AN ABSTRACT OF THE THESIS OF

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Abstract approved:

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Greater Sage-grouse (*Centrocercus urophasianus*) habitat research has historically focused on fine-scale (0.007 - 0.032 ha) vegetation structure and composition immediately surrounding sites selected by birds. However, little work has evaluated vegetation attributes important for Greater Sage-grouse at a landscape-scale or identified landscape attributes that influence habitat use patterns. Habitat use patterns by Greater Sage-grouse are complex and can occur across relatively large heterogeneous landscapes. This creates a major challenge for managers to interpret and predict habitat use patterns as well as to evaluate habitat suitability and prioritize habitats that are in need of ecological restoration. The goals of this research were to evaluate plot-level habitat characteristics found to be important in sustaining Greater Sage-grouse populations at a landscape-level and to identify landscape-level attributes associated with bird occurrence. Specific questions this research addressed were: 1) what is the variation in vegetation composition and structure at the plot versus landscape-level, 2) how does topography influence the distribution of vegetation composition and structure, and 3) what attributes at the landscape-level are most closely associated with Greater Sage-grouse habitat use? To address these questions we selected a 31,416 ha area in central Oregon surrounding a Greater Sage-grouse lek with a population that has been relatively stable since 1987. In February 2006, 50

Greater Sage-grouse were trapped, radio collared, and then tracked for two consecutive years. Four-hundred eighty bird UTM (Universal Transverse Mercator) coordinate location points were recorded for the entire population of birds during the duration of this study. Each collared Greater Sage-grouse was located on average every 15 ± 0.56 (mean ± SE) days, ranging from 1 to 154 days. Vegetation for the entire study area was mapped by cover types, which were defined by the dominant shrub species. When shrubs were not present in the plant community, cover types were separated by other surface characteristics such as bare ground, water, meadow, etc. A total of 23 cover types were delineated. Cover types were mapped using 0.5-m NAIP (National Agricultural Imagery Program) imagery. In addition to cover type, a set of biophysical predictor variables were created for the entire study area in a GIS (Geographic Information System) to evaluate the association with Greater Sage-grouse location points. These variables included elevation, slope, aspect, curvature, solar radiation, ruggedness index, northing, easting, and distance from roads, leks, and mesic habitats. A stratified random sample with cover types serving as the stratum was used to select random locations for sampling plot-level habitat variables. A total of 352 plots were sampled from 18 cover types across the study area with a minimum of 15 plots per cover type. Vegetation measurements collected were similar to those reported in the habitat guidelines developed by Connelly et al. (2000) and the Bureau of Land Management et al. (2000). Measurements included vegetation cover, height, and density of forbs recognized as important Greater Sage-grouse food species. Plot elevation, slope, aspect, curvature and landscape position were also recorded. Summary statistics were used to describe means and ranges within and between cover types. A combination of multiple linear regression and analysis of variance (ANOVA) were used to evaluate the effects of topographic attributes on the distribution of vegetation composition and structure. To address the third question, maximum entropy software was used to develop models that predict Greater Sage-grouse seasonal habitat use, generate maps from those models, and describe the shapes of the response curves as it relates Greater Sage-grouse habitat preference to individual landscape predictor variables.

Total shrub canopy cover across all cover types averaged 19.4%, ranging from 11.6 to 27.7%. Big (mountain and Wyoming) and low sagebrush canopy cover commonly varied between 2.6 and 16 fold within cover types. Deep-rooted perennial tussock grass cover averaged across all upland plots, was 26.7%, ranging from less than 1% to over 50%. Vegetation cover, Greater Sage-grouse food forb density, and sagebrush and grass height were significantly ($P < 0.05$) correlated with topographic attributes. Cover for the different plant life forms and food forb density increased with elevation. Cover for most of the herbaceous life forms was also greater on north than south aspects. Compared to Connelly et al. (2000) and the BLM et al. (2000) habitat guidelines, < 1% of the study area satisfied breeding and nesting guideline criteria, while < 31% satisfied the brood-rearing guideline criteria. Although most of the study area did not meet habitat recommendations presented in the guidelines, patches imbedded throughout the study area did and most areas satisfied many but not all of the guideline requirements. These results suggests that evaluating only mean values of community structure, both within and among cover types across the study area, limited the ability to fully identify patch variability and landscape heterogeneity as it relates to habitat suitability across large areas.

Maximum entropy results suggest Greater Sage-grouse habitat use during the breeding season increases near leks and within cover types of low sagebrush and low sagebrush/mountain big sagebrush complexes. Preferred summer habitat includes areas relatively high in elevation, distances that are close to leks, and within or a close proximity to habitats that harbor succulent vegetation through much of the summer. With Greater Sage-grouse utilizing resources within expansive landscapes, understanding the attributes that can be applied at a landscape-scale that attract disproportionate levels of habitat use can help managers predict where birds are likely to occur across the landscape. With the ability to discriminate between areas that Greater Sage-grouse are likely to use or avoid, managers can allocate limited resources to more effectively create, manipulate, and administer habitat conservation efforts where bird use is predicted and prioritize areas across the landscape in need of ecological restoration.

Linking Greater Sage-Grouse Habitat Use and Suitability across Spatiotemporal Scales in Central Oregon

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Mark T. Freese, Author

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Dr.’s Rick F. Miller and Dr. Steven L. Petersen contributed to the study design, writing, and editing of the entire thesis. Dr. W. Douglas Robinson contributed to the study design and editing of Chapter’s 2 and 3. Andrew C. Yost assisted with statistical analysis and editing of Chapter 3.

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CHAPTER 1: INTRODUCTION

A brief History of Greater Sage-Grouse and the Sagebrush Biome

Greater Sage-grouse once occurred in 12 western states and three Canadian provinces. Today, they occur in 11 states and 2 provinces, with complete extirpation from Nebraska and British Columbia (Connelly and Braun 1997). Population declines have been reported since the early 1900s which have continued with estimated losses since 1985 ranging between 17 and 47% in states with sufficient data (Crawford and Lutz 1985, Connelly and Braun 1997). The Greater Sage-grouse population declines are primarily attributed to habitat loss, landscape fragmentation, and degradation of the sagebrush biome (Connelly and Braun 1997, Miller & Eddleman 2001, Connelly et al. 2000, Crawford et al. 2004). Greater Sage-grouse habitat loss has been estimated at 44% in the Great Basin ecoregion from an area once encompassing 120,048,300 ha pre-settlement with its current distribution being 66,841,200 ha (Connelly et al. 2004).

Greater Sage-grouse population declines since the early 1900s coincided with much development in the West (Crawford and Lutz 1985, Connelly and Braun 1997). Extinction was predicted in Oregon during the 1920s and by 1940 Greater Sage-grouse occupied 50% of their former range (Crawford and Lutz 1985). Across the West major population declines occurred during the 1930s with weather and hunting thought to be the primary contributing factors (Connelly and Braun. 1997). Increases were reported in the late 1940s and early 1950s however, declines followed during the 1960s and 1970s (Connelly and Braun. 1997). Even though Greater Sage-grouse distribution has changed little in Oregon since 1940, estimated population declines of approximately 60% occurred between the late 1950s and early 1980s (Crawford and Lutz 1985). A 3.5% population decline per year was estimated to have occurred across the West between 1965 and 1985 (Connelly et al. 2004). Coinciding with population declines from the 1950s to the 1980s was excessive herbicide applications to sagebrush systems as well as an increase in fire frequency (Connelly and Braun 1997, Miller and Eddleman 2001). In Oregon, Greater Sage-grouse populations stabilized in the 1980s and most areas have seen an increase from the mid 1990s to

2005 (Hagan 2005). The Prineville BLM district is an exception which continuous to report population declines (Hagan 2005).

Noticeable anthropogenic influences on the landscape such as the construction of roads, agricultural fields, housing, towns, fences, and power lines, among other features resulted from settlement of the West. Habitat loss through land conversion is one of the greatest factors to have caused the decline in Greater Sage-grouse populations (Miller and Eddleman 2001, Crawford et al. 2004). An estimated 4,500,000 ha of sagebrush steppe have been converted to towns, communication corridors, or intensive agriculture (West 1999). In addition to habitat loss, intensive agricultural systems can act as ecological traps by attracting and killing Greater Sage-grouse as a result of chemical application, hay harvest, and introduction of domestic dogs, cats, and red foxes to the landscape (Connelly et al. 2004). However, agricultural systems can also benefit Greater Sage-grouse by providing succulent vegetation through much of the summer.

Further leading to Greater Sage-grouse habitat loss was habitat deterioration from excessive livestock grazing, herbicide applications, fire regime changes, invasive weed encroachment, woody species encroachment, and recreation (Connelly et al. 2000, Crawford et al. 2004). With no land use regulations from the beginning of westward expansion through the early 1900s the number of livestock peaked around the turn of the century (Holecheck et al. 2004). Sagebrush rangelands, which Greater Sage-grouse are dependent upon for survival, deteriorated by the 1930s with many exotic plant species being introduced (Miller and Eddleman 2001, Holecheck et al. 2004). In 1934 the passage of the Taylor Grazing Act occurred which placed administration of rangelands not formerly claimed by homesteaders under the Grazing Service, later becoming the Bureau of Land Management (BLM) (Holecheck et al. 2004). Great strides were made in range science through the 1930s and 1940s resulting in considerable improvements in range and Greater Sage-grouse habitat management by 1950 (Holecheck et al. 2004). However, herbicide application and mechanical removal of sagebrush (*Artemisia sp.*) were initiated in the late 1940s in order to increase the native grass component to benefit livestock (Miller and Eddleman 2001, Holecheck et al. 2004). Such sagebrush removal practices have been widely associated with population declines in Greater Sage-grouse (Schneegas 1967, Connelly et al. 2000). With herbicide application, mechanical treatment, and prescribed fire peaking from the 1950s to the 1980s, an estimated 1,762,391 ha was treated on BLM lands further adding to Greater Sage-grouse habitat detriment (Miller and Eddleman 2001). In addition, anthropogenic induced structural and compositional alterations in sagebrush plant communities as a result of grazing, herbicide application, mechanical treatment, introduced exotic plant species, and fire suppression has led to fire regime changes in sagebrush plant communities, further influencing Greater Sage-grouse habitat. In southeastern Idaho, fire frequency increased greater than 2,000% while burning more than 100,000 ha between 1959 and 1989 which removes sagebrush, an essential plant to Greater Sage-grouse for an extended amount of time (Connelly and Braun 1997). Miller and Eddleman (2001) presented two scenarios that are occurring as a result of poor land stewardship over the past century: 1) an increase in the dominance of woody species, a decline in fire frequency, and a decrease in perennial forbs and grasses; or 2) an increase in Eurasian weeds, an increase in fire frequencies, and loss of native perennial shrubs, forbs, and grasses. These two scenarios present further challenges to management on rangelands and Greater Sage-grouse habitat.

Adding to the detriment and depletion of Greater Sage-grouse habitat and intertwined with habitat loss and deterioration is landscape fragmentation. Habitat fragmentation is the process of subdividing a continuous habitat into smaller pieces (Andren 1994). Fragmentation involves four components, including loss of the original habitat, reduction in habitat patch size, increasing isolation of habitat patches, and an increase in new habitat (Andren 1994). Road development, recreation development, fences, power corridors, cell phone towers, wind towers, water lines, fuel lines, and fences among other anthropogenic features are examples of fragmentation occurring in many sagebrush habitats throughout the West (Miller and Eddleman 2001, Connelly et al. 2004, Hagan 2005). With landscapes becoming increasingly fragmented, Greater Sage-grouse populations can become isolated increasing the risk of extinction. A fragmented landscape can also result in increased survival risk for Greater Sage-grouse as birds have been reported being killed by such barriers as fences and roads (Connelly 2004, Aldridge 2005).

Coupled with habitat loss, fragmentation, and deterioration are changes in weather and climatic patterns that are altering sagebrush plant communities. Weather patterns and climate throughout sagebrush landscapes are highly variable with prolonged periods of above or below average precipitation being common (Miller and Eddleman 2001). Sagebrush plant communities occupying the landscape at the time of Eurasian settlement developed under several hundred years of cold, wet conditions during the little ice age, which ended in 1850. Between 1850 and 1916 climate conditions were wetter and milder compared to the remaining portion of the 20th Century (Miller and Eddleman 2001). Drought conditions were thought to be the key factor for contributing to Greater Sage-grouse population declines during the 1920s and 1930s (Connelly and Braun 1997). Drought can cause reductions in vegetation cover and the quantity and quality of food sources such as forbs and insects (Connelly and Braun 1997). In central Oregon, Hanf et al. (1994) noted that average lek counts were significantly correlated with precipitation from the previous year's water year. Heavy rainfall during egg-laying or extremely cold temperatures with precipitation during hatching may also negatively affect the success of chick survival (Wallestad 1975, Connelly et al. 2000).

To combat Greater Sage-grouse population declines, eight petitions have been filed with the United States Fish and Wildlife Service to protect Greater Sage-grouse under the Endangered Species Act (ESA) of 1973. No U.S. federal law provides Greater Sage-grouse extraordinary status at this time. Oregon considers Greater Sage-grouse a game bird and warrants no special status. However, Greater Sage-grouse are legally protected in Canada under schedule 1 of the Species at Risk Act, which is similar to the ESA of 1973 (Connelly et al. 2004).

Greater Sage-Grouse Biology

The Greater Sage-grouse belong to the order *Galliformes*, family *Phasianidae*, and subfamily *Tetraoninae* and are the largest species of grouse in North America. Two different Greater Sage-grouse species occur, Greater Sage-grouse found in 9 western states and 2 Canadian provinces and Gunnison Sage-grouse (*Centrocercus minimus*) only occurring in Colorado and Utah, which is not discussed further in this document. Greater Sage-grouse are sagebrush obligate species because of their dependence upon sagebrush for survival (Connelly et al. 2000). Forbs and insects also serve as key habitat components in the survival and successful reproduction of this species (Klebenow and Gray 1968, Barnett and Crawford 1994, Drut et al. 1994b). The quality and quantity of sagebrush, forbs, and insects vary temporally and spatially and are partially responsible for the dynamic diets and complex movements of Greater Sage-grouse (Connelly et al. 2000, Miller and Eddleman 2001, Crawford et al. 2004).

Greater Sage-grouse display complex seasonal movement patterns as a result of dynamic seasonal and annual variation in their habitat (Miller and Eddleman 2001). Breeding, summering, and wintering are temporal categories used to distinguish different habitat uses which are based on the different life cycle stages of Greater Sage-grouse (Connelly et al. 2000). These categories can be further separated into the following: breeding includes leking, pre-nesting, nesting, and early brood rearing; summering includes late-brood rearing, summering, and early autumn; and wintering includes late autumn and winter (Schroeder et al. 1999, Connelly et al. 2000, Crawford et al. 2004). Three types of populations can be defined: 1) non-migratory, Greater Sage-grouse do not make long-distance movement (i.e., >10 km one way); 2) one-stage migratory, grouse move between two distinct seasonal ranges; and 3) two-stage migratory, grouse move among three distinct seasonal ranges (Connelly et al. 2000). Non-migratory Greater Sage-grouse do not make one way movements between seasonal ranges greater than 10 km, while home ranges of migratory populations may exceed 270,000 ha (Connelly et al. 2000). Proposed explanations for the various movement patterns include differences in seasonal habitat selection, desiccation of succulent forbs, harsh weather conditions during the winter, and seasonal site fidelity (Klebenow 1969, Connelly et al. 2000).

Population dynamics of Greater Sage-grouse are characterized by high adult annual survival rates, low annual juvenile survival rates, and low productivity (Connelly et al. 2000, Crawford et al. 2004). Annual survival rates for breeding aged birds tend to be higher than 50% in most situations varying from 35-85% in females and 38-54% in males (Connelly et al. 2000, Crawford et al. 2004, Hagen 2005). In contrast to high annual adult survival rates, juvenile survival rates between egg hatch and following breeding season are low. Crawford et al. (2004) estimated a 10% juvenile survival rate based on several studies. Throughout the West, long-term ratios have varied from 1.40-2.96 juveniles per hen in the fall, but since 1985 ratios have declined to 1.21-2.19 juveniles per hen. Data suggest that ratios greater than 2.25 juveniles per hen in fall are the threshold for stable to increasing populations (Connelly and Braun 1997, Edelmann et al. 1998, Connelly et al. 2000).

In addition to low juvenile survival rates are low productivity rates, which can further be separated into clutch size, nest likelihood, re-nest likelihood, nest success, and annual reproductive success. Clutch size varies on average between 6-10 eggs (Schroeder et al. 1999). The average nest likelihood of Greater Sage-grouse was 79.9% ranging from 63-100% for 11 different studies (Connelly et al. 2004). Hanf et al. (1994) observed 68% (19/28) nest likelihood during the early 1990s in central Oregon with only 1 (1/28) re-nest attempt. The average re-nest likelihood was 28.9% for 9 different studies with a range of 9-87% (Connelly et al. 2004). Average nest success for 16 studies was 47.7% and ranged from 14.5-86.1% with annual reproductive success (probability of a female hatching ≥ 1 egg in a season) being slightly higher due to re-nesting attempts (Connelly et al. 2004). From 1991-1993 in central Oregon nest success was 30% (6/20) with 50% (3/6) raising successful broods, defined as a brood from which one chick was recruited into the August population (Hanf et al. 1994). At Hart Mountain National Wildlife Refuge in southeastern Oregon, nest success was 19.6% (n = 63) in the early 1990s and 36.5% (n=76) during the late 1990s (Gregg 1994, Coggins 1998).

Population dynamics with high annual survival and low recruitment and productivity are thought to be responsible for the cyclic patterns observed in Greater Sage-grouse populations. With high annual survival of breeding aged birds and a high reproductive potential, above average precipitation years can increase recruitment and productivity resulting in “boom” years that results in a cyclic pattern (Crawford et al. 2004).

Mortality factors directly affecting Greater Sage-grouse include weather, predation, hunting, parasites, disease, and anthropogenic structures (Schroeder et al. 1999, Connelly 2004). Greater Sage-grouse mortality is also indirectly linked with factors influencing plant communities such as alterations in fire regimes, weather patterns, excessive livestock grazing, herbicide application, conversion of rangeland to seeded pastures, introduction and spread of non-native species, and anthropogenic habitat creation among other factors (Connelly et al. 2000, Miller and Eddleman 2001, Crawford et al. 2004).

Greater Sage-Grouse Ecology

Greater Sage-grouse use a variety sagebrush and associated riparian and meadow habitats to complete their life cycle, in which they display complex seasonal movement patterns (Crawford et al. 2004). Greater Sage-grouse maintain traditional breeding sites known as leks that are characterized by low, sparse vegetation with higher amounts of bare ground than surrounding areas (Connelly et al. 2000). Leks are commonly located on landing strips, old lakebeds, low sagebrush (*A. arbuscula* Nutt.) flats, ridge-tops, roads, croplands, and burned areas (Connelly et al. 2000). Leks reflect the availability of surrounding nesting habitat and are commonly adjacent to dense stands of big sagebrush (*A. tridentata*) which they use for food and cover (Crawford et al. 2004, Ellis et al. 1989).

During the pre-laying period, defined as the 5 week period preceding incubation, Greater Sage-grouse are commonly found in areas of low sagebrush or Wyoming big sagebrush (*A. tridentata* Nutt. ssp. *wyomingensis* Beetle and Young) (Crawford et al. 2004). Sagebrush is the primary source of food by weight making up 50-80% of the diet but the nutrient contribution of forbs overshadows that of sagebrush (Crawford and Barnett 1994). In southeastern Oregon during a two-year study, Barnett and Crawford (1994) reported fewer forbs in the diet the second year coinciding with reduced productivity, illustrating the importance of the forb component during the pre-laying period.

With low nest success, the quality of nesting habitat is an important factor in the stability of Greater Sage-grouse populations. In central Oregon, Hanf et al. (1994) lost 65% of the nests (13/20) to predation primarily by ravens (*Corus coroux*) and coyotes (*Canis latrans*). It has been suggested that nest failure due to predation is in part due to the lack of adequate cover at nest sites (Gregg et al. 1994). Greater Sage-grouse hens need aerial and horizontal cover for concealment. Hens primarily nest under big sagebrush, but have also been reported to nest under rabbitbrush (*Chrysothamnus* sp. Nutt. and *Ericameria nauseosa* [Pall. ex Pursh] G.L. Nesom & Baird), bitterbrush (*Purshia tridentata* [Pursh] DC.), and greasewood (*Sarcobatus vermiculatus* (Hook.) Torr.), among other shrub species (Connelly et al. 2004). However nest success is greatest under big sagebrush species (Connelly et al. 2004). Shrub canopy cover between 15-25% with heights ranging from 40 to 80 cm and greater than 15% tall (> 18 cm) grass cover has been positively correlated with increased nest success (Gregg et al. 1994, Delong et al. 1995, Sveum et al. 1998).

During early brood-rearing, forbs and insects comprise the bulk of Greater Sage-grouse chick diets and habitats used are typically characterized by areas higher in forb and insect richness and abundance than random locations (Klebenow and Gray 1968, Klebenow 1969, Drut et al. 1994a,b). Juvenile success has been associated with increased forb intake, illustrating the importance of the forb component in chick diets (Barnett and Crawford 1994, Drut et al. 1994a,b). In Oregon, Drut et al. (1994b) found that chicks 1 to 11 weeks old consumed 122 different foods including 41 families of invertebrates, 34 genera of forbs, 2 genera of shrubs and 1 genus of grass. Drut et al. (1994a) reported home range sizes of birds in southeast Oregon ranged from 800 to 5,100 ha for two different populations over two years. As growing season progresses and birds transition to late brood-rearing, broods move to more mesic areas such as riparian areas, wet meadows, alfalfa fields, or up in elevation leaving areas where forb desiccation is occurring for areas where forbs are maturing (Klebenow 1969, Drut et al. 1994b, Connelly et al. 2000, Crawford et al. 2004). At about 12 weeks following hatching, sagebrush becomes a large component of chick diets. Broodless hens and males tend to display similar movements compared to hens with broods, however movements to more mesic habitats tend to occur earlier (Crawford et al. 2004). Movements from breeding and nesting habitat to summer ranges have been recorded as far as 82 km for migratory Greater Sage-grouse (Connelly et al. 1988).

Greater Sage-grouse use a variety of habitats during the fall, which is a transitional period from summer to wintering areas. Greater Sage-grouse movements have been recorded as being slow and meandering in Idaho between the months of August and December (Connelly et al. 1988, Connelly et al. 2000). Greater Sage-grouse respond to growing season dynamics and adapt by switching their diets to one primarily composed of sagebrush (Eng and Schladweiler 1972, Welch et al. 1991, Connelly et al. 2000, Crawford et al. 2004). Movements from summer use areas to wintering areas have been recorded up to 160 km with typical movements in Idaho being 48 km (Connelly et al. 2004).

Winter habitat selection is influenced by snow depth and hardness, elevation, slope, aspect, and vegetation height and cover (Eng and Schladweiler 1972, Connelly et al.

2000, Connelly et al. 2004). Since Greater Sage-grouse diets consist exclusively of sagebrush leaves during the winter, they require sagebrush that extends above the snow layer (Connelly et al. 2000). Hanf et al. (1994) observed sagebrush canopy cover was typically greater than 20% at winter use sites. This study also reported that 98% of the observations were in mountain big sagebrush (*A. tridentata* Nutt. ssp. *vaseyana* [Rydb.] Beetle), although winter use has been recorded in low sagebrush, basin big sagebrush (*A. tridenata* Nutt. ssp. *tridentata*), black sagebrush (*A. nova* A. Nelson), stiff sagebrush (*A. rigida* [Nutt.] A. Gray), and silver sagebrush (*A. cana* Pursh ssp. *bolanderi* [A. Gray] G.H. Ward) (Connelly et al. 2000). Topography influences snow depth, wind, and wind chill effect, which in turn influence Greater Sage-grouse site selection for foraging and maintaining their energy balance (Burke et al. 1989, Crawford 2004). Birds are commonly found on south and southwest facing aspects, windswept ridges, and swales when foraging and when roosting they are found in areas low in elevation that are wind-blocked (Connelly et al. 2004). Eng and Schladweiler (1972) found that birds in Montana were never encountered on steeper slopes even though dense sagebrush pockets were present and only moved off flat ridges when wind speeds exceeded 10-15 mph. Wintering habitat throughout most of Greater Sage-grouse range is not considered to be limiting (Connelly et al. 2000).

Landscape Ecology and Greater Sage-grouse

The advent and enhancement of geospatial technologies (remote sensing, Geographic Information Systems, Global Positioning Systems) has enabled researchers and managers to view and manage landscapes at multiple spatial scales relatively easily. Geospatial technologies are useful for viewing ecological patterns of plants and animals which are the result of different processes operating at different scales. Recognizing ecological patterns help managers and ecologists understand, interpret, and predict ecological processes (Swanson et al. 1998, Levin 1992). Ecologist ability to detect and describe these patterns depends on the extent and grain (resolution) under investigation (Weins 1989, Levin 1992). It is important to realize that no ideal scale exists to describe a system, but that doesn’t mean that all scales serve equally well, as different processes are important at different scales (Levin 1992). Ecological patterns are a predictable ordering of resources (nutrients, soils, water, vegetation, organisms, etc.) resulting from ecological processes (energy cycle, hydrologic cycle, disturbances, etc.) (Levin 1992, Miller and Eddleman 2001). Vegetation community structure and composition respond to the ordering of resources as a result of soil patterns and by means of temperature and moisture gradients (West et al. 1978, Winward 1980, Burke et al. 1989, Jensen 1989a,b, McArthur 1992, Miller and Eddleman 2001, Rosentreter 2004, Miller et al. in press,). By understanding the processes that influence vegetation patterns, ecologist and managers can predict vegetation patterns in turn predicting habitat use by wildlife.

Greater Sage-grouse extensive home ranges and temporally and spatially diverse habitat requirements make them a prime candidate for landscape-scale analysis. Edelmann et al. (1998) developed models linking Greater Sage-grouse population fitness parameters with habitat quality at the plot and landscape-levels. Greater Sage-grouse vital rates or the vital statistics associated with demographic parameters were linked to habitat characteristics based on estimates from professionals and 52 Greater Sage-grouse research documents. The attempt to link population vital rates with multiple scale habitat parameters provides a framework for additional research. Akcakaya et al. (2004) and Larson et al. (2004) have incorporated some of these ideas and developed new ones linking landscape simulation models, habitat suitability, and Population Viability Analysis (PVA) for sharp-tailed grouse (*Tympanuchus phasianellus*) and ovenbirds (*Seiurus aurocapillus*), respectfully. Anthropogenic influences on landscape-scale components over time were linked to habitat suitability and PVA estimates obtained from various studies. Such models have provided a useful tool for conservation planning by exploring the various management outcomes.

A regional scale model was developed by Wisdom et al. (2002a) that tested the risk of Greater Sage-grouse population extirpation as a result of current BLM and United State Forest Service (USFS) management and two restoration scenarios. Risk of historical extirpation was also calculated for comparative purposes. This approach provides evidence of model usefulness in conservation planning as their results suggest that both restoration scenarios will reduce the risk of Greater Sage-grouse expiration within the next 100 years to moderate levels from a high risk as was modeled under the current BLM and USFS management. Wisdom et al. (2002b) also developed a regional scale model linking habitat quality, quantity, and human disturbance factors with areas currently occupied by Greater Sage-grouse and areas where they have been extirpated. This model provided reliable predictions that poor environmental conditions resulted in Greater Sage-grouse extirpation. In a similar manner, Fuhlendorf et al. (2002) provided a multiple temporal and spatial scale model linking fragmentation to areas where prairie chickens (*Tympanuchus pallidicinctus*) populations have declined and are sustained. Metrics of landscape structure were analyzed (tree cover, cropland cover, edge density change, and landscape change) and mapped using geospatial technologies. In their results they observed that a single spatial scale would not have given complete results of the influences of landscape structural changes on prairie chicken populations, further illustrating the need for a multi-scale approach to Greater Sage-grouse habitat conservation.

Such modeling approaches of Edelmann et al. (1998), Fuhlendorf et al. (2002), Wisdom et al. (2002a,b), Akcakaya et al.(2004), Larson et al. (2004), have illustrated that models can aid in land use planning on the viability of wildlife populations. They also emphasize the need for research and management across multiple spatial and temporal scales. However, these models may be questionable and limited by not fully understanding the wildlife-habitat relationship. The direct effects of variation in habitat suitability on wildlife vital rates are often unknown (Larson et al. 2004). Through these models wildlife and their fitness parameters were indirectly linked to habitat by reports from previous studies or were estimated based on the best scientific literature.

However, Aldridge and Boyce (2007) directly linked Greater Sage-grouse occurrence and fitness to persistence by capturing, collaring, and tracking birds across their study area. Their results elucidated the Greater Sage-grouse habitat relationship during nesting and brood-rearing by identifying the habitat components that Greater Sage-grouse are attracted too and the amount of survival risk associated with each habitat. Based on empirical data, these models predicted nesting and brood-rearing source and sink habitats spatially across the landscape. This modeling approach enables managers to make decisions about which areas to protect and restore across the landscape. However, results from their study only apply to areas with similar attributes, therefore in landscapes with little human alterations results may differ.

Yost et al. (2008) also modeled Greater Sage-grouse nesting habitat occurrence as a function of environmental factors that can be modeled at the landscape-scale. Their research lacked fitness information but provided evidence that Greater Sage-grouse nest site location selection is influenced strongly by plant cover types. Aldridge and Boyce (2007) warned against using only occurrence or abundance data that lacked fitness parameters, as incorrect assessments of habitat importance may lead to ill-suited management actions. This point is valid and must be considered, but in landscapes where anthropogenic influences are relatively minimal such as Yost et al. (2008) study area, fitness parameters become less consequential. It is also often unknown and difficult to obtain the vital rates as they relate directly to the effects of variation in habitat suitability.

Aldridge and Boyce (2007) and Yost et al. (2008) research have provided validated models that predict habitat use, helping managers locate the nesting and brood-rearing habitat in need of restoring and protecting. Nonetheless, further empirical research is needed to identify the landscape-scale drivers associated with habitat selection through the summer and winter seasons as these landscape-level influences are currently unknown (Yost et al. 2008).

Conservation planning is an important aspect of land use decisions, which influence Greater Sage-grouse habitat quantity and quality. The benefits of conservation planning are currently limited by the lack of understanding of the animal-habitat relationships at multiple scales (Larson et al. 2004, Gregg 2006). With advanced technological resources, the capability of filling many of these knowledge gaps is at our fingertips.

Project Goal

After review of the previous Greater Sage-grouse habitat research, it became apparent a knowledge gap exist linking the plot-level vegetation characteristics to the landscape-level and a lack of information on how birds select habitat at the landscape-level. This study attempts to fill these knowledge gaps by evaluating plot-level habitat characteristics found to be important in sustaining Greater Sage-grouse populations at a landscape-level and to identify landscape-level attributes associated with bird occurrence. Specific questions this research addressed were: 1) what is the variation in habitat characteristics found to be important in sustaining Greater Sage-grouse populations at the plot versus landscape-scales, 2) how does topography influence the distribution of vegetation composition and structure, and 3) what attributes at the landscape-level are most closely associated with Greater Sage-grouse habitat use?

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CHAPTER 2: GREATER SAGE-GROUSE (*CENTROCERCUS UROPHASIANUS*) HABITAT SUITABILITY FROM A LANDSCAPE PERSPECTIVE: ISSUES OF SCALE

Abstract

Greater Sage-grouse (*Centrocercus urophasianus*) habitat research has previously focused on fine-scale (0.007 - 0.032 ha) vegetation structure and composition immediately surrounding sites selected by these birds. However, little work has evaluated vegetation attributes important for Greater Sage-grouse at a landscape-scale limiting biologist's and manager's understanding of landscape heterogeneity. Vegetation resources important to Greater Sage-grouse are arranged heterogeneously across broad landscapes, influencing Greater Sage-grouse movement patterns. This creates a major challenge for manager's, which are responsible for making decisions at the landscape-level, to interpret and predict movement patterns and evaluate habitat suitability across broad landscapes. The goal of this research was to evaluate plot-level habitat characteristics found to be important in sustaining Greater Sage-grouse populations in a landscape context. Specific objectives addressed were: 1) describe the variation of vegetation composition and structure related to the Greater sage-grouse habitat requirements at a landscape-level, 2) evaluate the relationship of micro and macro topography on vegetation composition and structure, and 3) evaluate the Greater Sage-grouse habitat guidelines in a landscape context. To address these questions, a 31,416 ha area was selected in central Oregon surrounding a Greater Sage-grouse lek with a population that has been relatively stable since 1987. To attain a landscape-scale perspective of vegetation characteristics across the study area both aerial imagery and field measurements were recorded. One-half meter NAIP imagery was used to map boundaries and attain estimates of the area covered by each cover type, which were defined by the dominant shrub species in the uplands and annual moisture persistence in lowlands. A stratified random sample with cover types serving as the stratum was used to select random locations for sampling plot-level habitat variables. A total of 352 plots were sampled from 18 cover types across the study area with a minimum of 15 plots per cover type. Vegetation measurements collected were

similar to those reported in the habitat guidelines developed by Connelly et al. (2000) and the Bureau of Land Management et al. (2000). Measurements included vegetation cover, height, and density of forbs recognized as important Greater Sage-grouse food species. Plot elevation, slope, aspect, curvature and landscape position were also recorded. Summary statistics were used to describe means and ranges within and between cover types. A combination of multiple linear regression and analysis of variance (ANOVA) were used to evaluate the effects of topographic attributes on the distribution of vegetation composition and structure. Total shrub canopy cover across all cover types averaged 19.4%, ranging from 11.6 to 27.7%. Big (mountain and Wyoming) and low sagebrush canopy cover typically varied between 2.6 and 16 fold within cover types. Deep-rooted perennial tussock grass cover averaged across all upland plots, was 26.7%, ranging from less than 1% to over 50%. Vegetation cover, Greater Sage-grouse food forb density, and sagebrush and grass height were significantly ($P < 0.05$) correlated with topographic attributes. Cover for the different plant life forms and food forb density increased with elevation. Cover for most of the herbaceous life forms was also greater on north than south-facing aspects. Compared to Connelly et al. (2000) and the BLM et al. (2000) habitat guidelines, < 1% of the study area satisfied breeding and nesting guideline criteria, while < 31% satisfied the brood-rearing guideline criteria. Although most of the study area did not meet habitat recommendations presented in the guidelines, patches imbedded throughout the study area did and most areas satisfied many but not all guideline requirements. These results suggests that evaluating only mean values of community structure, both within and among cover types across the study area, limited the ability to fully identify patch variability and landscape heterogeneity as it relates to habitat suitability across large areas.

Introduction

Past research has described important vegetation structural and compositional attributes necessary to provide suitable habitat for Great Sage-grouse (*Centrocercus urophasianus*)(Connelly et al. 2000). Greater Sage-grouse habitat was described using fine-scale measurements ranging from 0.007 - 0.032 ha in size for sites specifically selected by birds. However, little work has evaluated these attributes in the landscape context, which limits biologist's and manager's understanding of landscape heterogeneity. Vegetation resources important to Greater Sage-grouse are arranged heterogeneously across broad landscapes, influencing Greater Sage-grouse movement patterns. This creates a major challenge for manager's, which are responsible for making decisions at the landscape-level, to interpret and predict movement patterns and evaluate habitat suitability across broad landscapes.

Greater Sage-grouse use heterogeneous landscapes selecting habitat at multiple spatial scales with home ranges that can exceed 270,000 ha (Connelly et al. 2000, Leonard et al. 2000, Gregg 2006). Greater Sage-grouse display complex seasonal movement patterns as a result of annual changes in their biological requirements and the seasonal and annual variation in the composition and structure of sagebrush communities (Schroeder et al. 1999, Connelly et al. 2000, Miller and Eddleman 2001, Crawford et al. 2004, Gregg 2006). The ability of this species to move long distances allows them to take advantage of the spatial and temporal variation of sagebrush and associated plant communities within their home range (Miller and Eddleman 2001). The composition, structure, and arrangement of heterogeneous landscapes influence how Greater Sage-grouse select habitats and the resources available determine the success and stability of populations. The combination of resources these habitats must provide include forbs, insects, and sagebrush for consumption and sagebrush and grass for cover (Drut et al. 1994a, Delong et al. 1995, Coggins 1998, Sveum et al. 1998, Connelly et al. 2000, Crawford et al. 2004).

Managing Greater Sage-grouse habitat is challenging with a limited understanding relative to the spatial relationship of required resources across heterogeneous landscapes. Landscapes refer to the form of the land surface and associated ecosystems at scales of hectares to many square kilometers (Swanson et al. 1988). Landscapes are a mosaic of smaller identifiable ecological units such as landform features and patches having different spatial arrangements giving each landscape a unique pattern (Urban et al. 1987, Swanson et al. 1998). Patches are composed of plant communities that reoccur across the landscape in different seral states and with different ecological potential capabilities resulting in landscapes that are heterogeneous in space and through time. Variability within and among plant communities is a function of spatial heterogeneity related to soils, topography, geology, and disturbance history within a similar climate area (Jensen 1990, Miller and Eddleman 2001, Davies et al. 2007).

In an attempt to describe and predict Greater Sage-grouse habitat attributes in a landscape context, vegetation characteristics described by Connelly et al. (2000) and the Bureau of Land Management (BLM) et al. (2000) were measured across a 31,416 ha area surrounding a lek with a stable population of Greater Sage-grouse (ODFW unpublished lek count data 2008). Specific objectives addressed were: 1) describe the variation of vegetation composition and structure related to the Greater sage-grouse habitat requirements at a landscape-level, 2) evaluate the relationship of micro and macro topography on vegetation composition and structure, and 3) evaluate the Greater Sage-grouse habitat guidelines in a landscape context.

Study Area Description

The study area was located in Crook County, central Oregon (Fig. 2.1). To describe a landscape within Greater Sage-grouse habitat, the largest lek in the area was chosen as the center point (119º 53’ 22” W Longitude and 43º 48’ 31” N Latitude). The study was conducted within a 10 km radius surrounding this lek. The study area extent was defined in part, based on what the literature (Braun et al. 1977, Connelly et al. 2000) stated were some common distances that Greater Sage-grouse move from leks. Aldridge and Boyce (2007) noted that 90% of all nesting and brood-rearing source habitats occurred within 10 km of the lek. Supportive data also included an ongoing study by the Oregon State University, Department of Fisheries and Wildlife in this same area, in which collared Greater Sage-grouse were being tracked using radio telemetry (Bruce personal communication, 2006). After tracking collared birds through one breeding and summer season it appeared that this population was residential as 85% of the birds were contained within 10 km of the lek. After tracking collared Greater Sage-grouse in this population for two consecutive years, Bruce (2008) detected that collared birds used areas outside the study boundary during the winter season.

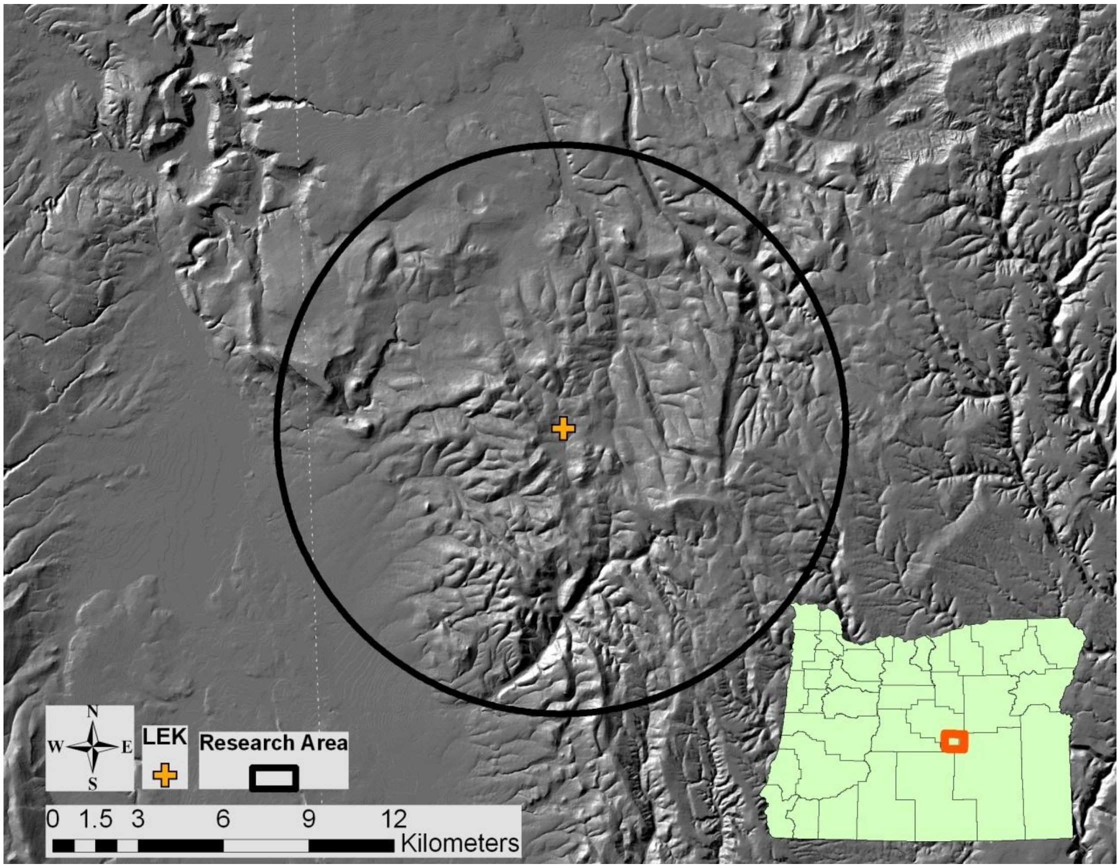

Figure 2.1. The 31,416 ha study area in central Oregon (10 km radius boundary) with the largest lek as the center point.

The study area was composed of both private and public lands with approximately 55% being managed under private ownership, 35% by the BLM, 6% by the United States Forest Service, and 4% by the state of Oregon. The area borders on the High Desert and John Day Ecological provinces, with geology and soils resembling more of the High Desert Ecological province (Anderson et al. 1998). The topography was characterized by elongated ridges with dissecting draws, rolling hills, rocky tablelands, and interspersed with buttes and plateaus capped with basalt or tuffaceous rock. Dominant soils are mapped in the mesic and frigid temperature, and xeric moisture regimes and include Argixerolls, Haploxerolls, Palexerolls, Haploxerents, and Durixerolls. Elevation generally increases from west to east ranging from 1,267 m to 1,715 m. Springs and perennial streams are abundant throughout the eastern half of the study area, but are limited in the western half. The prevailing winds generally blow from west to east throughout the year. Average precipitation at the nearest weather station (Paiute Butte located approximately 37 km from the center of the study area at an elevation of 1,250 m) is 300 mm (Fig. 2.2) (EOARC weather station records 1971-2000). The annual precipitation amount for the water year (October 1 – September 30) when the vegetation measurements were taken was 52% of the long-term average (EOARC weather station records 1971-2000). Average temperature throughout the year is 7.5° C, ranging from -29 to 38° C (EOARC weather station records 1971-2000).

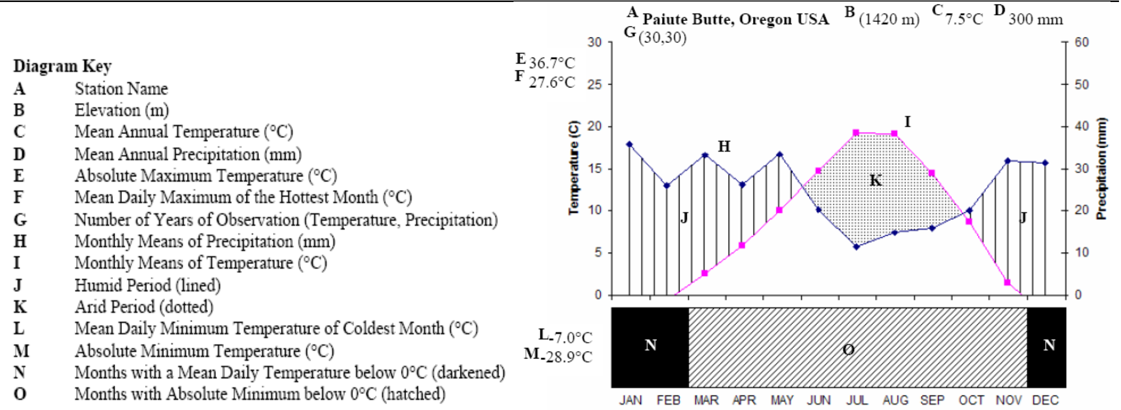

Figure 2.2. Walter Diagram for Paiute Butte weather station located 37 km from center of the study area at an elevation of 1,250 m.

The history of land use across the study area was dry-land farming primarily in lowlands and grazing by sheep, cattle, and horses in both the lowlands and uplands starting around 1870 and lasting to 1935 (Lundegren 2008). Since the mid 1930s, livestock grazing by cattle has been and continues to be the dominant land-use with irrigated alfalfa grown in a portion of the lowlands.

Methods

Field Reconnaissance

Prior to intensive sampling, 39 unique cover types were developed for this area based on field reconnaissance, but were narrowed to 18 (Table 2.1) as many only comprised a small fraction (< 0.1%) of the landscape. Cover types are classification categories defined by the dominant shrub species in the uplands and annual moisture persistence in lowlands. Cover types occupied by two dominant shrub species occurred as intermingled complexes of small (< 0.03 ha), clumped patches (e.g. low sagebrush and mountain big sagebrush) or co-dominant within the same patch. Cover types dominated by two shrub species were separated into a complex or co-dominant category if the canopy cover ratio of both species was 29.5/70.5 to 50/50. As a result of the reported sensitivity of the Greater Sage-grouse to vertical obstructions, cover types were further separated into categories with greater than and less than 5% juniper cover (Connelly et al. 2004). To obtain cover type area estimates, aerial 0.5-m National Agriculture Imagery Program (NAIP) imagery was used to map boundaries in a Geographic Information System (GIS).

Table 2.1. Eighteen cover types sampled including complexes (/) and co-dominant species (-) with the estimated amount of area and percent landscape composition.

Cover Type	Juniper Cover	Area Composed	Area (ha)
** Low Sagebrush	< 5	32.2%	10,111
** Low Sagebrush	≥ 5	7.2%	2,265
** Low Sagebrush/Mountain Big Sagebrush	< 5	1.5%	483
** Low Sagebrush/Mountain Big Sagebrush	≥ 5	0.1%	18
** Low Sagebrush/Wyoming Big Sagebrush	--	0.3%	87
Low Sagebrush-Green Rabbitbrush	--	--	--
Low Sagebrush-Grey Rabbitbrush	--	--	--
** Mountain Big Sagebrush	< 5	24.3%	7,638
** Mountain Big Sagebrush	≥ 5	4.8%	1,507
Mountain Big Sagebrush-Green Rabbitbrush	--	--	--
Mountain Big Sagebrush-Grey Rabbitbrush	--	--	--
Mountain Big Sagebrush-Bitterbrush	--	0.2%	76
** Wyoming Big Sagebrush	--	14.3%	4,496
Green Rabbitbrush	--	2.4%	755
Grey Rabbitbrush	--	0.4%	110
Perennial System	--	0.8%	250
Ephemeral System	--	--	--

Area was calculated from a vegetation map with an accuracy assessment of 82.9 % (Freese 2009). Mapped cover types represent 88.5 % of the research area. Cover types with no area did infact exist on the ground, but could not be accurately mapped from NAIP imagery.

**Cover types used to compare Connelly et al. (2000) and BLM et al. (2000) habitat guidelines.

Cover Type Description

The low sagebrush (*A. arbuscula* ssp. *arbuscula* Nutt.) cover type occurred at all elevations in the study area. Common associated grass species were Sandberg's bluegrass (*Poa secunda* J. Presl), bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Love), Idaho fescue (*Festuca idahoensis* Elmer), bottlebrush squirreltail (*Elymus elymoides* [Raf.] Swezey), and prairie junegrass (*Koeleria macrantha* [Ledeb.] Schult). The mountain big sagebrush (*A. tridentata* Nutt. ssp. *vaseyana* [Rydb.] Beetle) cover type was typically found at elevations above 1,400 m within the study area. Grass species commonly associated with this cover type included Idaho fescue and bluebunch wheatgrass. Occurring typically below elevations of 1,400 m was the Wyoming big sagebrush (*A. tridentata* Nutt. ssp. *wyomingensis* Beetle and

Young) cover type. Thurber's needlegrass (*Achnatherum thurberianum* [Piper] Barkworth), needle and thread (*Hesperostipa comata* [Trin. & Rupr.] Barkworth), and bluebunch wheatgrass were commonly associated with this cover type.

The green rabbitbrush (*Chrysothamnus* sp. Nutt.*)* cover type commonly found at lower elevations often had a cheatgrass (*Bromus tectorum* L.) understory. Green rabbitbrush found at higher elevations was commonly associated with Idaho fescue and Sandberg's bluegrass. The gray rabbitbrush (*Ericameria nauseosa* [Pall. ex Pursh] G.L. Nesom & Baird) cover type was commonly found adjacent to meadows with sedge (*Carex* sp. L.) species dominating the understory.

There were also several perennial and ephemeral stream systems scattered throughout the study area. Perennial systems supported riparian plant communities and plant communities that remained green throughout the entire summer. Springs, streams, and meadows composed the perennial systems cover type and were dominated by sedges (*Carex* sp), rushes (*Juncus* sp. L.), and grasses. Ephemeral and intermittent streams, springs, and meadows with desiccant vegetation during the summer composed the ephemeral systems cover type. Grasses dominated were typically dominant in this cover type.

In addition to these cover types, associated shrub species within the study area included basin big sagebrush (*A. tridenata* Nutt. ssp. *tridentata)*, early sagebrush (*A. arbuscula* Nutt. ssp. *longiloba* [Osterh.] L.M. Shultz), silver sagebrush (*A. cana* Pursh ssp. *bolanderi* [A. Gray] G.H. Ward), stiff sagebrush (*A. rigida* [Nutt.] A. Gray), antelope bitterbrush (*Purshia tridentata* [Pursh] DC.), horsebrush (*Tetradymia canescens* DC.), wax current (*Ribes cereum* Douglas), and snowberry (*Symphoricarpos oreophilus* A. Gray.). Western juniper (*Juniperus occidentalis* Hook.) was interspersed throughout the study area and rapidly encroaching in areas. Ponderosa pine (*Pinus ponderosa* C. Lawson) was dominant along the eastern boundary. Other tree species that occur within the study area in trace amounts included quaking aspen (*Populus tremuloides* Michx.), curlleaf mountain mahogany (*Cercocarpus ledifolius* Nutt.), plum species (*Prunus* L.), and willow species (*Salix* L.). Common perennial and annual forbs included common yarrow (*Achillea millefolium* L.), pussytoe species (*Antennaria* Gaertn), milkvetch species (*Astragulus* L.), fleabane species (*Erigeron* L.), buckwheat species (*Eriogonum* Michx.), lupine species (*Lipinus* L.), aster species (*Aster* L.), phlox species (*Phlox* L.), and slender phlox (*Microsteris gracilis* [Hook.] Greene).

Experimental Design

Based on field reconnaissance during the first field season, a stratified random sample design with the cover types representing the strata was used to select plot locations. Using a GIS, random sample points where generated across the 31,416 ha study area. To ensure 15 samples per cover type was obtained, a single random point was selected daily as a starting point for sampling. The next closest random point was visited and the cover type was visually assessed. It was sampled if it was a unique cover type for that day or otherwise skipped and the next closest random sample point visited. Restricting sampling to one sample per cover type per day ensured coverage across the study area for each of cover types. Employing this sampling design maximized the number of samples collected in a single field season across this large area with limited access.

Plot Setup and Description

At each random point selected for sampling, a 30 x 30 m plot was set up with the random point in the center of the plot to measure vegetation composition, structure, and topographic variables. Three, 30-m transects were placed parallel at 13-m intervals within each plot on the contour or in a north-south direction if on a flat surface. The 30 x 30 m plot incorporated adjacent cover types for the ephemeral systems cover type since it exhibited a long, narrow shape. Modifications in plot setup were made to avoid measuring vegetation composition and structure characteristics in adjacent cover types. Three, 30-m transects were placed end to end within the edges and in a parallel direction of the ephemeral system cover type.

Vegetation Sampling

Vegetation measurements collected were similar to those reported in the habitat guidelines (Connelly et al. 2000, BLM et al. 2000) and included vegetation cover, height, and density of Greater Sage-grouse food forbs. From mid-June to early September, 2007, 352 plots were sampled across the study area. Canopy cover was measured for trees and shrubs by species. Foliar cover for herbaceous vegetation was measured by life form, which included: deep-rooted perennial tussock grass (PG), shallow-rooted perennial tussock grass (SG), annual grass (AG), exotic grass (EG), perennial forb (PF), and annual forb (AF). The line-point intercept method from Herrick et al. (2005) was used to estimate canopy cover for tree and shrub species and foliar cover of herbaceous vegetation for each life form. Point contacts were recorded every 0.5 m along each of the 30-m transects for a total of 180 points. Shrub canopy cover was counted if the pin hit or was completely surrounded and within 5 cm of live shrub canopy. The point had to come into contact with herbaceous vegetation to be counted. Three dominant shrub heights and three deep-rooted perennial leaf and inflorescence tussock grass height measurements were recorded at 10 and 20 m intervals along each of the three transects for a total of 18 shrub and grass heights. Shrub height was measured to the tallest part of the living, vegetative structure, excluding inflorescences. The tallest natural height (droop-height) of the deep-rooted perennial tussock grass leaves and inflorescences were measured, whether the grass was alive or a residual from the previous year. Forb density was measured only for those species reported as Greater Sage-grouse food species (Table 2.2). Density of food forbs were recorded in a 0.5 x 30 m quadrat aligned along each of the three transects for a total of 45 m^2.

Table 2.2. Forbs commonly found in Greater Sage-grouse diets.

Achillea millefolium
Agoseris glauca
Agoseris heterophylla
Antennaria dimorpha
Antennaria luzuloides
Antennaria rosea
Aster sp.
Astragalus spp.
Calochortus macrocarpus
Calochortus nutallii
Castilleja spp.
Crepis acuminata
Crepis occidentalis
Erigeron bloomeri
Erigeron corymbosus
Erigeron filifolius
Erigeron linearis
Erigeron poliospermus
Erigeron pumilus
Eriogonum sphaerocephalum
Gayophytum spp.
Lactuca serrioke
Leptosiphon harnessii
Lomatium sp.
Microseris nutans
Microsteris gracilis
Mimulus nanas
Monolepis nutalliana
Nothocalais troximoides
Orobanche fasciculata
Orobanche uniflora
Phlox hoodii
Phlox longifolia
Ranuculus glaberrimus
Taraxacum officinale
Tragopogon dubius
Trifolium macrocephalum

Klebenow and Gray 1969, Drut et al. 1994b, Schroeder et al. 1999, Miller and Eddleman 2001, Gregg 2006, Petersen personal communication 2006, Bruce 2008.

Topographic Assessment

Topographic variables recorded at each plot location were elevation, aspect, slope, curvature, and landscape position. Elevation was recorded from a Garmin 60CS Global Positioning System (GPS) unit (altimeter ± 3 m). Aspect and slope were measured using a Suunto MC-2 compass and a Suunto PM-5/360PC clinometer respectively. Curvature was visually estimated as non-curvature (flat), concave, or convex. Landscape position classes were bottom, toeslope, sideslope, terrace, and ridgetop (Appendix A).

Cover Type Mapping

To estimate the area covered by each cover type, a map was created in a GIS using 0.5-m NAIP aerial color photographs to delineate dominant shrub species based on their distinct visual patterns. Cover types were further delineated using elevation, aspect, and vegetation data collected from field plots. Juniper was an exception to this scheme, as it was mapped using a supervised classification technique. A moving window approach with the window area being 254 m^2 was used to remove all juniper with less than 5% cover. If juniper patches with three or less trees remained after the moving window approach, then these patches were removed to avoid having patches with a single or few trees. The juniper dataset with greater than or equal to 5% cover was integrated (union) with the vegetation map to create cover types with greater than 5% juniper cover. The resolution of the map was 20 m^2 while having the same extent as the study area (31,416 ha).

An accuracy assessment was conducted across the study area using Cohen's Kappa Analysis Tools in Arcview 3.3 to produce an error matrix, which verifies the cover type map accuracy. Within each cover type, 40 random points spread greater than 25 m apart were generated in a GIS and then visited in the field for verification. The dominant cover type was visually assessed in the field and compared with the digitized map cover type. Overall map accuracy was 82.9% (Appendix B. Report 2).

Habitat Guidelines Comparison

To help agencies and private landowners assess Greater Sage-grouse habitat suitability and provide restoration guidance, Connelly et al. (2000) developed habitat guidelines based on past research. The guidelines identified the characteristics in sagebrush plant communities associated with productive Greater Sage-grouse habitat (Table 2.3). Similarly, the BLM et al. (2000) developed guidelines for Greater Sage-grouse habitat assessment (Table 2.4). Both guidelines were developed from fine-scale habitat measurements (0.007 - 0.032 ha) surrounding sites specifically selected by radio collared Greater Sage-grouse.

Table 2.3. Connelly et al. (2000) characteristics of sagebrush rangeland associated with productive Greater Sage-grouse habitat.

	Breeding		Brood-rearing		Winter[e]	
	Height (cm)	Cover (%)	Height (cm)	Cover (%)	Height(cm)	Cover (%)
Mesic sites[a]						
Sagebrush	40-80	15-25	40-80	10-25	25-35	10-30
Grass-forb	> 18[c]	≥ 25[d]	variable	> 15	N/A	N/A
Arid sites[a]						
Sagebrush	30-80	15-25	30-80	10-25	25-35	10-30
Grass/forb	>18[c]	≥ 15	variable	> 15	N/A	N/A
Area[a]	> 80		> 40		> 80	

[a] Mesic and arid sites should be defined on a local basis; annual precipitation, herbaceous understory, and soils should be considered (Tisdale and Hironaka 1981, Hironaka et al. 1983).
[b] Percentage of seasonal habitat needed with indicated conditions.
[c] Measured as "droop height"; the highest naturally growing portion of the plant.
[d] Coverage should exceed 15% for perennial grasses and 10% for forbs; values should be substantially greater if most sagebrush has a growth form that provides little lateral cover (Schroeder 1995)
[e] Values for height and canopy coverage are for shrubs exposed above snow.

Table 2.4. Bureau of Land Management et al. (2000) characteristics of sagebrush rangeland associated with productive Greater Sage grouse habitat.

	Nesting		Brood-rearing		Winter	
	Height (cm)	Cover (%)	Height (cm)	Cover (%)	Height(cm)	Cover (%)
Optimal						
Sagebrush	40-80	15-25	40-80	10-25	25-30[c]	10-30
Grass-forb	≥ 18	≥ 25[b]	N/A	> 25[b]	N/A	N/A
Suboptimal						
Sagebrush	N/A	N/A	40-80	≥ 14	N/A	N/A
Grass/forb	N/A	N/A	N/A	≥ 15	N/A	N/A
Area[a]	> 80		> 40		> 80	

[a] Percentage of habitat needed with suggested vegetation cover and height values.
[b] Perennial grass cover > 15% and forb cover > 10%.
[c] Sagebrush height values are for sagebrush above the snow.

Cover types that were solely dominated by sagebrush (168 plots) were used to evaluate the Greater Sage-grouse habitat guidelines produced by Connelly et al. (2000) and the BLM et al. (2000). Eight cover types (Table 2.3) comprising an estimated 88.4% of landscape were used in this analysis. In order for plots to be counted as meeting guideline criteria, all habitat requirements had to be satisfied.

Analysis

Summary statistics were calculated for all cover types using S-PLUS (2007). A combination of multiple linear regression and analysis of variance (ANOVA) was used to correlate topography with vegetation characteristics sampled at the plot-level. Differences were detected between categorical topographic variables, while a linear relationship was measured for continuous topographic variables only for upland cover types (excluding perennial and ephemeral systems). All five topographic factors were used in both a regression analysis and an ANOVA analysis and continuous variables were reported in the regression format, while categorical variables were reported in the ANOVA format. When exploring the data, if graphical displays provided evidence that the normality or non-constant variance assumptions were violated, then a transformation was used. In the case that non-constant variance existed, a Levenes F-test for equal variances was conducted in STATGRAPHICS (2001) and a decision to transform the data was then based on the significance of the test. A log transformation was used on total forb cover and perennial forb cover and results were back transformed and reported on the original scale. A rank-sum transformation was used on perennial grass cover, annual forb cover, all forb density measurements, and grass inflorescence and leaf heights. Therefore, the coefficients and means correspond to the rank and not to the value of the response variable. The largest ranks correspond to the largest values, while the smallest ranks correspond to the smallest values. A Bonferroni multiple comparisons of means test was conducted for each of the categorical variables. Cover types dominated by sagebrush were used to compare life form cover and height values to the values that Connelly et al. (2000) and the BLM et al. (2000) recommend for productive Greater Sage-grouse habitat. Plots that satisfied all guideline criteria were then compared to plots that failed to satisfy all guideline criteria using summary statistics for further analysis.

Results

Landscape Description

Means and ranges (minimum and maximum) of cover values measured at the plot-level for the different plant life forms were highly variable within and across cover types (Table 2.5). For all upland plots across the study area shrub canopy cover averaged 19.4%, however means between cover types ranged from 11.6 to 27.7%. Tall (mountain and Wyoming big sagebrush) and low sagebrush canopy cover varied between 2.6 and 16 fold within cover types. For example, sagebrush canopy cover in the Wyoming big sagebrush cover type ranged from 7.2 to 18.9%, while sagebrush canopy cover in the low sagebrush cover type with less than 5% juniper cover ranged from 1.7 to 27.2%. Average grass cover values for all upland plots was 26.7% for total grass, 17.6% for deep-rooted perennial tussock grass, 6.2% for shallow-rooted perennial tussock grass, 2.8% for exotic grass, and less than 1% for native annual grass. Among the different life forms, cover of deep-rooted perennial tussock grasses had the largest variation within and between cover types with plots ranging from less than 1% to over 50% across the study area. Exotic annual grasses generally accounted for less than 5% cover across the study area, however some plots exceeded 20% cover. Average total forb cover across all upland plots was 4.2% but averaged near 17% in the perennial system cover type. Perennial forb cover values across all upland plots was 3.3%, while ranging from 0 to 32.2% within the mountain big sagebrush cover type with greater than 5% juniper cover. Mean annual forb cover across all upland plots was less than 1%, while within the low sagebrush cover type with less than 5% juniper cover it ranged from 0 to 19.4%.

Table 2.5. Means and ranges of cover values and number of plots for different life forms reported by cover type.

Cover Type		**Percent Canopy Cover**								
		Tshrub	JUOC	Low SB	Tall SB	PG	SG	EG	PF	AF
Low Sagebrush < 5% Juniper	Mean:	18.4%	0.3%	15.6%	0.6%	12.7%	10.0%	1.5%	2.6%	2.7%
	Min:	2.2%	0.0%	1.7%	0.0%	0.0%	0.6%	0.0%	0.0%	0.0%
n = 24	Max:	31.7%	2.8%	27.2%	4.4%	28.3%	35.6%	15.0%	7.2%	19.4%
Low Sagbrush ≥ 5% Juniper	Mean:	11.6%	11.5%	9.5%	1.0%	13.9%	6.8%	1.4%	2.6%	1.0%
	Min:	2.8%	7.8%	2.2%	0.0%	2.2%	2.2%	0.0%	0.0%	0.0%
n = 20	Max:	23.9%	17.8%	20.0%	8.3%	32.8%	15.6%	13.9%	6.1%	3.3%
Low Sagebrush/ Mountain Big	Mean:	21.8%	0.2%	8.7%	9.2%	32.1%	3.4%	0.6%	5.3%	0.8%
Sagebrush < 5% Juniper	Min:	8.3%	0.0%	2.2%	2.2%	18.3%	0.6%	0.0%	0.6%	0.0%
n = 20	Max:	40.6%	2.8%	18.3%	17.2%	50.0%	11.7%	6.7%	13.3%	3.3%
Low Sagebrush/ Mountain Big	Mean:	16.7%	9.6%	7.8%	6.2%	16.3%	4.7%	0.8%	3.0%	0.8%
Sagebrush ≥ 5% Juniper	Min:	7.8%	5.0%	2.2%	2.2%	2.8%	0.0%	0.0%	0.6%	0.0%
n = 20	Max:	28.9%	19.4%	12.8%	12.8%	38.9%	15.0%	5.0%	8.9%	3.3%
Low Sagebrush/ Wyoming Big	Mean:	17.2%	--	6.9%	6.1%	18.3%	3.9%	0.1%	2.8%	0.3%
Sagebrush	Min:	11.7%	--	3.3%	3.3%	5.6%	0.0%	0.0%	1.1%	0.0%
n = 15	Max:	25.0%	--	12.2%	9.4%	32.8%	6.7%	1.1%	5.6%	2.8%
Low Sagebrush- Green	Mean:	17.0%	0.1%	6.7%	1.7%	11.6%	5.8%	2.1%	2.3%	0.7%
Rabbitbrush	Min:	4.4%	0.0%	0.0%	0.0%	2.8%	0.6%	0.0%	0.0%	0.0%
n = 20	Max:	26.1%	1.1%	12.2%	13.3%	22.8%	15.0%	28.3%	8.9%	8.3%
Low Sagebrush- Gray	Mean:	20.6%	0.3%	10.3%	1.1%	17.5%	4.8%	4.4%	3.0%	1.4%
Rabbitbrush	Min:	8.3%	0.0%	2.8%	0.0%	1.7%	0.0%	0.0%	0.6%	0.0%
n = 16	Max:	36.1%	4.4%	20.6%	5.6%	40.0%	11.1%	17.8%	10.6%	6.1%
Mountain Big Sagebrush < 5%	Mean:	25.0%	0.2%	0.5%	19.1%	23.0%	3.3%	3.9%	6.7%	1.6%
Juniper	Min:	15.0%	0.0%	0.0%	8.9%	2.8%	0.0%	0.0%	0.0%	0.0%
n = 24	Max:	37.2%	2.2%	4.4%	32.8%	46.1%	11.1%	35.6%	21.7%	7.8%
Mountain Big Sagebrush ≥ 5%	Mean:	17.9%	15.1%	0.8%	13.7%	28.1%	4.7%	0.6%	6.3%	0.3%
Juniper	Min:	4.4%	6.1%	0.0%	3.9%	5.6%	0.0%	0.0%	0.0%	0.0%
n = 21	Max:	45.6%	40.6%	3.9%	37.8%	57.8%	10.6%	5.6%	32.2%	1.7%
Mountain Big Sagebrush-	Mean:	20.2%	1.5%	0.5%	9.2%	16.3%	6.2%	2.9%	1.9%	0.4%
Green Rabbitbrush	Min:	10.0%	0.0%	0.0%	4.4%	0.6%	0.0%	0.0%	0.0%	0.0%
n = 20	Max:	35.0%	15.6%	3.3%	16.7%	37.2%	16.1%	10.6%	6.7%	3.9%
Mountain Big Sagebrush- Gray	Mean:	24.0%	1.8%	1.0%	10.4%	18.2%	4.6%	7.8%	2.9%	1.4%
Rabbitbrush	Min:	7.8%	0.0%	0.0%	3.3%	3.3%	1.1%	0.0%	0.6%	0.0%
n = 20	Max:	41.7%	15.0%	6.7%	21.7%	28.3%	10.0%	30.0%	10.0%	7.2%
Mountain Big Sagebrush-	Mean:	24.8%	0.9%	0.7%	9.1%	24.4%	6.5%	2.1%	3.5%	0.3%
Bitterbrush	Min:	16.7%	0.0%	0.0%	3.9%	8.3%	1.1%	0.0%	0.6%	0.0%
n = 16	Max:	34.4%	4.4%	3.9%	16.1%	37.2%	33.9%	10.0%	11.7%	2.2%
Wyoming Big Sagebrush	Mean:	16.5%	0.1%	--	13.0%	17.9%	5.8%	0.7%	2.7%	0.2%
	Min:	7.8%	0.0%	--	7.2%	6.7%	0.0%	0.0%	0.0%	0.0%
n = 19	Max:	23.9%	1.7%	--	18.9%	42.8%	22.8%	10.0%	8.9%	1.1%
Wyomiong Big Sagebrush-	Mean:	16.7%	0.3%	0.2%	8.4%	14.3%	4.7%	4.4%	2.8%	0.2%
Green Rabbitbrush	Min:	6.7%	0.0%	0.0%	2.8%	1.7%	0.0%	0.0%	0.0%	0.0%
n = 20	Max:	30.6%	6.1%	2.8%	20.6%	36.7%	13.3%	48.3%	8.9%	1.7%
Green Rabbitbrush	Mean:	15.5%	0.1%	0.4%	0.9%	13.3%	7.4%	8.9%	2.1%	0.6%
	Min:	4.4%	0.0%	0.0%	0.0%	1.7%	0.0%	0.0%	0.0%	0.0%
n = 21	Max:	31.1%	0.6%	2.8%	3.9%	42.8%	25.0%	43.9%	5.6%	3.9%
Gray Rabbitbrush	Mean:	27.7%	0.2%	0.1%	1.1%	2.3%	18.0%	2.3%	2.1%	0.2%
	Min:	8.3%	0.0%	0.0%	0.0%	0.0%	6.7%	0.0%	0.0%	0.0%
n = 17	Max:	46.7%	2.2%	1.1%	3.9%	11.7%	37.2%	12.2%	4.4%	1.1%
Perennial System	Mean:	--	1.8%	--	--	59.1%	9.2%	0.1%	16.8%	0.5%
	Min:	--	0.0%	--	--	0.0%	0.0%	0.0%	1.1%	0.0%
n = 20	Max:	--	33.9%	--	--	97.8%	62.8%	1.1%	36.1%	9.4%
Ephemeral System	Mean:	--	0.3%	--	--	44.5%	18.4%	0.3%	5.7%	0.1%
	Min:	--	0.0%	--	--	0.0%	0.0%	0.0%	0.6%	0.0%
n = 20	Max:	--	5.6%	--	--	90.6%	60.0%	5.6%	12.2%	0.6%

A. = Artemisia, Tshrub = total shrub, JUOC = juniper, Low SB = low sagebrush, Tall SB = tall sagebrush, PG = deep-rooted perennial tussock grass, SG = shallow-rooted perennial tussock grass, EG = exotic grass, PF = perennial forb, AF = annual forb, n = sample size

Density mean and range values for perennial and annual food forbs eaten by Greater Sage-grouse were highly variable both within and between cover types at the plot-level (Table 2.6). Total food forb density across all plots averaged 4.8/m^2 and ranged from 1.6/m^2 for gray rabbitbrush cover type to 6.7/m^2 for perennial systems and mountain big sagebrush-gray rabbitbrush cover types. Total food forb density varied between 8.8 and 280 fold within cover types. Perennial food forbs across all plots averaged 2.4/m^2 and ranged from 1.3 to 6.6/m^2 for low sagebrush-gray rabbitbrush and perennial system cover types, respectfully. Within the perennial system cover type, perennial food forb density ranged from 0 to 27.9/m^2. Annual food forbs ranged from 0 to 5.3/m^2 between ephemeral system and mountain big sagebrush-gray rabbitbrush cover types, respectfully with an average of 2.3/m^2 across all plots. Annual food forb density within the low sagebrush-gray rabbitbrush cover type ranged from 0 to 25.2/m^2.

Means and ranges of sagebrush heights and deep-rooted perennial tussock grass leaf and inflorescence heights were variable within and between cover types (Table 2.6). Sagebrush height ranged from 18 to 99 cm averaging 30.6 cm for low sagebrush, 62.4 cm for mountain big sagebrush, and 71.8 cm for Wyoming big sagebrush. For all upland plots, deep-rooted perennial tussock grass leaf height averaged 19.8 cm, while averages between cover types ranged from 16 to 24 cm. Within the mountain big sagebrush cover type with less than 5% juniper cover, deep-rooted perennial tussock grass leaf heights ranged from 13 to 45 cm. For the entire study area inflorescence height averaged 43.1 cm, while means ranged from 36 to 47 cm between cover types. Within the low sagebrush/mountain big sagebrush cover type inflorescence height ranged from 31 to 67 cm.

Table. 2.6. Means and ranges of Greater Sage-grouse food forb densities and number of plots sampled by different life forms and sagebrush and deep-rooted perennial tussock grass height values reported by cover type.

Cover Type		**Density/m^2**			**Height (cm)**				
		Tforb	PF	AF	ARAR	ARTRV	ARTRW	PG Leaf	PG Inf.
Low Sagebrush < 5% Juniper	Mean:	6.2	2.2	4.0	31	--	--	22	46
	Min:	0.5	0.3	0.0	23	--	--	14	36
n = 24	Max:	36.2	15.1	21.2	43	--	--	38	61
Low Sagbrush ≥ 5% Juniper	Mean:	4.4	1.5	2.9	28	--	--	21	44
	Min:	0.4	0.3	0.0	21	--	--	13	32
n = 20	Max:	13.7	4.6	13.3	39	--	--	30	57
Low Sagebrush/ Mountain Big Sagebrush < 5% Juniper	Mean:	6.0	2.8	3.2	30	60	--	18	40
	Min:	0.8	0.6	0.0	20	48	--	13	30
n = 20	Max:	25.7	6.0	21.5	40	71	--	24	51
Low Sagebrush/ Mountain Big Sagebrush ≥ 5% Juniper	Mean:	4.3	1.5	2.8	30	59	--	22	45
	Min:	1.2	0.4	0.1	18	33	--	13	39
n = 20	Max:	10.5	4.0	9.3	43	71	--	33	54
Low Sagebrush/ Wyoming Big Sagebrush	Mean:	4.7	2.3	2.4	28	--	67	20	44
	Min:	0.7	0.6	0.0	18	--	58	16	34
n = 15	Max:	10.7	5.0	9.3	32	--	79	29	53
Low Sagebrush- Green Rabbitbrush	Mean:	3.4	2.1	1.3	33	--	--	18	40
	Min:	0.0	0.0	0.0	25	--	--	12	31
n = 20	Max:	10.1	5.5	5.0	40	--	--	35	67
Low Sagebrush- Gray Rabbitbrush	Mean:	4.9	1.3	3.7	34	--	--	22	46
	Min:	0.0	0.0	0.0	26	--	--	17	36
n = 16	Max:	25.5	3.6	25.2	43	--	--	34	57
Mountain Big Sagebrush < 5% Juniper	Mean:	6.3	2.6	3.7	--	64	--	21	44
	Min:	0.2	0.2	0.0	--	41	--	13	34
n = 24	Max:	18.0	5.8	15.0	--	78	--	45	67
Mountain Big Sagebrush ≥ 5% Juniper	Mean:	4.8	1.7	3.1	--	59	--	18	45
	Min:	0.7	0.4	0.0	--	40	--	14	32
n = 21	Max:	13.2	3.6	11.5	--	98	--	35	60
Mountain Big Sagebrush- Green Rabbitbrush	Mean:	3.2	1.8	1.5	--	65	--	20	42
	Min:	0.0	0.0	0.0	--	40	--	15	30
n = 20	Max:	8.8	5.7	5.9	--	94	--	23	53
Mountain Big Sagebrush- Gray Rabbitbrush	Mean:	6.7	1.4	5.3	--	64	--	21	44
	Min:	0.5	0.1	0.3	--	45	--	16	31
n = 20	Max:	19.7	4.5	15.7	--	75	--	32	60
Mountain Big Sagebrush- Bitterbrush	Mean:	4.7	2.4	2.3	--	67	--	19	40
	Min:	0.0	0.0	0.0	--	55	--	14	33
n = 16	Max:	15.8	4.4	14.9	--	78	--	24	49
Wyoming Big Sagebrush	Mean:	3.3	1.4	1.9	--	--	74	19	47
	Min:	0.1	0.0	0.0	--	--	54	12	31
n = 19	Max:	11.7	3.7	10.8	--	--	88	26	57
Wyomiong Big Sagebrush- Green Rabbitbrush	Mean:	2.9	1.7	1.2	--	--	73	18	43
	Min:	0.1	0.0	0.0	--	--	53	13	32
n = 20	Max:	9.2	5.6	3.6	--	--	99	23	57
Green Rabbitbrush	Mean:	2.8	2.0	0.8	--	--	--	16	39
	Min:	0.1	0.0	0.0	--	--	--	12	27
n = 21	Max:	11.4	11.4	5.2	--	--	--	23	53
Gray Rabbitbrush	Mean:	1.6	1.4	0.2	--	--	--	24	53
	Min:	0.0	0.0	0.0	--	--	--	17	53
n = 17	Max:	5.3	5.3	3.4	--	--	--	32	53
Perennial System	Mean:	6.7	6.6	0.1	--	--	--	24	45
	Min:	0.0	0.0	0.0	--	--	--	15	32
n = 20	Max:	27.9	27.9	1.3	--	--	--	63	65
Ephemeral System	Mean:	5.2	5.2	0.0	--	--	--	18	36
	Min:	0.0	0.0	0.0	--	--	--	11	18
n = 20	Max:	20.0	20.0	0.0	--	--	--	24	50

Tforb = Total Forb (sum PF and AF), PF = perennial forb, AF = annual forb, ARAR = low sagebrush, ARTRV = mountian big sagebrush, ARTRW = Wyoming big sagebrush, PG Leaf = deep-rooted perennial tussock grass leaf, PG Inf. = deep-rooted perennial tussock grass inflorescence, n = sample size

Forb density only includes food forbs that are important in Greater Sage-grouse diets.

Topographical Influences

Vegetation cover was significantly ($P < 0.05$) correlated with topographic variables (Table 2.7). Cover of total vegetation, shrub, herbaceous, grass, and forb and all life forms increased with elevation. Total vegetation cover was the most responsive with a 7.6% increase with each 100 m increase in elevation. The relationship between aspect and cover was significant in all but two of the eight models with the north aspect most commonly expressing the greatest vegetation cover values, followed by east, west, and south aspects. Total herbaceous cover was 12.4% greater on north than south aspects. Perennial grass cover, which accounted for the majority of herbaceous cover was highest on north aspects and lowest on south aspects. Perennial forb cover was also greater on north than south aspects. Slope exhibited a positive relationship with cover of total vegetation, total herbaceous, total grass, and the deep-rooted perennial tussock grass life form. A 5% increase in slope was associated with a 2% increase in the mean cover value for total vegetation. Landscape position was significant for the deep-rooted perennial tussock grass, total forb, and perennial forb with terrace positions exhibiting the highest cover values followed by sideslope, toeslope, ridgetop, and bottom landscape positions. However, total shrub cover had the greatest cover values at bottom locations. Plots with no curvature exhibited significantly higher cover values for total vegetation, total herbaceous, and total grass than convex plots, while there was no difference between either flat (no curvature) or convex plots and concave plots.

Table 2.7. Topographical influences on canopy cover of life forms across all upland cover types.

COVER

Model	**Regression**			**ANOVA**									**R^2**
Tveg =	-59.8	+ **0.076(El)**	+ **0.394(Sl)** +	LAND POS +			**ASPECT** +			**CURVATURE**			0.3491
± SE	16.5	0.01	0.10	--			--			--			
p -value	0.0003	< 0.0001	0.0001	0.0587			< 0.0001			0.0019			
					Mean			*Mean*			*Mean*		
				Bottom	57.2	a	N	58.5	a	Flat	54.5	a	
				Toeslope	55.1	a	E	50.0	b	Concave	54.0	ab	
				Terrace	50.0	a	S	46.2	b	Convex	47.2	b	
				Sideslope	53.6	a	W	53.9	ab				
				Ridgetop	51.7	a							
Tshrub =	-21.5	+ **0.0302(El)**	+ 0.0463(Sl) +	**LAND POS** +			ASPECT +			CURVATURE			0.1686
± SE	9.3	0.01	0.06	--			--			--			
p -value	0.0218	< 0.0001	0.4181	< 0.0001			0.2359			0.1323			
					Mean			*Mean*			*Mean*		
				Bottom	26.0	a	N	20.7	a	Flat	19.9	a	
				Toeslope	21.1	ab	E	17.4	a	Concave	17.2	a	
				Terrace	17.5	b	S	18.1	a	Convex	18.4	a	
				Sideslope	18.8	b	W	20.1	a				
				Ridgetop	17.6	b							
Therb =	-34.1	+ **0.0402(El)**	+ **0.3068(Sl)** +	LAND POS +			**ASPECT** +			**CURVATURE**			0.3188
± SE	12.8	0.01	0.08	--			--			--			
p -value	0.0082	< 0.0001	0.0001	0.5013			< 0.0001			0.0042			
					Mean			*Mean*			*Mean*		
				Bottom	29.3	a	N	36.0	a	Flat	31.9	a	
				Toeslope	32.1	a	E	29.3	b	Concave	31.5	ab	
				Terrace	30.3	a	S	23.6	c	Convex	26.6	b	
				Sideslope	31.4	a	W	31.3	b				
				Ridgetop	31.6	a							
Tgrass =	-13.4	+ **0.0241(El)**	+ **0.2402(Sl)** +	LAND POS +			**ASPECT** +			**CURVATURE**			0.2217
± SE	12.2	0.01	0.07	--			--			--			
p -value	0.2722	0.0039	0.0014	0.4937			< 0.0001			0.0120			
					Mean			*Mean*			*Mean*		
				Bottom	25.9	a	N	30.9	a	Flat	27.6	a	
				Toeslope	28.2	a	E	25.7	b	Concave	26.4	ab	
				Terrace	25.8	a	S	20.5	c	Convex	23.1	b	
				Sideslope	26.9	a	W	27.0	b				
				Ridgetop	27.9	a							
PG =	-297.0	+ **0.2679(El)**	+ **1.5771(Sl)** +	**LAND POS** +			**ASPECT** +			CURVATURE			0.381
± SE	89.2	0.06	0.55	--			--			--			
p -value	0.0010	< 0.0001	0.0041	< 0.0001			< 0.0001			0.1286			
Note: perennial grass cover was transformed (rank-sum) so the coefficients and means corresponds to the rank of perennial grass cover and not to the values.					*Mean*			*Mean*			*Mean*		
				Bottom	89.0	a	N	187.6	a	Flat	159.5	a	
				Toeslope	169.7	b	E	172.9	ac	Concave	173.1	a	
				Terrace	175.7	b	S	85.6	b	Convex	140.4	a	
				Sideslope	160.6	b	W	158.1	c				
				Ridgetop	163.4	b							
Tforb =	0.002	+ **1.004(El)**	+ 1.009(Sl) +	**LAND POS** +			**ASPECT** +			CURVATURE			0.2661
± SE	3.5	1.00	1.01	--			--			--			
p -value	< 0.0001	< 0.0001	0.2182	0.0070			0.0194			0.8914			
Note: total forb cover was transformed (natural log) and back tranformed so the coefficients refers to a multiplicative effect on the median of total forb cover with a one unit increase in the mean of the explanatory variable.					*Median*			*Median*			*Median*		
				Bottom	1.8	a	N	2.5	a	Flat	2.6	a	
				Toeslope	1.9	ab	E	3.2	ab	Concave	2.9	a	
				Terrace	3.1	ab	S	2.0	b	Convex	2.6	a	
				Sideslope	2.9	b	W	2.5	ab				
				Ridgetop	2.3	ab							
PF =	0.003	+ **1.004(El)**	+ 1.0126(Sl) +	**LAND POS** +			**ASPECT** +			CURVATURE			0.2377
± SE	3.8	1.00	1.01	--			--			--			
p -value	< 0.0001	< 0.0001	0.1274	0.0010			0.0039			0.7351			
Note: perennial forb cover was transformed (natural log) and back tranformed so the coefficients refers to a multiplicative effect on the median of perennial forb cover with a one unit increase in the mean of the					*Median*			*Median*			*Median*		
				Bottom	1.4	a	N	2.6	a	Flat	1.9	a	
				Toeslope	1.4	a	E	2.0	ab	Concave	2.3	a	
				Terrace	2.8	b	S	1.3	b	Convex	2.0	a	
				Sideslope	2.1	ab	W	1.8	ab				
				Ridgetop	1.3	ab							
AF =	328.9	+ **0.3077(El)**	+ -0.3417(Sl) +	LAND POS +			ASPECT +			CURVATURE			0.1791
± SE	94.7	0.06	0.58	--			--			--			
p -value	0.0006	< 0.0001	0.5555	0.0514			0.2334			0.4801			
Note: annual forb cover was transformed (rank-sum) so the coefficients and means corresponds to the rank of annual forb cover and not to the values.					*Mean*			*Mean*			*Mean*		
				Bottom	147.1	a	N	143.8	a	Flat	159.0	a	
				Toeslope	163.7	a	E	148.9	a	Concave	139.7	a	
				Terrace	135.7	a	S	174.4	a	Convex	155.3	a	
				Sideslope	161.1	a	W	165.1	a				
				Ridgetop	178.8	a							

Tveg = total vegetation (sum of tree, Tshrub, and Therb), Tshrub = total shrub (sum of all shrub species), Therb = total herbaceous (sum of all grass and forb species), Tgrass = total grass (sum of all grass species), PG = deep-rooted perennial tussock grass, PG Leaf = deep-rooted perennial tussock grass, Tforb = total forb, PF = perennial forb, AF = annual forb, El = Elevation, Sl = Slope, LAND POS = landscape position, N = North, E = East, S = South, W = West

BOLD Items are significant at the P < 0.05

Topography significantly (P < 0.05) influenced Greater Sage-grouse food forb density (Table 2.8). Elevation had a positive relationship with total, perennial, and annual food forb density. Perennial food forb density tended to be greater on the cooler and wetter north and east aspects and lowest on the south aspects, while annual forb density was lowest on north aspects. Forb densities were consistently the lowest on bottomlands compared to the other landscape positions. Total and annual forb densities displayed a significant negative relationship with slope.

Table 2.8. Topographical influences on Greater Sage-grouse food forb density life forms across all upland cover types.

FORB DENSITY							
Model	**Regression**			**ANOVA**			**R^2**
Tforb	= -614.2	+ **0.4970(El)**	+ **-1.1924(Sl)** +	**LAND POS**	+ **ASPECT**	+ CURVATURE	0.3431
± SE	91.2	0.06	0.56	--	--	--	
p -value	< 0.0001	< 0.0001	0.0332	< 0.0001	0.0022	0.1861	
Note: total forb density was transformed (rank-sum) so the coefficients and means corresponds to the rank of the total forb density and not to the values.				*Mean* Bottom 96.8 ^{a} Toeslope 162.7 ^{b} Terrace 177.8 ^{b} Sideslope 157.3 ^{b} Ridgetop 174.8 ^{b}	*Mean* N 155.0 ^{a} E 171.2 ^{a} S 126.3 ^{b} W 168.0 ^{a}	*Mean* Flat 153.9 ^{a} Concave 155.7 ^{a} Convex 174.7 ^{a}	
PF	= -341.4	+ **0.3335(El)**	+ -0.3813(Sl) +	**LAND POS**	+ **ASPECT**	+ CURVATURE	0.2044
± SE	100.2	0.07	0.61	--	--	--	
p -value	0.0007	< 0.0001	0.5342	0.0095	0.0001	0.5494	
Note: total forb density was transformed (rank-sum) so the coefficients and means corresponds to the rank of the total forb density and not to the values.				*Mean* Bottom 121.7 ^{a} Toeslope 149.2 ^{ab} Terrace 184.5 ^{b} Sideslope 156.2 ^{ab} Ridgetop 149.0 ^{ab}	*Mean* N 173.4 ^{a} E 172.1 ^{a} S 111.6 ^{b} W 155.0 ^{a}	*Mean* Flat 153.8 ^{a} Concave 166.6 ^{a} Convex 164.7 ^{a}	
AF	= -568.8	+ **0.4407(El)**	+ **-2.2896(Sl)** +	**LAND POS**	+ **ASPECT**	+ **CURVATURE**	0.3726
± SE	89.3	0.06	0.55	--	--	--	
p -value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0330	0.0346	
Note: total forb density was transformed (rank-sum) so the coefficients and means corresponds to the rank of the total forb density and not to the values.				*Mean* Bottom 71.2 ^{a} Toeslope 167.2 ^{b} Terrace 169.9 ^{b} Sideslope 163.9 ^{b} Ridgetop 180.8 ^{b}	*Mean* N 140.5 ^{a} E 161.8 ^{ab} S 154.2 ^{ab} W 174.2 ^{b}	*Mean* Flat 153.8 ^{a} Concave 149.7 ^{ab} Convex 182.1 ^{b}	

Tforb = total forb, PF = perennial forb, AF = annual forb, El = Elevation, Sl = Slope, LAND POS = landscape position, N = North, E = East, S = South, W = West

BOLD Items are significant at the P < 0.05

Sagebrush height and deep-rooted perennial tussock grass leaf and inflorescence height were significantly (P < 0.05) correlated with topographic variables (Table 2.9). Both deep-rooted perennial grass leaf and inflorescence heights were correlated with landscape position and aspect with the tallest leaf and inflorescence occurring at bottom landscape positions and on south aspects. Leaf height was also positively correlated with slope and associated with tallest leaves at plots with flat or no curvature.

Table 2.9. Topographical influences on sagebrush height and deep-rooted perennial tussock grass leaf and inflorescence height across all upland cover types.

HEIGHT

Model	**Regression**			**ANOVA**			**R^2**
ARAR =	41.1	+ -0.0118(El)	+ -0.1509(Sl) +	LAND POS +	**ASPECT** +	CURVATURE	0.1728
± SE	12.3	0.01	0.08	--	--	--	
p -value	0.0011	0.1797	0.0587	0.0591	0.0445	0.8657	
				Mean	*Mean*	*Mean*	
				Bottom 23.2^{a}	N 29.5^{a}	Flat 30.6^{a}	
				Toeslope 29.5^{a}	E 29.9^{ab}	Concave 31.1^{a}	
				Terrace 31.1^{a}	S 30.4^{ab}	Convex 30.1^{a}	
				Sideslope 30.9^{a}	W 32.5^{b}		
				Ridgetop 30.7^{a}			
ARTRW =	144.4	+ -0.0286(El)	+ -0.0257(Sl) +	LAND POS +	ASPECT +	**CURVATURE**	0.3537
± SE	69.4	0.05	0.43	--	--	--	
p -value	0.0437	0.5819	0.9531	0.1505	0.3953	0.0044	
				Mean	*Mean*	*Mean*	
				Bottom 65.5^{a}	N 69.1^{a}	Flat 71.1^{a}	
				Toeslope 74.1^{a}	E 75.1^{a}	Concave 102.0^{b}	
				Terrace 71.7^{a}	S 71.0^{a}	Convex 70.2^{a}	
				Sideslope 69.2^{a}	W 72.1^{a}		
				Ridgetop 81.9^{a}			
ARTRV =	28.0	+ 0.0235(El)	+ 0.1515(Sl) +	LAND POS +	ASPECT +	CURVATURE	0.1133
± SE	19.0	0.01	0.09	--	--	--	
p -value	0.1440	0.0622	0.0957	0.5415	0.3980	0.6206	
				Mean	*Mean*	*Mean*	
				Bottom 66.7^{a}	N 64.0^{a}	Flat 62.7^{a}	
				Toeslope 61.5^{a}	E 61.7^{a}	Concave 62.8^{a}	
				Terrace 58.7^{a}	S 60.2^{a}	Convex 60.5^{a}	
				Sideslope 62.7^{a}	W 62.0^{a}		
				Ridgetop 62.5^{a}			
PG Inf. =	283.8	+ -0.0616(El)	+ 0.1627(Sl) +	**LAND POS** +	**ASPECT** +	CURVATURE	0.191
± SE	107.6	0.07	0.69	--	--	--	
p -value	0.0088	0.3869	0.813	< 0.0001	< 0.0001	0.2177	
Note: perennial grass inflorescence height was transformed (rank-sum) so the coefficients and means corresponds to the rank of perennial grass inflorescence				*Mean*	*Mean*	*Mean*	
				Bottom 238.4^{a}	N 160.7^{a}	Flat 180.1^{a}	
				Toeslope 137.0^{b}	E 142.9^{a}	Concave 152.4^{a}	
				Terrace 150.9^{b}	S 224.6^{b}	Convex 171.0^{a}	
				Sideslope 172.7^{b}	W 185.2^{ab}		
				Ridgetop 147.7^{b}			
PG Leaf =	76.8	+ 0.0554(El)	+ **1.6018(Sl)** +	**LAND POS** +	**ASPECT** +	**CURVATURE**	0.1803
± SE	108.3	0.07	0.69	--	--	--	
p -value	0.4789	0.4394	0.0211	< 0.0001	< 0.0001	0.0396	
Note: perennial grass leaf height was transformed (rank-sum) so the coefficients and means corresponds to the rank of perennial grass leaf height and not to the values.				*Mean*	*Mean*	*Mean*	
				Bottom 230.3^{a}	N 158.8^{a}	Flat 180.8^{a}	
				Toeslope 157.0^{b}	E 145.3^{a}	Concave 138.6^{b}	
				Terrace 152.0^{b}	S 229.0^{b}	Convex 178.3^{ab}	
				Sideslope 170.4^{b}	W 184.5^{a}		
				Ridgetop 154.5^{b}			

ARAR = low sagebrush, ARTRW = Wyoming big sagebrush, ARTRV = mountain big sagebrush, PG Inf = deep-rooted perennial tussock grass, PG Leaf = deep-rooted perennial tussock grass, El = Elevation, Sl = Slope, LAND POS = landscape position, N = North, E = East, S = South, W = West

Discussion

Shrub cover and height, grass cover and height, and Greater Sage-grouse food forb abundance have been correlated with increased nest success and brood survival (Barnett and Crawford 1994, Drut et al. 1994a,b, Gregg et al. 1994, Delong et al. 1995, Sveum et al. 1998, Coggins et al. 1998). Vegetation characteristics important to Greater Sage-grouse productivity were highly variable within and between the different cover types across the study area reflecting landscape heterogeneity. With highly variable cover and height values, plots satisfying values proposed in the habitat guidelines (Connelly et al. 2000, BLM et al. 2000) was also highly variable. However, a portion of this variability could be explained by topographic influences.

Landscape Description

Cover values recorded in this study for different life forms were similar to those reported by others across the northwest region of the sagebrush biome. Low sagebrush with scattered to no juniper trees present was the largest cover type covering nearly a third of the study area. The range of vegetation height and cover values for this cover type in the study area were within the range of height (30 – 50 cm) and cover values (15 – 25%) and (5 – 25%) described by Shiflet (1994) and Miller and Eddleman (2001), respectfully. Miller et al. (2000) reported that low sagebrush/Sandberg's bluegrass plots in southeastern Oregon and northeastern California with greater than 10% juniper cover had 8% Sandberg's bluegrass cover and 4.1% perennial forb cover, which was comparable to low sagebrush with greater than 5% juniper cover values from this study.

The mountain big sagebrush cover type covered the second largest amount of area in the study area. Shrub, grass, and forb cover were similar to values reported in Wyoming, where there was 25.4% mountain big sagebrush cover, 27.6% grass cover, and 8.5% forb cover (Burke et al. 1989). Sagebrush height and cover values were slightly less than Shiflet (1994) described (sagebrush height 88 – 100 cm; sagebrush cover 25 – 30%) for this cover type. Miller and Eddleman (2001) noted that forb cover values reported in the literature are typically less than 10% ground cover, which is consistent with the results of 8.3% from this study. Shrub and herbaceous cover values from this study were also similar to those reported by Miller and Heyerdahl (2008) in northeastern California and for Reinkensmeyer et al. (2007) in central Oregon. Shrub and herbaceous cover values reported by Miller et al. (2000), Miller and Heyerdahl (2008), and Reinkensmeyer et al. (2007) for the mountain big sagebrush cover type with greater than 5% juniper tree cover were also comparable to results from this study.

Wyoming big sagebrush, the third largest cover type in the study area had cover values similar to those reported by Davies et al. (2007) in late-seral Wyoming big sagebrush communities in southeast Oregon. Mean plant cover values they reported were 12.3% for sagebrush, 22.9% for total herbaceous, 12.2% for deep-rooted perennial tussock grass, 5.4% for shallow-rooted perennial tussock grass, 4.1% for perennial forb, and 0.6% for annual forb. Results from this study were also comparable to Burke et al. (1989) study, in which they measured 23.2% Wyoming big sagebrush cover, 15.1% grass cover, and 7% forb cover across 10 plots. Wyoming big sagebrush height values for plots in this study area exceeded those estimates proposed by Shiflet (1994) (40 – 55 cm). Shiflet (1994) suggested sagebrush cover values of 13 – 18% for this cover type, which was consistent with results from this study.

Topographical Influences

Elevation

Results from this study suggest that topography had a significant influence on vegetation structural and compositional characteristics important to Greater Sage-grouse. Cover values for all life forms and total categories were positively associated with elevation. An increase in elevation is often associated with higher moisture availability to plants, particularly during the growing season when precipitation is limited and temperatures are higher (Swanson et al. 1988). Increased moisture availability at higher elevations lengthens the growing season for plants. Since water is the major limiting factor to most rangelands, increased moisture amounts allow greater biomass production resulting in greater cover values (Toft et al. 1989, Anderson and Inouye 2001). However, in the Wyoming big sagebrush cover type Davies et al. (2007) reported no significant relationship between elevation and cover for total vegetation, Wyoming big sagebrush, total herbaceous, deep-rooted perennial tussock grasses, or perennial forbs.

Since deep-rooted perennial tussock grass cover increased with elevation, Greater Sage-grouse nesting at relatively higher elevations may increase nest success as tall grass cover has been shown to positively correlate with nest success by providing scent, visual, and physical barriers between nest and predators (Gregg et al. 1994, Delong et al. 1995, Sveum et al. 1998, Coggins et al. 1998). This may explain Greater Sage-grouse nesting patterns, as Yost et al. (2008) reported that females select nest site locations at relatively higher elevations than surrounding areas and leks.

Aspect

Total vegetation cover, total herbaceous cover, total grass cover, deep-rooted perennial grass cover, total forb cover, and perennial forb cover were associated with changes in aspect. In addition, total food forb density, perennial food forb density, annual food forb density, low sagebrush height, and perennial grass leaf and inflorescence height were also associated with aspect changes. Aspect influences air and ground temperature, in turn influencing moisture availability. (Swanson et al. 1988, Jensen et al. 1989a, Davies et al. 2007). South-facing slopes receive greater amounts of solar radiation than north-facing slopes, which results in warmer, drier conditions, in turn affecting vegetation composition and structure (Passey et al. 1982, Turner et al. 2001). Davies et al. (2007) used a direct incident radiation model based on aspect, slope, and latitude to test associations with plant species, life forms, and total categories for Wyoming big sagebrush communities. They reported a negative relationship between solar radiation and cover of total vegetation, total herbaceous, perennial grass, and perennial forbs. Results from this study were similar for all herbaceous life forms and totaled categories with the exception of annual forbs, which appeared not to respond to aspect. However, these results showed a different trend for deep-rooted perennial tussock grass leaf and inflorescence heights, as the tallest grasses were on south aspects. This may have occurred due to morphological differences between species as compositional shifts occurred with aspect changes. In the study area, south aspects commonly were dominated by bluebunch wheatgrass, while Idaho fescue, a shorter statured species dominated north aspects.

Perennial forbs have been reported to contribute major contributions to the diet of pre-laying hens and juvenile Greater Sage-grouse (Klebenow and Gray 1968, Barnett and Crawford 1994, Drut et al. 1994b). Perennial food forb density was lower on south aspects than all other aspects. Perennial food forb abundance was the highest on north aspects where soil moisture availability would be the most favorable. Increased competition and a decrease in unoccupied inter-space may be reducing annual food forb abundance on north aspects.

Slope

The influence of slope on vegetation was difficult to evaluate because it cannot be easily isolated from other predictor variables. Nevertheless, in this study cover values for total vegetation, total herbaceous, total grass, and deep-rooted perennial tussock grass were positively associated with slope. However, Davies et al. (2007) reported no association between slope and cover of total vegetation, Wyoming big sagebrush, total herbaceous, deep-rooted perennial tussock grass, or perennial forbs. They did find a negative relationship between slope and cover by grass species of Thurber’s needlegrass, squirreltail, and needle-and-thread, while Idaho fescue and bluebunch wheatgrass increased with increasing slopes. In another study in southeastern Oregon, Davies et al. (2006) reported deep-rooted perennial bunchgrass cover was greatest for Idaho fescue plots, followed by bluebunch wheatgrass, needle-and-thread, and Thurber’s needlegrass. Their combined results suggest that slope influences grass species differently and grasses found on increased slopes had greater cover values.

Though cover measurements were not recorded by grass species in this study, higher grass cover values with increased slope may be a function of the increased dominance of Idaho fescue or bluebunch wheatgrass. With increased grass cover on slopes, increased competition for soil resources may be inhibiting total and annual food forb densities as they were negatively associated with slope.

Landscape Position

Landscape position was significantly associated with cover of total shrubs, deep-rooted perennial tussock grasses, total forbs, and perennial forbs. Shrubs had significantly greater cover values at bottom positions than terrace, sideslope, or ridgetop positions. Landscape position affects the rate of flow and direction of movement of necessary plant resources such as soil material, nutrients, and water (Swanson et al. 1988). Resources are deposited and stored at bottom positions, resulting in greater resource availability to plants (Sulzman and Frey 2002). Increased water availability can result in greater shrub canopies at the bottom landscape position, as the deep root system of sagebrush can take advantage of water storage on these deeper soils (West 1983, Winward 2004). The gray rabbitbrush cover type which exhibited the greatest shrub cover values was often found at these bottom landscape positions, influencing this trend. Deep-rooted perennial tussock grass cover, total forb cover, total food forb density, perennial food forb density, and annual food forb density were significantly less at bottom landscape positions. With little to no livestock management during the late 1800s and early 1900s and livestock preference for lowland areas and near water sources, historical grazing may explain the decreased herbaceous component and increased shrub cover at bottom landscape positions (Mueggler 1965, Gillen 1984, Stuth 1991, Miller and Eddleman 2001).

Curvature

Cover of total vegetation, total herbaceous, and total grass was significantly greater for non-curvature (flat) micro-topographical plots than convex curvature plots. Landscape curvature affects soil, nutrient, and water resource pools by acting as sources, sinks, or neutral entities (Swanson et al. 1988, Burke et al. 1989). Convex areas may act as sources losing resources such as soil and moisture to adjacent areas. This could explain increased height in Wyoming big sagebrush in concave plots. However, low sagebrush or mountain big sagebrush heights were not associated with curvature. Davies et al. (2007) found no height correlations between Wyoming big sagebrush and its environment.

Limitations

Since vegetation sampling occurred during the summer, results may not be consistent throughout an entire year. For example, the forb component can be very dynamic seasonally and these results may not accurately reflect forb characteristics during the spring. Further caution must be used in model interpretation as unexplained variation resulted. Unexplained variation can be partially attributed to information lacking for soils, disturbance history, and the countless interactions among species (Jensen 1989a, Jensen 1990, Davies et al. 2007).

Habitat Guideline Comparison

Plots in the study area varied in their ability to produce vegetation cover and height values that satisfied guideline criteria produced by Connelly et al. (2000) and the BLM et al. (2000) (Fig 2.3). Two and a half percent and 1.2% of the plots in the study area satisfied all requirements in Connelly et al. (2000) breeding guidelines and the BLM et al. (2000) nesting guidelines, respectfully. Based on the cover type map, the estimated percent of landscape area satisfying the breeding and nesting guideline criteria was less than 1%. The forb cover requirement most often limited the ability of plots to satisfy the breeding and nesting guidelines in the study area (Table 2.10). However, precipitation for the year when field measurements were conducted was 48% below the long-term precipitation average. Increasing precipitation to average or above average would probably increase forb abundance and most likely the number of plots that would satisfy all guideline criteria. If sampling was conducted during late spring and early summer a greater number of plots also may have satisfied guideline forb cover requirements. These results are consistent with Davies et al. (2007) findings in the Wyoming big sagebrush cover type where they found 0 of 107 plots meeting the BLM et al. (2000) nesting habitat guidelines and 19 of 107 (18%) plots meeting Connelly et al. (2000) breeding habitat guidelines.

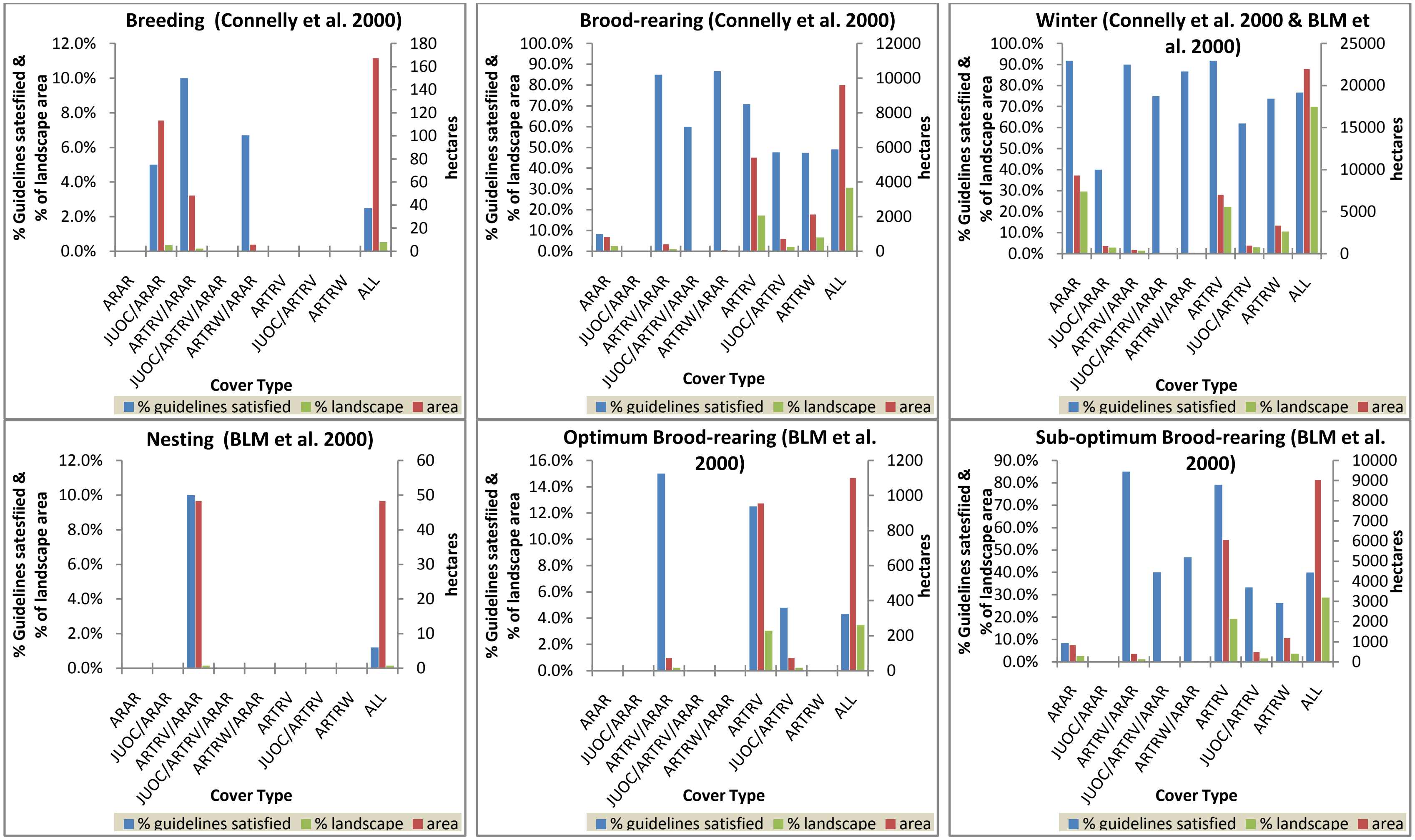

Figure 2.3. Percent of plots (168), percent of the landscape, and the number of hectares that satisfied all guideline (Connelly et al. 2000 and BLM et al. 2000) criteria for productive Greater Sage-grouse habitat.

Note: ARAR = low sagebrush < 5% juniper cover, JUOC/ARAR = low sagebrush ≥ 5% juniper cover, ARTRV/ARAR = mountain big sagebrush/low sagebrush < 5% juniper cover, JUOC/ARTRV/ARAR = mountian big sagebrush/low sagebrush ≥ 5% juniper cover, ARTRW/ARAR = Wyoming big sagebrush/low sagebrush, ARTRV = mountain big sagebrush < 5% juniper cover, JUOC/ARTRV = mountain big sagebrush ≥ 5% juniper cover, ARTRW = Wyoming big sagebrush

Table 2.10. Percent of life forms satisfying Connelly et al. (2000) and the BLM et al. (2000) habitat guidelines.

Giudelines and Author	SB cover	SB Ht	THB cover	PG cover	PG Ht	Forb Cover
Breeding (Connelly et al. 2000)	38.0%	79.8%	--	73.6%	60.1%	**22.7%**
Nesting (BLM et al. 2000)	38.0%	68.7%	--	58.3%	62.6%	**9.8%**
Brood-rearing (Connelly et al. 2000)	70.6%	**68.7%**	95.1%	--	--	--
Optiumum Brood-rearing (BLM et al. 2000)	70.6%	68.7%	--	58.3%	--	**9.8%**
Sub-optimum Brood-rearing (BLM et al. 2000)	54.6%	**68.7%**	95.7%	--	--	--
Winter (Connelly et al. 2000)	**76.7%**	99.4%	--	--	--	--
Winter (BLM et al. 2000)	**76.7%**	99.4%	--	--	--	--

SB = sagebrush, THB = Total herbaceous, PG = deep-rooted perennial tussock grass, Ht = Height
BOLD values least satisfying guideline criteria.

For the brood-rearing season 49.1, 4.3, and 39.9% of the plots in the study area satisfied Connelly et al. (2000) brood-rearing guidelines and the BLM et al. (2000) optimum and suboptimum brood-rearing guidelines, respectfully (Fig. 2.3). This amounted to 31, 3, and 29% of the study area, respectfully. Davies et al. (2007) and results from this study were similar for the Wyoming big sagebrush cover type as their plots satisfied 64 and 30% and plots from this study satisfied 47.4 and 26.3% of Connelly et al. (2000) brood-rearing guidelines and the BLM et al. (2000) suboptimum brood-rearing guidelines, respectively.

Winter guidelines for both Connelly et al. (2000) and the BLM et al. (2000) were the same with 76.7% of plots satisfying criteria, which comprised 70% of the study area (21,952 ha) (Fig. 2.3). These results suggest that winter habitat was not limiting. Results from this study are similar to what Davies et al. (2007) reported for both Connelly et al. (2000) and the BLM et al. (2000) winter guidelines in the Wyoming big sagebrush cover type with 73.7% of plots from this study and 70% of plots form their study being satisfied.

Plots that met the guidelines versus those not meeting the guidelines were not distributed evenly across the landscape (Table 2.11). The low sagebrush/mountain big complex and mountain big sagebrush cover types most consistently satisfied the brood-rearing and winter habitat guidelines. This suggests that these cover types most often provided Greater Sage-grouse with all the required resources during the brood-rearing and winter seasons. North aspects and concave micro-topographical areas also most consistently satisfied the brood-rearing and winter habitat guidelines, while south aspects and convex plots most often failed to satisfy brood-rearing habitat guideline requirements. Results from the topographical models also suggest that north aspects provided the best brood-rearing habitat as they were associated with the greatest cover values and food forb densities. Both the topographical and guideline comparison results consistently suggest that south aspects are poor brood-rearing habitat.

Table 2.11. Plots satisfying Connelly et al. (2000) and BLM et al. (2000) guideline criteria versus those failing to satisfy the guideline criteria.

	Connelly Brood-rearing Guidelines (N = 163, S = 80)			**BLM suboptimum brood-rearing Guidelines (N = 163, S**			**Connelly and BLM Winter Guidelines (N = 163, S = 125)**		
	Categorical Variables								
Veg Type	*n*	*S*	*p*	*n*	*S*	*p*	*n*	*S*	*p*
ARAR	24	2	8.3%	24	2	8.3%	24	22	91.7%
JUOC/ARAR	20	0	0.0%	20	0	0.0%	20	8	40.0%
ARTRV/ARAR	20	17	85.0%	20	17	85.0%	20	18	90.0%
JUOC/ARTRV/ARAR	20	12	60.0%	20	8	40.0%	20	15	75.0%
ARTRW/ARAR	15	13	86.7%	15	7	46.7%	15	13	86.7%
ARTRV	24	17	70.8%	24	19	79.2%	24	22	91.7%
JUOC/ARTRV	21	10	47.6%	21	7	33.3%	21	13	61.9%
ARTRW	19	9	47.4%	19	5	26.3%	19	14	73.7%
Aspect									
East	29	15	51.7%	29	12	41.4%	29	21	72.4%
North	50	27	54.0%	50	26	52.0%	50	42	84.0%
South	28	11	39.3%	28	8	28.6%	28	21	75.0%
West	56	27	48.2%	56	19	33.9%	56	41	73.2%
Landscape Position									
Bottom	4	3	75.0%	4	1	25.0%	4	3	75.0%
Ridgetop	19	9	47.4%	19	5	26.3%	19	17	89.5%
Sideslope	107	50	46.7%	107	43	40.2%	107	81	75.7%
Terrace	22	11	50.0%	22	10	45.5%	22	15	68.2%
Toeslope	11	7	63.6%	11	6	54.5%	11	9	81.8%
Curvature									
Concave	17	11	64.7%	17	8	47.1%	17	14	82.4%
Convex	31	14	45.2%	31	8	25.8%	31	24	77.4%
Flat	115	55	47.8%	115	49	42.6%	115	87	75.7%
	Numerical Variables								
	k	*S*		*k*	*S*		*k*	*S*	
Elevation									
Mean	1481	1480		1481	1491		1481	1485	
Median	1478	1483		1478	1486		1478	1485	
Slope									
Mean	13.7	14.2		13.7	16.7		13.7	13.8	
Median	10.0	11.0		10.0	13.0		10.0	10.0	

Landscape Position, N - total number of plots, S - number of plots that satisfied guideline criteria, n - plot sample size, p - proportion of sites that met guidelines to all sites

ARAR = low sagebrush < 5% juniper cover, JUOC/ARAR = low sagebrush ≥ 5% juniper cover, ARTRV/ARAR = mountain big sagebrush/low sagebrush < 5% juniper cover, JUOC/ARTRV/ARAR = mountian big sagebrush/low sagebrush ≥ 5% juniper cover, ARTRW/ARAR = Wyoming big sagebrush/low sagebrush, ARTRV = mountain big sagebrush < 5% juniper cover, JUOC/ARTRV = mountain big sagebrush ≥ 5% juniper cover, ARTRW = Wyoming big sagebrush

Areas that met the breeding, nesting and optimum brood-rearing guidelines were not compared or reported for areas not meeting the guidelines because of the amount of plot numbers that met the guidelines was extremely low, which does not accurately reflect where key habitats occur across the landscape.

The low sagebrush/mountain big sagebrush cover type provided the most valuable Greater Sage-grouse habitat throughout the entire year, based on the ability of plots in the study area to satisfy all guideline criteria. Very little information exists in the literature about the influence of intermingled complexes of small (< 0.03 ha), clumped patches of low and mountain big sagebrush complexes and how they influence habitat selection by Greater Sage-grouse. However, Miller and Eddleman (2001) stated that low sagebrush communities that form a mosaic with mountain big sagebrush can provide excellent habitat.

Although a large proportion of the study area did not meet habitat recommendations presented in the guidelines, patches embedded throughout the study area did and a much larger portion satisfied many but not all the guideline requirements. Evaluating only mean values of community structure both within and among cover types across landscapes can limit the ability to fully identify patch variability and landscape heterogeneity as it relates to habitat suitability. Vegetation structure and life form composition at the plot-level were highly variable (Table 2.5, 2.6), illustrating the diversity and variability found within and between cover types. This variability exemplifies the heterogeneity found across landscapes and emphasizes that mean values both within and across cover types poorly represent the heterogeneity at the landscape-scale. Increased variance occurs when changing the assessment of plant community characteristics from plots to landscapes, as a result of landscape heterogeneity (Wiens 1989). Ignoring these scale-dependent patterns can lead to improper application of plot-level results when applied to landscapes (Contanza and Maxwell 1994, Fuhlendorf et al. 2002). Therefore, placing issues into a multiple scale context could avoid confusion and circumvent ill-suited extrapolations.

Assessment and application of habitat requirements to sustain successful Greater Sage-grouse populations has lead to confusion and debate (BLM et al. 2000, Connelly et al. 2000, Davies et al. 2006). This in part has been a result of comparing results from studies asking different research questions at different scales. Connelly et al.

(2000) and the BLM et al. (2000) guidelines addressed the fine-scale (0.007 - 0.032 ha) description of vegetation characteristics surrounding points selected by Greater Sage-grouse. Measurements were not selected randomly to characterize the cover types or landscapes. Results have shown that Greater Sage-grouse preferentially select sites for specific compositional and structural vegetation attributes that often do not characterize the landscape as a whole, both within and across plant cover types (Klebenow 1969, Eng and Schladweiler 1972, Ellis et al. 1989, Welch et al. 1991, Drut et al. 1994a, Gregg et al. 1994, Sveum et al. 1998,). These results imply Greater Sage-grouse selectively take advantage of heterogeneous vegetation mosaics to meet their needs. This supports the hypothesis developed by Kolasa and Waltho (1998) that habitats, particularly for species using large areas, will usually be subunits embedded within the area they are using. In contrast to studies evaluating vegetation composition and structure around points selected by Greater Sage-grouse, other studies have addressed the question of potential composition and structure of specific plant alliances and associations. Davies et al. (2006) randomly selected sites across southeast Oregon to describe plant composition and structure in the Wyoming big sagebrush alliance. Their conclusions were that the majority of plant associations within this alliance did not meet the habitat requirements for Greater Sage-grouse. However, based on 1) studies characterizing habitat variables selected by the Greater Sage-grouse, 2) the apparent selectivity by birds for specific patches, and 3) studies reporting the limits of plant communities to consistently meet these requirements, we hypothesize that landscape and cover type heterogeneity are important for meeting habitat requirements.

Conclusion

Results from this study suggest that interpreting habitat characteristics at the plot-level will lead to different answers than interpretation at the landscape-level as a result of changes in variability with scale (Wiens 1989). It becomes apparent as scale increases that patches meeting species habitat requirements are embedded within the larger landscape mosaic. We hypothesize that habitat can remain suitable for Greater Sage-grouse even when only a small percentage of the landscape may satisfy all requirements. Areas satisfying all resource requirements are not often apparent as areas may appear to be a homogenous patch. However, due to variation within patches some areas satisfy all requirements while other areas only satisfy partial requirements. Habitats that do not meet all Greater Sage-grouse requirements individually, but collectively satisfy all requirements probably remain suitable as Greater Sage-grouse posses the ability to move long distances. If this is the case, then juxtaposition and spatial arrangement is probably an important factor influencing habitat use patterns. It is essential, when managing habitat for species that select habitat at multiple scales and utilize resources within large home ranges, to understand and manage for landscape heterogeneity as it is probably important for meeting all resource requirements.

With topography influencing vegetation characteristics that contribute to nest success and brood survival, managers can use topographical variables to predict the spatial distribution or potential of important Greater Sage-grouse habitat variables across a landscape. Topography can also help managers develop reasonable and ecologically defensible wildlife habitat objectives over relatively large spatial scales in a time efficient and cost-effective manner without having to obtain costly field measurements. For example, topography can be used to determine where potential optimal nesting habitat may be located across home ranges. Results from this study suggest that such habitat attributes important to Greater Sage-grouse increase with elevation and moving from south to north aspects. Topography is another tool managers can use to interpret, assess, and administer management prescriptions since it helps explain landscape heterogeneity. Supplementary information that will further aid wildlife managers in the decision making process is how the amount and spatial arrangement of resources influence habitat suitability and the number of birds an area can sustain.

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CHAPTER 3: SPATIAL AND TEMPORAL LANDSCAPE ATTRIBUTES ASSOCIATED WITH GREATER SAGE-GROUSE (*CENTROCERCUS UROPHASIANUS*) HABITAT USE

Abstract

Greater Sage-grouse (*Centrocercus urophasianus*) habitat research has previously focused on fine-scale (0.007 - 0.032 ha) vegetation structure and composition with little work evaluating habitat requirements at the landscape-level. However, Greater Sage-grouse utilize broad landscapes and land management agencies are responsible for making decisions at the landscape-level. Insufficient information regarding Greater Sage-grouse habitat requirements that can be applied at the landscape-level limits a manager's ability to interpret and predict habitat use patterns, assess habitat suitability, and target areas for ecological restoration. The goal of this research was to identify landscape attributes associated with Greater Sage-grouse occurrence. To accomplish this, in 2006, 50 Greater Sage-grouse were captured, radio-collared, and tracked with their UTM (Universal Transverse Mercator) coordinate location points being recorded. The birds were tracked year long from March 2006 to March 2008 across a 31,416 ha study area in central Oregon. In addition, landscape-scale predictor variables were created in a GIS (Geographic Information System) to measure the association of landscape structure on Greater Sage-grouse occurrence. The predictor variables included in this assessment were elevation, slope, aspect, curvature, solar radiation, ruggedness index, northing, easting, distance from roads, distance from leks, distance from mesic habitats, and cover type. Maximum entropy, an ecological modeling procedure was used to develop models predicting Greater Sage-grouse seasonal resource use, generate maps from those models, and describe the shapes of the response curves as it relates Greater Sage-grouse habitat preference to individual landscape predictor variables. Results from this analysis suggests that Greater Sage-grouse habitat use during the breeding season increases near leks and within cover types of low sagebrush/mountain big sagebrush complexes and low sagebrush. Preferred summer habitat were areas relatively high in elevation, within a close proximity to leks, and within areas or a close proximity to habitats that harbor

succulent vegetation through much of the summer. With Greater Sage-grouse utilizing resources within expansive landscapes, understanding the attributes that can be applied at a landscape-scale that attract disproportionate levels of habitat use can help managers predict where birds are likely to occur across the broad areas. With the ability to discriminate between areas that Greater Sage-grouse are likely to use or avoid, managers can allocate limited resources to more effectively create, manipulate, and administer habitat conservation efforts where bird use is predicted to occur and target areas in need of ecological restoration.

Introduction

Greater Sage-grouse (*Centrocercus urophasianus*) habitat research has previously focused on fine-scale (0.007 - 0.032 ha) vegetation structure and composition with little work evaluating habitat requirements at the landscape-level. Past research has been instrumental in explaining the vegetative components necessary for Greater Sage-grouse survival and reproduction (Klebenow and Gray 1969, Eng and Schladweiler 1972, Drut et al. 1994a, Gregg et al. 1994, Delong et al.1995, Coggins 1998, Sveum et al.1998). However, Greater Sage-grouse utilize broad landscapes and land management agencies are responsible for making decisions at the landscape-level. Insufficient information regarding Greater Sage-grouse habitat requirements that can be applied at the landscape-level limits a manager's ability to interpret and predict habitat use patterns, assess habitat suitability, and target areas for ecological restoration.

Greater Sage-grouse select habitat at multiple spatial scales with home ranges that can exceed 270,000 ha (Connelly et al. 2000, Leonard et al. 2000, Gregg 2006). Complex movement patterns by Greater Sage-grouse are correlated with phenological changes in plant communities and their seasonal metabolic requirements for maintenance and reproduction (Connelly et al. 2000, Crawford et al. 2004, Gregg 2006). The ability of this species to move long distances allows them to take advantage of the spatial and temporal variation of sagebrush and associated plant communities within their home range (Miller and Eddleman 2001). Variation in composition and structure, as well as the arrangement of sagebrush and associated plant communities form heterogeneous landscapes that influence how Greater Sage-grouse select habitat. This heterogeneous distribution of plant communities and resources makes it difficult to determine what combination of components attract disproportionate levels of Greater Sage-grouse habitat use.

Like Greater Sage-grouse, prairie chickens (*Tympanuchus pallidicinctus*) display similar movement patterns across large landscapes. Fuhlendorf et al. (2002) reported that a single spatial scale was insufficient to characterize the influences of landscape structure on prairie chickens, illustrating the need for research and management across spatiotemporal scales. With Greater Sage-grouse utilizing resources across expansive and heterogeneous landscapes and agencies managing habitat at a landscape-level, identifying the attributes that are associated with habitat use and that can be applied at landscape-levels could better enable managers to predict use patterns across broad areas (Connelly et al. 2000, Crawford et al. 2004, Gregg 2006). With the ability to predict habitat use, managers could allocate limited resources more effectively in implementing habitat conservation efforts.

The goal of this research was to identify landscape-level attributes associated with Greater Sage-grouse occurrence during the breeding, summer, and winter seasons. This can be accomplished by generating habitat suitability models for individual seasons using global positioning systems (GPS) technology to correlate point locations of radio collared birds with a set of biophysical landscape predictor attributes. Maximum Entropy (Maxent) (Phillips et al. 2006) was used to develop models that predict Greater Sage-grouse seasonal resource use, generate maps from those models, and describe the shapes of the response curves as it relates Greater Sage-grouse habitat preference to individual landscape predictor variables.

Study Area Description

The study area is located in Crook County, central Oregon (Fig. 3.1). The largest lek, in the area (119º 53’ 22” W 43º 48’ 31” N) was chosen as the center of the 31,416 ha study area. This area consist of both private and public lands, with approximately 55% managed by private owners, 35% by the U.S. Bureau of Land Management (BLM), 6% by the U.S. Forest Service (USFS), and 4% by the state of Oregon. The area borders the High Desert and John Day Ecological provinces, with geology resembling more closely the High Desert Ecological province (Anderson et al. 1998). The topography is characterized by elongated ridges with dissecting draws, rolling hills, rocky tablelands, and interspersed with buttes and plateaus capped with basalt or tuffaceous rock. Dominant soils are mapped in the mesic and frigid temperature and xeric moisture regimes and include Argixerolls, Haploxerolls, Palexerolls, Haploxerents, and Durixerolls. Elevation generally increases from west to east ranging from 1,267 m to 1,715 m. Springs and perennial streams are abundant throughout the eastern half and lacking in the western half. The prevailing winds generally blow from west to east throughout the year. Average precipitation (1971-2000) at the nearest weather station (Paiute Butte is approximately 37 km from the center of the study area at an elevation of 1,250 m) is 300 mm (Figure 3.2) (EOARC weather station records 1971-2000). The annual precipitation amount from the first year the birds were collared (March 2006 – February 2007) was 64 % of the long term average and the second year (March 2007 – February 2008) was 60 % of the long-term average (EOARC weather station records 1971-2000). Average temperature for the study area throughout an entire year is 7.5° C, ranging from -29 to 38° C (EOARC weather station records 1971-2000).

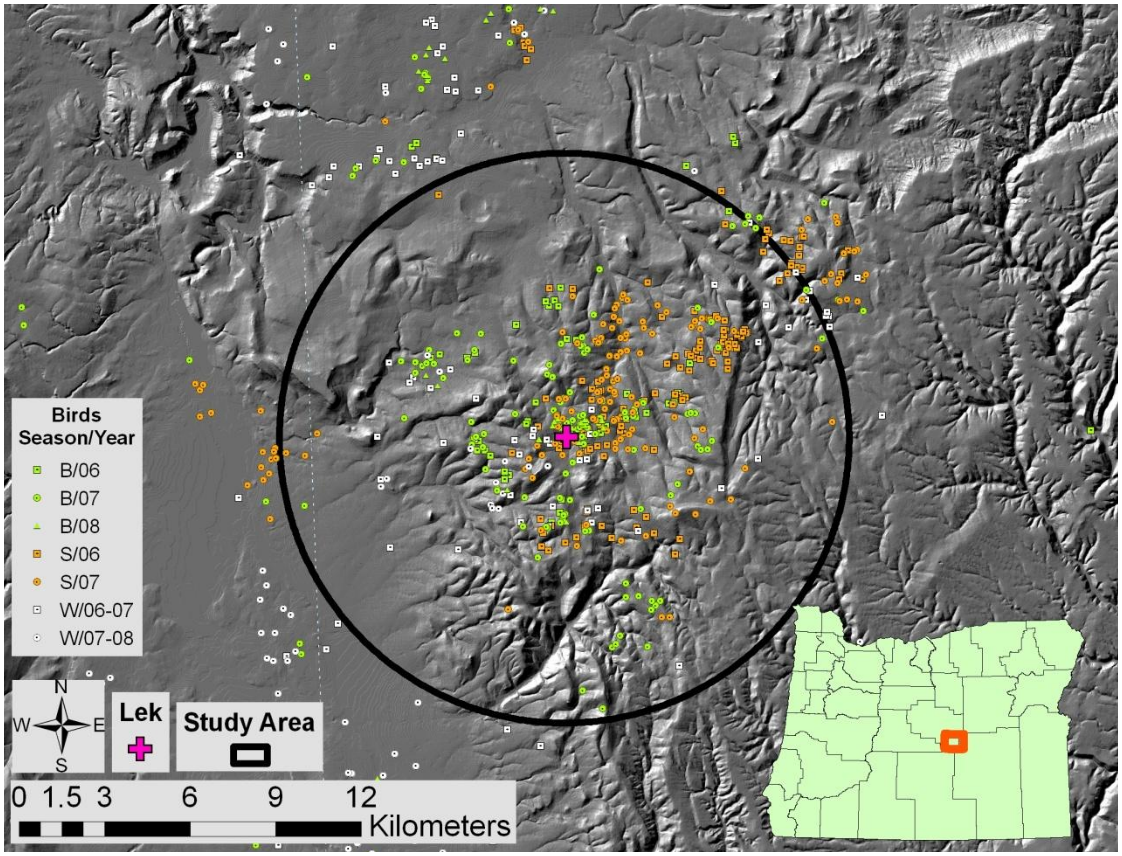


Figure 3.1. Greater Sage-grouse location points by season (B=Breeding, S=Summer, W=Winter) and year surrounding and within the 31,416 ha study area in central Oregon (10 km radius boundary) and the largest lek used as the center point for the study area.

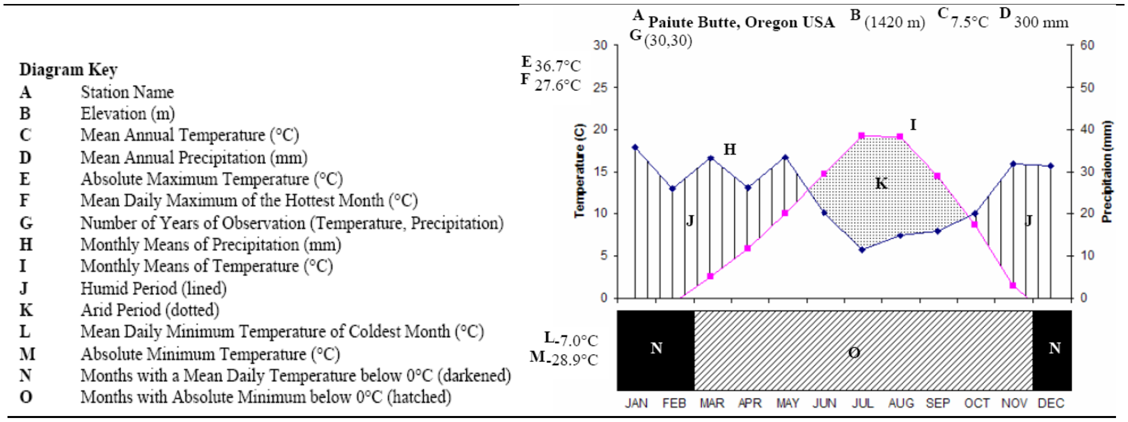


Figure 3.2. Walter Diagram for Paiute Butte weather station located 37 km from the center of the study area at an elevation of 1,250 m.

The history of land use across the study area was dry-land farming primarily in lowlands and grazing by sheep, cattle, and horses in both the lowlands and uplands starting around 1870 and lasting to 1935 (Lundegren 2008). Since the mid 1930s, livestock grazing by cattle has been and continues to be the dominant land-use with irrigated alfalfa grown in a portion of the lowlands.

Methods

Greater Sage-Grouse Location Points

Radio telemetry techniques were used to obtain Greater Sage-grouse occurrence data. Greater Sage-grouse were opportunistically captured from March 2006 through March 2007. Spotlighting techniques were used to capture the birds at night similar to procedures described by Giesen et al. (1982). A total of 50 male and female birds were trapped near six leks or roosting areas; three from Ibex lek, two from Willow lek, 19 from Rickman lek, and 13 from roosting locations across the study area. Greater Sage-grouse were also captured outside the study area, including five from Glass Butte lek, three from Swamp Lake lek, and five from other roosting locations. Of the birds collared for this study, 20 were female and 30 were male. Advanced Telemetry Systems Model A4060 radio transmitters, weighing 22 grams each were fitted around the bird's neck. An Advanced Telemetry Systems Model R2000 portable receiver with a three-element Yagi antenna was used to locate each bird (± 4 m). Each collared bird was located on average every 15 ± 0.56 (mean ± SE) days, ranging from 1 to 154 days at which time a GPS location point was acquired. A total of 480 location points were recorded using Universal Transverse Mercator (UTM) projection system (zones 10 and 11) from March 2006 to March 2008. Of these location points, 250 were obtained during the breeding season, 207 during the summer season, and 23 during the winter season. These seasons are temporal categories used to distinguish changes in the amounts and quality of habitat resources and the different habitat resource needs of Greater Sage-grouse (Schroeder et al. 1999, Connelly et al. 2000, Crawford et al. 2000). Since habitat selection by Greater Sage-grouse changes by season, models were developed based on each season. The limited number of collared location points

(23) within the study area during the winter season prevented the development of reliable models. However, observations of winter bird habitat use were reported. The dates used to separate the seasons were based on behavioral and habitat changes by the collared birds and changes in habitat quality such as forb desiccation described by Connelly et al. (1988), Schroeder et al. (1999), and Connelly et al. (2000) (Table 3.1).

Table 3.1. Dates used to define Greater Sage-grouse habitat use seasons.

	Dates	
Season	**Start**	**End**
Breeding	15-Feb-06	14-Jun-06
Summer	15-Jun-06	31-Oct-06
Winter	1-Nov-06	14-Feb-07
Breeding	15-Feb-07	14-Jun-07
Summer	15-Jun-07	31-Oct-07
Winter	1-Nov-07	14-Feb-08
Breeding	15-Feb-08	26-Mar-08

Landscape Predictor Variables

A suite of landscape predictor variables, referred to as predictor variables through the remainder of this chapter, were developed using ArcGIS 9.3 to test for associations with Greater Sage-grouse occurrence (Table 3.2). Two, 10 x 10 m raster datasets with cell attributes representing east and north UTM spatial coordinates were created and used as predictor variables (Easting and Northing) to assess the amount of spatial autocorrelation within the dataset (referred to as spatial predictor variables for the remainder of this chapter). A raster is a spatial data model that defines space as an array of equally sized cells arranged in rows and columns which forms a matrix with each cell containing an attribute value and location XY coordinates. A 10-m Digital Elevation Model (DEM) was obtained from the Oregon Geospatial Data Clearinghouse and used to develop numerous raster files all with the same resolution (10-m), with the exception of the ruggedness index. Aspect, slope, and curvature raster datasets were developed using standard Arcview functions. Based on the curvature function, negative values represent concave curvatures while positive values represent convex curvatures. The DEM was also used to create a hillshade raster representing relative incident solar radiation. To compute this, the azimuth and altitude of the sun was averaged from March 1st through September 1st between the hours of 9 am and 5 pm. The hillshade raster has integer values ranging from 0, areas receiving very little incident solar radiation to 255, areas receiving extreme incident solar radiation. Using standard Arcview functions, UTM locations of leks were used to calculate a raster layer representing distance from lek centers (Lek distance). An Integrated Moisture Index (IMI) (Iverson et al. 2001) and a Ruggedness Index (RI) (Sappington et al. 2007) were created using the 10-m DEM. The IMI was used as a relative rating of moisture availability with concave, north facing aspects exhibiting highest moisture conditions (61.25) and convex, south facing aspects exhibiting the driest moisture conditions (3.1). This modified IMI model was based on hillshade, flow accumulation, and curvature, which contributes 50, 35, and 15% to the model, respectively. Landscape ruggedness was calculated using the Vector Ruggedness Measure (VRM) to estimate terrain ruggedness as a function of slope and aspect. VRM estimates the degree of terrain ruggedness by applying a geomorphological method for measuring vector dispersion. VRM is different from other ruggedness indices, in that it’s more independent of slope, distinguishing the two as separate variables (Sappington et al. 2007). Like Sappington et al. (2007), we also used a 3 x 3 neighborhood on the 10-m DEM in order to produce the finest resolution results. The RI grain is 30 m with values near 1 representing extremely rugged terrain and values near 0 representing relatively flat terrain.

Table 3.2. Landscape predictor variables and their definitions.

Attribute	Definition
Easting	Easting UTM coordinate
Northing	Northing UTM coordinate
Elevation	Meters above sea-level
Aspect	Cardinal direstion the slope is facing (e.g. North, South, etc.)
Slope	Degrees of slope steepness
Curvature	Micro-topography based on the curvature function (e.g. concave)
Solar Radiation	Relative incident radiation based on hillshade function
Road Distance	Meter distance from roads
Lek Distance	Meter distance from leks
Green Distance	Meter distance from perennial systems, resiviors, or meadows
Integrated Moisture Index (IMI)	Relative moisture
Ruggedness Index (RI)	Relative terrain ruggedness
Cover Type	Dominant vegetation cover, bare ground, water, etc.

Cover Type Variable

Vegetation plant communities, bare soil, water, and anthropogenic features were delineated and categorized as cover types. Cover types are classification categories with distinct patterns. These patterns were determined using field-based observations and 0.5-m National Agriculture Imagery Program (NAIP) aerial color photographs (Table 3.3). Since dominant species define spatial patterns on the landscape, the dominant tree and/or shrub species were used to delineate and name each vegetation cover type (Turner et al. 2001). Cover types were further delineated using elevation, aspect, and vegetation data collected from field plots (Freese 2009). Cover types occupied by two dominant shrub species occurred as intermingled complexes of small (< 0.03 ha), clumped patches (e.g. low sagebrush [*A. arbuscula* ssp. *arbuscula* Nutt.] and mountain big sagebrush [*A. tridentata* Nutt. ssp. *vaseyana (*Rydb.*)* Beetle]) and were mapped as a unique category. As a result of the reported sensitivity of the Greater Sage-grouse to vertical obstructions, cover types that composed greater than 1.5% percent of the landscape and with a Western juniper (*Juniperus occidentalis* Hook.) influence greater than 5% canopy cover were further sub-divided into classes with greater than or less than 5% juniper cover (Connelly et al. 2004). To accomplish this, a unique juniper map was created using a supervised classification scheme to map juniper with greater than 5% cover. Next, a moving window approach with window size of 254 m^2 was used to remove juniper with less than 5% cover from the juniper dataset. The juniper dataset that contained greater than or equal to 5% cover was integrated (union) with the cover type map to create cover types with greater than or less than 5% juniper cover. When three or fewer trees occurred in one juniper cover type, that class was combined with the cover class containing less than 5% juniper cover. The final vector-based cover type map, including juniper classes, was then converted into a raster file (10-m resolution) for analysis.

Table 3.3. Cover types (23) classified in the study area with the amount and percent of area composed.

Cover Type	Juniper Cover	Area Composed	Area (ha)
Roads	--	0.3%	79
Low Sagebrush	< 5	32.2%	10,111
Low Sagebrush	≥ 5	7.2%	2,265
Low Sagebrush/Mountain Big Sagebrush	< 5	1.5%	483
Low Sagebrush/Mountain Big Sagebrush	≥ 5	0.1%	18
Low Sagebrush/Wyoming Big Sagebrush	--	0.3%	87
Mountain Big Sagebrush	< 5	24.3%	7,638
Mountain Big Sagebrush	≥ 5	4.8%	1,507
Mountain Big Sagebrush/Bitterbrush	--	0.2%	76
Wyoming Big Sagebrush	< 5	14.3%	4,496
Wyoming Big Sagebrush	≥ 5	1.0%	325
Green Rabbitbrush	--	2.4%	755
Grey Rabbitbrush	--	0.4%	110
Perennial System	--	0.8%	250
Meadow	--	0.5%	148
Stock pond/Resevior	--	0.1%	46
Ponderosa Pine	--	5.7%	1,794
Quaking Aspen	--	0.0%	0
Curleaf Mountain Mohgany	--	0.0%	5
Bare Soil	--	0.0%	11
Burned area (within 20 years)	< 5	3.7%	1,165
Burned area (within 20 years)	≥ 5	0.0%	14
Other: Silver Sagebrush, salt licks, ect.	--	0.1%	38

Additional predictor variables created from the cover type variable included a raster representing the distance from roads (Road distance) and distance from green vegetation (Green Distance). Both these predictor variables were created using standard Arcview functions. The green distance predictor variable is a measure of the distance from green areas, which includes cover types perennial system, meadow, and stock-pond/reservoir (Table 3.3). Areas that remain green through the summer are easily detected and accurately mapped from color aerial photographs by appearing green or black (water) in color. Vegetation within this cover type is dominated by grass, sedge, rush, and willow species. This cover type also harbors forbs eaten by Greater Sage-grouse such as common yarrow (*Achillea millefolium* L.) and common dandelion (*Taraxacum officinale* F.H. Wigg.) that remain succulent through much of the summer (Freese 2009).

An accuracy assessment was conducted for the cover type variable across the study area using Cohen's Kappa Analysis Tools in Arcview 3.3 to produce an error matrix, which quantifies the accuracy of the cover type variable. Within each cover type, 40 random points spread greater than 25 m apart were generated in a GIS and then field verified. In the field the dominant cover type was visually assessed and compared with the digitized map. Road and quaking aspen cover types comprised a small portion of the landscape, subsequently only 39 and 2 random pointes were generated and visited, respectively. Overall map accuracy was initially 78% with differing accuracy levels for each cover type (Appendix B: Report 1). While conducting the field verification assessment, areas were identified that were incorrectly mapped on screen. These areas were corrected and another report was generated with 82.9% overall accuracy and differing accuracy levels for each cover type (Appendix B: Report 2). This second map was used in the statistical analysis to test any associations with Greater Sage-grouse occurrence. The error of commission field identifies the probability of an error associated with picking a random point on the digitized map that actually represents that correct cover type on the ground (Lunetta et al. 1991). There was a high error of commission for cover types low sagebrush/mountain big sagebrush (with both < and > 5% juniper cover), low sagebrush/Wyoming big sagebrush (*Artemisisa tridentata* Nutt. ssp. *wyomingensis* Beetle and Young), and Wyoming big sagebrush (> 5% juniper cover). Removing the low sagebrush/mountain big sagebrush (with both < and > 5% juniper cover) and the low sagebrush/Wyoming big sagebrush cover types (comprising 2.91% of the total area) improved the overall accuracy of the map to 89 % (Appendix B. Report 3). Thus, overall accuracy for the cover type map for 97.9% of the study area was reliable.

Cover Type Description

Dominant plant species associated with each cover type were identified by field-based observations (Freese 2009). The low sagebrush cover type occurred at all elevations in the study area. Early sagebrush (*A. arbuscula* Nutt. ssp. *longiloba* [Osterh.] L.M. Shultz) and stiff sagebrush (*A. rigida* [Nutt.] A. Gray) were included in the low sagebrush cover type as no distinguishing characteristics were apparent from the aerial imagery. However, it was noted in field-based observations that these two shrub species were rarely dominant (Freese 2009). Common grass species associated with this cover type were Sandberg's bluegrass (*Poa secunda* J. Presl), bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Love), Idaho fescue (*Festuca idahoensis* Elmer), bottlebrush squirreltail (*Elymus elymoides* [Raf.] Swezey), and prairie junegrass (*Koeleria macrantha* [Ledeb.] Schult.). The mountain big sagebrush cover type was typically found at relatively higher elevations within the study area. Grass species commonly associated with this cover type included Idaho fescue and bluebunch wheatgrass. Occurring at relatively low elevations was the Wyoming big sagebrush cover type. Thurber's needlegrass (*Achnatherum thurberianum* [Piper] Barkworth), needle and thread (*Hesperostipa comata* [Trin. & Rupr.] Barkworth), and bluebunch wheatgrass were commonly associated with this cover type.

The green rabbitbrush (*Chrysothamnus* sp. Nutt.*)* cover type found at relatively lower elevations often supported a cheatgrass (*Bromus tectorum* L.) understory. At relatively higher elevations, this cover type was commonly associated with Idaho fescue and Sandberg's bluegrass. The gray rabbitbrush (*Ericameria nauseosa* [Pall. ex Pursh] G.L. Nesom & Baird) cover type was commonly adjoined to meadows with sedge (*Carex* sp. L.) species dominating the understory.

There were also several perennial systems, meadow, and reservoir cover types scattered throughout the study area. Perennial systems supported riparian plant communities and were characterized by having access to water throughout the entire year. Many springs and streams composed this cover type with dominant species being sedges (*Carex* sp), rushes (*Juncus* sp. L.), and grasses. Meadows appeared adjacent to perennial system cover types and were mapped as meadows only in areas where the cross section of the green stream system exceeded 15 m or otherwise was mapped as a perennial system. Meadow cover types were dominated by grasses. Stock-pond/reservoir cover types contained grasses, sedges, and rushes. This cover type both contained water and were dry during the summer.

The ponderosa pine (*Pinus ponderosa* C. Lawson) cover type was dominant along the eastern boundary, but was not sampled in the field as Greater Sage-grouse have not been reported to occur in this cover type (Freese 2009). Other cover types with no reports of Greater Sage-grouse occurrence include quaking aspen (*Populus tremuloides* Michx.) and curl-leaf mountain mahogany (*Cercocarpus ledifolius* Nutt.).

Burned area cover types contained scattered shrubs of green rabbitbrush, gray rabbitbrush, and horsebrush (*Tetradymia canescens* DC.), typically with a higher abundance of grasses than adjacent areas. Dominant grass species commonly included bluebunch wheatgrass and Thurber’s needlegrass with a patchy distribution of cheatgrass.

The other cover type included areas with any structures (old homesteads, hay corrals, etc.), silver sagebrush (*A. cana* Pursh ssp. *bolanderi* [A. Gray] G.H. Ward) playa’s, salt licks, or any other features not fitting into any of the previous cover type categories.

In addition to these cover types, associated shrub and tree species within the study area included basin big sagebrush (*A. tridenata* Nutt. ssp. *tridentata)*, antelope bitterbrush (*Purshia tridentata* [Pursh] DC.), wax current (*Ribes cereum* Douglas), snowberry (*Symphoricarpos oreophilus* A. Gray.), plum species (*Prunus* L.), and willow species (*Salix* L.). A diversity of forbs occurred in the understory which included but is not limited to common yarrow, pussytoe species (*Antennaria* Gaertn.), milkvetch species (*Astragulus* L.), fleabane species (*Erigeron* L.), buckwheat species (*Eriogonum* Michx.), lupine species (*Lipinus* L.), aster species (*Aster* L.), and phlox species (*Phlox* L.).

Analysis

Greater Sage-grouse Population Characteristics

Population characteristics aid in understanding if habitat components are failing or succeeding in providing adequate resources for Greater Sage-grouse. Population dynamics were calculated for this population of Greater Sage-grouse including daily survival rate (DSR), seasonal survival rate (SSR), and annual survival rate (ASR). Since many birds were collared during a season and not tracked through the entirety of each season, daily survival rates were calculated for the population of birds by counting the total number of days within each season birds were alive. This number was then divided by the number of deaths that occurred during each season and subtracted from one to get the daily survival rate. The seasonal survival rate was calculated by multiplying the daily survival rate by the number of days occurring within each season. Annual survival rates were calculated by multiplying the three seasonal survival rates within the year.

The amount of area occupied by active leks, all collared birds, and collared birds only captured in the study area was estimated in Arcview using the Create Minimum Convex Polygons function in the Hawth's Tools extension.

Maximum Entropy

Maximum Entropy (Maxent) predictive modeling and mapping (Phillips et al. 2006) was used to analyze the relationships between Greater Sage-grouse and the 13 predictor variables. From these relationships continuous maps were created depicting the geographic distribution of Greater Sage-grouse seasonal habitat use. Maxent is a general purpose machine learning method, which makes predictions based on incomplete information such as our "presence-only" dataset over geographical space (Phillips et al. 2006). Since all predictor variables are in a raster format and have digital geographical representation, the pixels of the study area make up the space on which the target probability distribution is defined. This target distribution is estimated by finding the probability distribution that is closest to uniform, subject to the landscape predictor constraints. Maxent uses the Greater Sage-grouse occurrence records as sample points to generate a Maxent probability distribution relative to the predictor variables and their constraints. The Maxent probability distribution takes on the form:

$$\boxed{q_{\lambda}(x) = \frac{e^{\lambda \bullet f(x)}}{Z_{\lambda}}}$$

where λ is a vector of n real-valued coefficients or attribute weights, f denotes the vector of all n attributes, and Z_{λ} is a normalizing constant ensuring that q_{λ} sums to 1. The program starts with a uniform distribution and performs a number of iterations, each of which increases the probability of Greater Sage-grouse sample locations. The probability of Greater Sage-grouse occurrence is displayed in terms of "gain", which is the log of the number of grid cells minus the log loss (average of the negative log probabilities of the sample locations). Gain is the measure of the likelihood of bird samples and the target distribution gain or uniform gain is 0. So the gain can be interpreted as how much better the Maxent probability distribution fits the sample points (Greater Sage-grouse UTM location data) than the uniform distribution. For example, if the gain is 1, the average sample likelihood is exp(1) = 2.7 times higher than that of a random background pixel.

The receiver operating characteristic (ROC) analysis was also used to evaluate how well the Maxent model compared to random prediction. The area under the ROC function (AUC) is an index of performance because it provides a single measure of overall model accuracy that is independent of any particular threshold (Deleo 1993). The ROC analysis assigns a threshold to the modeled probability values by which sampling units are classified as positive or negative for species presence. The sensitivity for a particular threshold is the fraction of all positive instances that are classified as present and specificity is the fraction of all negative instances that are classified as not-present. A ROC plot is obtained by plotting all sensitivity values (true positive fraction) on the *y* axis against their equivalent (1-specificity) values (false positive fraction) for all available thresholds on the *x* axis. In other words, a point (x, y) in the plot indicates that for some threshold, the classifier classifies a fraction x of negative examples as positive and a fraction y of positive examples as positive. Maxent treats the randomly selected background pixels as negative instances and the pixels in which the presence data fall as positive instances. The value of the AUC is typically between 0.5 and 1.0. A value of 0.8 indicates that 80% of random selections from the positive group will have a score greater than a random selection from the negative class. A value of 0.5 indicates the model is no better than a random prediction. However, when ROC analysis is used on presence-only data, the maximum AUC is less than one (Wiley et al., 2003) and is smaller for wider-ranging species. The maximum achievable AUC can be shown to be equal to 1- *a*/2, where *a* is the fraction of pixels covered by the species' distribution. Maxent output also includes an analysis of the relative contribution of each predictor variable to the Maxent model.

Model Building

The objective of the analysis was to build a full prediction model with a complete set of predictor variables ($n = 13$) to explore their quantitative relationships with the set of Greater Sage-grouse location points. The spatial predictor variables easting and northing supply the model with explanatory information beyond the information not accounted for in the remaining set of predictor variables. Therefore, a second model was built by excluding the spatial predictor variables to determine the spatial autocorrelation with Greater Sage-grouse location points.

Linear, quadratic, product, and hinge functions of the predictor variables were selected for inclusion in the model to account for variable interactions and non-linear responses. Model settings that allow the algorithm to get close to convergence are the maximum number of iterations, set to 1000, and the convergence threshold, set to 10^{-5}. The regularization multiplier was set to the default value of one. The jackknife test of variable importance was used to compare the training gain generated by the model with the predictors chosen for the full model and all combinations of a one-variable model and a full model after omitting a single variable.

Success of the model can also be evaluated by visually inspecting how well the probability values in the output grid (map) fit with the bird location points. Output grids were generated from application of the Maxent model to the set of GIS grids that represent each predictor variable. A good model will produce regions of high probability that cover the majority of presence records and areas of low probability should contain few to no presence points.

Results

Greater Sage-grouse Population Characteristics

This population of Greater Sage-grouse occupied 10 known leks with the leks encompassing approximately 35,363 ha. The population of birds captured from these leks and surrounding roosting locations occupied an area of 263,353 ha for the duration of the study. The Greater Sage-grouse that were collared within the study area used 134,396 ha. An annual survival rate for this population of birds during the first year of tracking was 58.3%, while it decreased to 46.9% during the second year (Table 3.4).

Table 3.4. The number of Greater Sage-grouse location points per season and population dynamics.

	Locations	**Population Dynamics**					
Season	**n**	**Start**	**Cap.**	**Died**	**DSR**	**SSR**	**ASR**
Breeding	48	--	15	1	99.9%	87.3%	58.3%
Summer	125	14	6	3	99.8%	81.1%	
Winter	18	17	6	4	99.8%	82.4%	
Breeding	186	19	23	16	99.6%	62.2%	46.9%
Summer	82	26	--	6	99.8%	79.4%	
Winter	5	20	--	1	100.0%	95.1%	
Breeding	16	19	--	1	99.9%	85.5%	--

Start = the number of birds that started that season, Cap = captured, DSR = Daily Survival Rate, SSR = Seasonal Survival Rate, ASR = Annual Survival Rate

Breeding Season including Spatial Predictor Variables

All 13 predictor variables were used in the initial model. The IMI variable had a strong correlation with variables solar radiation and curvature and was subsequently removed from further analysis. After removing the IMI, the area under the ROC curve was 0.944, representing overall model accuracy. The distance to lek predictor variable contributed 51.2% to the Maxent model with a training gain of 1.61, therefore the average sample likelihood was 5.0 times higher than a random background pixel. This can be interpreted as the models prediction of habitat use patterns was 5.0 times better than assuming Greater Sage-grouse select habitat randomly. The distance to lek variable was expected to be a strong predictor of Greater Sage-grouse habitat selection during the breeding season (Schroeder et al. 1999, Connelly et al. 2000, Crawford et al. 2004). Therefore, the distance to lek variable was removed in order to elucidate how the remaining predictor variables influenced Greater Sage-grouse habitat selection. After omitting the distance to lek variable, overall model accuracy for the remaining variables for the breeding season was 0.905 from the ROC analysis AUC. Northing and easting predictor variables contributed the most to the Maxent model (Fig. 3.3). Visual inspection of the distribution map suggests a good fitting model as the majority of the birds were contained in areas that predict a high probability of use, while few birds were associated with low probabilities of use.

Predictor Variable	**Contribution to Maxent Model**
Northing	42.2
Easting	25.4
Cover Type	13.4
Elevation	12.0
Green Distance	2.3
Ruggedness	1.7
Solar Radiation	1.2
Curvature	0.8
Road Distance	0.5
Slope	0.2
Aspect	0.1
Model	100.0

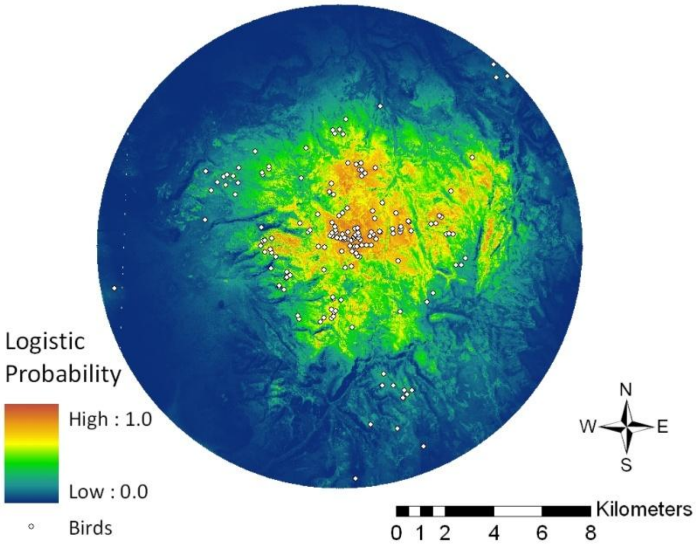


Figure 3.3. Contribution of each predictor variable in the Maxent model predicting breeding habitat use including spatial predictor variables (left) and the Maxent probability distribution map (right) with warmer colors representing better predicted habitat conditions.

The full model's training gain was 1.08, meaning the models prediction of preferred habitat was 2.95 times better than assuming preferred habitat was randomly distributed based on Greater Sage-grouse location points (Fig. 3.4). Northing had the highest gain when used in isolation, suggesting it was the single most important predictor variable in terms of the gain produced by a one-variable model. Northing also decreased the full model training gain the most when omitted from the analysis, suggesting it contained the most information not contained within the other variables.

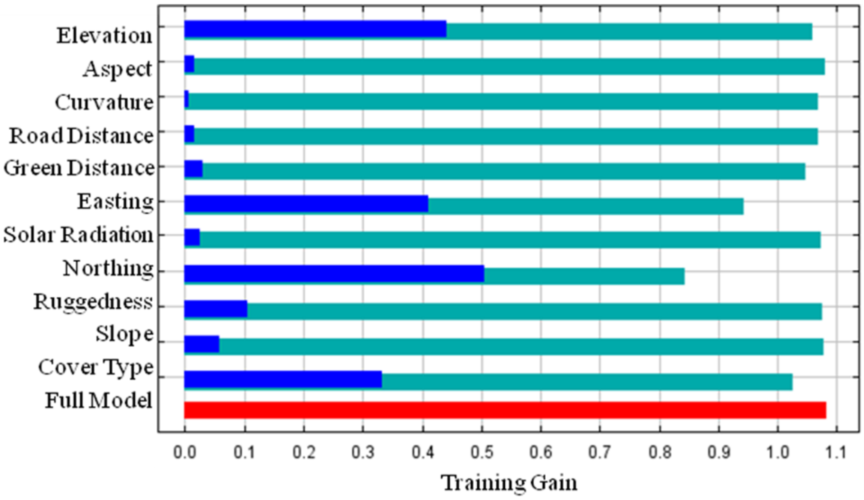


Figure 3.4. Results from a jackknife test of variable importance for the breeding season including spatial predictor variables. The full model training gain is displayed in red, the training gain for each predictor variable alone is blue, and the drop in training gain when the predictor variable is omitted from the full model is in green.

<u>Breeding Season excluding Spatial Predictor Variables</u>

After omitting the spatial predictor variables, elevation and cover type contributed the greatest weight to the model (Fig. 3.5). Model accuracy without the spatial predictor variables and distance to lek variable was 0.89 from the ROC analysis AUC. The full model's training gain was 1.11, meaning the models prediction of preferred habitat was 3.03 times better than assuming preferred habitat was randomly distributed (Fig. 3.6). Elevation had the highest gain when used in isolation followed by cover type, ruggedness index, green distance, slope, solar radiation, road distance, curvature, and aspect. Elevation also decreased the full model training gain the most when omitted from the analysis followed by cover type, green distance, road distance, ruggedness index, curvature, aspect, and slope.

Predictor Variable	Contribution to Maxent Model
Elevation	38.2
Cover Type	36.9
Green Distance	10.8
Ruggedness	7.4
Road Distance	4.0
Curvature	1.2
Solar Radiation	0.7
Aspect	0.5
Slope	0.3
Model	100.0

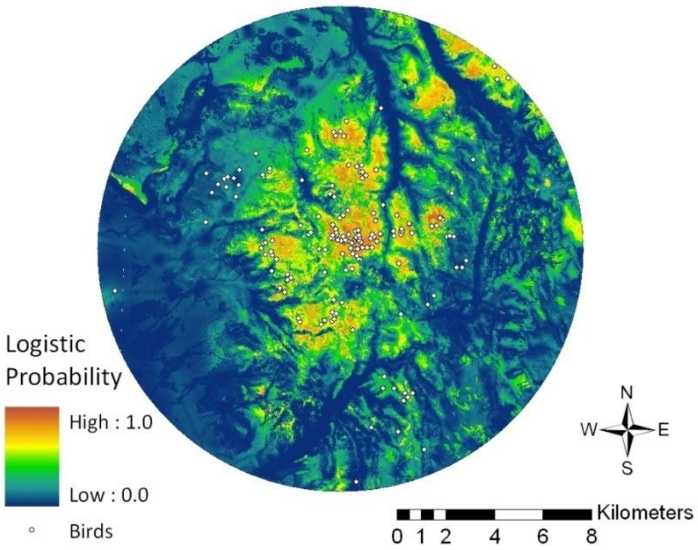


Figure 3.5. Contribution of each predictor variable in the Maxent model predicting breeding habitat use excluding spatial predictor variables (left) and the Maxent probability distribution map (right) with warmer colors representing better predicted habitat conditions.

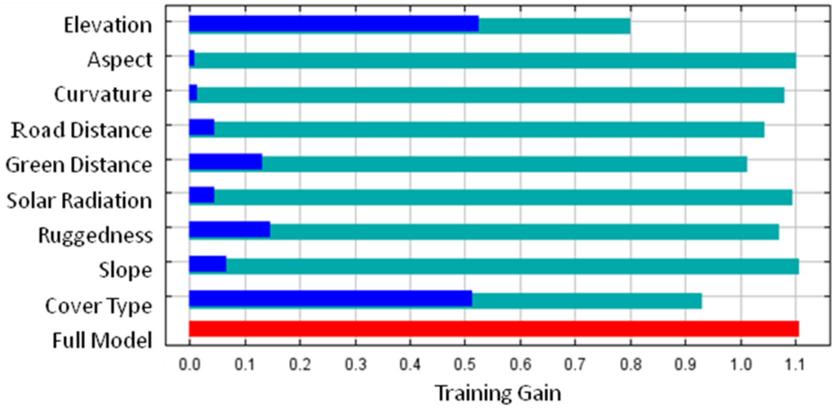
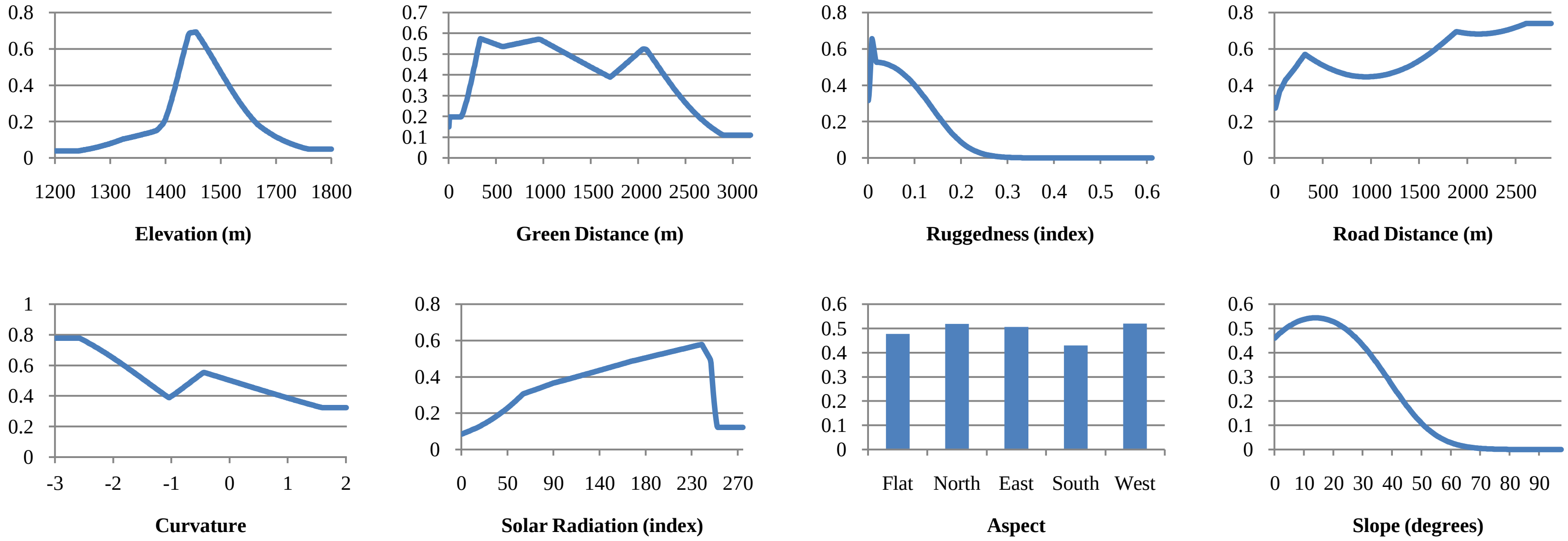
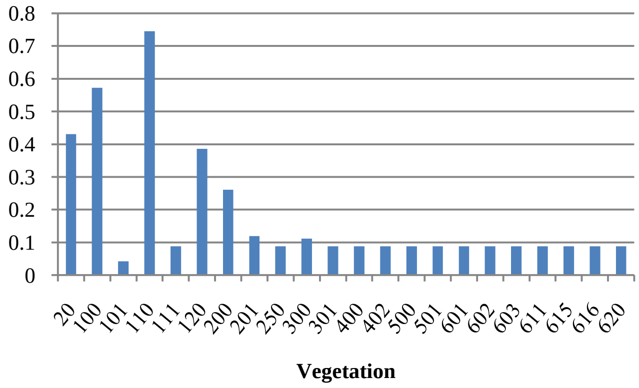


Figure 3.6. Results from a jackknife test of variable importance for the breeding season excluding spatial predictor variables. The full model training gain is displayed in red, the training gain for each predictor variable alone is blue, and the drop in training gain when the predictor variable is omitted from the full model is in green.

Response curves created with the Maxent model illustrate the logistic prediction of better habitat conditions or the areas where Greater Sage-grouse are more likely to be encountered (Fig. 3.7). The elevation response curve indicates that the presence of birds rapidly increased between 1,400 and 1,450 m and then declined with increasing elevation. Preferred cover types during the breeding season were low sagebrush/mountain big sagebrush with less than 5% juniper cover and low sagebrush with less than 5% juniper cover. Cover types with less than 5% juniper cover were preferred by Greater Sage-grouse over similar cover types with greater than 5% juniper cover. Areas that were less rugged and with less slope steepness were also likely to have increased bird presence. The presence of birds increased with increasing solar radiation.





Code	Cover Type Key	juniper
20	Roads	--
100	Low Sagebrush	< 5%
101	Low Sagebrush	≥ 5%
110	Low Sagebrush/Mountain Big Sagebrush	< 5%
111	Low Sagebrush/Mountain Big Sagebrush	≥ 5%
120	Low Sagebrush/Wyoming Big Sagebrush	--
200	Mountain Big Sagebrush	< 5%
201	Mountain Big Sagebrush	≥ 5%
250	Mountain Big Sagebrush/Bitterbrush	--
300	Wyoming Big Sagebrush	< 5%
301	Wyoming Big Sagebrush	≥ 5%
400	Green Rabbitbrush	--
402	Grey Rabbitbrush	--
500	Perennial System	--
501	Meadow	--
503	Stock pond/Resevior	--
601	Ponderosa Pine	--
602	Quaking Aspen	--
603	Curleaf Mountain Mohgany	--
611	Bare Soil	--
615	Burned area (within 20 years)	< 5%
616	Burned area (within 20 years)	≥ 5%
620	Other: Silver Sagebrush, salt licks, ect.	--

Figure 3.7. Response curves depicting changes in the logistic prediction (y-axis) of preferred habitat with associated changes in each predictor variable. Response curves depicting a one variable model with variables displayed from the breeding season excluding spatial predictor variables Maxent model.

Summer Season including Spatial Predictor Variables

The area under the ROC curve was 0.937, representing overall model accuracy. Northing and easting contributed the greatest weight to the Maxent model (Fig. 3.8). Visual inspection shows strong agreement between Greater Sage-grouse location points and the Maxent probability distribution.

Predictor Variable	Contribution to Maxent Model
Easting	38.5
Northing	27
Lek Distance	17.1
Green Distance	6.6
Road Distance	4.3
Cover Type	1.5
Curvature	1.3
Elevation	1.2
Solar Radiation	1.1
Ruggedness	0.7
Aspect	0.5
Slope	0.4
Model	100

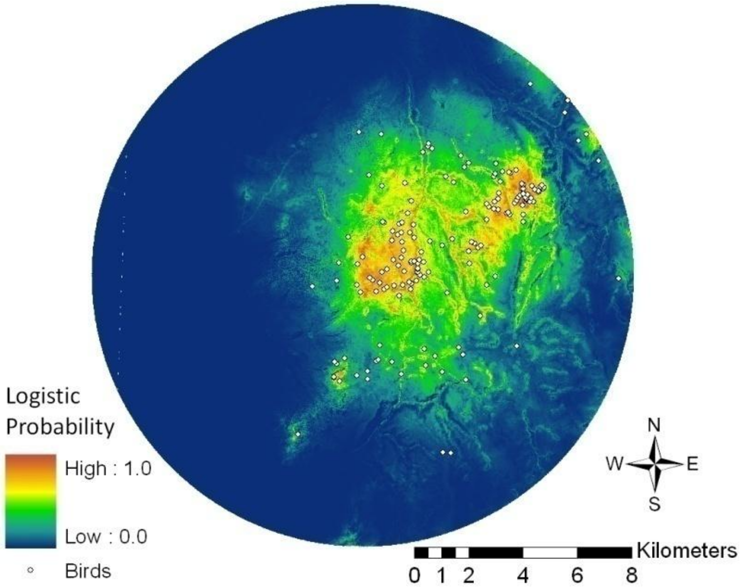


Figure 3.8. Contribution of each predictor variable in the Maxent model predicting summer habitat use including spatial predictor variables (left) and the Maxent probability distribution map (right) with warmer colors representing better predicted habitat conditions.

The models prediction of habitat use patterns was 4.5 times better than assuming Greater Sage-grouse selected habitat randomly since the full model's training gain was 1.5 (Figure 3.9). Easting had the highest gain when used in isolation and contained the most information not contained within the other variables. Northing also provided a great deal of information by itself, while green distance contained the second greatest amount of information not contained within the other variables.

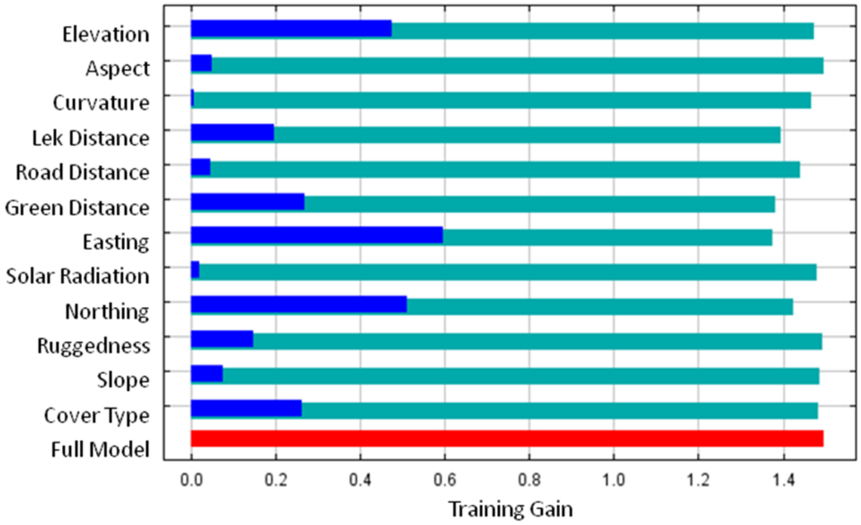


Figure 3.9. Results from a jackknife test of variable importance for the summer season including spatial predictor variables. The full model training gain is displayed in red, the training gain for each predictor variable alone is blue, and the drop in training gain when the predictor variable is omitted from the full model is in green.

Summer Season excluding Spatial Predictor Variables

After omitting the spatial predictor variables, elevation became the greatest contributor to the Maxent model followed by lek distance and green distance (Fig 3.10). Model accuracy without the spatial predictor variables was 0.912 from the ROC analysis AUC. The full model's training gain was 1.28, thus the models prediction of preferred habitat was 3.6 times better than assuming preferred habitat was randomly distributed (Fig. 3.11). Elevation contained the greatest amount of information by itself followed by cover type, green distance, and lek distance. Lek distance contained the greatest amount of information not contained within the other variables, followed by solar radiation, and green distance.

Predictor Variables	Contribution to Maxent Model
Elevation	35
Lek Distance	26.4
Green Distance	18.3
Road Distance	8.8
Cover Type	3.4
Ruggednes	3.3
Curvature	2.1
Solar Radiation	1.6
Slope	0.6
Aspect	0.5
Model	100

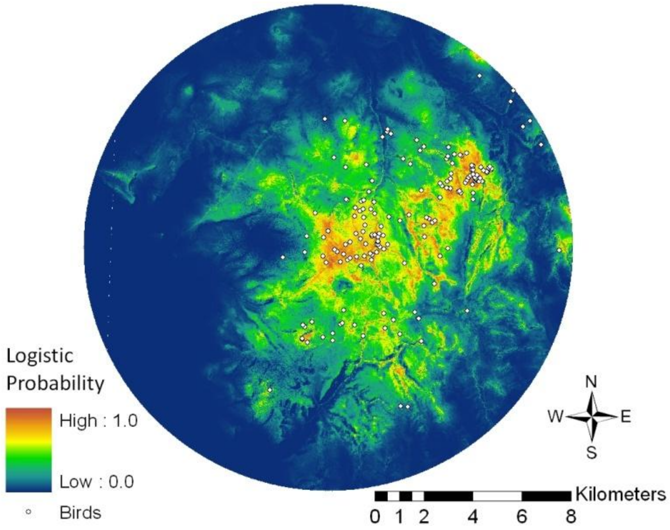


Figure 3.10. Contribution of each predictor variable in the Maxent model predicting summer habitat use excluding spatial predictor variables (left) and the Maxent probability distribution map (right) with warmer colors representing better predicted habitat conditions.

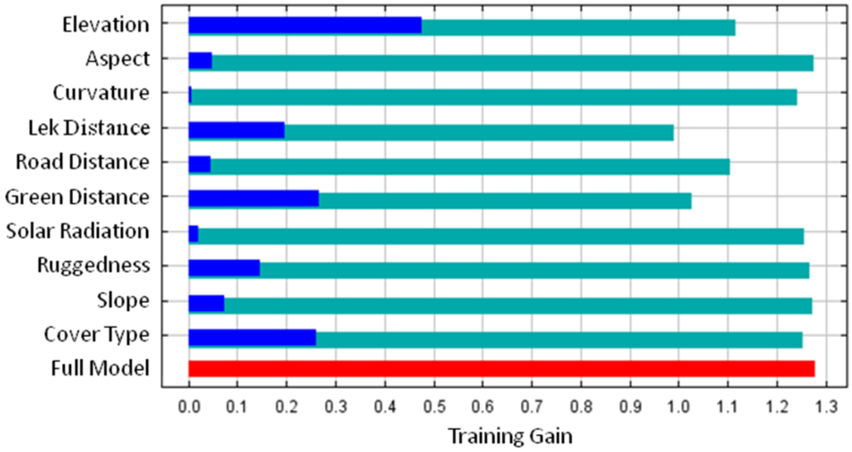
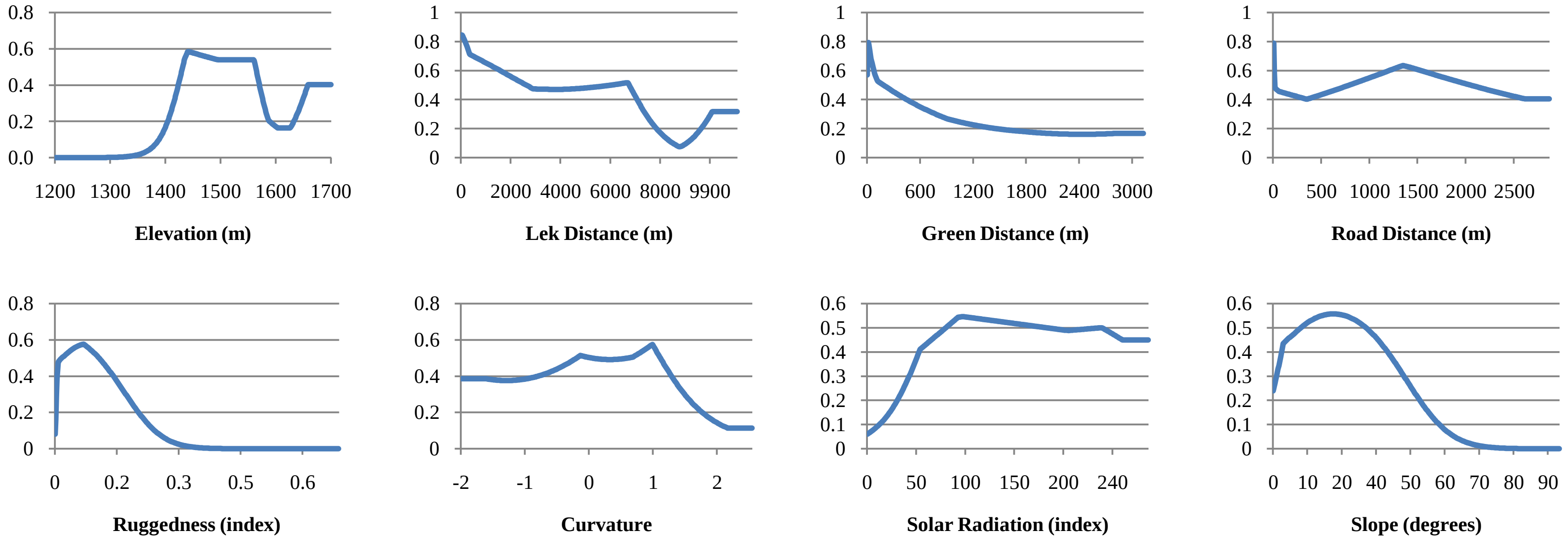
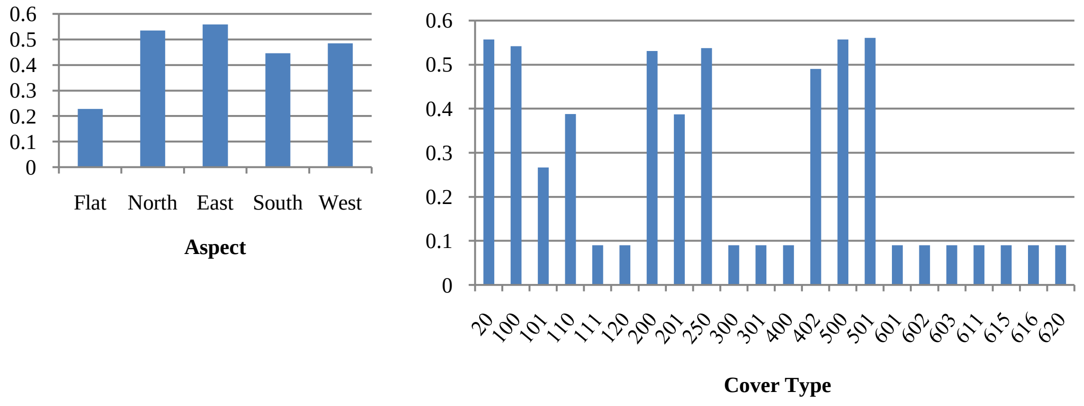


Figure 3.11. Results from a jackknife test of variable importance for the summer season excluding spatial predictor variables. The full model training gain is displayed in red, the training gain for each predictor variable alone is blue, and the drop in training gain when the predictor variable is omitted from the full model is in green.

The presence of Greater Sage-grouse rapidly increased between 1,400 and 1,450 m and persisted until about 1,625 m before declining (Fig. 3.12). Habitat use was highest near leks and decreased as the distance from leks increased. Preferred cover types for the summer season included perennial systems, meadows, roads, low sagebrush with less than 5% juniper cover, mountain big sagebrush/bitterbrush, mountain big sagebrush with less than 5% juniper cover, and gray rabbitbrush. Greater Sage-grouse preference increased for cover types with less than 5% juniper canopy cover compared to those same cover types with greater than 5% juniper canopy cover. Mirroring Greater Sage-grouse preference for mesic cover types, they also showed a strong affinity to be near areas with green vegetation and/or water sources.





Code	Cover Type Key	juniper
20	Roads	--
100	Low Sagebrush	< 5%
101	Low Sagebrush	≥ 5%
110	Low Sagebrush/Mountain Big Sagebrush	< 5%
111	Low Sagebrush/Mountain Big Sagebrush	≥ 5%
120	Low Sagebrush/Wyoming Big Sagebrush	--
200	Mountain Big Sagebrush	< 5%
201	Mountain Big Sagebrush	≥ 5%
250	Mountain Big Sagebrush/Bitterbrush	--
300	Wyoming Big Sagebrush	< 5%
301	Wyoming Big Sagebrush	≥ 5%
400	Green Rabbitbrush	--
402	Grey Rabbitbrush	--
500	Perennial System	--
501	Meadow	--
503	Stock pond/Resevior	--
601	Ponderosa Pine	--
602	Quaking Aspen	--
603	Curleaf Mountain Mohgany	--
611	Bare Soil	--
615	Burned area (within 20 years)	< 5%
616	Burned area (within 20 years)	≥ 5%
620	Other: Silver Sagebrush, salt licks, ect.	--

Figure 3.12. Response curves depicting changes in the logistic prediction (y-axis) of preferred habitat with associated changes in each predictor variable. Response curves depicting a one variable model with variables displayed from the summer season excluding spatial predictor variables Maxent model.

Discussion

Greater Sage-grouse Population Characteristics

This study lacked genetic evidence linking the different leking systems. However, birds from different leking systems had a considerable amount of overlap in their home ranges, thus were considered a single population. Collared Greater Sage-grouse didn’t utilize distinct seasonal habitat, suggesting that the study population was non-migratory. However, many birds did travel over 10 km, which according to Connelly et al. (2000) would be defined as a migratory population. Therefore, difficulties arose in determining if this population was migratory or non-migratory based on Connelly’s et al. (2000) guidelines. This population is best described as a non-migratory population with a large home range and overlapping seasonal use areas. However, there did appear to be sub-populations of birds that may be one-stage migratory, moving between a distinct winter area and integrated breeding and summering areas

Annual Greater Sage-grouse survival rates in this study were comparable to rates estimated by Crawford et al. (2004) who found that the survival rate of breeding aged bird populations were greater than 50%. Since male Greater Sage-grouse have lower survival rates than females and this study collared more male birds, survival rates were expected to be lower. A large number of birds perished the second breeding season which coincided with a larger snowpack compared to the first breeding season. Long term lek count data from 1987-2008 (ODFW unpublished lek count data 2008) suggests that this population of Greater Sage-grouse is stable.

Landscape Predictor Variables

Similarities between Breeding and Summer Seasonal Models

After omitting the distance to lek predictor variable for the breeding season model, results indicate that northing and easting were important variables for predicting habitat use. However, northing and easting are not easily applied to areas outside of the study area. Therefore, a models use in management application becomes limited when spatial predictor variables are included (Phillips et al. 2006). However, these spatial constraints can be useful because they encapsulate combinations of predictor variables. Greater Sage-grouse moved from the center of the study area during the breeding season in a northeast direction to preferred summer habitat. This directional movement resulted in a measurable preference for specific habitat components in a combination of predictor variables. The shift in habitat preference resulted in an increase in elevation, cover types with relatively higher moisture conditions, and a decrease in the distance from perennial system, meadow, and reservoir cover types (green distance). In south-central, Oregon Yost et al. (2008) reported similar spatial movement patterns from the lek to preferred nesting locations. They found that birds moved in a westerly direction from leks, corresponding to increasing elevation, higher use of shrub cover types which typically produces greater cover values, and areas with greater cover type richness. Understanding the combined effects of landscape attributes that attract birds enable biologist and managers to predict the general directional movements of birds from leks to nesting locations and from breeding to summer seasonal habitats.

Locations where Greater Sage-grouse were most likely to be encountered for both breeding and summer seasons rapidly increased between 1,400 and 1,450 m elevation. The likelihood of bird habitat use quickly declined during the breeding period at elevations between 1,450 and 1,600 m, while summer habitat use remained high to 1,640 m. An increase in elevation is often associated with higher moisture availability to plants, particularly during the growing season when precipitation is limited and temperatures are higher (Swanson et al. 1988). Increased moisture availability at higher elevations lengthens the time that forbs remain succulent, potentially explaining Greater Sage-grouse preference for higher elevations during the summer season. Similarly, Klebenow (1969) found that Greater Sage-grouse moved up in elevation following a gradient of green food plant availability in Idaho. In addition to succulent forb availability, a greater abundance of forbs that Greater Sage-grouse consume was associated with increased elevation within the study area (Freese 2009).

The bimodal response during the summer season with increasing preference at the highest elevations corresponded to there being two birds above 1,683 m elevation (representing 63 ha). Since elevation above 1,683 m represented such a small area, these two location points disproportionately inflated habitat preference values. Since the percent of area is low, it is recommended using caution when interpreting trends above 1,640 m elevation.

Elevation is similar to the spatial predictor variables in that it encapsulates various environmental expressions such as changes in the kinds, amounts, and proportions of vegetation (Davies et al. 2007, Freese 2009). Elevation also doesn't generalize well to areas outside the study area, consequently limiting manager's ability to predict habitat use. More applicable is the relationship between Greater Sage-grouse and the predictor variables which can be explained biophysically and applied to new locations. With the relationship between Greater Sage-grouse and landscape attributes having biophysical relevance, managers can better predict Greater Sage-grouse habitat use across landscapes.

In addition to the spatial predictor variables and elevation, similar trends that occurred between the breeding and summer season models that does have biophysical relevance was the influence of juniper cover. During both the breeding and summer seasons, Greater Sage-grouse preferred cover types with less than 5% juniper canopy cover compared to those same cover types with greater than 5% juniper canopy cover. Greater Sage-grouse were periodically observed shading under single trees or a small group of trees, but this still only occurred where tree canopy cover was less than 5%. Juniper trees may act as perch sites for raptors, which may be directly influencing Greater Sage-grouse avoidance of cover types with greater than 5% juniper cover. Juniper may also indirectly influence birds avoidance of habitats through its influences on plant community compositional and structural changes, such as a reduction in the herbaceous understory (Burkhardt and Tisdale 1969, Knapp and Soule 1998, Miller et al. 2000).

Breeding Season excluding Spatial Predictor Variables

The distance to lek variable was the strongest predictor for Greater Sage-grouse habitat selection during the breeding season. Other studies support these findings, showing that Greater Sage-grouse congregate around leks during this season (Schroeder et al. 1999, Connelly et al. 2000, Crawford et al. 2004), which supports the reliability of this model.

After omitting the distance to lek variable and second to elevation, cover type was the next strongest predictor variable predicting Greater Sage-grouse habitat selection for the breeding season. The low sagebrush/mountain big sagebrush cover type with less than 5% juniper cover was most preferred by Greater Sage-grouse. This cover type had 11% greater shrub cover, 45% greater deep-rooted perennial tussock grass cover, 38% greater perennial forb cover, 29% more perennial food forbs, and 19% more annual food forbs than the average for the entire study area (Freese 2009). With greater cover values, the low sagebrush/mountain big sagebrush cover type may attract birds for nesting and roosting. In southeastern Oregon, Gregg et al. (1994) and in south-central Washington, Sveum et al. (1998) reported Greater Sage-grouse selected nest site locations with greater shrub and deep-rooted perennial tussock grass cover than random locations. Providing increased cover values may also increase nest success (Gregg et al. 1994, Delong et al. 1995, Sveum et al. 1998). The low sagebrush/mountain big sagebrush cover type may also be attracting male birds during the breeding season as Ellis et al. (1989) reported roosting areas were associated with increased shrub cover. With an increased amount of forb species eaten by Greater Sage-grouse, the low sagebrush/mountain big sagebrush cover type may attract hens during pre-laying and brood-rearing. In addition, increased forb availability may result in increased productivity (Barnett and Crawford 1994, Drut et al. 1994a,b). If increased forb availability attracted Greater Sage-grouse during the breeding season, then this would also explain the preference for the low sagebrush cover type, which had 9% greater perennial food forb density and 35% greater annual food forb density than the study area average (Freese 2009).

Biased occurrence data resulting from increased sampling intensity on and near roads may explain the preference of Greater Sage-grouse habitat use for this cover type. The distance to roads predictor variable verifies that sampling intensity on roads is probably overestimated as habitat preference increases as distance increases from roads during the breeding season. These results are similar to what Aldridge and Boyce (2007) reported in southern Alberta, Canada where nesting females had a strong avoidance of anthropogenically created habitats.

Summer Season excluding Spatial Predictor Variables

Second in model strength to elevation was the distance to lek variable, suggesting that Greater Sage-grouse habitat use decreases with increasing distance from leks. These results support the idea that leks may act as the center of annual activity (Braun et al. 1977, Connelly et al. 2000).

The green distance predictor variable was another strong predictor with increased Greater Sage-grouse habitat preference near green habitats. These results are consistent with Klebenow's (1969) observations as he reported Greater Sage-grouse in Idaho gathered near permanent water sources in late August where green vegetation remained succulent. He noted that throughout the summer birds left areas where forb desiccation occurred for areas where forbs were maturating. Connelly et al. (1988) also reported that Greater Sage-grouse moved near agricultural land or more mesic habitats where succulent vegetation was likely to occur during the summer season.

Results identifying preferred cover types indicated that meadows and areas that are moist throughout a significant part of the summer were preferred. In addition to forbs remaining succulent through much of the summer, both perennial systems and meadows contained a greater density of Greater Sage-grouse food forbs than all cover types in the study area (Freese 2009). Similarly, Drut et al. (1994a) reported an increased use of lakebeds and meadows during late brood-rearing (summer season) in southeastern Oregon. In addition to harboring succulent forbs longer into the summer season, Drut et al. (1994b) and Ersch (2009) found that insect abundance increased in mesic habitats. Areas with increased insect and forb abundance may provide important food sources for late brood-rearing and for broods that are a result of second or third re-nesting attempts.

Winter Season Observations

Greater Sage-grouse used areas with little to no topographical relief that covered large areas (> 15,000 ha) during the winter season. This study area contained a limited amount of relatively large, low topographical relief areas, which may explain why many birds moved outside the study area for the winter season. Interestingly, 70% of the study area satisfied vegetation requirements for productive winter habitat proposed by Connelly et al. (2000) and the BLM et al. (2000) (Freese 2009). With the majority of the study area satisfying Greater Sage-grouse habitat requirements and the birds moving outside the study area suggests that habitat components in addition to the vegetation components described in the guidelines are influencing habitat selection.

Maximum Entropy Model with all Birds Combined

All 480 bird UTM coordinates were combined into a single model (Appendix C). This model resulted in a less accurate and weaker model than either the breeding or summer seasonal models alone (after omitting the spatial predictor variables) (Table 3.5). This supports the literature that bird habitat use differs between seasons and provides evidence that use patterns are detectable at the landscape-scale (Schroeder et al. 1999, Connelly et al. 2000, Crawford et al. 2004). Greater Sage-grouse seasonal habitat use pattern differences can be attributed to changes in habitat and their life-cycle requirements. Habitat changes influencing distribution patterns include annual cyclic patterns of insect population declines, forb desiccation, and a decline in sagebrush toxicity (Schroeder et al. 1999, Crawford et al. 2004, Rosentreter 2004). Life-cycle requirements influencing habitat use patterns include but is not limited to consuming high protein forbs during pre-laying and brood consumption of insects (Barnett and Crawford 1994, Drut et al. 1994b).

Table 3.5. An accuracy and strength comparison of three models excluding spatial predictor variables.

Model	All Birds Combined	Breeding Season	Summer Season
Accuracy[1]	0.857	0.89	0.912
Strength[2]	0.75	1.11	1.28

[1] measured from the ROC analysis AUC

[2] measured in training gain

Conclusion

With Greater Sage-grouse utilizing resources within expansive landscapes, identifying the attributes that can be applied at a landscape-scale provides land management agencies information relevant to the scale at which they manage habitat. Understanding the landscape attributes that attract disproportionate levels of habitat use enables managers to predict where birds are likely to occur across the landscape. Results from this study suggest Greater Sage-grouse habitat use during the breeding season increases near leks and within cover types of low sagebrush/mountain big sagebrush complexes and low sagebrush. Preferred summer habitat includes areas relatively high in elevation, within close proximity to leks, and within or a close proximity to habitats that harbor succulent vegetation through much of the summer. With the ability to discriminate between areas that Greater Sage-grouse are likely to use or avoid, managers can allocate limited resources to more effectively create, manipulate, and administer habitat conservation efforts where bird use is predicted to occur and prioritize areas for ecological restoration.

Greater Sage-grouse habitat use patterns between unique landscapes may differ. Therefore, it is recommended that results from this study be applied only to similar landscapes. Similar landscapes include areas with a high degree of vegetation heterogeneity and with variable topography. Dissimilar landscapes may be characterized by homogenous vegetation and limited topographic relief such as portions of the Upper Snake River Plain described by Klebenow (1969) and Connelly et al. (1993). Limitations also included the extent and resolution that this research was conducted at, which should be carefully scrutinized and accounted for in further replication.

Further replication and research that can elucidate the Greater Sage-grouse habitat use patterns across multiple spatiotemporal scales is needed through all seasons, with improved predictor variables that generalize well, and with combined fitness parameters. After further replication and research more reliable and empirically based models may be used to predict habitat use and discriminate between suitable and unsuitable habitats for management applications. With juniper expansion occurring throughout much of the West, further research addressing the influence of juniper abundance on Greater Sage-grouse habitat avoidance would help management planning efforts. In addition, conservation planning efforts could benefit from better understanding the influence of low sagebrush/mountain big sagebrush complex cover types on Greater Sage-grouse habitat preference. Additional research that addresses the differences between use and non-use areas could aid managers in determining if non-use areas are the result of degraded habitat. This could enrich a manager’s ability to make decisions about the location where ecological restoration efforts will provide the most benefit to Greater Sage-grouse. Supplemental information addressing the influence of patch and resource spatial distribution across landscapes on Greater Sage-grouse population sustainability would further augment conservation efforts. In addition, developing reliable landscape mapping techniques that accurately discriminate between sagebrush species would greatly improve research questions that could be answered and management actions that could be applied.

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CHAPTER 4: GENERAL CONCLUSIONS

Scale as an Imperative Issue

This research identified several landscape-level attributes that influence Greater Sage-grouse habitat use and distribution patterns during the breeding and summer seasons. This study also attempted to debunk the controversies and discrepancies in managing Greater Sage-grouse habitat by placing plot-level vegetation characteristics reported to be important for Greater Sage-grouse survival and reproduction into a landscape context. Scaling-up from plot to landscapes resulted in increased heterogeneity, illustrating the importance of considering multiple spatial scales and challenges ecologist and managers to recognize scale as an imperative piece of all management and research issues (Wiens 1989).

Two Notes

Culminating from both manuscripts were two components that deserves discussion. The low sagebrush/mountain big sagebrush complex (< 5% juniper cover) provided the most valuable Greater Sage-grouse habitat throughout the entire year, based on the ability of plots across the study area to satisfy all guideline criteria (BLM et al. 2000, Connelly et al. 2000). This cover type was also the most preferred by Greater Sage-grouse during the breeding season and remained a preferred community through the summer season. The low sagebrush/mountain big sagebrush cover type ranked fourth out of 18 cover types for greatest total forb cover (6.1%) and fifth for greatest density of Greater Sage-grouse food forbs (6.0/m^2). It also contained the greatest deep-rooted perennial tussock grass cover (32.1%) of all upland cover types and had a mean combined (across both low and mountain big sagebrush) canopy cover of 17.9%. Being a complex of small (< 0.03 ha), clumped, intermingled patches of short and tall plants provided Greater Sage-grouse with both low sagebrush and mountain big sagebrush plant community composition and structure all within close proximity. We hypothesize that at the plot-level, adjoining tall and short statured sagebrush patches and their associated understory plant species may be providing balanced resource tradeoffs between the two plant communities. Little information exists in the literature about low sagebrush/mountain big sagebrush complexes and the influence on Greater Sage-grouse habitat preference. However, Miller and Eddleman (2001) made a general statement that mosaic's of low sagebrush and mountain big sagebrush cover types can provide excellent habitat. The low sagebrush/mountain big sagebrush complex cover type proved to be difficult to map from aerial photographs and did have the second highest error of commission, which somewhat discredits its accuracy. However, based on chapters two and three it is recommended that further research explore the influence of low sagebrush/mountain big sagebrush cover types in providing suitable Greater Sage-grouse habitat.

The second component worth discussing is that during the winter season, 80% of the Greater Sage-grouse location coordinates were outside the study area when most plots (76.7%) and the majority of the landscape (70%) within the study area satisfied habitat guideline criteria produced by Connelly et al. (2000) and the BLM et al. (2000). However, during the breeding and summer seasons when the majority of birds were attracted to the study area, less than 2.5% of plots satisfied the breeding and nesting guideline criteria and less than 50% of plots satisfied the brood-rearing guideline criteria. This suggests that something other than the vegetation characteristics described in the guidelines are influencing how Greater Sage-grouse are selecting habitat. Based on winter observations of the birds, it appears that topography may be influencing habitat selection during the winter as birds selected areas with relatively greater topographic relief during the breeding and summer seasons. Further research is necessary to determine if/which attributes are influencing habitat selection or if site fidelity may be responsible for habitat use patterns during the winter season.

Improvements

The following are recommendations and considerations for similar studies:

1. Since this was a joint project with the Department of Fisheries and Wildlife with two master's projects, this research relied heavily on the goals, objectives, and outcomes of another master's project. Differences in the two projects

goals and objects restricted the ability to fully synthesize all data. As such, it is recommended merging the two approaches into a single PhD project so that a single investigator has full control. Additional items to consider are:

   a. Focus capture efforts in one centralized area. This would enable the number of location points to increase.
   b. Locate the collared birds on the ground (more accurate) rather than in flight because the error associated with flight locations is too great for use in some analysis.
   c. Sample vegetation both at random locations, similar to the sampling scheme used in this study and at collared location points using consistent sampling techniques for comparison purposes.
   d. Attempt to capture fitness parameters similar to Aldridge and Boyce (2007) and separate the breeding season into sub-categories (e.g. pre-laying, leking, nesting, early brood-rearing, late brood-rearing).
   e. Carefully designate the season for individual birds as behavioral patterns may differ (e.g. one bird may display breeding season signs in February, while others display signs for the winter season in March.

2. To collect data at random locations, use a complete random sampling design to select plots for sampling or a stratified random sampling design that accounts for the cover type area amount. Collect data to the species-level for cover and use a multivariate technique such as Davies et al. (2006) to group the data. This would be an objective approach and allow the investigator to group plant communities by alliances and associations which would better summarize and explain different ecological relationships within cover types (e.g. Wyoming big sagebrush/Thurber’s needlegrass, Wyoming big sagebrush/bluebunch wheatgrass, etc).

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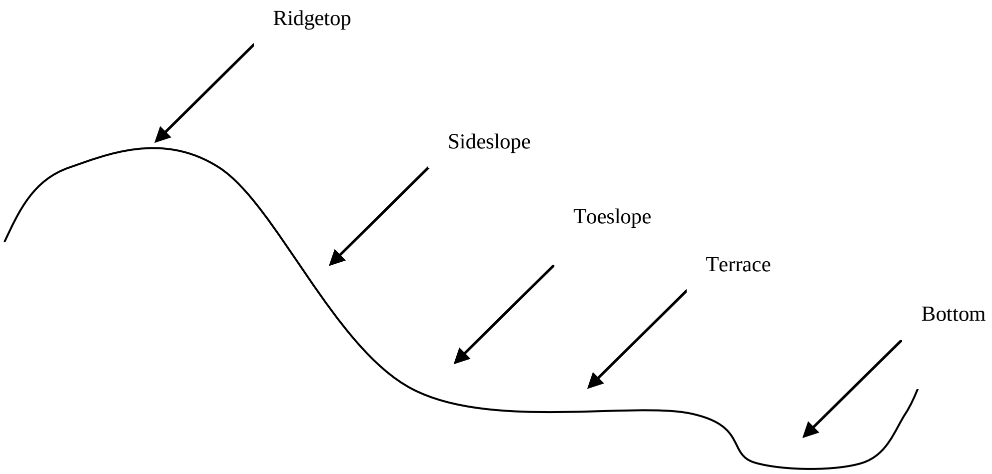
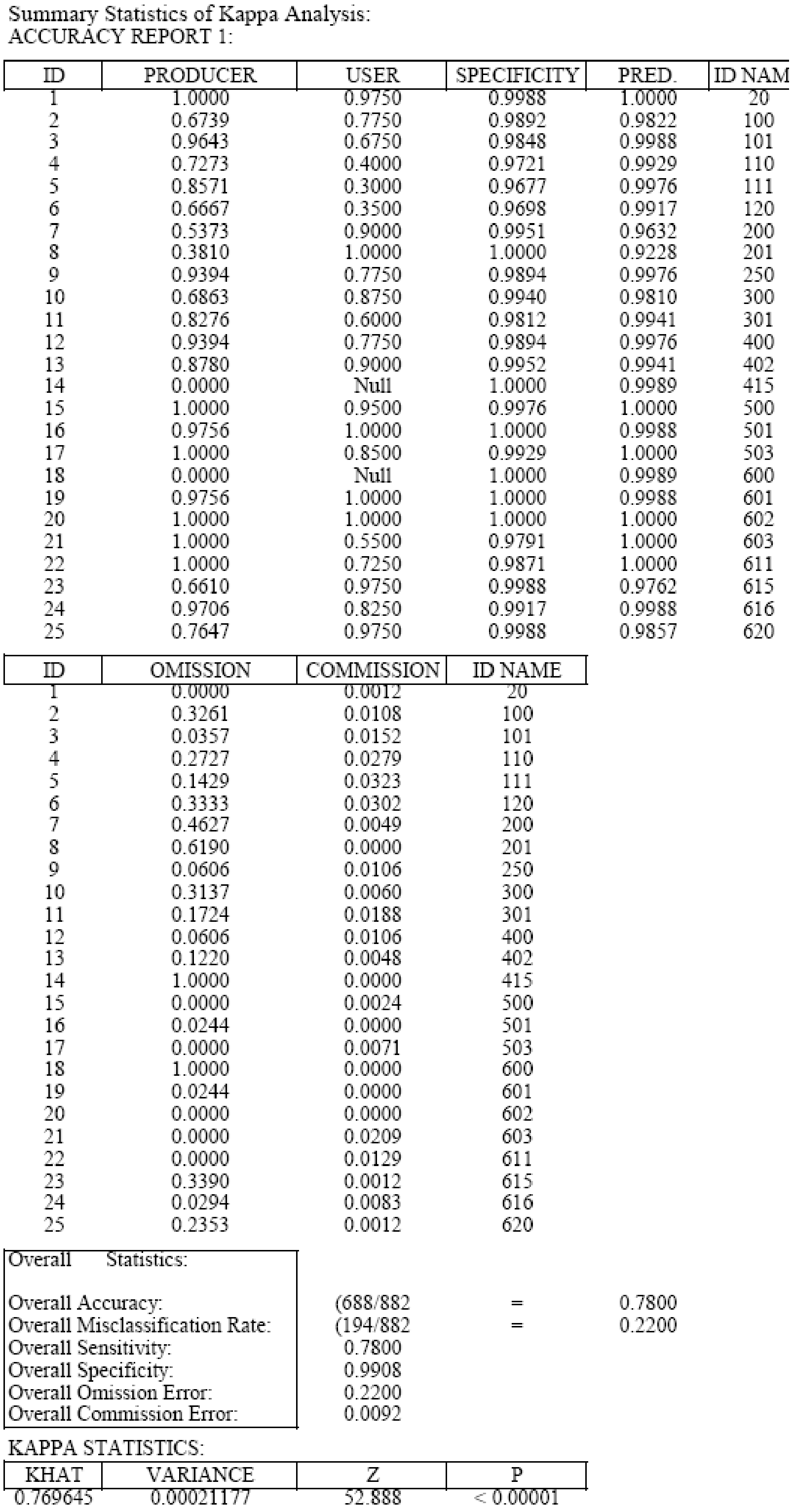
APPENDICES

Appendix A: Landscape Position Diagram



Appendix B: Accuracy Assessment Reports



Summary Statistics of Kappa Analysis:
ACCURACY REPORT 1:

ID	PRODUCER	USER	SPECIFICITY	PRED.	ID NAM
1	1.0000	0.9750	0.9988	1.0000	20
2	0.6739	0.7750	0.9892	0.9822	100
3	0.9643	0.6750	0.9848	0.9988	101
4	0.7273	0.4000	0.9721	0.9929	110
5	0.8571	0.3000	0.9677	0.9976	111
6	0.6667	0.3500	0.9698	0.9917	120
7	0.5373	0.9000	0.9951	0.9632	200
8	0.3810	1.0000	1.0000	0.9228	201
9	0.9394	0.7750	0.9894	0.9976	250
10	0.6863	0.8750	0.9940	0.9810	300
11	0.8276	0.6000	0.9812	0.9941	301
12	0.9394	0.7750	0.9894	0.9976	400
13	0.8780	0.9000	0.9952	0.9941	402
14	0.0000	Null	1.0000	0.9989	415
15	1.0000	0.9500	0.9976	1.0000	500
16	0.9756	1.0000	1.0000	0.9988	501
17	1.0000	0.8500	0.9929	1.0000	503
18	0.0000	Null	1.0000	0.9989	600
19	0.9756	1.0000	1.0000	0.9988	601
20	1.0000	1.0000	1.0000	1.0000	602
21	1.0000	0.5500	0.9791	1.0000	603
22	1.0000	0.7250	0.9871	1.0000	611
23	0.6610	0.9750	0.9988	0.9762	615
24	0.9706	0.8250	0.9917	0.9988	616
25	0.7647	0.9750	0.9988	0.9857	620

ID	OMISSION	COMMISSION	ID NAME
1	0.0000	0.0012	20
2	0.3261	0.0108	100
3	0.0357	0.0152	101
4	0.2727	0.0279	110
5	0.1429	0.0323	111
6	0.3333	0.0302	120
7	0.4627	0.0049	200
8	0.6190	0.0000	201
9	0.0606	0.0106	250
10	0.3137	0.0060	300
11	0.1724	0.0188	301
12	0.0606	0.0106	400
13	0.1220	0.0048	402
14	1.0000	0.0000	415
15	0.0000	0.0024	500
16	0.0244	0.0000	501
17	0.0000	0.0071	503
18	1.0000	0.0000	600
19	0.0244	0.0000	601
20	0.0000	0.0000	602
21	0.0000	0.0209	603
22	0.0000	0.0129	611
23	0.3390	0.0012	615
24	0.0294	0.0083	616
25	0.2353	0.0012	620

Overall Statistics:

Overall Accuracy:	(688/882	=	0.7800
Overall Misclassification Rate:	(194/882	=	0.2200
Overall Sensitivity:	0.7800		
Overall Specificity:	0.9908		
Overall Omission Error:	0.2200		
Overall Commission Error:	0.0092		

KAPPA STATISTICS:

KHAT	VARIANCE	Z	P
0.769645	0.00021177	52.888	< 0.00001

Summary Statistics of Kappa Analysis:
ACCURACY REPORT 2:

ID	PRODUCER	USER	SPECIFICITY	PRED.	ID NAM
1	1.0000	0.9750	0.9988	1.0000	20
2	0.6739	0.8158	0.9916	0.9822	100
3	0.9643	0.6750	0.9848	0.9988	101
4	0.7273	0.4000	0.9721	0.9929	110
5	0.8571	0.3000	0.9677	0.9976	111
6	0.6667	0.5000	0.9837	0.9918	120
7	0.5373	0.8780	0.9939	0.9631	200
8	0.5429	1.0000	1.0000	0.9418	201
9	0.9394	0.7750	0.9894	0.9976	250
10	0.6923	0.9000	0.9952	0.9810	300
11	0.8276	0.6316	0.9836	0.9941	301
12	0.9394	0.8611	0.9941	0.9976	400
13	0.8780	0.9000	0.9952	0.9941	402
14	1.0000	0.9500	0.9976	1.0000	500
15	0.9756	1.0000	1.0000	0.9988	501
16	1.0000	1.0000	1.0000	1.0000	503
17	0.9756	1.0000	1.0000	0.9988	601
18	1.0000	1.0000	1.0000	1.0000	602
19	1.0000	1.0000	1.0000	1.0000	603
20	1.0000	0.7250	0.9871	1.0000	611
21	0.9833	0.9672	0.9976	0.9988	615
22	0.9412	0.8205	0.9917	0.9976	616
23	0.8824	0.9783	0.9988	0.9928	620

ID	OMISSION	COMMISSION	ID NAME
1	0.0000	0.0012	20
2	0.3261	0.0084	100
3	0.0357	0.0152	101
4	0.2727	0.0279	110
5	0.1429	0.0323	111
6	0.3333	0.0163	120
7	0.4627	0.0061	200
8	0.4571	0.0000	201
9	0.0606	0.0106	250
10	0.3077	0.0048	300
11	0.1724	0.0164	301
12	0.0606	0.0059	400
13	0.1220	0.0048	402
14	0.0000	0.0024	500
15	0.0244	0.0000	501
16	0.0000	0.0000	503
17	0.0244	0.0000	601
18	0.0000	0.0000	602
19	0.0000	0.0000	603
20	0.0000	0.0129	611
21	0.0167	0.0024	615
22	0.0588	0.0083	616
23	0.1176	0.0012	620

Overall Statistics:			
Overall Accuracy:	(731/882)	=	0.8288
Overall Misclassification Rate:	(151/882)	=	0.1712
Overall Sensitivity:	0.8288		
Overall Specificity:	0.9922		
Overall Omission Error:	0.1712		
Overall Commission Error:	0.0078		

KAPPA STATISTICS:

KHAT	VARIANCE	Z	P
0.820139	0.00017667	61.702	< 0.00001

Summary Statistics of Kappa Analysis:
ACCURACY REPORT 3:

ID	PRODUCER	USER	SPECIFICITY	PRED.	ID NAM
1	1.0000	0.9750	0.9986	1.0000	20
2	0.7561	0.8158	0.9905	0.9864	100
3	0.9643	0.6750	0.9826	0.9986	101
4	0.0000	Null	1.0000	0.9948	110
5	0.0000	Null	1.0000	0.9974	111
6	0.0000	Null	1.0000	0.9948	120
7	0.7059	0.8780	0.9931	0.9795	200
8	0.6951	1.0000	1.0000	0.9651	201
9	1.0000	0.7750	0.9879	1.0000	250
10	0.8571	0.9000	0.9945	0.9918	300
11	0.8571	0.6316	0.9812	0.9946	301
12	0.9688	0.8611	0.9933	0.9986	400
13	0.9474	0.9000	0.9946	0.9973	402
14	1.0000	0.9500	0.9973	1.0000	500
15	0.9756	1.0000	1.0000	0.9986	501
16	1.0000	1.0000	1.0000	1.0000	503
17	0.9756	1.0000	1.0000	0.9986	601
18	1.0000	1.0000	1.0000	1.0000	602
19	1.0000	1.0000	1.0000	1.0000	603
20	1.0000	0.7250	0.9852	1.0000	611
21	0.9833	0.9672	0.9972	0.9986	615
22	0.9412	0.8205	0.9905	0.9973	616
23	0.8824	0.9783	0.9986	0.9918	620

ID	OMISSION	COMMISSION	ID NAME
1	0.0000	0.0014	20
2	0.2439	0.0095	100
3	0.0357	0.0174	101
4	1.0000	0.0000	110
5	1.0000	0.0000	111
6	1.0000	0.0000	120
7	0.2941	0.0069	200
8	0.3049	0.0000	201
9	0.0000	0.0121	250
10	0.1429	0.0055	300
11	0.1429	0.0188	301
12	0.0313	0.0067	400
13	0.0526	0.0054	402
14	0.0000	0.0027	500
15	0.0244	0.0000	501
16	0.0000	0.0000	503
17	0.0244	0.0000	601
18	0.0000	0.0000	602
19	0.0000	0.0000	603
20	0.0000	0.0148	611
21	0.0167	0.0028	615
22	0.0588	0.0095	616
23	0.1176	0.0014	620

Overall Statistics:

Overall Accuracy:	(689/774)	=	0.8902
Overall Misclassification Rate:	(85/774)	=	0.1098
Overall Sensitivity:	0.8902		
Overall Specificity:	0.9950		
Overall Omission Error:	0.1098		
Overall Commission Error:	0.0050		

KAPPA STATISTICS:

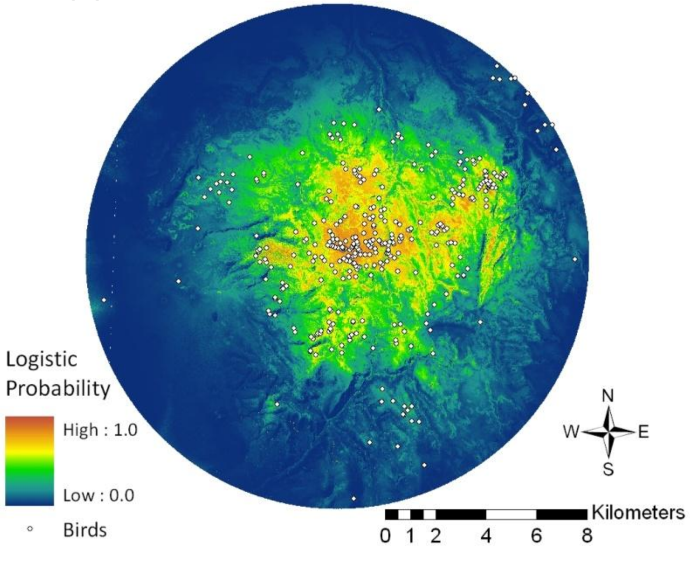
KHAT	VARIANCE	Z	P
0.883862	0.00014084	74.478	< 0.00001

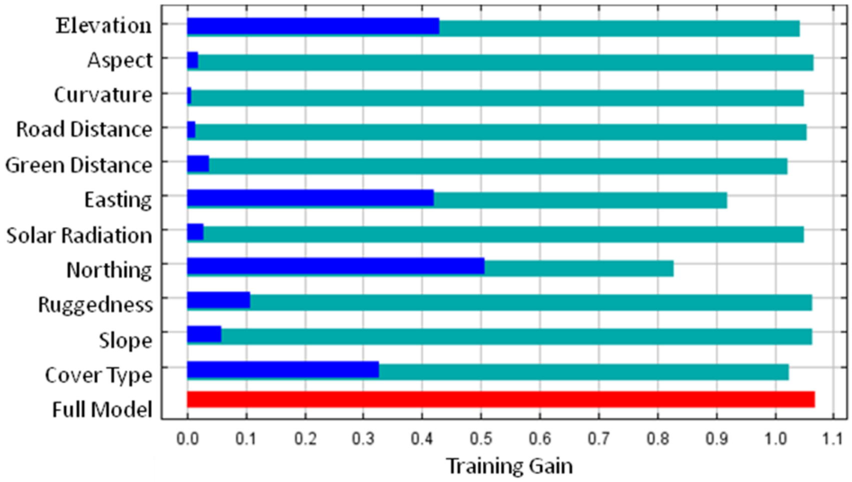
Appendix C: All Birds Combined Model

All Birds with Spatial Coordinates

All 480 Greater Sage-grouse UTM coordinates were used as sample points in this analysis. Overall model accuracy was 0.92 from the ROC analysis AUC. The distance to lek landscape predictor variable contributed 40.2 % to the Maxent model. Since 250 of the 480 UTM coordinates correspond to the breeding season, it is expected that the distance to lek is a strong predictor. As such, we removed the distance to lek variable. After omitting the distance to lek variable, the overall model accuracy for all seasons was 0.903 from the ROC analysis AUC. The average sample likelihood is 2.9 times higher than a random background pixel since the full model's training gain is 1.07 (below).

Predictor Variable	**Contribution to Maxent Model**
Northing	40.6
Easting	26.9
Elevation	12.6
Cover Type	11.6
Green Distance	3.4
Solar Radiation	1.7
Curvature	1.3
Ruggedness	1.2
Road Distance	0.5
Slope	0.2
Aspect	0.1
Model	100.0

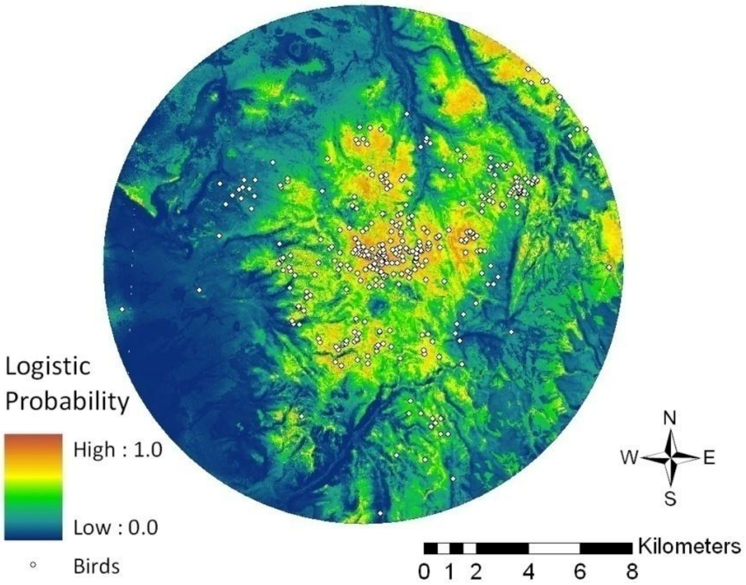


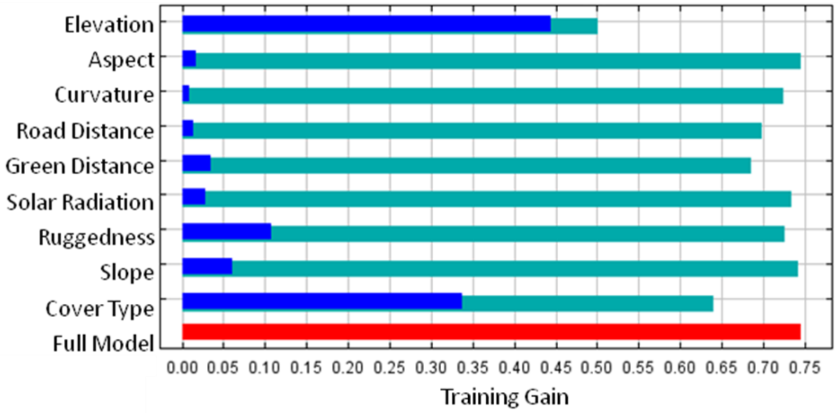


All Birds without Spatial predictor variables

Overall model accuracy without the spatial predictor variables was 0.857 from the ROC analysis AUC. The full model's training gain is 0.75, therefore the average sample likelihood is 2.1 times higher than a random background pixel.

Predictor Variable	**Contribution to Maxent**
Elevation	53.1
Cover Type	25.7
Ruggedness	7.9
Green Distance	5.0
Road Distance	2.8
Solar Radiation	2.4
Curvature	2.1
Slope	1.0
Aspect	0.0
Model	100





Caution must be used when interpreting the results for all birds combined model since the breeding season and summering season over-represented the winter season with 250, 207, and 23 UTM coordinates representing each season respectively. As such, these results give the strongest weight to the breeding season, followed by the summer season and finally the winter season with very little representation. Analyzing the bird use on an annual basis may not accurately describe how birds are selecting habitat. Rather, these results may better describe how they are selecting habitat as they are transitioning between the breeding and summer seasonal use areas. As such, we recommend that management prescriptions be based on seasonal habitat requirements.