) within a used-available study design (Manly et al. 2002). We used a mixed-effects, logistic regression with a random intercept for individuals, comparing descriptive variables at use versus available (random) locations within the biologically-defined study area. Females with broods in multiple years were considered in our analysis, but represented a relatively small number (*N*=12; 10 PRET, 2 POST) of individuals. To capture availability, we generated 1 000 random locations and then removed those that fell within the reservoir, leaving 914 random locations (13.7 locations per km^2). To ensure we adequately characterized the study area, random locations were generated at densities equal to or greater than those used in previous studies of habitat selection by sage-grouse (1 – 2 km^{-2}) (Aldridge and Boyce 2007; Aldridge et al. 2008; Carpenter et al. 2010; Fedy et al. 2014; Fedy et al. 2015). We then down-weighted random locations to have the same weight as use locations (Hirzel et al. 2006). Because our study was based on a use-availability and not presence-absence design, our RSFs represented relative probabilities of use, given our data (1998-2016) and the available resource units in our study area.

We did not assess habitat selection for both early and late brood-rearing periods, which in some areas has been shown to differ (Atamian et al. 2010; Drut et al. 1994; Wallestad 1971). In the majority of these cases, broods moved to more mesic areas at higher elevations as herbaceous plants desiccated at lower elevations. Strawberry Valley as a whole is characterized as a high-elevation, high-precipitation, mesic area. Thus, brood habitat selection in our study area was unlikely to differ between early and late brood-rearing periods.

Geographic Information System (GIS) Explanatory Variables

We extracted landscape-level variables potentially influencing sage-grouse habitat selection using a geographic information system (GIS) (Westover et al. 2016). We separated variables into one of four categories: topographic, anthropogenic, vegetative, and treatment (Table 1). Topographic features were derived from a 10-m National Elevation Dataset (NED). Anthropogenic variables included distances to different landscape features associated with humans (e.g., power lines, roads). Vegetative variables were derived from a National Agriculture Imagery Program (NAIP) classification (Westover et al. 2016). From the classification, we estimated distance to vegetation types, as well as to edges consisting of two contrasting vegetation types (e.g., riparian and trees). For treatment variables, distance to treatment edge was set up such that locations falling inside a treatment polygon were given a negative distance and locations outside polygons were given positive distances, with a location on a treatment edge a distance of 0 m. We squared these values to create a second variable that, in combination with the first, allowed us to capture a nonlinear relationship between relative probability of use and distance to treatment edge. We tested for a difference between pre-treatment and post-treatment habitat selection of sage-grouse by including an interaction term between a binary predictor (0 for pre-treatment, 1 for post-treatment) and distance to treatment (continuous). A significant negative coefficient for the interaction term would indicate that post-treatment females selected for areas nearer treatment edges than did pre-treatment females. To estimate distance to the edge of a feature (e.g., water, treatment), we used the Euclidean distance tool in the Spatial Analyst extension in ArcMap 10.3, and then intersected use and available points with the layer. For all other variables, we simply intersected the locations with the layer. We standardized all variables prior to model development $[(x_i - \bar{x})/s]$.

Model Development and Assessment

We developed *a priori* models (hypotheses) within an information theoretic framework (Burnham and Anderson 2002). We selected hypotheses based on sage-grouse brooding ecology (Aldridge et al. 2008; Crawford et al. 2004; Dahlgren et al. 2006) and previous research in Strawberry Valley (Westover et al. 2016). We used a 2-stage hierarchical approach. For each stage, we developed a unique set of univariable and multivariable *a priori* models, avoiding highly correlated variables ($r \geq |0.6|$) in the same model. In stage 1, we developed hypotheses for all four categories of variables. For each category we identified competitive ($AIC_c \leq 2.0$) models and advanced those models (maintaining model structure) to the second step (Carpenter et al. 2010). In step 2, we generated a new set of *a priori* hypotheses based on combinations of model structures that advanced from step 1. We reported all models from step 2 with ≥ 1% of AIC_c weight. An entire list of models developed in each step can be found in the Chapter 1 Appendix.

Models may contain uninformative variables despite having some measure of AIC_c weight (Arnold 2010). We used AIC_c values and model composition to identify the most supported models and which variables were informative (Arnold 2010). For example, if a model with a lower AIC_c differed by the addition of only one variable and approximately 2.0 AIC_c from a similar model ranked above it, we considered that model uninformative and advanced the top (more parsimonious) model. In the case of multiple models with support, we did not model average beta coefficients (Cade 2015). Instead, we used the merTools package (Knowles and Frederick 2015) in R 3.1.3 (R Core Team 2015) to produce predicted responses with 85% confidence intervals, then averaged those values based on the relative AIC_c weight of the most-supported models. We followed this procedure, first, to produce a graphical representation of the relative probability of use as a function of distance to a treatment edge. Second, we generated two predictive maps, one each for PRET and POST, by applying this procedure to each raster pixel in our study area. We then used 5 equal-area bins to categorize the relative probabilities of use for each pixel from low to high (Fedy et al. 2015).

To help assess final models, we used variance inflation factors (VIF) to further test for multicollinearity among variables. We considered VIF > 10 to indicate evidence of multicollinearity (Aldridge and Boyce 2007; Coates and Delehanty 2010; Holloran et al. 2015; O'Brien 2007). To assess predictive ability of our final models, we performed a *k*-folds cross validation with *k*=5 (Long et al. 2009). We randomly sorted observations into 5 partitions, with an approximately equal number of locations in each partition. During each iteration of this procedure, we used four partitions (80% of the data) as the training set to estimate model coefficients and the remaining partition (20% of the data) to test model predictions. We repeated this procedure until all observations were used both as the test set and as part of the training set.

RESULTS

Vegetation Response

Mechanical treatments significantly reduced crown area, shrub height, and shrub cover in POST vs PRET samples (Table 2). Mean percent shrub cover at POST sites was roughly half (0.16 ± 0.01) that of PRET (0.32 ± 0.01) sites (Fig. 2). Percent grass cover was higher POST (0.31 ± 0.02) compared to PRET (0.12 ± 0.01). Statistically, grass richness (mean number of species per site detected in 0.25 m^2 quadrats) POST (1.73 ± 0.09) was higher than PRET (1.40 ± 0.04) although the effect size was relative small (estimated difference of 0.15). Forb richness (1.51 ± 0.06 PRET, 1.31 ± 0.11 POST) and percent forb cover (0.12 ± 0.01 PRET, 0.13 ± 0.01 POST) were not different between POST and PRET periods.

Sage-Grouse Response

We used 418 locations from 72 sage-grouse (mean, 5.8 ± 0.7 locations per individual; range, 1 - 28) to build models in our mixed-effects logistic regression analysis. Of the 418 locations, 333 were from 61 PRET sage-grouse, and 85 were from 11 POST sage-grouse. We compared these use locations to 918 random locations (453 locations PRET, 461 locations POST). Mean distance (± SE) of brood locations to future treatment edge was 823.9 ± 66.6 m PRET while POST mean distance to those same edges after treatment was 208.2 ± 46.2 m. Only 37.2% (124 of 333) of PRET brood locations were within 90 m of a future treatment edge. Conversely, 75.3% (64 of 85) of POST brood locations were ≤ 90 m from a treatment edge (Fig. 3). Seventy five percent of PRET locations were within 955.4 m of the future treatment edges, while 75% of POST locations were within 84.5 m of treatment edges after mechanical treatment.

Overall, greater sage-grouse selected areas that were 1) far from trees, paved roads, and powerlines, 2) high in elevation, 3) near treatment edges, and 4) consisting of gentle slopes (Tables 3 and 4). Post-treatment sage-grouse showed stronger selection for areas near treatments than did pre-treatment sage-grouse (Fig. 4). All models with ≤ 2 ΔAIC_c contained slope (negative), elevation (positive), distance to trees (positive), distance to paved roads (positive), distance to powerlines (positive), distance to treatment (negative), squared distance to treatment (positive), interaction term of distance to treatment and binary PRET/POST variable (negative), and squared interaction term of squared distance to treatment and binary PRET/POST variable (positive). The interaction term and distance to treatment had the greatest and second greatest influence, respectively, on habitat selection in our sample (Table 4).

We disregarded one of the three models with $\Delta AIC_c \leq 2$ due to an uninformative parameter (Arnold 2010) (Table 3). The third-ranked model was 2 AIC_c higher than the top ranked model, with the addition of only one variable. Distance to an edge consisting of riparian and trees was uninformative, with confidence intervals overlapping zero (β=0.03, [-0.20; 0.25]; Table 4). Using coefficients from the two informative models with $\Delta AIC_c < 2$, we projected relative probability of use across the landscape within the study area for PRET (Fig. 5) and

POST (Fig. 6). Mean predictive ability of the top performing models from the five-fold cross validation was high (Spearman $\rho = 0.95$; $P < 0.05$). We found no evidence for collinearity among predictor variables in any of our final models (VIF < 5), with the exception of distance to treatment and distance to treatment squared, which was expected.

DISCUSSION

Our study provides before-and-after evidence that habitat selection by sage-grouse in Strawberry Valley changed in response to mechanical treatments of sagebrush. Distance to treatment edges had the greatest influence on overall habitat selection, while the negative, significant interaction term indicated POST females with broods selected for areas nearer to treatment edges than did PRET females with broods. A significant increase in use in and near treated areas by sage-grouse with broods provides managers some measure of validation for electing to use mechanical alterations for improving brood-rearing habitat in mountain big sagebrush. Linking use of treated areas with brood survival would provide additional justification for using mechanical treatments in areas dominated by mountain big sagebrush.

Use of treated areas by sage-grouse broods has been documented in other areas (Dahlgren et al. 2006; Dahlgren et al. 2015; Klebenow 1970; Thacker 2010). Moreover, similar preferences for treatment edges were observed in other studies performed in mountain big sagebrush in northern and southern Utah (Dahlgren et al. 2006; Dahlgren et al. 2015). In northern Utah, 80% of sage-grouse were found within 60 m of a treatment edge (Dahlgren et al. 2015). On Parker Mountain in southern Utah, analysis from sage-grouse pellet surveys showed a dramatic decline in number of pellets between 20 and 30 m from Dixie-harrow treatments (Dahlgren et al. 2006). Our results support findings from previous studies while adding a valuable GIS component that allowed us to determine the influence of sagebrush removal relative to other potential factors influencing brood habitat selection.

Non-treatment variables in our top models and their effect sizes were generally consistent with sage-grouse brooding ecology. Sage-grouse broods exhibited avoidance of trees (Baruch-Mordo et al. 2013; Casazza et al. 2011; Knick et al. 2013; Wisdom et al. 2011); powerlines and paved roads (Doherty et al. 2008; Holloran et al. 2005; Lyon and Anderson 2003; Wisdom et al. 2011), and slopes > 20° (Atamian et al. 2010; Knick et al. 2013). Sage-grouse also tended to select areas with high elevations in our study area. Sage-grouse broods are often associated with riparian areas and wet meadows which are generally situated in valley bottoms (Connelly et al. 2000; Crawford et al. 2004; Drut et al. 1994; Klebenow 1970). One potential explanation for sage-grouse not selecting for valley bottoms in our study area may be due to the mesic nature of Strawberry Valley where forbs and grasses retain succulence late into the summer even at high elevations. Another explanation may be associated with the fragmentation of sagebrush caused by Strawberry Reservoir. As the reservoir filled, it created islands and small peninsulas with gentle slopes on top (preferred by female sage-grouse with broods), but it also left steep (> 50° slope) terrain along the perimeter of the reservoir where sage-grouse broods were unlikely to be found. Consequently, tops of islands and peninsulas that were higher in elevation had greater probability of use than areas of lower elevation.

Vegetation response to mechanical treatment was similar to data from other studies in mountain big sagebrush. When shrub cover was reduced, grass cover increased (Dahlgren et al. 2006; Davies et al. 2012c). Forb cover did not increase in association with sagebrush removal in our area as we predicted, neither did it decrease (Davis and Crawford 2015). This result differs from other studies where forb cover increased 2-3% in the years immediately following treatment (Dahlgren et al. 2006; Davies et al. 2012a). This difference may be due to a slight decrease in annual precipitation in 2013 and 2014 (when vegetation measurements were taken) compared to historic mean precipitation, increased resource competition between grasses and forbs, or a potential lag effect in establishment of forbs following treatment (Sturges 1993).

Our results demonstrated selection for mechanically-altered habitat by sage-grouse during the brooding period similar to other studies (Dahlgren et al. 2006; Dahlgren et al. 2015; Thacker 2010), while adding important empirical evidence from spatial modeling with an interactive term that captured differences between pre- and post-treatment. Although additional sites, years, and sage-grouse locations post-treatment would certainly strengthen this analysis, our *k*-folds cross validation suggests that the altered pattern in habitat selection by sage-grouse we observed was a real effect and not overly influenced by modest sample sizes.

Sage-grouse showed a dramatic increase in selection for areas in and near the 2009 treatment, in particular. The percent area inside or within 90 m of 2009 treatment polygons that was in the medium-high category for relative probability of use decreased from 44.5% to 15.9%, while the percent area in the high category increased from 49.5% prior to treatment to 83.9% following mechanical alteration. The area treated in 2011 followed a similar pattern, although not as strong a contrast between PRET and POST (medium-high, 21.4% to 13.0%; high, 72.1% to 86.9%). The 2014 treatment held a slightly different pattern, with the percent area in the medium-high and high categories both increasing PRET to POST, from 56.8% to 61.6% and 6.9% to 38.0%, respectively. Habitat selection is a function of availability and the 2009 treatment may have influenced sage-grouse selection for the later treatments. Nonetheless, an overall increase in the quantity of predicted habitat in and near treatment plots suggests that vegetation treatments improved brood-rearing habitat in our study area.

MANAGEMENT IMPLICATIONS

Our results highlight the use of mechanical treatments of sagebrush as a method for managers to increase the amount of brood habitat. Greater sage-grouse with broods selected for areas in and near mechanical treatment plots, where shrub cover was dramatically reduced and graminoid cover increased following implementation of sagebrush treatments. We suggest that mechanical treatment of mountain big sagebrush may be an appropriate method to enhance sage-grouse brood habitat when treatments target specific locales of dense (> 40%) sagebrush, avoid crucial nesting or winter habitat, and leave a mosaic of sagebrush and herbaceous cover. In areas where brood-rearing habitat is not limiting or vegetation is unlikely to respond favorably, sagebrush treatments are not recommended for conservation of sage-grouse and other species such as mule deer (Beck et al. 2009; Beck et al. 2012; Davies et al. 2009; Davies et al. 2012b; Fischer et al. 1996). These concerns, however, are generally not as applicable to treatments performed in mountain big sagebrush (Dahlgren et al. 2006; Davies et al. 2012c; Davis and Crawford 2015; this study). Additional research is needed to address the relationship between use of treatments by sage-grouse and population vital rates.

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FIGURES

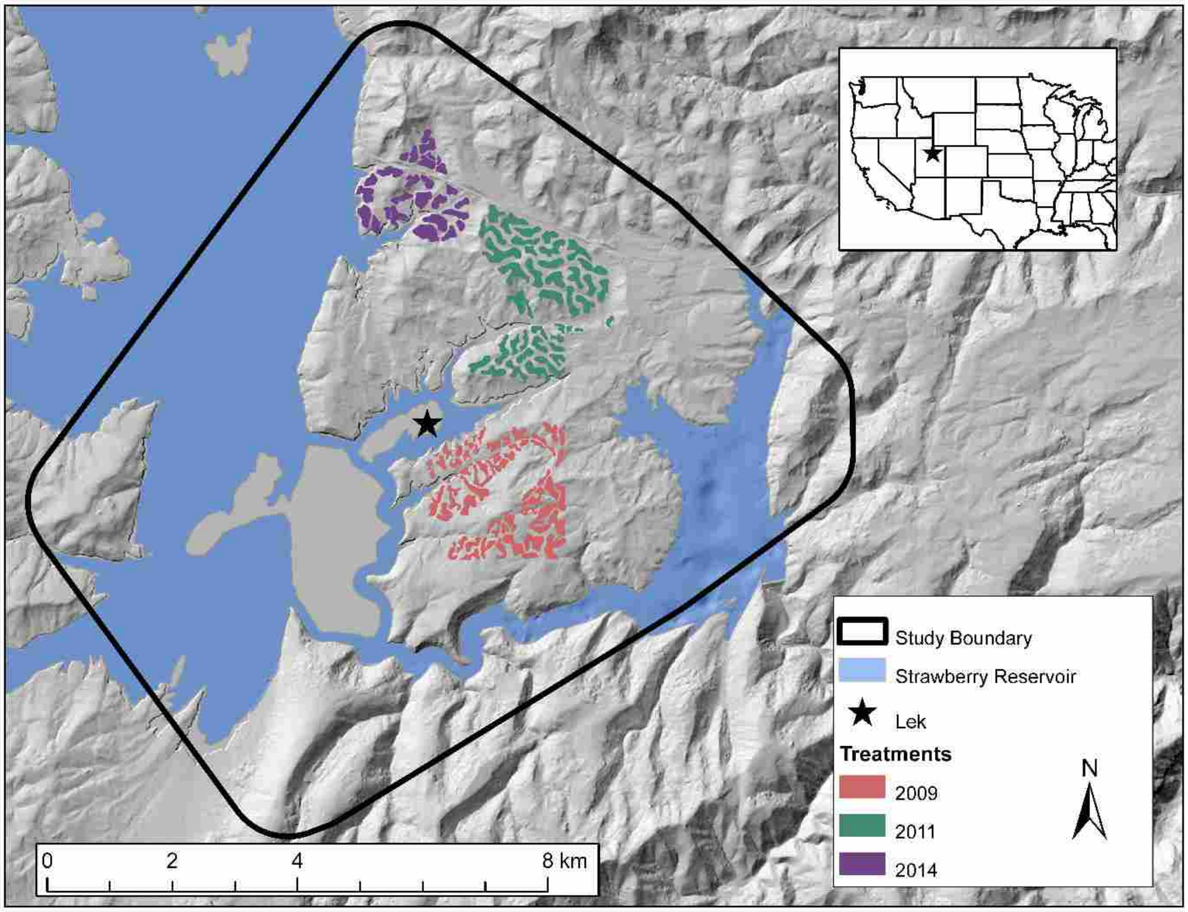

Figure 1–1. Map of Strawberry Valley in north central Utah, USA where we assessed habitat selection by greater sage-grouse (*Centrocercus urophasianus*) with broods in response to mechanical treatment of sagebrush (*Artemisia tridentata vaseyana*). The boundary (black outline) of the study area was based on a 1-km buffer around a 50% minimum convex polygon of all greater sage-grouse brood locations from 1998-2016, centered on the lek nearest to the mechanical treatments.

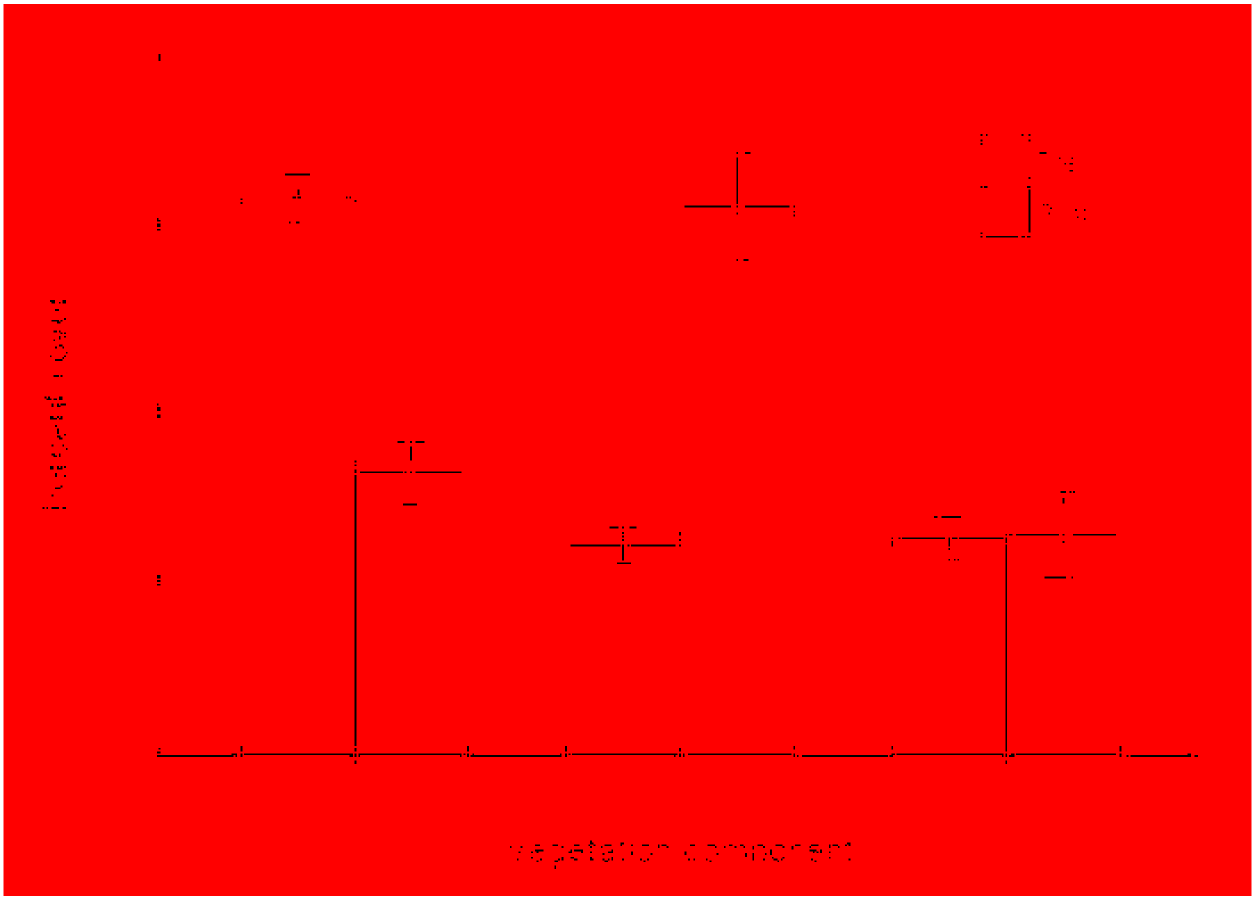

Figure 1–2. Percent cover of vegetation components before (1998-2009) and after (2010-2016) mechanical treatment of mountain big sagebrush (*Artemisia tridentata vaseyana*) in Strawberry Valley, Utah, USA. Error bars are 95% confidence intervals.

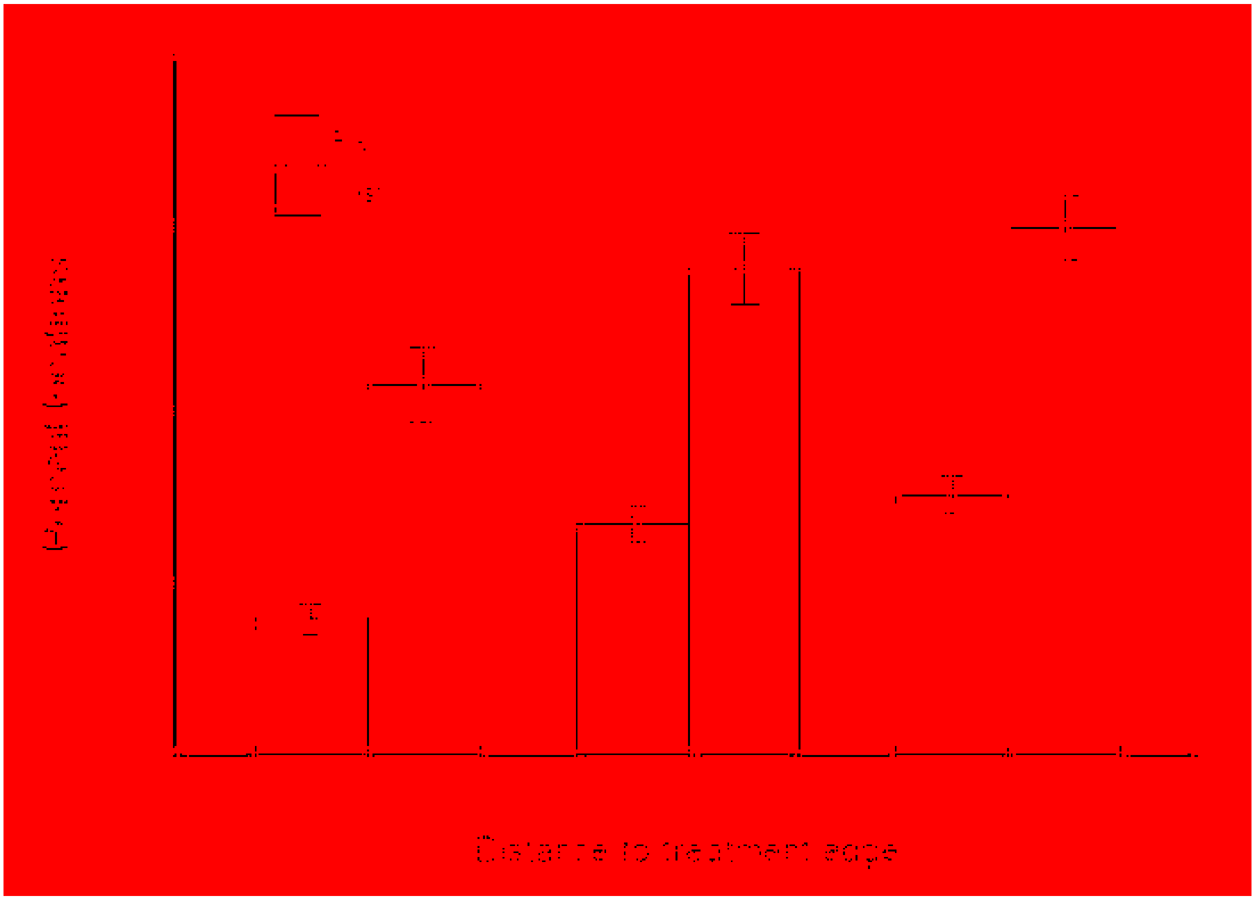

Figure 1–3. Percent of greater sage-grouse (*Centrocercus urophasianus*) brood locations in Strawberry Valley, Utah, USA found within 30 m, 60 m, and 90 m of a treatment edge both before (pre-treatment, 1998-2009) and after (post-treatment, 2010-2016) mechanical alteration of sagebrush (*Artemisia tridentata vaseyana*). Error bars are standard errors.

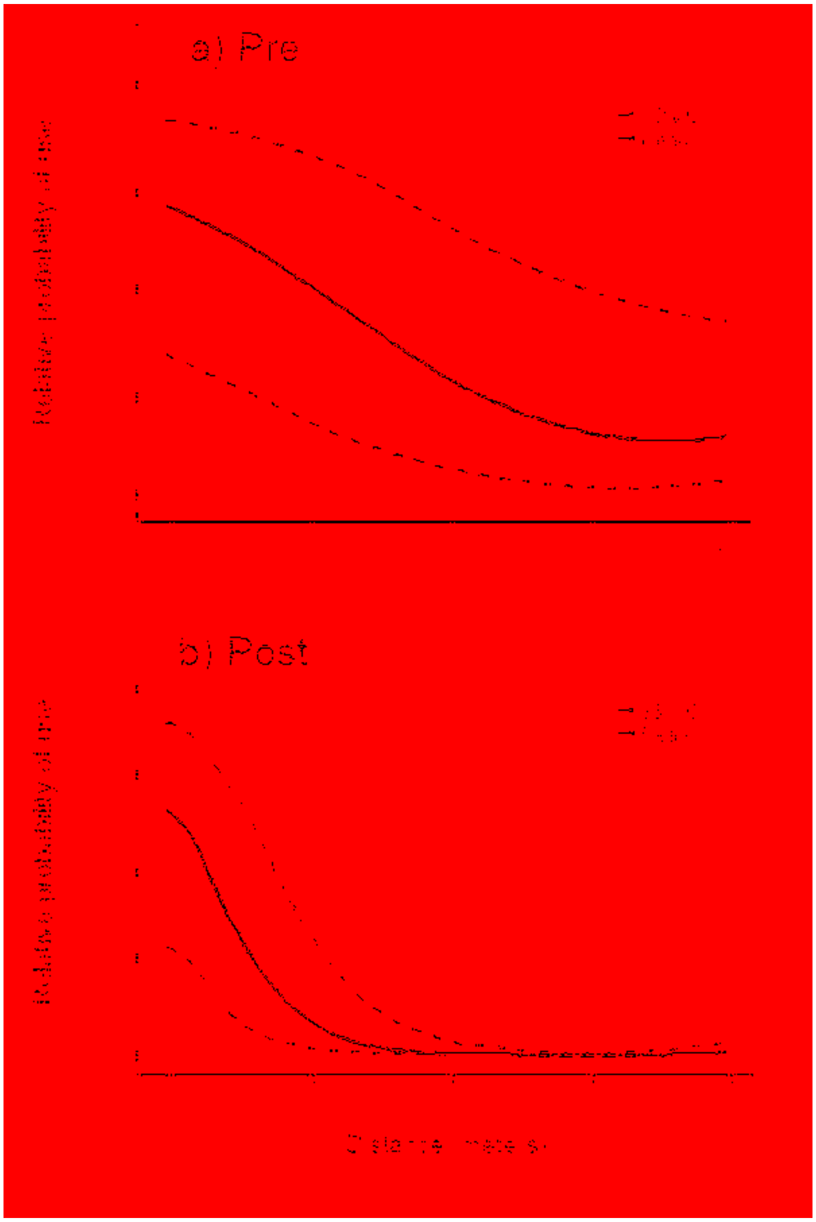

Figure 1–4. Resource selection functions showing relative probability of use for greater sage-grouse (*Centrocercus urophasianus*) in Strawberry Valley, Utah, USA as related to distance to edges of mechanically altered sagebrush (*Artemisia tridentata vaseyana*) a) prior to implementation of treatments (1998-2009) and b) in the years following treatment (2010-2016).

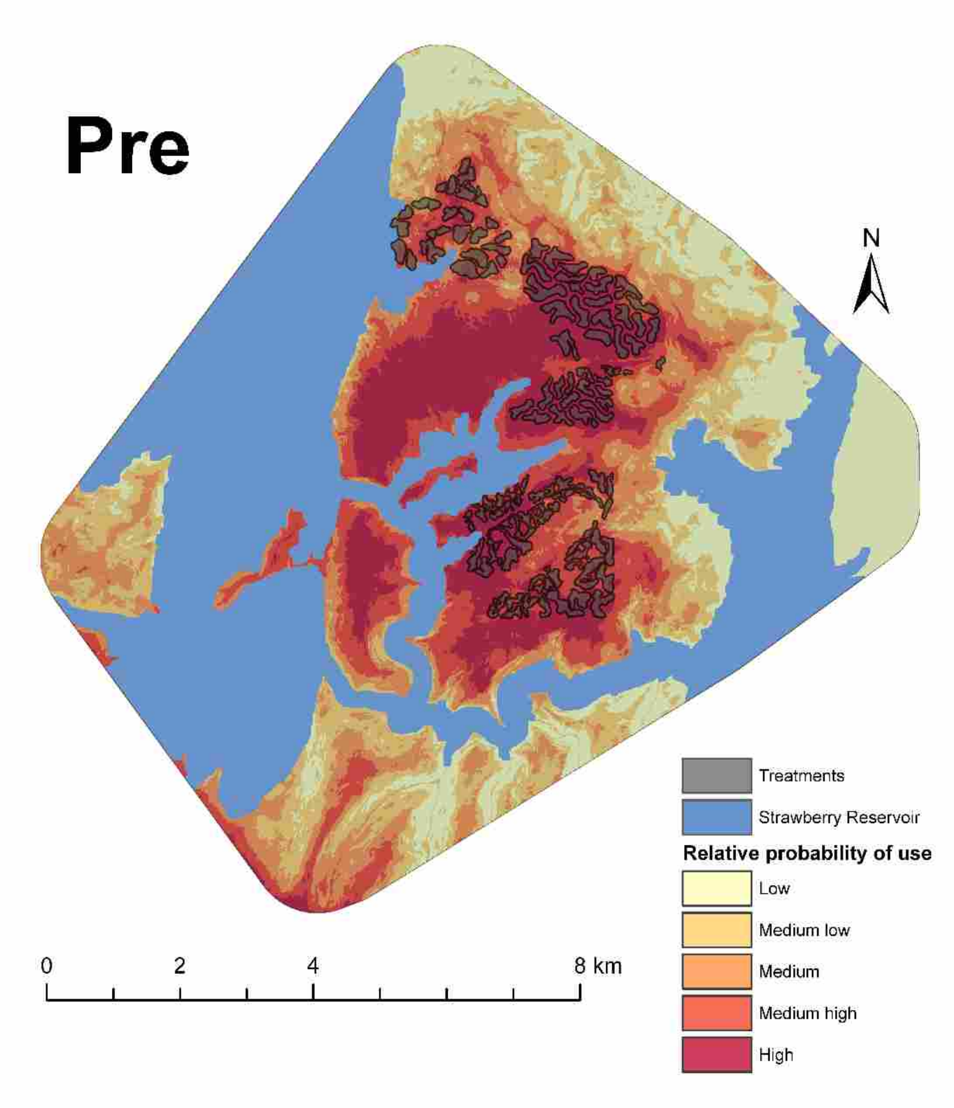

Figure 1–5. Relative probabilities of selection by greater sage-grouse (*Centrocercus urophasianus*) with broods in Strawberry Valley, Utah, USA based on mixed-effects logistic regression models. The figure shows the study area prior (1998-2009) to mechanical treatment of sagebrush (*Artemisia tridentata vaseyana*). Relative probability of use was binned into 5 categories, from low (yellow) to high (red).

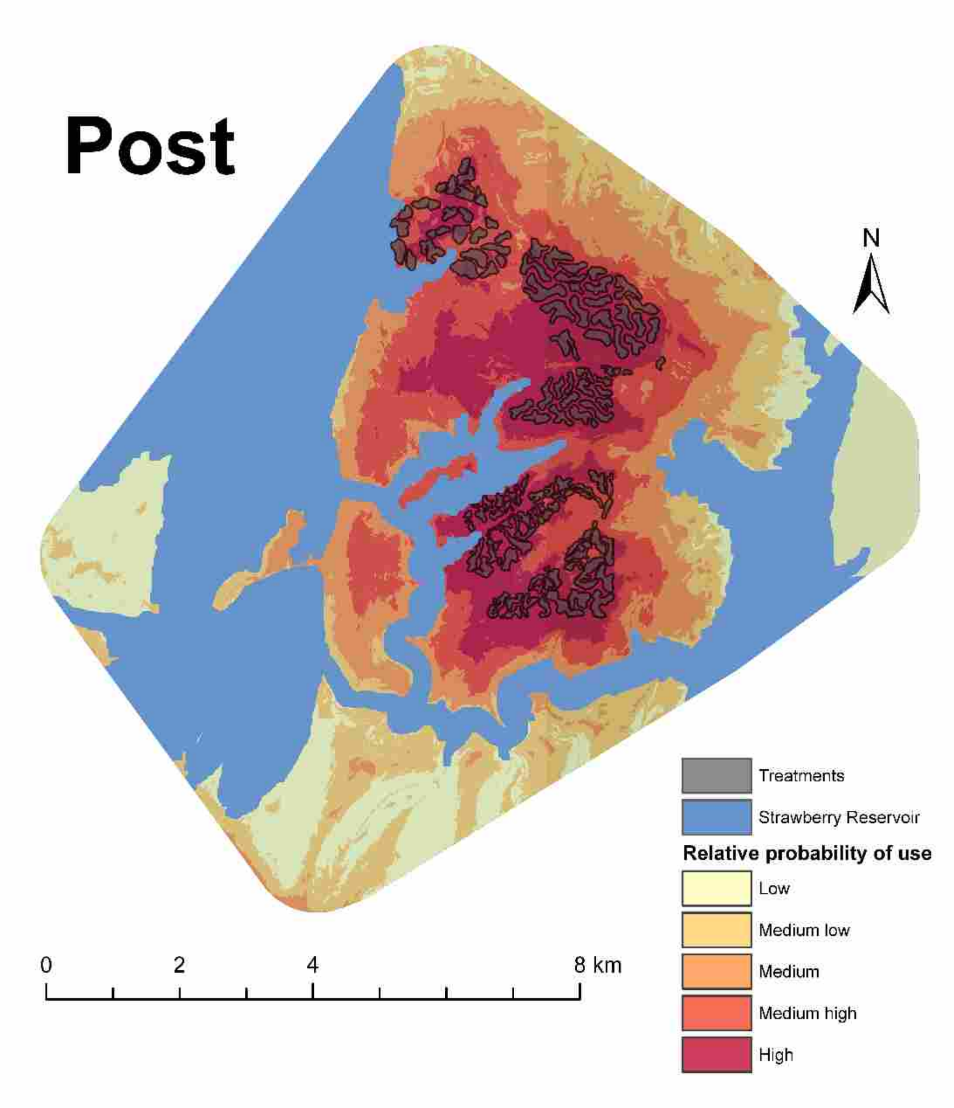

Figure 1–6. Relative probabilities of selection by greater sage-grouse (*Centrocercus urophasianus*) with broods in Strawberry Valley, Utah, USA based on mixed-effects logistic regression models. The figure shows the study area in the years following (2010-2016) mechanical alteration of sagebrush (*Artemisia tridentata vaseyana*). Relative probability of use was binned into 5 categories, from low (yellow) to high (red).

TABLES

Table 1-1. Geographic information system (GIS) predictor variables potentially associated with greater sage-grouse (*Centrocercus urophasianus*) use sites in Strawberry Valley, Utah, USA 1998-2016. Topographic data are 10-m resolution. Anthropogenic, vegetation, and treatment data are 1-m resolution

Variable name	**Description**
Topographic	
ASPECTBIN	Aspect binned to the four cardinal directions
ELEV	Elevation in meters
SLOPE	Slope in degrees
TPI25	Topographic Position Index[a] with a 25-cell neighborhood
TPI50	Topographic Position Index[a] with a 50-cell neighborhood
TPI100	Topographic Position Index[a] with a 100-cell neighborhood
VRM5	Vector Ruggedness Measure[b] with a 5-cell neighborhood
VRM7	Vector Ruggedness Measure[b] with a 7-cell neighborhood
VRM11	Vector Ruggedness Measure[b] with a 11-cell neighborhood
Anthropogenic	
D.PLINE	Distance to power lines
D.PSTRUCT	Distance to permanent structure
D.ROAD2T	Distance to 2-track road
D.ROADHUD	Distance to high-use dirt road
D.ROADPAV	Distance to paved road
Vegetative	
HabType	Land cover class[c] (shrub, riparian, etc.)
D.BA.TR	Distance to an edge consisting of bare ground and trees
D.BAREG	Distance to bare ground
D.GRASS	Distance to grass
D.RI.TR	Distance to an edge consisting of riparian and trees
D.RIP	Distance to riparian
D.SH.GR	Distance to an edge consisting of shrub and grass
D.SH.RI	Distance to an edge consisting of shrub and riparian
D.SH.TR	Distance to an edge consisting of shrub and trees
D.SH.WA	Distance to an edge consisting of shrub and water
D.SHRUB	Distance to shrub
D.TREE	Distance to tree
D.WATER	Distance to water
Treatment	
IN.OUT	Binary variable where 0=outside a treatment and 1=inside a treatment
PERIOD	Binary variable where 0=Pre and 1=Post
N.TREAT	Distance to treatment
N.TREAT2	Distance to treatment, squared
PRE.POST	Interaction between *PERIOD* and *N.TREAT*
PRE.POST2	Interaction between *PERIOD* and *N.TREAT2*

[a]Jenness and Beier (2013)

[b]Sappington et al. (2007)

[c]Westover et al. (2016)

Table 1-2. Mean (±SE) vegetation measurements taken at random locations prior to and following mechanical treatments of mountain big sagebrush (*Artemisia tridentata vaseyana*) in Strawberry Valley, Utah, USA. Difference in means with 95% confidence intervals is also shown.

		Pre	Post	Difference	95% Confidence Interval
		Mean ± SE	Mean ± SE		
Crown Area*	cm^2	6118.8 ± 629.13	1095.55 ± 120.73	-5023.25	[-6278.84, -3767.66]
Horizontal obscurity	%	90.91 ± 0.96	87.75 ± 1.22	-3.2	[-6.2, -0.2]
Decadence*	%	24.82 ± 1.18	30.09 ± 1.95	5.26	[0.79, 9.73]
Shrub height	cm	36.38 ± 1.23	33.54 ± 1.52	-2.84	[-6.67, 0.99]
Shrub canopy cover*	%	31.81 ± 0.70	16.16 ± 0.89	-15.7	[-17.9, -13.5]
Grass richness*	# spp.	1.40 ± 0.04	1.73 ± 0.09	0.32	[0.14, 0.51]
Forb richness	# spp.	1.51 ± 0.06	1.31 ± 0.11	-0.19	[-0.43, 0.05]
Grass cover*	%	12.02 ± 0.51	31.33 ± 1.52	19.3	[16.2, 22.4]
Forb cover	%	12.39 ± 0.61	12.58 ± 1.23	0.2	[-2.5, 2.9]
Moss	%	3.02 ± 0.92	0.47 ± 0.15	-2.6	[-4.4, -0.8]
Bare ground	%	13.24 ± 0.92	13.15 ± 0.92	-0.1	[-2.6, 2.4]
Rock*	%	9.18 ± 1.33	2.00 ± 0.34	-7.2	[-9.9, -4.5]
Litter*	%	46.73 ± 1.04	34.67 ± 1.02	-12.1	[-14.9, -9.3]

Table 1-3. Model results (≥ 0.01 model weight) for habitat selection by greater sage-grouse (*Centrocercus urophasianus*) with broods in Strawberry Valley, Utah, USA in relation to mechanical alteration of sagebrush (*Artemisia tridentata vaseyana*) showing number of parameters (*K*), corrected Akaike's Information Criterion (AIC_c), ΔAIC_c, model weight (ω_i), and log likelihood (LL). Variable names match those in Table 1.

Model Number	Model Structure	*K*	AIC_c	ΔAIC_c	ω_i	LL
47	D.GRASS+D.TREES+SLOPE+ELEV+D.ROADPAV+D.ROAD2T+D.PLINE+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2+IN.OUT	14	815.62	0.00	0.41	-393.65
51	D.RI.TR+D.TREES+D.SH.WA+SLOPE+ELEV+D.ROADPAV+D.ROAD2T+D.PLINE+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2	14	817.22	1.60	0.18	-394.45
43[a]	D.GRASS+D.RI.TR+D.TREES+SLOPE+ELEV+D.ROADPAV+D.ROAD2T+D.PLINE+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2+IN.OUT	15	817.61	1.99	0.15	-393.62
53	D.RI.TR+D.SHRUB+D.TREES+SLOPE+ELEV+D.ROADPAV+D.ROAD2T+D.PLINE+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2+IN.OUT	15	819.01	3.39	0.07	-394.32
48	D.GRASS+D.TREES+SLOPE+VRM11+ELEV+D.PLINE+D.ROADPAV+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2	13	820.09	4.47	0.04	-396.91
41	D.RI.TR+D.TREES+SLOPE+D.ROADPAV+D.ROAD2T+D.PLINE+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2+IN.OUT	13	820.83	5.21	0.03	-397.28
44	D.RI.TR+D.TREES+D.SH.WA+SLOPE+VRM11+ELEV+D.PLINE+D.ROADPAV+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2	14	821.04	5.42	0.03	-396.36
45	D.TREES+SLOPE+D.ROADPAV+D.ROAD2T+D.PLINE+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2+IN.OUT	12	821.10	5.48	0.03	-398.43
54	D.RI.TR+D.TREES+SLOPE+VRM11+ELEV+D.PLINE+D.ROADPAV+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2	13	821.35	5.73	0.02	-397.54
52[a]	D.GRASS+D.RI.TR+D.TREES+SLOPE+VRM11+ELEV+D.PLINE+D.ROADPAV+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2	14	822.08	6.46	0.02	-396.88
49	D.SHRUB+D.TREES+SLOPE+D.ROADPAV+D.ROAD2T+D.PLINE+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2	12	823.06	7.44	0.01	-399.41
55	NULL	2	1138.18	322.56	0.00	-567.09

[a]Uninformative model based on AIC_c and variables

Table 1-4. β coefficients and 85% confidence intervals for variables in models (≥ 1% of model weight) explaining habitat selection by greater sage-grouse (*Centrocercus urophasianus*) with broods in Strawberry Valley, Utah, USA in relation to mechanical alteration of sagebrush (*Artemisia tridentata vaseyana*). Blanks indicate the variable was not included in that model and asterisks (*) indicate the confidence interval did not overlap zero. Model numbers match those in Table 3. Variable names match those in Table 1.

Model Number	β coefficients and 85% confidence intervals																
	Intercept	SLOPE	VRM11	ELEV	D.RI.TR	D.TREES	D.SHRUB	D.GRASS	D.SH.WA	D.ROADPAV	D.ROAD2T	D.PLINE	N.TREAT	N.TREAT2	PRE.POST	PRE.POST2	IN.OUT
47	-0.70* [-0.99; -0.42]	-0.47* [-0.65; -0.28]		0.39* [0.18; 0.59]		0.72* [0.56; 0.89]		0.13 [-0.01; 0.28]		0.59* [0.31; 0.86]	0.24* [0.07; 0.41]	0.39* [0.16; 0.62]	-2.58* [-3.28; -1.87]	1.96* [1.33; 2.59]	-2.66* [-3.52; -1.80]	1.36* [0.17; 2.56]	-0.55* [-0.98; -0.12]
51	-0.76* [-1.04; -0.47]	-0.48* [-0.66; -0.30]		0.48* [0.24; 0.73]	0.04 [-0.13; 0.20]	0.76* [0.58; 0.93]			-0.23* [-0.44; -0.03]	0.48* [0.21; 0.76]	0.23* [0.06; 0.40]	0.31* [0.08; 0.55]	-2.31* [-2.98; -1.64]	1.76* [1.17; 2.36]	-2.60* [-3.46; -1.74]	1.30* [0.04; 2.55]	
43[a]	-0.70* [-0.99; -0.42]	-0.47* [-0.65; -0.28]		0.37* [0.15; 0.59]	0.03 [-0.14; 0.19]	0.72* [0.54; 0.89]		0.13 [-0.02; 0.28]		0.59* [0.32; 0.87]	0.24* [0.07; 0.41]	0.38* [0.15; 0.62]	-2.56* [-3.27; -1.84]	1.95* [1.32; 2.58]	-2.67* [-3.53; -1.80]	1.37* [0.18; 2.56]	-0.55* [-0.99; -0.12]
53	-0.71* [-0.99; -0.43]	-0.48* [-0.67; -0.30]		0.35* [0.13; 0.58]	0.04 [-0.12; 0.20]	0.73* [0.55; 0.90]	-0.05 [-0.21; 0.10]			0.61* [0.33; 0.89]	0.24* [0.07; 0.41]	0.34* [0.11; 0.58]	-2.52* [-3.23; -1.81]	1.95* [1.32; 2.58]	-2.67* [-3.53; -1.80]	1.36* [0.17; 2.56]	-0.52* [-0.95; -0.09]
48	-0.76* [-1.04; -0.48]	-0.41* [-0.60; -0.23]	0.03 [-0.15; 0.20]	0.35* [0.15; 0.55]		0.72* [0.56; 0.88]		0.12 [-0.03; 0.26]		0.57* [0.30; 0.84]		0.52* [0.30; 0.73]	-2.30* [-2.96; -1.63]	1.70* [1.10; 2.29]	-2.66* [-3.51; -1.81]	1.37* [0.17; 2.57]	
41	-0.68* [-0.96; -0.40]	-0.48* [-0.66; -0.30]			0.16* [0.01; 0.30]	0.70* [0.53; 0.87]				0.82* [0.58; 1.06]	0.22* [0.05; 0.39]	0.16 [-0.04; 0.36]	-2.35* [-3.05; -1.65]	1.94* [1.31; 2.56]	-2.66* [-3.53; -1.80]	1.37* [0.18; 2.57]	-0.49* [-0.92; -0.07]
44	-0.77* [-1.05; -0.50]	-0.44* [-0.62; -0.26]	-0.01 [-0.19; 0.16]	0.44* [0.20; 0.69]	0.04 [-0.12; 0.20]	0.77* [0.59; 0.94]			-0.21* [-0.42; -0.01]	0.51* [0.23; 0.79]		0.42* [0.20; 0.65]	-2.27* [-2.93; -1.60]	1.69* [1.10; 2.28]	-2.72* [-3.57; -1.88]	1.43* [0.27; 2.58]	
45	-0.67* [-0.95; -0.39]	-0.48* [-0.66; -0.30]				0.75* [0.59; 0.91]				0.85* [0.61; 1.08]	0.21* [0.04; 0.38]	0.16 [-0.03; 0.36]	-2.44* [-3.14; -1.75]	1.99* [1.37; 2.62]	-2.62* [-3.48; -1.75]	1.33* [0.13; 2.53]	-0.46* [-0.88; -0.04]
54	-0.77* [-1.05; -0.48]	-0.43* [-0.61; -0.25]	0.01 [-0.17; 0.18]	0.33* [0.11; 0.55]	0.04 [-0.12; 0.20]	0.73* [0.57; 0.90]				0.58* [0.31; 0.85]		0.48* [0.27; 0.70]	-2.25* [-2.92; -1.58]	1.69* [1.09; 2.28]	-2.68* [-3.53; -1.84]	1.39* [0.19; 2.58]	
52[a]	-0.76* [-1.04; -0.48]	-0.41* [-0.60; -0.23]	0.03 [-0.14; 0.20]	0.34* [0.12; 0.55]	0.03 [-0.14; 0.19]	0.71* [0.54; 0.88]		0.11 [-0.03; 0.26]		0.58* [0.31; 0.85]		0.51* [0.29; 0.73]	-2.28* [-2.95; -1.60]	1.69* [1.09; 2.29]	-2.67* [-3.52; -1.81]	1.37* [0.18; 2.57]	
49	-0.70* [-0.99; -0.41]	-0.44* [-0.62; -0.26]				0.71* [0.55; 0.88]	-0.07 [-0.22; 0.08]			0.83* [0.59; 1.06]	0.18* [0.01; 0.35]	0.19 [-0.01; 0.38]	-2.24* [-2.90; -1.58]	1.82* [1.22; 2.42]	-2.53* [-3.41; -1.64]	1.23 [-0.06; 2.53]	
55	0.13																

	[-0.02; 0.28]

[a]Uninformative parameter based on AIC_c and variables

CHAPTER 2

Factors Influencing Nest Predation of Greater Sage-Grouse: Testing the Edge Effect Hypothesis

Jared J. Baxter, Rick J. Baxter, and Randy T. Larsen
Department of Plant and Wildlife Sciences, Brigham Young University, Provo, UT

ABSTRACT

The "edge effect" hypothesis states that habitat edges are associated with reduced nest success for birds. Edges between two contrasting vegetation communities can facilitate movement by predators into core habitat or improve detection of nests, thereby increasing mortality of adults and/or decreasing reproductive success. Predation accounts for > 90% of nest failures of greater sage-grouse (*Centrocercus urophasianus*) and may be elevated near edges. We tested the edge effect hypothesis using an 18-year dataset of greater sage-grouse nests (1998-2015; 155 nest locations from 114 sage-grouse). We derived edge metrics for 11 habitat cover types at multiple spatial extents and used an information theoretic approach to determine which variables may have affected nest predation. Of the 155 nests, 86 successfully hatched ≥ 1 egg; the remaining 69 nests were depredated. We found support for the edge effect hypothesis in that predation of greater sage-grouse nests was influenced by edge density of paved roads at the largest extent (1500 m). Edge density of paved roads was in every model with $\Delta AIC_c < 2.0$, except one. Increasing the edge density of paved roads increased the probability of predation (85% confidence intervals did not overlap zero). Likewise, edge density of high-use dirt roads was a significant discriminant between successful and depredated nests, positively influencing nest predation. We provide evidence that the edge effect hypothesis may apply to greater sage-

grouse and their habitats. Based on our results, we recommend minimizing disturbances that fragment critical nesting habitat of greater sage-grouse.

INTRODUCTION

Boundaries between adjacent land cover or habitat types due to natural or anthropogenic influences are termed edges. Edges can be the result of natural processes, such as wildfire, encroachment of pinyon/juniper woodlands into sagebrush (Artemisia sp.) habitats, or drought. Often, though not always, natural events result in "soft" edges, or gradual transitions between two cover types. Conversely, anthropogenic disturbances, such as rangeland conversion to agriculture, construction of largescale infrastructure (i.e. energy development, transmission lines, or roads and highways), or urbanization tend to create "hard" edges where clearly defined boundaries are visible. The greater the proportion of edges in a landscape, the greater the fragmentation of the natural land cover or habitat types. Both naturally-occurring fragmentation and that induced by anthropogenic disturbances produce edges within core habitat. Habitat edges can be associated with reduced abundance and productivity of prey species, and this is termed the "edge effect" (Murcia 1995). The edge effect hypothesis states that risk of predation increases as core habitat is fragmented, increasing the amount of edge available to predators. Edges can influence the distribution and/or abundance of predators; their movement on the landscape into and through prey habitat; or improve their ability to detect of prey, thereby leading to increased mortality of adults and/or decreased reproductive success (Gates and Gysel 1978; Schneider et al. 2012).

The influence of edges on nest success of avian species has received considerable attention (Chalfoun et al. 2002; Lahti 2001; Paton 1994; Vetter et al. 2013), as nest predation is the leading cause of nest failure for many birds (Martin 1993). However, evidence that edges are associated with increased nest mortality is ambiguous (Batáry and Báldi 2004; Chalfoun et al. 2002; Lahti 2001; Paton 1994). Support for the edge effect in the literature often depends on region, habitat or vegetation type, species of interest, and scale (Bar-Massada et al. 2012; Batáry and Báldi 2004; Cox et al. 2012; Vetter et al. 2013). For example, decreased nest survival of yellow warblers (*Setophaga petechia*) was associated with forest/woodland edges in two separate studies in the western United States (Cain et al. 2003; Tewksbury et al. 2006), yet no edge effect was apparent for nests of the yellow warbler in Minnesota (Hanski et al. 1996). Landscape fragmentation and composition had greater influence on predation of nests of black grouse (*Tetrao tetrix*) than drivers at the local scale (e.g., distance to edge) (Kurki et al. 2000). Probability of predation of artificial nests in black grouse habitat did not increase with decreasing distance to edge (Huhta et al. 2015). Moreover, beyond the difficulties in detecting an edge effect is the challenge of measuring its magnitude, which is more meaningful than simply identifying the presence of an effect for species of conservation or management concern (Gurevitch et al. 1992; Johnson 1999).

Conservation and informed management of habitat-obligate species is increasingly important given recent human-caused changes to habitats and landscapes (Davies et al. 2011b). Greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) are a species of conservation concern in sagebrush rangelands of western North America. Loss and fragmentation of core sagebrush habitat, largely due to anthropogenic influence, have led to a dramatic decline in numbers of sage-grouse (Knick et al. 2013; Schroeder et al. 2004). Energy development, agriculture, roads, reservoirs, and transmission lines have contributed to loss and fragmentation of sage-grouse habitat, including crucial nesting habitat (Lyon and Anderson

2003; Naugle et al. 2011; Wisdom et al. 2011). Roads, discharge ponds, well pads, buildings, fences, large-scale fire, and powerlines have also fragmented sagebrush landscapes, resulting in edges that increase accessibility of sage-grouse habitat by predators (Bui et al. 2010; Naugle et al. 2011; Walker et al. 2007). Moreover, human activity and infrastructure have been linked to increased abundance of predators (Bui et al. 2010; Kirol et al. 2015a; Wisdom et al. 2011).

The edge effect hypothesis, which postulates that increased abundance of edges leads to increased nest predation, has not been tested in sagebrush landscapes. The influence of "distance-to-feature" variables on nest survival of sage-grouse has been studied extensively (Baxter et al. 2009; Kirol et al. 2015a; Kirol et al. 2015b; Lockyer et al. 2015). However, the influence of edge metrics on the rate of nest predation has not been evaluated. Our objective was to assess the influence of edges in sagebrush habitat on predation of sage-grouse nests at multiple spatial extents, while accounting for other biotic and abiotic variables with the potential to influence nest survival (e.g., grass height, shrub canopy cover; Baxter et al. 2009; Connelly et al. 2000; Crawford et al. 2004; Holloran et al. 2005; Sveum et al. 1998). Specifically, we used GIS software to estimate edge and patch metrics for 11 land cover types at three different spatial extents (50 m, 500 m, 1500 m) to see if predation of sage-grouse nests correlated with amount of edge. To account for other variables with potential to influence nest predation, we also measured biotic (e.g., grass height, shrub cover) and abiotic (e.g., bare ground, rock) components at the nest microsite. We predicted 1) greater abundance of edges in sagebrush habitat at the largest spatial extent (1500 m) would be positively associated with nest predation, and 2) increased grass height at the nest micro-site would be associated with a reduced probability of nest predation (Crawford et al. 2004; Hansen et al. 2016; Lockyer et al. 2015).

METHODS

Study Area

The Strawberry Valley core study area was located in Wasatch County, Utah, south and east of the Uinta and Wasatch mountain ranges, respectively (UTM 12T, 490900 E, 4446500 N). Strawberry Reservoir was the dominant feature in the valley comprising nearly 7000 surface ha at full pool. Elevations in the core study area ranged from 2300-2600 m. The climate was characterized by cool summers (13.5° C mean air temperature) and cold winters (-8.7° C mean air temperature) with mean annual precipitation of 77.5 cm. Mountain big (*Artemisia tridentata vaseyana*) and silver (*A. cana*) sagebrush were the dominant shrubs in the western portion of the study area, typical of mesic sagebrush ecosystems. Common forbs found in our study area included silvery lupine (*Lupinus argenteus*), sticky purple geranium (*Geranium viscosissimum*), and sulphur-flower buckwheat (*Eriogonum umbellatum*). Common grasses included needle-and-thread (*Stipa comata*), Kentucky bluegrass (*Poa pratensis*), and prairie Junegrass (*Koeleria cristata*). To the east of the core study area was a lower-elevation, migratory area. Elevations ranged from 2000-2600 m. Wyoming big sagebrush (*A. t. wyomingensis*) was the dominant shrub in the area, with pinyon-juniper woodlands common throughout. Cheatgrass (*Bromus tectorum*) occurred at low densities in the eastern portion of the study area. Potential predators of sage-grouse nests were common raven (*Corvus corax*), coyote (*Canis latrans*), red fox (*Vulpes vulpes*), and American badger (*Taxidea taxus*) (Coates et al. 2008; Moynahan et al. 2007).

Sage-Grouse Capture and Monitoring

From 1998-2015 we captured female sage-grouse in Strawberry Valley during March-May using a spotlight method (Wakkinen et al. 1992) and ATV or backpack generator. From 2003-2008, 336 sage-grouse were translocated from four source populations around the state of Utah to Strawberry Valley (Baxter et al. 2013). For all birds, we identified age of females based on feather characteristics (adult or yearling; Bihrle 1993; Crunden 1963) and fitted them with a 22-g necklace radio-transmitter (Advanced Telemetry Systems, Inc., Isanti, MN and Sirtrack, New Zealand). Sage-grouse captured in Strawberry Valley were released at the capture site, and translocated sage-grouse were released over an active lek in Strawberry Valley.

Following capture and release, we located radio-marked females at nest sites using a 4-element Yagi antenna and TR-2 receiver (Telonics Incorporated®, Mesa, AZ) or R-1000 digital radio receiver (Communication Specialists Incorporated®, Orange, CA). After visual confirmation (i.e., binoculars) of a nesting sage-grouse, we monitored each nest 2-3 times each week at a distance of $\geq$ 10 m until nest hatch or failure. We considered a nest successful if $\geq$ 1 egg hatched. Successful nests were confirmed by evidence of separation of the egg membrane from the shell and/or flushing the marked female shortly after hatching and locating chicks (Klebenow 1969; Peck et al. 2012). Nest failures were categorized as predated or other, based on evidence such as crushed egg shells, punctures in otherwise whole eggs, etc. (Baxter et al. 2009; Coates et al. 2008). We did not attempt to distinguish between nest failures caused by mammalian vs avian predators (Coates et al. 2008). Nests that were abandoned due to weather events or observer error, as well as nests where fate was indeterminable were censored from the analysis. We used a handheld global positioning system (GPS) to record coordinates (UTMs) at sage-grouse nest sites in the NAD83 datum. Trapping and handling of sage-grouse was permitted and approved by the Utah Division of Wildlife Resources (Certificate of Registration numbers 1COLL6817 and 4BAND9604) and by the Institutional Animal Care and Use Committee at Brigham Young University (most recent protocol number 16-0404).

Vegetation Measurements and Analysis

We used T^2 analysis (Bonham 1989) and the line intercept method (Ludwig and Reynolds 1988) to measure shrub overstory components, including shrub crown area (Bunnell et al. 2004), shrub height, horizontal obscurity, and shrub decadence. We used a modified 0.25 m^2 quadrat (Daubenmire 1959) and ocular estimation to measure percent cover and species richness of grasses and forbs in the understory (Baxter et al. 2009; Bunnell et al. 2004). We identified shrubs, grasses, and forbs to species or genus.

Edge Metrics and GIS Predictor Variables

We extracted edge metrics from a 1-m NAIP classification (Westover et al. 2016) using Fragstats 4.2 (McGarigal et al. 2012) and ArcGIS Pro 1.3 (ESRI®, Redlands, CA). The classification contained 11 unique cover types (Table 1). We buffered each nest location by 50 m, 500 m, 1500 m, and 3000 m, similar to previous studies (Fedy et al. 2014; Lockyer et al. 2015). At each buffer extent and for each cover type, we used Fragstats 4.2 to estimate four metrics: percentage of the landscape (PLAND), mean patch size (AREA), edge density (ED), and contrast-weighted edge density (CWED; Table 1). The CWED metric requires a user-defined weight for each pair of cover types. Edges consisting of shrubs and any other cover type were given full weight (1.0), while all remaining combinations of edges were given one quarter weight (0.25), with the hypothesis that edges occurring throughout essential nesting habitat would have the greatest influence on nest predation. Mean patch size, edge density, and contrast-weighted edge density were again estimated at each buffer extent, this time using all cover types in the calculation. Finally, we used the Generate Near Table tool in ArcGIS Pro 1.3 to estimate distance from nest locations to the nearest edge of each cover type, as well as to powerlines and permanent structures.

Statistical Analysis and Validation

We used model selection and an information theoretic approach to identify metrics that best explained nest predation. Prior to full model development, we took multiple steps to identify meaningful variables. First, we compared the base null model (intercept plus a random effect for individual birds) with the base null model plus an additional random effect for year. The random effect for year was 9.5 AIC_c lower than the base null model, so all models from this step forward contained both random effects. Second, we competed univariate models against the null model (Fedy et al. 2015; Kirol et al. 2015a). Only variables with AIC_c lower than the null model were advanced. Third, when necessary, we compared variables that were estimated at multiple buffer sizes and only advanced the one with the lowest AIC_c (Fedy et al. 2015; Kirol et al. 2015a). Finally, we removed highly correlated variables ($|r| \geq 0.65$), retaining the variable with the lower AIC_c value or, if AIC_c values were similar (≤ 0.5 AIC_c), the variable of greater interest (e.g., edge density instead of percentage of the landscape). Using the remaining variables, we developed *a priori* models potentially explaining nest predation. To avoid overfitting our data, no model contained more than four explanatory variables.

We assessed predictive ability of our competitive models using a *k*-fold cross validation with k=5 (Long et al. 2009; Baxter et al. in press). Data were randomly sorted into 5 partitions.

We used 4 partitions as the training set, and the remaining 1/5th of the data as the test set. We did not model average beta coefficients (Cade 2015), instead we used the merTools package (Knowles and Frederick 2015) in R 3.1.3 (R Core Team 2015) to produce predicted responses for the cross validation. We averaged the predicted responses based on the relative AIC$_c$ weight of competitive models. To graphically represent relationships between predation risk and explanatory variables, we produced predicted responses with 85% confidence intervals (Arnold 2010). We calculated variance inflation factors (VIF) to test for collinearity among variables in the same model. Multicollinearity among variables was indicated by VIF > 10 (Aldridge and Boyce 2007; Coates and Delehanty 2010; Holloran et al. 2015; O'Brien 2007).

RESULTS

We used 155 nest locations from 114 sage-grouse (mean, 1.36 ± 0.07; range, 1-5) in our analysis. We recorded multiple nests from 25 females, but only 6 of the 25 birds attempted two nests in the same year. Of the 155 nests, 86 successfully hatched ≥ 1 egg. The remaining 69 nests were depredated. Based on variables included in the information theoretic modeling approach, predation of sage-grouse nests was most influenced by edge density of paved roads at the largest extent (1500 m). Edge density of paved roads was in every model with $\Delta AIC_c < 2.0$, except one (Table 3), and it positively influenced probability of predation in each case (85% confidence intervals did not overlap zero, Arnold 2010; Fig. 2A). Likewise, edge density of high-use dirt roads was a significant discriminant between successful and predated nests, positively influencing probability of predation (Fig. 2B). Models with edge density of high-use dirt roads and edge density of paved roads were consistently ranked higher than models with edge density of high-use dirt roads and any other variable. No VIF was > 10; in fact, all VIF values were < 1.5, indicating extremely low collinearity among variables in the most supported models. Predictive ability of our top models was moderate (Spearman's $\rho = 0.7$) but comparable to previous work (Fedy et al. 2015).

Only three microhabitat variables were more informative than the null model (Fig. 3). Crown area of shrubs nearest to the nest bowl positively influenced probability of nest predation. Mean height of all shrubs from our T^2 analysis was negatively associated with nest predation. Percent of the canopy that was sagebrush was found in two of the 13 competitive models (Table 3), but was likely uninformative due to its lack of significance in either model (85% confidence intervals overlapped zero; Arnold 2010).

DISCUSSION

We found evidence that the anthropogenic "hard" edge associated with roads, was positively associated with predation of sage-grouse nests. Edge density of paved and gravel roads, but not two-track roads, were the most supported variables explaining variation in nest predation. Edge density of paved roads was in 12 of the 13 most supported models, and high-use dirt roads was in seven (Table 3). However, our prediction that the density of sagebrush edges would also be positively associated with nest predation received no support. No variable relating to sagebrush edges was in any of the final models (Table 3). Paved and gravel roads represent a "hard" edge, whereas edges of sagebrush may be "soft", or more gradual transitions (Malt and Lank 2007) which may influence detectability of sage-grouse nests or habitat use by predators.

Nest site selection and distance to roads has been studied extensively (Dinkins et al. 2014; Dzialak et al. 2011; Holloran 2005). Sage-grouse nests in south-central Wyoming were found in areas with low road densities, but nest survival was not evaluated (Dinkins et al. 2014).

Predation of sage-grouse nests was independent of road metrics in both Alberta, Canada and north-central Wyoming (Aldridge and Boyce 2007; Kirol et al. 2015b). In these examples, however, calculations of edge density associated with roads were not completed. Our study is the first to link increased predation risk with increasing edge density of paved and high-use dirt roads.

Our prediction that grass height would decrease the probability of predation had no support, as it was less informative than the null model (Table S1). This finding is in contrast to other studies that have identified grass height as an influential predictor of nest survival (Doherty et al. 2011; Gregg et al. 1994; Holloran et al. 2005). Strawberry Valley, however, is a high-elevation, high-precipitation zone where grass height does not vary substantially, which may have influenced the lack of statistical significance. Additionally, livestock grazing was largely absent from our study area which may have led to less variation in grass height.

Variables at larger extents generally outcompeted those at smaller extents. Of the 11 variables that were used to construct models, seven were estimated at multiple spatial extents. Four of the seven had more support at the largest extent (1500 m), two at the second largest extent (500 m), with only one at the 50-m extent. This finding was consistent with general sage-grouse ecology, which in recent years has highlighted the importance of large-scale processes (Fedy et al. 2015; Knick and Connelly 2011; Lockyer et al. 2015). Sage-grouse are a landscape species (Knick and Connelly 2011), selecting habitat at large spatial scales (Fedy et al. 2015; Lockyer et al. 2015). Even though we found support for variables measured at large spatial extents, our maximum extent (1500 m) was much smaller than that used in other studies (e.g., 6440 m, Fedy et al. 2015; 7030 m, Lockyer et al. 2015). We were limited in selecting larger spatial extents due to the small, fragmented nature of sagebrush in Strawberry Valley.

Nonetheless, we found agreement with other studies in that sage-grouse used landscapes at larger scales even in our relatively smaller fragmented study area.

IMPLICATIONS

Based on our findings, we recommend minimizing disturbances that fragment critical nesting habitat with "hard" edges. Anthropogenic developments are of special concern in sage-grouse habitat (Holloran 2005; Leu and Hanser 2011; Lyon and Anderson 2003). Paved and high-use dirt roads, in particular, may substantially increase nest predation. Additional research is needed to identify the mechanisms underlying this relationship and potential mitigation strategies that could be used to reduce nest predation risk for sage-grouse (Fedy et al. 2015; Kirol et al. 2015b). Variables related to vegetation, including sagebrush edges and grass height, did not explain nest predation in our study area as we had predicted. However, we urge caution when interpreting these results, given the climatic differences between Strawberry Valley (high elevation, mesic, mountain big sagebrush) and much of the rest of the range of sage-grouse (xeric, low productivity of grasses and forbs). We also suggest future studies consider large spatial extents when evaluating nest survival of sage-grouse.

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FIGURES

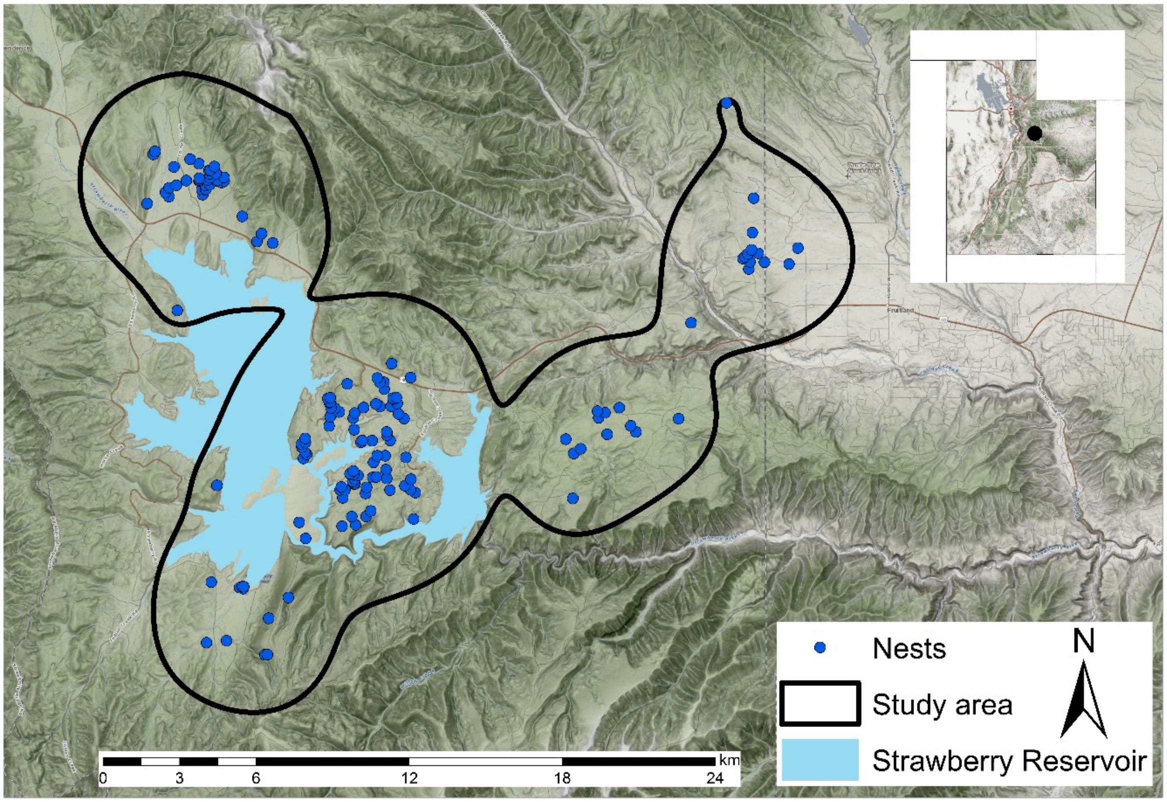

Figure 2–1. Map of Strawberry Valley in north-central Utah, USA were we assessed nest predation of greater sage-grouse in relation to habitat edges. The boundary of the study area was based on a 95% kernel density of all sage-grouse nests.

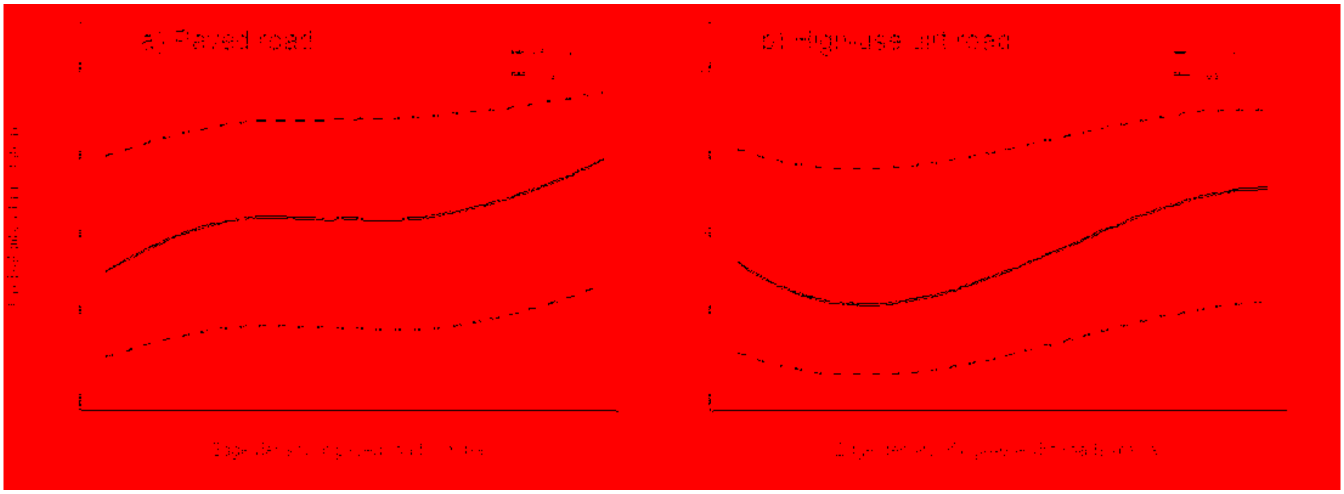

Figure 2–2. Response curves showing probability of predation of greater sage-grouse (Centrocercus urophasianus) nests in relation to edge density of a) paved roads and b) high-use dirt roads in Strawberry Valley, Utah, 1998-2015. Solid lines represent mean estimate and dashed lines represent 85% confidence intervals.

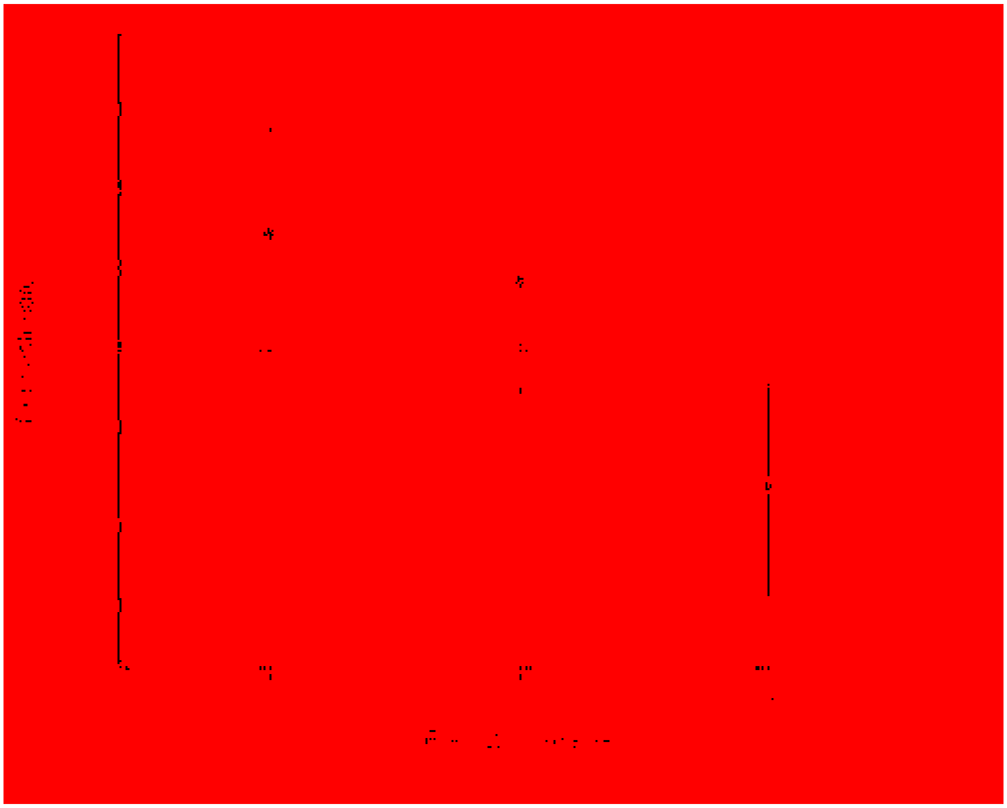

Figure 2–3. β estimates and 85% confidence intervals for crown area of shrubs, grass height, and shrub height in relation to predation of greater sage-grouse (*Centrocercus urophasianus*) nests in Strawberry Valley, Utah, 1998-2015.

TABLES

Table 2-1. Geographic information system (GIS) predictor variables potentially associated with greater sage-grouse (*Centrocercus urophasianus*) use sites in Strawberry Valley, Utah, USA 1998-2016. Topographic data are 10-m resolution. Anthropogenic, vegetation, and treatment data are 1-m resolution.

Variable name	Description
Res	Resident or translocated sage-grouse
Microhabitat	
NShSp2	Binary variable for shrub species nearest nest bowl (1=sagebrush, 0=other)
COV_GAVG	% cover of grass
COV_FAVG	% cover of forbs
Moss	% cover of moss
BareGr	% cover of bare ground
Rock	% cover of rock
Litter	% cover of litter
NGrHgt	Grass height (cm) at nest bowl
NShDist	Distance (cm) from nest bowl to nearest shrub
NShDec	% decadence of shrub nearest nest bowl
NShHgt	Height (cm) of shrub nearest nest bowl
NShCA	Crown area (cm2) of shrub nearest to the nest bowl
CovSage	% canopy cover (*Artemisia* spp. only)
CovShb	% canopy cover (all shrub species)
AvgCA	Mean crown area (cm2) of shrubs in T2 analysis
HO2	% horizontal obscurity at 2.5 m from nest bowl
HO5	% horizontal obscurity at 5 m from nest bowl
HO10	% horizontal obscurity at 10 m from nest bowl
AvgShDec	Mean % decadence of shrubs in T2 analysis
AvgShHgt	Mean height (cm) of shrubs in T2 analysis
PerSage	% of total canopy cover (*CovShb*) that is *Artemisia* spp.
Edge/patch metrics	
PLAND[a]	Percent of landscape
ED[b]	Edge density
AREA[b]	Mean patch size
CWED[b]	Contrast-weighted edge density
Distance to features	
DistToAgriculture	Distance to cover type "agriculture"
DistToBareGround	Distance to cover type "bare ground"
DistToHighUseDirt	Distance to cover type "high use dirt road"
DistToTwoTrack	Distance to cover type "two track road"
DistToPaved	Distance to cover type "paved road"
DistToRiparian	Distance to cover type "riparian"
DistToShrub	Distance to cover type "shrub"
DistToTrees	Distance to cover type "trees"
DistToWater	Distance to cover type "reservoir"
DistToAnyEdge	Distance to any edge
DistToPermStruc	Distance to permanent structure
DistToPowerLines	Distance to powerlines

Table 2-2. Cover types derived from 1-m NAIP classification (Westover et al. 2016).

Cover type	Abbreviation in analysis
Trees	Trees
Bare ground	BareGround
Shrub	Shrub
Grass	Grass
Riparian	Riparian
Two-track road	TwoTrack
High-use dirt road	HighUseDirt
Paved road	Paved
Agriculture	Agriculture
Reservoir	Water
River	River

Table 2-3. Model results ($\Delta AIC_c < 2$) for nest predation of greater sage-grouse (*Centrocercus urophasianus*) in Strawberry Valley, Utah, USA, 1998-2015, in relation to microhabitat features and edge metrics showing number of parameters (*K*), corrected Akaike's Information Criterion (AIC_c), ΔAIC_c, model weight (ω_i), and log likelihood (LL). Variable names match those in Table 1.

Model Number	Model Structure	*K*	AIC_c	ΔAIC_c	ω_i	LL
76	Paved_ED1500+HighUseDirt_ED500+NShCA+DistToRiparian	7	200.72	0.00	0.065	-92.977
71	Paved_ED1500+HighUseDirt_ED500+BareGround_PLAND1500+NShCA	7	200.85	0.14	0.061	-93.046
30	Paved_ED1500+HighUseDirt_ED500	5	201.09	0.37	0.054	-95.343
40	Paved_ED1500+HighUseDirt_ED500+BareGround_PLAND1500	6	201.39	0.67	0.047	-94.410
47	Paved_ED1500+AvgShHgt+DistToRiparian	6	201.51	0.80	0.044	-94.473
46	Grass_PLAND1500+AvgShHgt+BareGround_CWED50	6	201.93	1.22	0.035	-94.682
63	Paved_ED1500+HighUseDirt_ED500+NShCA+Trees_PLAND1500	7	202.02	1.30	0.034	-93.629
70	Paved_ED1500+HighUseDirt_ED500+NShCA+PerSage	7	202.06	1.35	0.033	-93.651
53	Paved_ED1500+Grass_PLAND1500+Trees_PLAND1500	6	202.19	1.48	0.031	-94.813
18	Paved_ED1500+AvgShHgt	5	202.28	1.56	0.030	-95.936
15	Paved_ED1500+NShCA	5	202.29	1.58	0.030	-95.946
62	Paved_ED1500+HighUseDirt_ED500+Grass_PLAND1500+PerSage	7	202.35	1.63	0.029	-93.795
11	Paved_ED1500	4	202.55	1.83	0.026	-97.141
21	Paved_ED1500+BareGround_CWED50	5	202.98	2.27	0.021	-96.291
38	Paved_ED1500+Grass_PLAND1500+BareGround_PLAND1500	6	203.05	2.34	0.020	-95.242
65	Paved_ED1500+HighUseDirt_ED500+BareGround_PLAND1500+Trees_PLAND1500	7	203.08	2.36	0.020	-94.159
37	Paved_ED1500+BareGround_PLAND1500+NShCA	6	203.12	2.40	0.020	-95.276
43	Paved_ED1500+BareGround_CWED50+BareGround_PLAND1500	6	203.45	2.74	0.017	-95.443
69	Paved_ED1500+BareGround_CWED50+NShCA+Trees_PLAND1500	7	203.61	2.89	0.015	-94.423
25	HighUseDirt_ED500+NShCA	5	203.70	2.98	0.015	-96.648
35	Water_PLAND500+Grass_PLAND1500	5	203.70	2.98	0.015	-96.648
66	Grass_PLAND1500+AvgShHgt+NShCA+DistToRiparian	7	203.84	3.12	0.014	-94.537
51	HighUseDirt_ED500+BareGround_PLAND1500+PerSage	6	204.00	3.29	0.013	-95.718
23	Paved_ED1500+Trees_PLAND1500	5	204.13	3.41	0.012	-96.862
52	Paved_ED1500+AvgShHgt+Trees_PLAND1500	6	204.21	3.50	0.011	-95.823
78	Paved_ED1500+BareGround_CWED50+BareGround_PLAND1500+PerSage	7	204.29	3.57	0.011	-94.765
3	Water_PLAND500	4	204.30	3.59	0.011	-98.019
55	Water_PLAND500+Grass_PLAND1500+DistToRiparian	6	204.35	3.63	0.011	-95.891
6	HighUseDirt_ED500	4	204.40	3.68	0.010	-98.064
48	Paved_ED1500+BareGround_CWED50+Trees_PLAND1500	6	204.40	3.68	0.010	-95.915
60	Grass_PLAND1500+BareGround_CWED50+DistToRiparian	6	204.46	3.74	0.010	-95.947
29	Grass_PLAND1500+BareGround_CWED50	5	204.51	3.79	0.010	-97.053

APPENDIX CHAPTER 1

Table 3-1-APPENDIX 1. All results from steps 1 and 2 in our model selection process assessing habitat selection by greater sage-grouse (*Centrocercus urophasianus*) with broods in Strawberry Valley, Utah, USA in relation to mechanical alteration of sagebrush (*Artemisia tridentata vaseyana*) showing number of parameters (*K*), corrected Akaike's Information Criterion (AIC_c), ΔAIC_c, model weight (ω_i), and log likelihood (LL). In step 1, *a priori* models were developed within each of four categories: topographic, vegetation, anthropogenic, and treatment. In step 2, models were again developed *a priori*, this time only using variables that advanced from step 1. Variable names match those in Table 1.

STEP 1

Topographic

Model number	Model structure	*K*	AIC_c	ΔAIC_c	ω_i	LL
1	SLOPE	3	387.90	0.00	0.37	-190.94
6	SLOPE+VRM11	4	388.75	0.85	0.24	-190.36
7	SLOPE+ELEV	4	388.94	1.04	0.22	-190.46
13	SLOPE+VRM11+ELEV	5	389.82	1.92	0.14	-189.89
5	SLOPE+ASPECTBIN	7	394.29	6.39	0.02	-190.10
11	SLOPE+ASPECTBIN+VRM11	8	395.16	7.26	0.01	-189.53
12	SLOPE+ASPECTBIN+ELEV	8	395.20	7.30	0.01	-189.55
10	VRM11+ELEV	4	406.61	18.71	0.00	-199.29
4	ELEV	3	409.53	21.63	0.00	-201.75
3	VRM11	3	410.29	22.39	0.00	-202.14
14	ASPECTBIN+VRM11+ELEV	8	412.91	25.01	0.00	-198.40
15	NULL	2	414.59	26.69	0.00	-205.29
9	ASPECTBIN+ELEV	7	415.48	27.58	0.00	-200.70
8	ASPECTBIN+VRM11	7	416.91	29.01	0.00	-201.41
2	ASPECTBIN	6	420.93	33.03	0.00	-204.43

Vegetation

Model number	Model structure	*K*	AIC_c	ΔAIC_c	ω_i	LL
11	D.RI.TR+D.TREES	4	369.98	0.00	0.19	-180.97
22	D.RI.TR+D.SHRUB+D.TREES	5	370.71	0.74	0.13	-180.33
17	D.GRASS+D.RI.TR+D.TREES	5	370.95	0.98	0.12	-180.45
24	D.RI.TR+D.TREES+D.SH.WA	5	371.07	1.09	0.11	-180.51
4	D.TREES	3	371.25	1.28	0.10	-182.62
13	D.SHRUB+D.TREES	4	371.46	1.48	0.09	-181.71

8	D.GRASS+D.TREES	4	371.81	1.83	0.08	-181.89
15	D.TREES+D.SH.WA	4	372.45	2.47	0.05	-182.21
25	D.SHRUB+D.TREES+D.SH.WA	5	372.57	2.60	0.05	-181.26
21	D.GRASS+D.TREES+D.SH.WA	5	372.73	2.75	0.05	-181.34
19	D.GRASS+D.SHRUB+D.TREES	5	373.12	3.15	0.04	-181.54
10	D.RI.TR+D.SHRUB	4	390.56	20.58	0.00	-191.27
23	D.RI.TR+D.SHRUB+D.SH.WA	5	392.04	22.06	0.00	-191.00
16	D.GRASS+D.RI.TR+D.SHRUB	5	392.29	22.32	0.00	-191.12
6	D.GRASS+D.RI.TR	4	395.53	25.55	0.00	-193.75
18	D.GRASS+D.RI.TR+D.SH.WA	5	396.83	26.85	0.00	-193.39
2	D.RI.TR	3	398.35	28.37	0.00	-196.17
3	D.SHRUB	3	399.40	29.43	0.00	-196.69
12	D.RI.TR+D.SH.WA	4	400.08	30.10	0.00	-196.03
7	D.GRASS+D.SHRUB	4	400.88	30.90	0.00	-196.43
14	D.SHRUB+D.SH.WA	4	401.13	31.16	0.00	-196.55
20	D.GRASS+D.SHRUB+D.SH.WA	5	402.51	32.54	0.00	-196.23
1	D.GRASS	3	407.46	37.48	0.00	-200.72
9	D.GRASS+D.SH.WA	4	409.05	39.07	0.00	-200.51
26	NULL	2	414.59	44.61	0.00	-205.29
5	D.SH.WA	3	416.58	46.60	0.00	-205.28

Anthropogenic

Model number	Model structure	K	AIC_c	ΔAIC_c	ω_i	LL
7	D.ROADPAV+D.ROAD2T+D.PLINE	5	406.37	0.00	0.39	-198.17
4	D.PLINE+D.ROADPAV	4	407.32	0.94	0.24	-199.64
6	D.ROADPAV+D.ROAD2T	4	408.91	2.54	0.11	-200.44
1	D.ROAD2T	3	409.06	2.69	0.10	-201.52
5	D.PLINE+D.ROAD2T	4	409.28	2.91	0.09	-200.63
2	D.PLINE	3	410.28	3.91	0.06	-202.13
8	NULL	2	414.59	8.21	0.01	-205.29
3	D.ROADPAV	3	415.93	9.56	0.00	-204.96

Treatment

Model number	Model structure	K	AIC_c	ΔAIC_c	ω_i	LL
9	N.TREAT+D.TREAT2+PRE.POST+PRE.POST2	6	324.85	0.00	0.64	-156.40

10	N.TREAT+D.TREAT2+PRE.POST+PRE.POST2+IN.OUT	7	326.03	1.17	0.36	-155.97
6	N.TREAT+D.TREAT2+PRE.POST	5	346.24	21.39	0.00	-168.10
8	N.TREAT+PRE.POST+IN.OUT	5	351.29	26.44	0.00	-170.62
4	N.TREAT*PERIOD	4	352.87	28.01	0.00	-172.42
7	N.TREAT+D.TREAT2+IN.OUT	5	366.53	41.68	0.00	-178.24
5	N.TREAT+D.TREAT2	4	366.58	41.72	0.00	-179.27
3	N.TREAT+IN.OUT	4	378.67	53.82	0.00	-185.32
2	N.TREAT	3	384.43	59.57	0.00	-189.20
1	IN.OUT	3	397.40	72.55	0.00	-195.69
11	NULL	2	414.59	89.73	0.00	-205.29

STEP 2

Final

Model number	Model structure	K	AIC_c	ΔAIC_c	ω_i	LL
47	D.GRASS+D.TREES+SLOPE+ELEV+D.ROADPAV+D.ROAD2T+D.PLINE+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2+IN.OUT	14	815.62	0.00	0.41	-393.65
51	D.RI.TR+D.TREES+D.SH.WA+SLOPE+ELEV+D.ROADPAV+D.ROAD2T+D.PLINE+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2	14	817.22	1.60	0.18	-394.45
43	D.GRASS+D.RI.TR+D.TREES+SLOPE+ELEV+D.ROADPAV+D.ROAD2T+D.PLINE+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2+IN.OUT	15	817.61	1.99	0.15	-393.62
53	D.RI.TR+D.SHRUB+D.TREES+SLOPE+ELEV+D.ROADPAV+D.ROAD2T+D.PLINE+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2+IN.OUT	15	819.01	3.39	0.07	-394.32
48	D.GRASS+D.TREES+SLOPE+VRM11+ELEV+D.PLINE+D.ROADPAV+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2	13	820.09	4.47	0.04	-396.91
41	D.RI.TR+D.TREES+SLOPE+D.ROADPAV+D.ROAD2T+D.PLINE+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2+IN.OUT	13	820.83	5.21	0.03	-397.28
44	D.RI.TR+D.TREES+D.SH.WA+SLOPE+VRM11+ELEV+D.PLINE+D.ROADPAV+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2	14	821.04	5.42	0.03	-396.36
45	D.TREES+SLOPE+D.ROADPAV+D.ROAD2T+D.PLINE+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2+IN.OUT	12	821.10	5.48	0.03	-398.43
54	D.RI.TR+D.TREES+SLOPE+VRM11+ELEV+D.PLINE+D.ROADPAV+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2	13	821.35	5.73	0.02	-397.54
52	D.GRASS+D.RI.TR+D.TREES+SLOPE+VRM11+ELEV+D.PLINE+D.ROADPAV+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2	14	822.08	6.46	0.02	-396.88
49	D.SHRUB+D.TREES+SLOPE+D.ROADPAV+D.ROAD2T+D.PLINE+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2	12	823.06	7.44	0.01	-399.41
50	D.TREES+SLOPE+VRM11+D.PLINE+D.ROADPAV+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2+IN.OUT	12	824.43	8.81	0.00	-400.09
46	D.SHRUB+D.TREES+SLOPE+VRM11+D.PLINE+D.ROADPAV+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2	12	825.49	9.87	0.00	-400.63
42	D.RI.TR+D.SHRUB+D.TREES+SLOPE+VRM11+D.PLINE+D.ROADPAV+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2	13	825.81	10.19	0.00	-399.77
20	N.TREAT+N.TREAT2+PRE.POST+PRE.POST2+D.TREES	7	891.21	75.59	0.00	-438.56
31	N.TREAT+N.TREAT2+PRE.POST+PRE.POST2+D.ROADPAV+D.ROAD2T+D.PLINE	9	895.36	79.74	0.00	-438.61
18	D.PLINE+D.ROADPAV+N.TREAT+N.TREAT2+PRE.POST+PRE.POST2	8	897.32	81.70	0.00	-440.60
32	N.TREAT+N.TREAT2+PRE.POST+PRE.POST2+IN.OUT+D.PLINE+D.ROADPAV	9	899.19	83.57	0.00	-440.53
19	N.TREAT+N.TREAT2+PRE.POST+PRE.POST2+SLOPE	7	928.91	113.29	0.00	-457.41
33	SLOPE+D.RI.TR+D.TREES+D.ROADPAV+D.ROAD2T+D.PLINE	8	934.18	118.56	0.00	-459.04

35	SLOPE+ELEV+D.GRASS+D.RI.TR+D.TREES+D.ROADPAV+D.ROAD2T+D.PLINE	10	937.00	121.38	0.00	-458.42
40	SLOPE+D.RI.TR+D.SHRUB+D.TREES+D.PLINE+D.ROADPAV	8	938.58	122.96	0.00	-461.24
34	SLOPE+VRM11+D.RI.TR+D.SHRUB+D.TREES+D.PLINE+D.ROADPAV	9	940.53	124.91	0.00	-461.20
39	SLOPE+ELEV+D.GRASS+D.TREES+D.ROADPAV+D.ROAD2T+D.PLINE	9	941.89	126.27	0.00	-461.87
36	SLOPE+VRM11+ELEV+D.RI.TR+D.TREES+D.SH.WA+D.PLINE+D.ROADPAV	10	942.70	127.08	0.00	-461.27
37	SLOPE+VRM11+ELEV+D.TREES+D.ROADPAV+D.ROAD2T+D.PLINE	9	942.82	127.20	0.00	-462.34
38	SLOPE+VRM11+D.SHRUB+D.TREES+D.PLINE+D.ROADPAV	8	946.80	131.18	0.00	-465.35
22	SLOPE+D.RI.TR+D.TREES	5	948.11	132.49	0.00	-469.03
25	SLOPE+VRM11+ELEV+D.RI.TR+D.TREES+D.SH.WA	8	948.11	132.49	0.00	-466.00
24	SLOPE+ELEV+D.GRASS+D.RI.TR+D.TREES	7	951.45	135.83	0.00	-468.68
23	SLOPE+VRM11+D.RI.TR+D.SHRUB+D.TREES	7	951.66	136.04	0.00	-468.79
14	N.TREAT+N.TREAT2+PRE.POST+PRE.POST2	6	956.85	141.23	0.00	-472.39
16	SLOPE+D.TREES	4	957.76	142.14	0.00	-474.86
15	N.TREAT+N.TREAT2+PRE.POST+PRE.POST2+IN.OUT	7	958.32	142.70	0.00	-472.12
27	SLOPE+ELEV+D.GRASS+D.TREES	6	959.19	143.57	0.00	-473.57
26	SLOPE+VRM11+D.SHRUB+D.TREES	6	960.58	144.96	0.00	-474.26
30	D.RI.TR+D.TREES+D.ROADPAV+D.ROAD2T+D.PLINE	7	967.83	152.21	0.00	-476.88
29	D.RI.TR+D.TREES+D.PLINE+D.ROADPAV	6	968.25	152.63	0.00	-478.09
28	D.SHRUB+D.TREES+D.ROADPAV+D.ROAD2T+D.PLINE	7	975.02	159.40	0.00	-480.47
8	D.RI.TR+D.TREES+D.SH.WA	5	976.18	160.56	0.00	-483.07
6	D.RI.TR+D.SHRUB+D.TREES	5	976.81	161.19	0.00	-483.39
17	D.TREES+D.PLINE+D.ROADPAV	5	976.83	161.21	0.00	-483.39
5	D.RI.TR+D.TREES	4	976.91	161.29	0.00	-484.44
7	D.GRASS+D.RI.TR+D.TREES	5	977.19	161.57	0.00	-483.57
10	D.SHRUB+D.TREES	4	986.46	170.84	0.00	-489.22
11	D.GRASS+D.TREES	4	987.22	171.60	0.00	-489.60
9	D.TREES	3	987.95	172.33	0.00	-490.97
21	SLOPE+D.PLINE+D.ROADPAV	5	1032.58	216.96	0.00	-511.27
2	SLOPE+VRM11	4	1043.77	228.15	0.00	-517.87
1	SLOPE	3	1044.67	229.05	0.00	-519.32
4	SLOPE+VRM11+ELEV	5	1045.55	229.93	0.00	-517.75
3	SLOPE+ELEV	4	1046.35	230.73	0.00	-519.16
12	D.ROADPAV+D.ROAD2T+D.PLINE	5	1100.50	284.88	0.00	-545.23
13	D.PLINE+D.ROADPAV	4	1112.34	296.72	0.00	-552.15
55	NULL	2	1138.18	322.56	0.00	-567.09

APPENDIX CHAPTER 2

Table 4-1-APPENDIX 2. All results from univariable models from initial model selection process assessing nest predation of greater sage-grouse (Centrocercus urophasianus) in Strawberry Valley, Utah, USA, 1998-2015, in relation to microhabitat features and edge metrics showing number of parameters (K), corrected Akaike's Information Criterion (AICc), ΔAICc, model weight (ωi), and log likelihood (LL). Variable names match those in Table 1.

Model number	Model structure	K	AIC_c	ΔAIC_c	ω_i	LL
119	Paved_PLAND1500	4	202.44	0.00	0.07	-97.09
120	Paved_ED1500	4	202.55	0.11	0.07	-97.14
160	DistToPaved	4	202.97	0.52	0.06	-97.35
99	Water_PLAND500	4	204.30	1.86	0.03	-98.02
72	HighUseDirt_ED500	4	204.40	1.95	0.03	-98.06
75	Paved_PLAND500	4	204.41	1.97	0.03	-98.07
101	Water_AREA500	4	204.42	1.98	0.03	-98.08
76	Paved_ED500	4	204.58	2.14	0.02	-98.16
74	HighUseDirt_CWED500	4	204.65	2.21	0.02	-98.19
73	HighUseDirt_AREA500	4	204.70	2.26	0.02	-98.22
71	HighUseDirt_PLAND500	4	204.70	2.26	0.02	-98.22
122	Paved_CWED1500	4	205.09	2.65	0.02	-98.41
111	Grass_PLAND1500	4	205.19	2.75	0.02	-98.46
77	Paved_AREA500	4	205.25	2.81	0.02	-98.49
78	Paved_CWED500	4	205.51	3.07	0.02	-98.62
113	Grass_AREA1500	4	205.81	3.37	0.01	-98.77
114	Grass_CWED1500	4	206.11	3.67	0.01	-98.92
100	Water_ED500	4	206.31	3.87	0.01	-99.02
112	Grass_ED1500	4	206.39	3.95	0.01	-99.06
21	AvgShHgt	4	206.58	4.14	0.01	-99.16
46	River_CWED50	4	206.68	4.24	0.01	-99.21
44	River_ED50	4	206.69	4.25	0.01	-99.21
43	River_PLAND50	4	206.78	4.34	0.01	-99.26
102	Water_CWED500	4	206.85	4.41	0.01	-99.29
26	BareGround_CWED50	4	206.92	4.48	0.01	-99.33
107	BareGround_PLAND1500	4	207.07	4.63	0.01	-99.40
45	River_AREA50	4	207.14	4.70	0.01	-99.44
13	NShCA	4	207.30	4.86	0.01	-99.52
22	PerSage	4	207.41	4.97	0.01	-99.57
24	BareGround_ED50	4	207.51	5.07	0.01	-99.62
37	Paved_AREA50	4	207.54	5.10	0.01	-99.64

36	Paved_ED50	4	207.54	5.10	0.01	-99.64
38	Paved_CWED50	4	207.54	5.10	0.01	-99.64
35	Paved_PLAND50	4	207.54	5.10	0.01	-99.64
23	BareGround_PLAND50	4	207.55	5.10	0.01	-99.64
135	Trees_PLAND1500	4	207.59	5.15	0.01	-99.66
70	Grass_CWED500	4	207.60	5.16	0.01	-99.67
161	DistToRiparian	4	207.63	5.19	0.01	-99.68
168	NULLModel	3	207.65	5.21	0.01	-100.75
155	All_CWED1500	4	207.69	5.25	0.01	-99.71
134	Shrub_CWED1500	4	207.70	5.26	0.01	-99.72
132	Shrub_ED1500	4	207.70	5.26	0.01	-99.72
130	River_CWED1500	4	207.71	5.27	0.01	-99.72
153	All_ED1500	4	207.71	5.27	0.01	-99.72
68	Grass_ED500	4	207.76	5.32	0.01	-99.74
123	Riparian_PLAND1500	4	207.76	5.32	0.01	-99.75
54	Trees_CWED50	4	207.82	5.38	0.00	-99.78
154	All_AREA1500	4	207.85	5.41	0.00	-99.79
109	BareGround_AREA1500	4	207.87	5.43	0.00	-99.80
137	Trees_AREA1500	4	207.88	5.44	0.00	-99.81
82	Riparian_CWED500	4	207.97	5.53	0.00	-99.85
80	Riparian_ED500	4	208.08	5.64	0.00	-99.91
108	BareGround_ED1500	4	208.09	5.65	0.00	-99.91
124	Riparian_ED1500	4	208.20	5.76	0.00	-99.97
166	DistToPermStruc	4	208.29	5.84	0.00	-100.01
110	BareGround_CWED1500	4	208.31	5.87	0.00	-100.02
133	Shrub_AREA1500	4	208.35	5.91	0.00	-100.04
25	BareGround_AREA50	4	208.42	5.97	0.00	-100.07
127	River_PLAND1500	4	208.49	6.05	0.00	-100.11
40	Riparian_ED50	4	208.49	6.05	0.00	-100.11
8	Litter	4	208.52	6.08	0.00	-100.12
128	River_ED1500	4	208.53	6.09	0.00	-100.13
67	Grass_PLAND500	4	208.55	6.11	0.00	-100.14
145	Water_AREA1500	4	208.56	6.12	0.00	-100.15
65	BareGround_AREA500	4	208.57	6.13	0.00	-100.15
121	Paved_AREA1500	4	208.57	6.13	0.00	-100.15
146	Water_CWED1500	4	208.58	6.14	0.00	-100.15
1	Res	4	208.58	6.14	0.00	-100.16
159	DistToHighUseDirt	4	208.60	6.16	0.00	-100.17
85	River_AREA500	4	208.63	6.19	0.00	-100.18
90	Shrub_CWED500	4	208.66	6.21	0.00	-100.19

88	Shrub_ED500	4	208.66	6.21	0.00	-100.19
2	NShSp2	4	208.66	6.22	0.00	-100.20
152	All_CWED500	4	208.68	6.24	0.00	-100.21
79	Riparian_PLAND500	4	208.68	6.24	0.00	-100.21
15	CovShb	4	208.78	6.34	0.00	-100.26
150	All_ED500	4	208.78	6.34	0.00	-100.26
98	TwoTrack_CWED500	4	208.80	6.36	0.00	-100.27
3	COV_GAVG	4	208.80	6.36	0.00	-100.27
17	HO2	4	208.82	6.38	0.00	-100.27
144	Water_ED1500	4	208.84	6.40	0.00	-100.29
143	Water_PLAND1500	4	208.84	6.40	0.00	-100.29
86	River_CWED500	4	208.84	6.40	0.00	-100.29
126	Riparian_CWED1500	4	208.86	6.42	0.00	-100.30
19	HO10	4	208.88	6.44	0.00	-100.31
129	River_AREA1500	4	208.88	6.44	0.00	-100.31
62	Water_CWED50	4	208.89	6.44	0.00	-100.31
61	Water_AREA50	4	208.89	6.44	0.00	-100.31
59	Water_PLAND50	4	208.89	6.44	0.00	-100.31
60	Water_ED50	4	208.89	6.44	0.00	-100.31
117	HighUseDirt_AREA1500	4	208.89	6.45	0.00	-100.31
138	Trees_CWED1500	4	208.97	6.53	0.00	-100.35
91	Trees_PLAND500	4	208.98	6.54	0.00	-100.36
125	Riparian_AREA1500	4	208.99	6.55	0.00	-100.36
18	HO5	4	209.01	6.57	0.00	-100.37
9	NGrHgt	4	209.06	6.62	0.00	-100.40
84	River_ED500	4	209.07	6.62	0.00	-100.40
148	All_AREA50	4	209.09	6.64	0.00	-100.41
83	River_PLAND500	4	209.09	6.65	0.00	-100.41
34	HighUseDirt_CWED50	4	209.12	6.68	0.00	-100.42
33	HighUseDirt_AREA50	4	209.12	6.68	0.00	-100.42
31	HighUseDirt_PLAND50	4	209.12	6.68	0.00	-100.42
32	HighUseDirt_ED50	4	209.12	6.68	0.00	-100.42
116	HighUseDirt_ED1500	4	209.18	6.74	0.00	-100.46
39	Riparian_PLAND50	4	209.18	6.74	0.00	-100.46
50	Shrub_CWED50	4	209.19	6.75	0.00	-100.46
48	Shrub_ED50	4	209.19	6.75	0.00	-100.46
69	Grass_AREA500	4	209.21	6.77	0.00	-100.47
167	DistToPowerLines	4	209.21	6.77	0.00	-100.47
42	Riparian_CWED50	4	209.21	6.77	0.00	-100.47
118	HighUseDirt_CWED1500	4	209.22	6.78	0.00	-100.48

115	HighUseDirt_PLAND1500	4	209.25	6.81	0.00	-100.49
30	Grass_CWED50	4	209.26	6.82	0.00	-100.50
96	TwoTrack_ED500	4	209.27	6.83	0.00	-100.50
95	TwoTrack_PLAND500	4	209.29	6.85	0.00	-100.51
158	DistToGrass	4	209.30	6.86	0.00	-100.52
156	DistToAgriculture	4	209.32	6.88	0.00	-100.52
105	Agriculture_AREA1500	4	209.33	6.89	0.00	-100.53
94	Trees_CWED500	4	209.34	6.90	0.00	-100.54
136	Trees_ED1500	4	209.36	6.92	0.00	-100.55
63	BareGround_PLAND500	4	209.40	6.96	0.00	-100.57
149	All_CWED50	4	209.42	6.98	0.00	-100.58
29	Grass_AREA50	4	209.42	6.98	0.00	-100.58
12	NShHgt	4	209.43	6.98	0.00	-100.58
5	Moss	4	209.43	6.99	0.00	-100.58
164	DistToWater	4	209.46	7.02	0.00	-100.60
52	Trees_ED50	4	209.48	7.04	0.00	-100.61
47	Shrub_PLAND50	4	209.49	7.05	0.00	-100.61
97	TwoTrack_AREA500	4	209.50	7.06	0.00	-100.62
41	Riparian_AREA50	4	209.50	7.06	0.00	-100.62
163	DistToTrees	4	209.53	7.09	0.00	-100.63
11	NShDec	4	209.56	7.12	0.00	-100.65
92	Trees_ED500	4	209.59	7.15	0.00	-100.66
56	TwoTrack_ED50	4	209.60	7.16	0.00	-100.67
104	Agriculture_ED1500	4	209.60	7.16	0.00	-100.67
103	Agriculture_PLAND1500	4	209.61	7.16	0.00	-100.67
53	Trees_AREA50	4	209.61	7.17	0.00	-100.67
16	AvgCA	4	209.61	7.17	0.00	-100.67
28	Grass_ED50	4	209.61	7.17	0.00	-100.67
142	TwoTrack_CWED1500	4	209.64	7.20	0.00	-100.69
157	DistToBareGround	4	209.65	7.21	0.00	-100.69
162	DistToShrub	4	209.66	7.22	0.00	-100.70
27	Grass_PLAND50	4	209.67	7.23	0.00	-100.70
106	Agriculture_CWED1500	4	209.67	7.23	0.00	-100.70
20	AvgShDec	4	209.68	7.24	0.00	-100.71
87	Shrub_PLAND500	4	209.68	7.24	0.00	-100.71
51	Trees_PLAND50	4	209.68	7.24	0.00	-100.71
14	CovSage	4	209.69	7.24	0.00	-100.71
66	BareGround_CWED500	4	209.69	7.25	0.00	-100.71
89	Shrub_AREA500	4	209.69	7.25	0.00	-100.71
57	TwoTrack_AREA50	4	209.69	7.25	0.00	-100.71

55	TwoTrack_PLAND50	4	209.71	7.27	0.00	-100.72
165	DistToAnyEdge	4	209.71	7.27	0.00	-100.72
151	All_AREA500	4	209.71	7.27	0.00	-100.72
58	TwoTrack_CWED50	4	209.71	7.27	0.00	-100.72
81	Riparian_AREA500	4	209.72	7.28	0.00	-100.72
10	NShDist	4	209.72	7.28	0.00	-100.73
7	Rock	4	209.73	7.29	0.00	-100.73
64	BareGround_ED500	4	209.73	7.29	0.00	-100.73
147	All_ED50	4	209.74	7.30	0.00	-100.74
6	BareGr	4	209.74	7.30	0.00	-100.74
141	TwoTrack_AREA1500	4	209.76	7.32	0.00	-100.74
4	COV_FAVG	4	209.76	7.32	0.00	-100.75
93	Trees_AREA500	4	209.76	7.32	0.00	-100.75
140	TwoTrack_ED1500	4	209.76	7.32	0.00	-100.75
49	Shrub_AREA50	4	209.76	7.32	0.00	-100.75
139	TwoTrack_PLAND1500	4	209.76	7.32	0.00	-100.75
131	Shrub_PLAND1500	4	209.76	7.32	0.00	-100.75