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Factors Influencing the Ecology of Greater Sage-Grouse Inhabiting the Bear Lake Plateau and Valley, Idaho and Utah

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FACTORS INFLUENCING THE ECOLOGY OF GREATER SAGE-GROUSE INHABITING THE BEAR LAKE PLATEAU AND VALLEY, IDAHO AND UTAH

by

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ABSTRACT

Factors Influencing the Ecology of Greater Sage-Grouse Inhabiting

the Bear Lake Plateau and Valley, Idaho and Utah

by

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Greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) occupy an estimated 56% of the potential pre-European settlement range. Prior to this study, little was known about the seasonal movements and habitat-use patterns of sage-grouse that inhabit the Idaho-Utah Bear Lake Plateau and Valley (BLPV) relative to landscapes and existing land uses. From 2010–2012, I captured, radio-marked, and monitored 153 sage-grouse (females and males) on the BLPV study area to determine factors affecting vital rates, seasonal movement, and habitat-use. Average annual survival rates of sage-grouse inhabiting the BLPV were 52.8% (±3.4%), with average female survival of 57.4% (±13.7%) and average male survival of 49.7% (±11.4%). Survival was best modeled by seasonal variation, with highest survival rates in the fall. Nest survival was low in comparison to range-wide estimates (15–86%), with average nest survival rates 23.2% (95% CL=17.6–28.8%). Brood success varied between 2011 and 2012, with higher brood survival in 2012. Some individuals were migratory, with close to half of radio-marked sage-grouse making seasonal movements >10 km. Average annual home range for BLPV radio-marked sage-grouse was 100.8 km^2. Radio-marked sage-grouse used seasonal habitat in Utah, Idaho and Wyoming, suggesting that a tri-state management plan could benefit population conservation.

Habitat selection was modeled using MaxEnt. MaxEnt software models species occurrence using presence-only data and geographic information systems environmental layers. Presence-only data are subject to sampling bias and cannot be used to determine abundance, though MaxEnt uses post-transformation of the raw output in an attempt to predict species prevalence across the landscape. Ten landscape-extent environmental and anthropological habitat variables were included in models to predict core use and connection areas. Models produced using these variables and BLPV sage-grouse locations ranked good to excellent fits (AUC >0. 81). The variables with the highest weight for predicting sage-grouse prevalence were distance to major road, distance to habitat edge, distance to tall vertical structure, and vegetation cover type. The habitat selection model was projected to an expanded area to identify potential habitat surrounding the BLPV. Coupling state-defined habitat with MaxEnt habitat models could provide baseline data to create and implement a tri-state management plan.

(202 pages)

PUBLIC ABSTRACT

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Greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) are a sagebrush obligate species and as such an indicator of sagebrush (*Artemisia* spp.) habitat quality and quantity. Sage-grouse populations have declined across western North America. This decline has been attributed to habitat loss and degradation of the sagebrush ecosystem. To determine factors that may cause localized declines in sage-grouse populations, managers may need site-specific information on the ecology and habitat use patterns of meta-populations. This information is currently lacking for sage-grouse populations that inhabit the Bear Lake Plateau and Valley (BLPV), encompassing parts of Idaho, Utah and Wyoming. I captured, radio-marked and monitored 153 sage-grouse in the BLPV from 2010–2012 to assess nest success, brood survival, mortality factors, and habitat use. Reproductive success was lower than range-wide averages, with especially low success in 2011. Nesting and brood rearing both showed higher success rates in 2012. Survival was very similar to estimates found elsewhere. Females had higher survival rates than males, and yearlings had higher survival probability than adults. Sage-grouse mortality was highest in summer and spring, and lowest in fall. Individual sage-grouse completed large scale movements, often using habitats in Idaho, Utah, and Wyoming. Important factors in sage-grouse habitat selection included distance to major road, distance to habitat edge, distance to vertical structure (i.e., communication towers, wind turbines, and transmission lines), and vegetation cover types. Sage-grouse tended to avoid major road and vertical structures (i.e., communication towers, wind turbines, and transmission lines). They also selected habitat further away from habitat edge. Vegetation types preferred by sage-grouse included shrubland habitats, wet meadows, and grassland. MaxEnt models did not place highest importance on sagebrush habitats, which are critical for sage-grouse presence. This could have occurred because the vegetation layers used in the model did not assess habitat quality. Models produced using the ten landscape variables and BLPV sage-grouse locations ranked good to excellent fits. State-defined habitat covered a larger extent than MaxEnt predicted habitat. MaxEnt predicted habitat areas may be used to further refine state identified core areas to assist in prioritization of conservation efforts to protect the BLPV sage-grouse population.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

The greater sage-grouse (*Centrocercus urophasianus*; sage-grouse), the largest grouse species in North America, is a sagebrush (*Artemisia* spp.) obligate, that requires large expanses of sagebrush habitat to complete its annual life cycle (Dalke et al. 1963, Connelly et al. 1988, Connelly et al. 2000b, Leonard et al. 2000). Schroeder et al. (2004) estimated that sage-grouse currently occupy about 668,412 km^2, <60% of the likely historic range in western North America, which includes 11 states and 2 Canadian Provinces.

Sage-grouse were designated as a candidate species in March 2010 by the U.S. Fish and Wildlife Service (USFWS) for protection under the Endangered Species Act (ESA) of 1973 (USFWS 2010). In the 12–month finding, the USFWS determined that sage-grouse range-wide warranted protection under the ESA, but their listing was precluded because of higher conservation priorities. Declines in sage-grouse populations have mainly been attributed to habitat loss and degradation of the sagebrush-steppe ecosystem (Braun 1998, Connelly et al. 2004, Knick and Connelly 2011). Sage-grouse population trends largely reflect variations in annual and long-term productivity, survival, and recruitment (Crawford et al. 2004, Connelly et al. 2011a, Taylor et al. 2012).

SAGE-GROUSE ECOLOGY AND SEASONAL HABITAT REQUIREMENTS

Seasonal Migration

Sage-grouse populations may use up to three distinct ranges as breeding, summer, and winter habitats. Individual sage-grouse may engage in long distance movements throughout their life stages as they move between seasonal ranges (Connelly et al. 1988, Bradbury et al. 1989, Jensen 2006, Fedy et al. 2012, Reinhart et al. 2013, Smith 2013). Sage-grouse migrations have been defined as movements greater than 10 km between distinct ranges (Connelly et al. 2000b, Fedy et al. 2012). Some sage-grouse have been known to migrate over 161 kilometers (Patterson 1952, Smith 2013).

Connelly et al. (2000b) classified sage-grouse populations based on reported movements as: 1) non-migratory; 2) one-stage migratory with two distinct ranges; and 3) two-stage migratory with three distinct ranges. Migration differences among sage-grouse populations may correspond with differences in habitat quality, distribution on the landscape, and changes in weather (Dalke et al. 1963, Berry and Eng 1985, Fedy et al. 2012). Within populations, migration distance may also vary by age and sex (Connelly et al. 1988). Migration information is needed to determine meta-population boundaries, identify seasonal habitats, and define how birds may respond to changes in land use (Connelly et al. 1988). This is important because relationships may exist between movement patterns, survival, and productivity (Beck et al. 2006).

Breeding Biology

Sage-grouse are a lekking species. Males typically gather seasonally on a lek to display and attract females for breeding (Scott 1942, Patterson 1952). The highest male abundance on leks occurs from early to late April (Eng 1963) with peak female attendance occurring from late-March to mid-April depending on weather conditions (Eng 1963, Schroeder 1997, Connelly et al. 2011a). Leks tend to be in the same location every year (Scott 1942, Patterson 1952), and are usually located in areas with sparse vegetation (Patterson 1952, Schroeder et al. 1999) that are within or immediately adjacent to good nesting habitat (Bradbury et al. 1989, Connelly et al. 2000b).

Nesting Biology

Annual variation in the likelihood of a sage-grouse hen initiating a nest ranges from 63–100% and is dependent on location and age (Connelly et al. 1993, Connelly et al. 2011a). Females tend to lay two eggs every three days, and incubation occurs after a complete clutch is laid (Patterson 1952). Clutch size varies between 6.3 and 9.1 eggs, with renests tending to be smaller than initial nests (Schroeder et al. 1999, Connelly et al. 2011a). Incubation typically lasts about 27 days after egg laying is complete (Schroeder et al. 1999). Nest success varies widely depending on the population. In a review of the literature, nest success rates were found to vary between 15–86% depending on hen age, habitat condition, and predator community (Schroeder et al. 1999, Connelly et al. 2011a). Nest success has been identified as a major parameter affecting population trends (Crawford et al. 2004, Taylor et al. 2012).

Most sage-grouse nests are located under sagebrush, though some female sage-grouse use other vegetation types as nest cover (Patterson 1952, Connelly et al. 1993, Schroeder et al. 1999, Crawford et al. 2004). Females often exhibit site fidelity to previous nesting locations and will nest within several kilometers from the previous year’s nest, and often within a few hundred meters (Berry and Eng 1985, Fischer et al. 1993, Kaczor 2008). Nests are often located relatively close to a lek often within 5 km, but nest placement may depend more on other habitat components than distance to the lek (Wakkinen et al. 1992, Connelly et al. 2011b).

Brood-rearing Biology

Broods prefer a mosaic of habitat types (Schroeder et al. 1999). Early brood rearing habitat is typically located relatively close to the nest because of limited mobility of chicks (Connelly et al. 2011b). Because broods rely heavily on arthropods and succulent forbs (Dahlgren 2009, Gregg and Crawford 2009, Harju et al. 2013, Robinson and Messmer 2013), it is important that early brood-rearing habitat readily supply these necessary diet components. Additionally, brood habitat contains open space, as sage-grouse chicks have limited mobility before flight (Connelly et al. 2003). Young are able to make short flights within one to two weeks of hatching (Crawford et al. 2004, Gregg and Crawford 2009, Connelly et al. 2011a).

Survival rates of chicks and juveniles vary temporally and spatially. Some factors affecting chick and juvenile survival are habitat quality, food availability, predation, and weather (Crawford et al. 2004, Gregg and Crawford 2009, Connelly et al. 2011b). Chick survival is measured from hatching to brood breakup (about 10 weeks) and juvenile survival is measured from brood breakup (about 10 weeks old) to recruitment to the breeding population in the following spring. Gregg and Crawford (2009) estimated survival of chicks from hatching to 28 days as 0.39. In Utah, Dahlgren (2009) estimated chick survival rates of 0.50 from hatching to 42 days, and Guttery et al. (2013) estimated a chick survival probability of 0.47. Holloran (1999) combined chick and juvenile survival and determined 60% of individuals survive from hatching to breeding age. Beck et al. (2006) estimated fall and winter juvenile survival between 64–86%. Bunnell (2000) reported juvenile survival of 7% in his Utah study area.

Fall Biology

Sage-grouse may form flocks in autumn that contain both sexes and all age groups (Patterson 1952, Dalke et al. 1963). During autumn, flocks may use transitional habitats located between summer and winter range (Connelly et al. 1988, Connelly et al. 2000b). Connelly et al. (2011b), in a review of published literature, concluded that diets on transitional ranges change from forbs and arthropods to predominantly sagebrush.

Winter Biology

Sage-grouse flocks in wintering grounds often are segregated by sex (Patterson 1952). Dalke et al. (1963) reported that flocks increased in size as weather conditions deteriorated. Snow depth often determines the habitat that flocks are using (Patterson 1952, Dalke et al. 1963). Sage-grouse depend entirely on sagebrush for winter habitat. Sagebrush is the major winter food source (Patterson 1952, Dalke et al. 1963, Caudill 2011), although sage-grouse are selective about which sagebrush they feed on (Beck 1977, Remington and Braun 1985, Thacker 2010, Frye et al. 2013). Sagebrush leaves selected in winter are characterized by high nutrient and low plant secondary metabolites (Frye et al. 2013, Forbey et al. 2013). Sagebrush is also important as shelter for sage-grouse in the winter (Patterson 1952, Beck 1977), although selection is more highly influenced by forage availability and quality than cover potential (Remington and Braun 1985, Frye et al. 2013). As snow melts sage-grouse return to their strutting grounds (Dalke et al. 1963).

Survival

Many factors influence sage-grouse survival rates. Survival rates from hatching to recruitment into the breeding population (see above) are often measured separately from survival rates of breeding-age individuals. Published survival estimates for breeding-age individuals range from 30–78% (Connelly et al. 2011a). Most mortality is a result of predation (Connelly et al. 2011a). Predators of sage-grouse include mammals, (e.g., coyotes, foxes, and badgers), raptors, and corvids (Hagen 2011). Survival rates are often partitioned by age class, sex, and season. Reported estimates of survival for chicks from hatching to independence ranges from 10–60% (Holloran 1999, Crawford et al. 2004). Annual range-wide survival estimates for breeding-age females and males range from 37–78% and 30–60%, respectively (Holloran 1999, Bunnell 2000, Wik 2002, Connelly et al. 2011a), and higher survival in females could be due to sexual dimorphism (Schroeder et al. 1999). Yearling survival rates tend to be higher than adults (Connelly et al. 2011a), potentially due to inconspicuous behavior during the first breeding season (Crawford et al. 2004). Sage-grouse are most vulnerable during the breeding season, and survival tends to be lowest during spring, summer, and fall (Connelly et al. 2000a, Wik 2002, Connelly et al. 2011a, Duvuvuei 2013). Sage-grouse tend to have high over winter survival (Connelly et al. 2000a, Wik 2002, Connelly et al. 2011a).

POPULATION AND SPATIAL INTERACTION

Defining Population Units

Defining sage-grouse populations boundaries can be challenging, as sage-grouse do not fit the typical paradigm for upland game birds (Connelly et al. 2011a). Population delineation requires information on demography, vital rates, genetics, habitat availability, corridors and connectivity, and seasonal movement patterns (Garton 2002). Sage-grouse populations may be defined on a temporal and spatial basis (Connelly et al. 1988).

Connelly et al. (2003) defined a breeding population as a group of sage-grouse associated with one or more occupied leks in the same geographic area separated from other leks by >20 km. Connelly et al. (2004) defined breeding population as concentrated areas of leks separated from the nearest concentration of leks by at least 30 km or separated by unsuitable habitat such as mountain ranges, desert, or large areas of cropland. It is important to assess the delineation of a population using the appropriate measurable demographic units, because landscape properties can determine the distance of separation between populations (Merriam 1998, Bissonette 2003). Sage-grouse populations can be connected by individuals moving between concentrations of leks or using habitat patches to travel through unsuitable habitat to distant populations (Knick and Hanser 2011).

Landscape Spatial Pattern Influence on Sage-grouse Populations

The spatial patterns of sage-grouse on sagebrush landscapes can provide insights for managing populations and maintaining population viability (Knick and Hanser 2011, Burnett 2013). Sage-grouse respond to sagebrush landscape features, such as quantity, composition, and configuration, and these can be used to identify core areas (Wisdom et al. 2002, Doherty et al. 2011). Defining core areas of biological value represents a proactive attempt to identify conservation targets for maintaining viable and connected populations (Doherty et al. 2011). Translating landscape structure into species response has proven elusive (Milne 1992, Wiens and Milne 1989, Wiens 2002, Calabrese and

Fagan 2004) and relies on our ability to understand how a species perceives its environment (Wiens et al. 1993, With et al. 1997, Baguette and Van Dyck 2007). Landscape metrics describing physical attributes of habitats and important resources can be integrated into spatial data layers using geographical information system technology (Calabrese and Fagan 2004, Taylor et al. 2006). Changes in the land cover mosaic can influence the spatial and temporal dynamics of a natural system. Taking spatial and temporal landscape dynamics into consideration during population assessment can help guide management decisions (Shugart 1998). Additionally, it is important to assess landscape metrics over broad scales, because wildlife populations do not perceive political boundaries (Stiver et al. 2006).

Connectivity

Structural connectivity in landscapes is based on metrics describing habitat availability and arrangement of resources (Li and Reynolds 1994, Turner et al. 2001). Connectivity analysis provides information on how spatial pattern of a species' habitat influence individuals and populations (Taylor et al. 1993). Analyzing connectivity requires information on landscape pattern, resource selection, and population characteristics to identify core areas or locations that link core areas, and pathways important for conserving a species (Crooks and Sanjanyan 2006, Noss and Daly 2006, Smith 2013). Modeling functional relationships of sage-grouse to sagebrush habitats is challenging because important habitat characteristics may only detected at spatial domains dictated by the spatial and temporal resolutions and extents over which the characteristics can be effectively measured (Aldridge and Boyce 2007, Aldridge et al.

2008). Fine-scale attributes of sagebrush habitats may influence within-season movements and vital rates, including survival and productivity (Connelly et al. 2000b, Crawford et al. 2004). Population dynamics of sage-grouse within core components similarly may depend on the amount and quality of sagebrush or level of disturbance (Knick and Hanser 2011). The impact of disturbance on sage-grouse populations depends on extent, frequency, and impact of habitat (Knick and Hanser 2011). Sage-grouse moving between seasonal ranges may be more sensitive to the broader-scale matrix and traverse areas that do not contain suitable habitats (Connelly et al. 1988, Leonard et al. 2000).

SAGEBRUSH ECOLOGY AND CHANGE

Habitat Classifications

The sagebrush biome extends across much of the western United States (Connelly et al. 2004). Current sage-grouse habitat has been divided into sage-grouse management zones based on similarities in climate, elevation, topography, geology, soils, and floristics (West 1983, Miller and Eddleman 2001). Sagebrush steppe vegetation types are typically structured by four layers: 1) shrubs, 0.3–1.0 m tall, 2) forbs and tuft grasses 1.2–0.6 m tall, 3) low-growing grasses and forbs <.02 m tall, and 4) biological soil crusts (Miller et al. 2011). Species composition in sagebrush ecosystems is influenced by climate, soil, topography, and disturbance history (Connelly et al. 2004, Miller et al. 2011). The Intermountain West is dominated by the *A. tridentata* group of big sagebrush (*A. tridentata*) species, and the low sagebrush (*A. arbuscula* and *A. nova*) species (Connelly et al. 2004).

Landscape Change

Sagebrush ecosystems have been altered in patterns, processes, and components since Euro-American settlement in the late 1800s (West and Young 2000, Bunting et al. 2003). The dominant factors that influence sagebrush habitats across their range include: invasive species, wildfire, global climate change, land use changes, wild ungulate browsing, and energy development (Connelly et al. 2004, Miller et al. 2011). Land use has modified sagebrush habitat due to land surface occupied by anthropogenic features and large-scale conversion of sagebrush land cover to agricultural land, rural development, and energy developments (Leu and Hanser 2011). In areas of sagebrush alteration, specific site changes are most often studied, though large scale factors are also important (Holloran and Anderson 2005, Aldridge et al. 2008, Doherty et al. 2008, Connelly et al. 2011b).

There is strong evidence that wildfire regimes have changed throughout the Western United States (Miller and Eddleman 2001, Connelly et al. 2004, Baker 2011). The area of habitat that burns varies widely each year. Fire regimes are determined by climate factors, ignition sources, season, fuel load, and vegetation patterns (Connelly et al. 2004). High-severity fires are common in sage-brush habitat and this fire type can remove sagebrush cover across landscapes (Baker 2011).

The presence of invasive species has increased as a notable threat to sagebrush habitat (Connelly et al. 2004). Invasive species can affect sagebrush ecosystems by changing ecological function or community structure (Miller et al. 2011). A large number of invasive plants influence sagebrush ecosystems throughout the west (Miller et al. 2011). Exotic annual grasses such as cheatgrass (*Bromus tectorum*) and medusahead

(*Taeniatherum caput-medusae*) pose a major threat to sagebrush habitats. A moderate to high probability of presence by cheatgrass was predicted for large portions of the Intermountain West and Great Basin (Miller et al. 2011). Woodland species (*Juniperus spp.*, *Pinus spp.*) expansion also may impact sagebrush ecosystems (Connelly et al. 2004). Woodland species can expand into sagebrush communities at higher elevations (Connelly et al. 2004), which causes a decline of sagebrush cover (Miller et al. 2011).

Moisture levels vary seasonally and annually, and this affects vegetation structure, composition, and abundance (Miller et al. 2011). Global climate change models predict severe and variable weather events, higher temperatures, and drier summer soil conditions (Schneider 1993, Connelly et al. 2004). Climate change may affect long term trends in temperature, precipitation, and atmospheric characteristics in sagebrush habitats (Miller et al. 2011). The change in precipitation levels may impact sagebrush habitats and could possibly shift competition between plant species.

Human uses of sagebrush ecosystems have had impacts on the habitat. Agricultural conversion, livestock grazing, habitat treatment, and urban development are all activities that have affected sagebrush habitat (Knick et al. 2003). An estimated 10% of sagebrush steppe has been converted to agriculture, causing habitat loss and fragmentation (Connelly et al. 2004). A large portion of the sagebrush ecosystems are managed for livestock grazing (Boyd et al. 2014). Heavy livestock grazing can reduce grass and forb cover, reduce species diversity, and cause changes in water and nutrient cycling (Connelly et al. 2004, Boyd et al. 2014). Sagebrush landscapes have been manipulated by means of prescribed fire, herbicides, and mechanical and biological treatment (Knick et al. 2003). These manipulations can be performed to improve forage production, reduce exotic species or woody cover, or reduce fire hazards (Knick et al. 2003, Connelly et al. 2004). Human populations have grown and expanded in the sagebrush biome since 1900. Development of urban areas removed sagebrush habitat (Connelly et al. 2004), and the increase of roads also removed and fragmented sagebrush ecosystems (Lyon and Anderson 2003).

Energy development threatens to affect the sagebrush biomes as areas currently under development are located within large areas of intact sagebrush ecosystems. Development could affect habitat quality by introducing non-native species and reducing the number and cover of native species (Bergquist et al. 2007). Infrastructure associated with energy development may also affect sage-grouse habitats, because roads and power lines fragment intact habitat (Knick et al. 2003, Lyon and Anderson 2003, Holloran 2005). Disturbance from traffic on the roads, and noise and activity associated with energy development has been documented to disturb sage-grouse activity, and can cause avoidance of development areas (Lyon and Anderson 2003, Holloran 2005). Energy development threatens to occur in sagebrush of high biological value. Of these areas, Doherty et al. (2011) identified 44% as being at risk.

SAGE-GROUSE CONSERVATION THREATS

Habitat Loss

Sage-grouse require large expanses of sagebrush to meet all of their seasonal habitat requirements (Connelly et al. 1988, Hagen 1999, Connelly et al. 2000b). Habitat loss could affect seasonal ranges and alter movements. Extensive loss and fragmentation of sagebrush habitats has contributed to reported range-wide declines (Connelly and

Braun 1997, Connelly et al. 2004, Crawford et al. 2004). Range reduction, fragmentation, and isolation may reduce connectivity between populations leading to loss of genetic diversity and population loss due to natural disaster (Reese and Connelly 1997, Benedict et al. 2003, Oyler-McCance et al. 2005, Aldridge et al. 2008).

The structure of landscape habitat may also affect an animals' ability to move across the landscape (Smith 2013). Knick and Hanser (2011) reported important environmental predictors for lek persistence and connectivity were proportion of sagebrush and burned area within a 54 km radius of the lek, and the level of human footprint, the cumulative effects of human actions on the landscape, within 5 km of a lek. In a model of historical and current populations, probability of sage-grouse persistence was greatest in areas containing more than 30% sagebrush within a 30–km radius of a given point and with a human density less than 4 km^2 (Aldridge et al. 2008). Thus human activity such as urbanization and recreation could potentially further fragment sage-grouse habitats and disturb breeding behavior (Bureau of Land Management 2003).

Inadequacy of Existing Regulatory Mechanisms

The USFWS (2010) identified the lack of effective regulatory mechanisms to protect the species across jurisdictional boundaries as a major range-wide sage-grouse conservation threat. Stiver et al. (2006) defined seven range-wide management zones based on floristic provinces, not political boundaries. In the U.S., sage-grouse are considered a resident game bird, and each state has the authority to manage the species (Connelly et al. 2004, Stiver 2011). Because each state manages sage-grouse individually, implementation of a range-wide conservation strategy is problematic (Stiver et al. 2006). A bi-state plan was prepared to address conservation issues of sage-grouse that inhabit the California /Nevada border (Stiver et al. 2006), but no plan has been developed to address the other possible interstate populations.

For sage-grouse that span more than one jurisdictional boundary, management requires coordinated plans among different agencies, land owners, and the public (Hemker and Braun 2001). Unidentified funding strategies and limited funds make range-wide conservation and multi-jurisdictional population management difficult (Stiver et al. 2006). Local working groups have been organized to develop conservation plans for sage-grouse to prevent their listing (Stiver 2011). Interdepartmental work has been started to begin conservation efforts to improve sage-grouse populations. The Western Association of Fish and Wildlife Agencies (WAFWA) developed the Greater Sage-grouse Comprehensive Conservation Strategy to help states prioritize and guide conservation regional actions to reverse the decline of the species (Stiver et al. 2006).

SAGE-GROUSE IN IDAHO, UTAH, AND WYOMING

Idaho

In Idaho, sage-grouse habitat has declined by approximately 53% throughout the state from historical estimates (Idaho Sage-grouse Advisory Committee [ISAC] 2006). Idaho's sage-grouse population estimates have declined by 40–60% from 1960 to the present (Connelly and Braun 1997, Connelly et al. 2004). There are 13 sage-grouse planning areas throughout the state (ISAC 2006). Twelve local working groups (LWGs) were formed to assist with sage-grouse management efforts throughout the state, and thus far ten conservation plans have been completed with one still in progress (ISAC 2011, IDFG 2013). A standard hunting season is permitted for populations where 3–year averages of lek counts exceed 150% of the 1996–2000 average, and a restrictive season is allowed in areas where lek counts are between 50% and 150% of the 1996–2000 average. Seasons are closed in areas where the 3–year average of lek counts are less than 50% of the 1996–2000 average counts, there are less than 100 males observed, or where lek counts are not conducted (ISAC 2006). Sage-grouse hunting is currently allowed in 23 counties, though with restricted harvest limits and a required permit (IDFG 2011).

Utah

Sage-grouse habitat has been reduced by an estimated 41% of the historical range (Beck et al. 2003). Sage-grouse are currently found in 26 counties, and were historically found in 29 counties. They are classified as a "species of special concern" by the Utah Division of Wildlife Resources (UDWR). There are currently 10 sage-grouse LWGs that have completed conservation plans (www.utahcbcp.org). Sage-grouse hunting in Utah is permitted when populations meet minimum criteria established by the UDWR, i.e., when breeding populations exceed 500 birds for more than three years. Harvest has been limited to permit hunting, and harvest is allowed in only four counties (UDWR 2009).

Wyoming

Sage-grouse habitat has declined by about 44% in Wyoming (Wyoming Sage-grouse Working Group (WSGWG) 2003, Miller et al. 2011). Long term declines in population estimates are between 33–48% for the state (Connelly and Braun 1997, Connelly et al. 2004). Sage-grouse are currently and historically found in some part of all 23 Wyoming counties (WGFD 2013). The statewide Sage-grouse Conservation plan established 11 local planning areas for the state. Eight LWGs were created in the state, all of which have finished Conservation Plans (USGS 2012). Hunting is currently allowed in two areas of the state (including some area of 12 counties), and is closed in two areas of the state (including some areas in 14 counties) (WGFD 2011).

Bear Lake Valley and Plateau

Sage-grouse populations inhabiting the BLPV which includes portions of Idaho, Wyoming, and Utah are included in the Wyoming Basin Sage-grouse Management Zone (Stiver et al. 2006). Populations of sage-grouse at the edge of a population zone often depend on dispersal from connecting leks to sustain the genetic variation of these populations (Knick and Hanser 2011). Because sage-grouse are capable of migrating considerable distances (Patterson 1952, Connelly et al. 1988), sage-grouse inhabiting the BLPV are believed to use seasonal habitats in three states. Pilot research conducted in 2010 supported this belief, but the magnitude and importance of the interchange is uncertain (C. J. Cardinal, Utah State University, unpublished data). Obtaining this information could be paramount to the conservation of the Bear Lake Plateau and Valley sage-grouse population if the seasonal movements include multiple states where they are subjected to the jurisdiction of different state laws and management plans (Connelly et al. 2004). Little is known about the ecology, seasonal movements, and habitat-use patterns of the sage-grouse populations that inhabit the BLPV relative to existing or potential land uses for application to management. Migration information is important to delineate population dynamics (e.g., a meta-population, source-sink, and other spatial complications), identify essential habitats, and determine the potential effects of land-use on species conservation.

RESEARCH PURPOSE AND OBJECTIVES

The purpose of this research is to describe the ecology, seasonal movements, and habitat-use patterns of sage-grouse that inhabit the BLPV relative to existing landscapes and land-uses. Because the BLPV is subject to both natural and anthropogenic barriers and fragmentation, defining population vital rates, seasonal movements, and habitat-use relative to land use and jurisdictional boundaries of this population will be important as the basis for management cooperation among Idaho, Utah, and Wyoming. Sage-grouse land use research can help define the core use areas of important BLPV seasonal and temporal habitats. This could be important to prioritize future conservation efforts.

Chapter 2 assesses the vital rates of sage-grouse that inhabit the BLPV. This chapter models differences in survival related to sex, age class, and land-use patterns. It also assesses the reproductive rates of this population.

Chapter 3 presents BLPV sage-grouse seasonal habitat-use patterns. This chapter documents how natural and anthropogenic land-use patterns and activities may contribute to habitat loss by fragmentation of BLPV sage-grouse habitats. Habitat selection was modeled using Maximum Entropy and a variety of environmental and anthropogenic variables.

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CHAPTER 2

ECOLOGY OF THE BEAR LAKE GREATER SAGE-GROUSE POPULATION INHABITING THE NORTHWESTERN WYOMING BASIN

ABSTRACT

Although range-wide greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) populations have declined, factors influencing the ecology of sage-grouse vary by population and geography. Declines have been largely attributed to habitat loss and fragmentation, but specific factors limiting local sage-grouse populations may be site-dependent. Little is known about the ecology, seasonal movements, and habitat-use patterns of the sage-grouse populations that inhabit the Bear Lake Plateau and Valley (BLPV) in the Wyoming Basin for application to their management and conservation. Sage-grouse monitoring through lek counts in this area has been conducted by state agencies since the 1960s. From 2010–2012, I captured, radio-marked, and monitored 153 sage-grouse (59 females and 94 males) throughout the BLPV study area which encompassed parts of Bear Lake County, Idaho, and Rich County, Utah to determine the factors affecting vital rates, seasonal movement, and habitat-use. No sage-grouse were captured in Wyoming, but radio-marked individuals were documented to move from Idaho and Utah into Wyoming. The average annual survival rate of sage-grouse inhabiting the BLPV was 52.8% (±3.4%) which is comparable to range-wide population estimates. Survival varied between seasons with highest survival rates in the fall and highest mortality in summer. Sage-grouse hen nest success on the BLPV was low in comparison to range-wide estimates, with average nest survival rates of 36 days from the

beginning of egg laying to hatching was 23.2% (95% CL=17.6–28.8%). Brood success varied between 2011 and 2012, with higher brood survival observed in 2012. Many individuals were migratory, with half the monitored sage-grouse engaging in seasonal movements >10 km. Annual home ranges for sage-grouse on the BLPV were within the range of previously reported sage-grouse range-wide, with average annual KDE home ranges sizes of 100.8 km^2. This sage-grouse population used seasonal habitat in three states, suggesting that a tri-state management plan will be needed to conserve this population.

INTRODUCTION

Greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) populations have declined throughout the western United States. In March 2010, the species was designated by the U.S. Fish and Wildlife Service (USFWS) as a candidate for protection under the Endangered Species Act (USFWS 2010). Sage-grouse are a sagebrush (*Artemisia* spp.) obligate species that currently occupy about 668,412 km^2 (Schroeder et al. 2004). This current distribution is estimated to be <60% of the pre-settlement range, and includes 11 states and 2 Canadian Provinces (Fig. 2-1).

Sage-grouse populations may use distinct breeding, summer, and winter ranges (Connelly et al. 2011a, Fedy et al. 2012). The size of seasonal ranges can reflect historical land uses working in concert with spatial habitat needs. Sage-grouse migrations have been defined as movements greater than 10 km between distinct ranges (Connelly et al. 2000b, Fedy et al. 2012). Migration information is needed to determine meta-population boundaries, identify important seasonal habitats, and define how the birds may respond to changes in land use (Connelly et al. 1988, Fedy et al. 2012). This is important because a strong relationship exists between movement patterns, survival, and productivity (Beck et al. 2006, Connelly et al. 2011a).

Most sage-grouse nests are located under sagebrush, though some female sage-grouse occasionally use other vegetation types as nest cover (Connelly et al. 1993, Schroeder et al. 1999, Crawford et al. 2004, Dahlgren 2006). Females exhibit high site fidelity to previous nesting locations and may nest within a kilometer of the previous nest and sometimes within several hundred meters (Berry and Eng 1985, Fischer et al. 1993). Nests are often located within 5 km of a lek, but nest placement may depend more on other habitat components than distance (Wakkinen et al. 1992a, Herman-Brunson 2007). Nest success varies widely depending on the population. In a review of the literature, Connelly et al. (2011a) reported that nest success rates varied between 15–86% depending on hen age, habitat condition, and predator community.

Broods prefer a mosaic of habitat types (Schroeder et al. 1999). Because broods rely heavily on arthropods and succulent forbs (Dahlgren 2009, Gregg and Crawford 2009, Harju et al. 2013, Robinson and Messmer 2013), it is important that early brood-rearing habitat readily supply these necessary diet components. Nest locations are often in close proximity to early brood-rearing habitat, so that newly hatched chicks with limited mobility have an available food source (Connelly et al. 2011b). Young are able to make short flights within one to two weeks of hatching (Patterson 1952). Some factors affecting chick and juvenile survival are habitat quality, food availability, predation, and weather (Crawford et al. 2004, Gregg and Crawford 2009, Connelly et al. 2011a).

Sage-grouse may form flocks in the autumn that contain both sexes and all age groups (Beck 1977). During the autumn, these flocks may use transitional habitats located between summer and winter range (Connelly et al. 2000b). Connelly et al. (2011b) concluded that diets on transitional ranges changed from forbs and arthropods to predominantly sagebrush. Sage-grouse may briefly occupy the autumn range before migrating to winter habitat (Connelly et al. 1988).

Sage-grouse flocks in wintering grounds often are segregated by sex (Beck 1977). Dalke et al. (1963) reported that flocks increased in size as weather conditions deteriorated. Snow depth often determines the habitat that flocks use (Dalke et al. 1963), although recent research shows that winter habitat selection has much to do with sagebrush phytochemistry (Frye et al. 2013). Sage-grouse depend entirely on sagebrush for winter habitat. Sagebrush is the major winter source of food, though sage-grouse are very selective about which sagebrush they feed on (Beck 1977, Remington and Braun 1985, Thacker 2010, Frye et al. 2013). Winter selection of sagebrush is characterized by high nutrient and low plant secondary metabolites (Frye et al. 2013). Sagebrush is also important as shelter for sage-grouse in the winter (Dalke et al. 1963, Beck 1977). As snow melts sage-grouse will start to return to their strutting grounds (Dalke et al. 1963).

Sagebrush ecosystem patterns, processes, and composition have been altered since Euro-American settlement in the late 1800s (West and Young 2000, Bunting et al. 2003). Declines in sage-grouse populations have mainly been attributed to sagebrush-steppe ecosystem loss and degradation (Braun 1998, Connelly et al. 2004, Knick and Connelly 2011). Sage-grouse require large expanses of sagebrush to meet all of their seasonal habitat requirements (Connelly et al. 1988, Hagen 1999, Connelly et al. 2000b).

The movement and dispersal of individuals is a useful measure of the effects of habitat fragmentation on populations (Wiens 1994, Fedy et al. 2012). Sage-grouse have been known to make large movements over ~160 km which may be associated with migration or dispersal (Patterson 1952, Smith 2013). Habitat loss could affect the seasonal ranges and alter movements by creating barriers to movement for individuals. Range reduction, fragmentation, and isolation may reduce connectivity between populations leading to loss of genetic diversity and population loss due to natural disaster (Reese and Connelly 1997, Benedict et al. 2003, Oyler-McCance et al. 2005, Aldridge et al. 2008).

Lack of effective regulatory mechanisms to protect the species across jurisdictional boundaries was also identified as a major range wide sage-grouse conservation threat (USFWS 2010). The range-wide management zones defined by Stiver et al. (2006) were based on floristic provinces, not political boundaries. In the U.S., sage-grouse are considered a resident game bird, and each state has the authority to manage species take (Connelly et al. 2004, Stiver 2011). The ecology of unstudied populations could be important for management of sage-grouse populations, especially for populations that span more than one jurisdictional boundary. For sage-grouse that span more than one jurisdictional boundary, management requires coordinated plans among different agencies, land owners, and the public (Hemker and Braun 2001). Little is known about the ecology, seasonal movements, and habitat-use patterns of the sage-grouse populations that inhabit the BLPV relative to existing or potential land uses for application to management.

The objective of this research was to describe the ecology, seasonal movements, and habitat-use patterns of sage-grouse that inhabit the BLPV relative to existing land-uses and jurisdictional boundaries. I reported population vital rates including survival rates, nest and brood success rates, home range sizes for individual sage-grouse, and distance of nest and brood locations from the lek of capture and the nearest lek. This information could be used to develop conservation strategies and implement management actions to conserve these meta-populations.

STUDY AREA

The BLPV was located in Bear Lake County, Idaho, Rich County, Utah, and Lincoln County, Wyoming (Fig. 2-2). The BLPV encompassed 2450 km^2 (245,000 ha) comprised of different land ownership and management entities and constitutes the northwestern portion of the Wyoming Basin (Stiver et al. 2006). Approximately 58% of the area was privately-owned, 8.8% state-owned land, 8.1% managed by the U.S. Forest Service (USFS), 24.4% managed by the Bureau of Land Management (BLM), and 0.7% managed by the USFWS (Fig. 2-3). Several population centers were within the BLPV study area. In Idaho, Fish Haven, St. Charles, Bloomington, Paris, and Ovid are located on the western edge of the valley; Montpelier is on the eastern edge of the valley; and Geneva and Raymond are along the Wyoming border. In Utah, Laketown is located in the valley, south of Bear Lake. In Wyoming, Cokeville is on the eastern edge of the plateau.

Topography

The elevation of the study area ranged from 1800–2500 m above mean sea level. The structural basins consist of north-south plateaus that parallel one another. The valley contains Bear Lake, a 282 km^2 surface area lake, and the 77 km^2 USFWS Bear Lake

National Wildlife Refuge which is comprised mainly of bulrush (*Scripus* spp.) marsh, flooded sedge meadows (*Carex* spp.), and open water, (Palacios et al. 2007, USFWS 2013). The plateau is dominated by sagebrush steppe. In Idaho, Caribou National Forest borders the plateau on the west side, and on the north edge of the valley. In Utah, Cache National Forest borders the plateau on the west side. Cache and Caribou National Forests are characterized by high elevation tree stands consisting of lodgepole pine (*Pinus contorta*), spruce (*Picea* spp.), fir (*Abies* spp.), and aspen (*Populus tremuloides*), and sage-brush steppe in lower elevations (O'Brien and Pope 1997).

Climate

The climate of the study area is typical of intermountain highlands with cold winters and hot summers. Temperatures range from average lows of -14.2°C in January, and highs of 28.8°C in July. The area receives between 25.4 and 43.2 cm of precipitation annually most which occurs between September and June as snow in winter and rain in summer. The average annual snowfall varies through the site varying between 83 and 235 cm, most of this occurs from October to March (Western Regional Climate Center 2013).

Vegetation

Vegetation was dominated by sagebrush steppe communities. The dominant shrubs included Wyoming big sagebrush (*A. tridentata. wyomingensis*), mountain big sagebrush (*A. t. vaseyana*), basin big sagebrush (*A. t. tridentata*), black sagebrush (*A. nova*), serviceberry (*Amelanchier utahensis*), snowberry (*Symphoricarpos* spp.), and rabbitbrush **(***Chrysothamnus* spp.). Common grasses included wheatgrasses (*Agropyron* and *Pseudoroegneria* spp.), bromegrass (*Bromus* spp.), bluegrass (*Poa* spp.)

and wild rye (*Elymus* spp.). Common forbs included: *Phlox* spp., Redtop (*Agoseris glauca*), Hawksbeard (*Crepis acuminata),* groundsel (*Baccharis salicina*), rosy pussytoes **(***Antennaria rosea*) milk vetch (*Astragalus* spp.), penstemon (*Penstemon* spp.) and daisy (*Erigeron* spp.).

The primary land use was grazing by domestic livestock. Some grazing areas have been manipulated by brush removal and reseeded with introduced grasses. Because of the presence of Bear Lake, the BLPV is a major seasonal recreation area, with most use occurring in summer. Residential development is occurring at the base of Bear Lake on both the east and west sides of the study area. On the plateau west of Bloomington, Idaho, a mining corporation has been exploring for phosphate. The corporation has deployed minor exploration equipment and developed some roads to test sites in this area.

Sage-Grouse Monitoring

Personnel with the Idaho Department of Fish and Game (IDFG), Utah Division of Wildlife Resources (UDWR), and Wyoming Game and Fish Department (WGFD) have monitored sage-grouse leks in the area since the 1960s (Fig. 2-4). However, not all leks are counted each year. Every few years, state agencies may conduct aerial surveys to census all leks in the area.

Sage-grouse harvest varies though the study area by state. Sage-grouse hunting is closed in southeastern Idaho (IDFG 2011). Utah allows for the harvest of 2 birds with a permit (UDWR 2009). Wyoming does not require a special permit for sage-grouse hunting and allows for a daily take of 2 birds and a possession limit of 4 (Christiansen 2010).

METHODS

Captures

Sage-grouse were trapped at leks and roost sites throughout the study area in the spring and fall from March 2010–April 2012. Spotlights and binoculars were used to locate roosting grouse, and grouse were captured using a dip net (Wakkinen et al. 1992b, Connelly et al. 2003). We used all-terrain vehicles (ATVs) and foot capture methods because rough terrain limited the use of larger vehicles. Sage-grouse were handled according to procedures approved under the Utah State University (USU) Institutional Animal Care and Use Committee permit #1463, and with a Certificate of Registration from the UDWR #3BAND8430, and a Wildlife Collection Permit from IDFG, #100419. Sage-grouse were classified by sex (male or female) and age (juvenile, yearling, or adult) using size and plumage (Dalke et al. 1963). Each sage-grouse was assessed for body condition, and females and juveniles were weighed using a Pesola™ (Pesola, Zug, Baar, Switzerland) 2,500–g spring scale. Females and males were fitted with individually numbered leg bands, and 18–26g necklace style very high frequency (VHF) radio-transmitters (Advanced Telemetry Systems, Insanti, MN; American Wildlife Enterprises, Monticello, FL; Wildlife Materials, Murphysboro, IL; Sirtrack, Havelock North, New Zealand). Radio frequencies ranged from 148.000–152.999 MHz. Frequencies were checked with state wildlife projects in the area to insure there was no frequency overlap.

Lek Counts

Lek counts are used range-wide to monitor sage-grouse populations (Connelly and Schroeder 2007), but due to the variable nature of the data, interpretations can be limited (Beck and Braun 1980, Walsh et al. 2004, Johnson and Rowland 2007). A true population estimate cannot be obtained using lek count data because not all leks are known, not all known leks are counted, leks may be not well defined, and sex ratios are unknown (Johnson and Rowland 2007). However, population trends can be assessed using lek count data (Walsh et al. 2004, Johnson and Rowland 2007, Garton et al. 2011). Counts are made during the spring breeding season, when males are displaying on the lekking grounds. Counts are taken one-half-hour before sunrise to one hour after sunrise. Leks are not counted during days when conditions are poor, for example, if there was wind >15 mph, or heavy precipitation. States attempt to count leks three times per spring to obtain a peak attendance count. Leks were often selected for counts by states because they were prominent, accessible, and contained large number of males (Schroeder et al. 1999). Lek count data can be difficult to evaluate, because peak lek attendance varies inter- and intra- seasonally (Jenni and Hartzler 1978, Emmons and Braun 1984), accessibility to leks can change between years, observer accuracy varies (Johnson et al. 2007), and agency schedule can limit number of visits. Leks on the BLPV have been monitored by state agencies since the 1950. I used data collected by the state and data collected during my study to report trends in BLPV sage-grouse lek counts. Lek counts became standardized in the 1970s (Connelly and Schroeder 2007), and the data collected by the states represents data collected using lek count protocols.

Nesting

A pilot study was initiated in 2010 to document sage-grouse movement patterns. No sage-grouse nests were monitored that year. In 2011 and 2012, radio-marked hens were located using telemetry one or more times per week from April to August. Sage-grouse nesting activity was confirmed by carefully approaching hens which have confined their movements to specific areas and observing from at least 10 m away with binoculars. A hen was considered nesting when it was under the same bush for 3 consecutive days. Precautions were taken to avoid disturbance and nest failure by avoiding flushing hens off nests. Also, because of the presence of aerial predators and scavengers, suspected nest locations were inconspicuously marked and the global position system (GPS) location recorded to mitigate the risk of observer-induced depredation. Nest information was obtained for 28 radio-marked sage-grouse hens. Fifty-nine hens were marked during the study but due to lost birds, collar failure, and logistical constraints, not all nest attempts were discovered. Nest success was estimated by monitoring nest incubation time, and locating nest remains after success or failure. Successful nests had one or more eggshells with loose membranes present (Girard 1939). I attempted to determine cause of depredation of unsuccessful nests by assessing eggshells and predator sign, but these do not provide completely accurate predator results (Coates 2007). Covariates used to analyze nest success included: aspect, slope, percent big sagebrush cover, average sagebrush height, percent forb cover, average forb height, percent grass cover, average grass height, distance to nearest fence, distance to nearest road, and distance to nearest anthropomorphic structure.

Nest Site Vegetation

Nest vegetation was measured after nest fate was determined. Random points within 5 km of each nest were selected using geographic information system technology

(ArcMap GIS 10.1 program) and vegetation measurements were taken to compare selection of available nesting habitat in the study area (Connelly et al. 2003). I monitored and measured vegetation characteristics at 25 nest and 21 paired random sites. Aspect and slope were recorded at each nest and random site. From the nest bowl or random UTM point, a 15–m intercept transect was established with and initial random compass bearing and then three more transects were established at 90 degree angles to measure shrub cover (Canfield 1941). Along these transects herbaceous cover was measured every 3–meters using Daubenmire frames (40 cm x 25 cm, Daubenmire 1959). A Robel pole (Robel et al. 1970) was used to measure visual cover or obstruction (VOR). The VOR was recorded at 5–m from the nest bowl location along each transect at 100 cm high, looking into and out from the Robel pole.

Brood Monitoring

Brood success was determined by observing hens that had nested successfully and counting the number of chicks. Hens were approached during the day by walking up or were spotlighted at night (Dahlgren et al. 2010b). When broods were too young to fly (<14 days), I attempted to observe chicks without flushing the hen. Broods were not flushed more than once a week to avoid distress to the chicks. A hen produced a successful brood if any chicks survived over 51 days. Because chicks were not individually monitored, and sage-grouse may have a propensity for brood-mixing and flock forming (Dahlgren et al. 2010a), the proportion of chicks surviving to independence was not measured. Brood information was obtained for 8 radio-marked sage-grouse hens. Additionally, 64 unmarked females with broods were flushed over the course of the study, and their locations were recorded.

Brood Site Vegetation

After finding a brood, a GPS location was recorded and 5–7 days later, vegetation was measured at that site. This precaution was taken to avoid disturbance to the brood and possible attraction of predators. Locations of broods without a radio-marked hen were also recorded, and vegetation was measured at these sites. At brood sites, vegetation was measured along a 10–m line-intercept transect at a random compass bearing, and then at three subsequent 90° angles. I used Daubenmire frames (40 cm x 25 cm) to measure ground cover (percent grass, forb, bare ground, litter, and rock) every 2.5 m along the line intercept transects. The VOR was recorded at 5–m from the brood site along each transect at 100 cm high. Aspect and slope were recorded at each site. Random points within 5 km of each brood were selected in GIS and vegetation measurements were taken to compare selected habitats to possible habitat nearby (Connelly et al. 2003). Nineteen brood sites and 9 paired random sites were measured. In the pilot year, unmarked broods were observed and vegetation was recorded, but due to time constraints, not all random matched locations were measured.

Survival

Radio-transmitters deployed on the grouse were equipped with an eight hour mortality sensor. When a mortality signal was detected, the collar was located and the cause of mortality was determined by examining carcass and remains. If there were a large number of pulled feathers and bones left intact, I assumed an avian predator. If few bones remained and the collar was chewed, I assumed a mammalian predator (Small et al. 1991, Thirgood et al. 1998). I evaluated survival by year, gender, and area of capture. I also determined if differences existed in survival rates between migratory and non-migratory grouse (Beck et al. 2006).

Movements

I attempted to locate radio-marked sage-grouse one or more times per week during spring and summer (15 March-15 September), once a month during fall (15 September-15 December), and once or twice during each winter (15 December-15 March). I used ground telemetry to triangulate locations of sage-grouse during spring, summer, and fall. I used aerial telemetry from a fixed-wing aircraft to obtain locations when the site was inaccessible or if birds were missing. Aerial locations were included in location analysis, although they were not confirmed on the ground. Because frequencies were checked for overlap with other telemetry projects, I assumed the frequencies discovered using aerial telemetry were sage-grouse. When sage-grouse were flushed, a GPS location was recorded and the number of birds present was recorded. All sage-grouse spatial locations were recorded using the geographic coordinate system Universal Transverse Mercator (UTM) Zone 12 T.

Home Range

I calculated home range size for individual sage-grouse. Individuals that had <10 locations recorded were removed from analysis because of inadequate samples (Rudeen 2012). I used the kernel density estimator in GME (Geospatial Modelling Environment, GME 0.7.2.1, Beyer 2012), minimum convex polygon estimates in GME, and local convex hull (LoCoH; Getz and Wilmers 2004) in Program R (R Development Core Team 2012). For easier comparison to other studies, I included estimates for minimum convex polygon (MCP), local convex hull (LoCoH), and kernel density estimator (KDE). I employed all of these methods, because past sage-grouse literature gives calculations for home ranges using all three techniques. A KDE was calculated using Least Square Cross Validation for the algorithm (Lichti and Swihart 2011), a cell size of 10, and the default scaling factor of 1,000,000 (Sheather and Jones 1991, Seaman et al. 1999, Lichti and Swihart 2011, Burnett 2013). Isopleths representing probability surfaces were created to contain 95% of the volume of the KDE raster surface using GME (GME 0.7.2.1). LoCoH utilization distributions were estimated at 100.1%, which encompassed a greater amount of area in the case that points used did not fully capture the true utilization distribution. MCP home ranges were calculated using 100% of each individual's points.

Data Analysis

Nest Success

A nest was considered successful if at least one egg hatched. I analyzed nest success using the Mayfield maximum likelihood estimator for ragged monitoring data (Johnson 1979, Dinsmore et al. 2002, Rotella et al. 2004). Using this method, I calculated daily survival rates using R (R Development Core Team 2012), package RMark (Laake and Rexstad 2013), to construct models for program MARK (White and Burnham 1999). Nest success was calculated by daily survival rate raised to the power of total combined nest laying and incubation time period (36 days). Nest success confidence intervals were calculated using the Delta method (Seber 1982). Females with no detected nest were not included in the analysis. Effect of covariates on nest success were evaluated using RMark. I ranked competing models using Akaike information criterion corrected for small sample size (AIC*c*) (Burnham and Anderson 2002). When multiple models were found to be supported by the data (AIC*c* $\leq$2), the most parsimonious models were retained for interpretation (Arnold 2010).

Vegetation differences between successful and unsuccessful nest sites were compared using AIC*c* model selection in RMark. Habitat characteristics including nest shrub height and diameter, cover and heights of shrubs, forbs, grasses, and percentages of bare ground, litter, and rock were assessed for impact on nest success. Vegetation at nest sites was compared to random sites, which had been selected using GIS, to determine if vegetation impacted selected nest sites. All random points were selected within potential nesting cover. I analyzed vegetation variables using logistic regression (PROC LOGISTIC, SAS® System for Windows 9.3, Cary, NC). Habitat characteristics were compared at distances of 3 m, 6 m, 9 m, and 12 m from site.

Brood Survival

A hen was considered to have a successful brood if at least one chick survived until 51 days post hatching. Due to low sample sizes, descriptive statistics were used to describe brood success. I analyzed brood selection vegetation variables using logistic regression (PROC LOGISTIC, SAS). Brood sites were compared to random sites which had been selected using GIS. All habitat characteristics, including height and percent cover of shrubs, forbs, grasses, and percent of bare ground, litter, and rock were assessed for impact on brood site selection. Habitat characteristics were compared for differences at 2.5 m, 5 m, 7.5 m, and 10 m from the brood and random sites.

Survival

Survival was estimated using program RMark (White and Burnham 1999, R Development Core Team 2012). Survival was estimated using the Mayfield Maximum Likelihood Estimator for ragged telemetry data (Johnson 1979, Dinsmore et al. 2002, Rotella et al. 2004). The interval survival rate was calculated for both month and season. Covariates that were assessed for an effect on survival included: sex, age, year, month, season, and capture lek. Survival models assessing covariates were evaluated in RMark, and ranked using AIC. The 95% confidence intervals and variance for survival was calculated using the Delta Method (Seber 1982).

Movement Analysis

All sage-grouse spatial locations were downloaded into the Geographic Information System, and were transformed into shapefiles. Using individual bird shapefiles, I assessed seasonal path metrics for grouse between locations using Geospatial Modeling Environment (Version 0.7.2.1). Because birds were not monitored at regular intervals, I was unable to calculate step lengths and movement angles between each individual location. I obtained a distance and movement bearing between each seasonal range. I assessed these seasonal path metrics for differences related to grouse sex and age using a Pool's t-test (PROC TTEST, SAS), and I used an ANOVA to assess differences between season (PROC GLM, SAS). I also used location data to assess distance of grouse locations from capture lek (DCL) and nearest lek (DNL) in relation to age, sex, and season. I compared differences in sex and age using a Pool's t-test (PROC TTEST, SAS), and I compared seasonal DCL and DNL using an ANOVA (PROC GLM, SAS). Finally, I assessed each location shapefile in GIS to determine if the individual was migratory. Individuals with two distinct ranges >10 km apart were defined as one-stage migratory, and individuals with three distinct ranges >10 km apart were defined as two-stage migratory (Connelly et al. 2011a). Individuals that did not survive for a full year were classified as undetermined as distances moved by individual between seasonal ranges could not be accurately defined (Fedy et al. 2012, Reinhart et al. 2013).

Home Range

Using location data, I calculated home range size for individual sage-grouse with ≥10 locations. I compared differences in estimated home range size obtained by minimum convex polygon, local convex hull, and kernel density estimator. I assumed home range size could be affected sex, age, and capture lek. I used a Pool's t-test to assess differences related to grouse sex and age, and I used ANOVA to assess differences related to capture lek (PROC TTEST and PROC GLM, SAS). To assess the impact of location number on the size of the home range, I tested for a linear relationship between the number of locations and the size of the home range using linear regression (PROC REG, SAS). I also plotted the number of locations against home range size to determine if there was a minimum location number for home range area (Hagen 1999).

RESULTS

Captures

During the study, I captured 162 sage-grouse and deployed 153 radio-transmitters (71 adult males, 21 yearling males, 2 juvenile males, 35 adult females, 22 yearling females, and 2 juvenile females; Table 2-1). Deployment of collars occurred over three years from six different leks and fall roosting areas. In 2010, between March-April, Utah

State University and Idaho Department of Fish and Game researchers captured and radio-marked 39 sage-grouse near leks 2B002, 2B015, and 2B043 (17 adult males, 6 yearling males, 8 adult females, and 8 yearling females). Female weights ranged from 1250–1500 g. In September-October, I captured and radio-marked 7 sage-grouse on fall roosting areas (6 adult females and 1 juvenile female). Female weights ranged from 1080–1400 g. Males were not weighed during capture. In 2011, between April-May, I captured and radio-marked 51 sage-grouse at leks: 2B015, 2B025, 2B032, 2B043 (Fig. 2-4; 28 adult males, 7 yearling males, 6 adult females, 10 yearling females). Female weights ranged from 1200–1625 g. From August-October an additional 17 sage-grouse were captured and radio-marked at fall brooding locations (7 adult males, 2 juvenile males, 5 adult females, 2 yearling females, and 1 juvenile female). Female weights ranged from 1140–1500 g. In 2012, from March-April, I captured 39 sage-grouse at leks: 2B003, 2B015, 2B025, 2B032, and 2B043 (Fig. 2-4; 19 adult males, 8 yearling males, 10 adult females, and 2 yearling females). Female weights ranged from 1320–1615 g.

Lek Counts

Lek count efforts on the BLPV vary based on state efforts with different numbers of leks being counted in each state. Wyoming lek count effort has varied by decade. Four leks were counted from 1958–1964 which yielded counts from 40 to 156 birds and averages birds per lek ranging from 10 to 57 (Figs. 2-5 and 2-6). Highest average birds per lek were observed during this time period (Fig. 2-6). Count data were very sparse from 1965–1977, with only one recorded lek count of zero birds during that time. From 1978–1988 the state monitored one or two leks annually, with several years of no counts.

Counts ranged between 2–37, and average birds per lek ranging from 2-14 (Figs. 2-5 and 2-6). Two new leks were monitored in the area beginning in 1985. Leks that had been monitored through the 1960s had reduced in bird number, with several considered unoccupied. From 1988–1994, lek data were infrequent, with only counts of zero recorded. From 1995 to the present, four leks have been monitored regularly, with none of the original 1960s leks being occupied. Total count numbers range from 7–37 (Fig. 2-5). Average birds per lek range from 2-13 (Fig. 2-6). All known leks in the area were monitored in 2007 and 2009, with only one lek having birds observed.

Lek monitoring efforts in Utah began in 1967. From 1967–1981 less than three leks were monitored annually. Total counts ranged from 0–59 birds, and average birds per lek ranged from 6-23 (Figs. 2-5 and 2-6). From 1982–1984, no lek count data were obtained in this area. From 1985 to the present, at least one lek was counted in the BLPV, with all of the known leks in the area (seven leks) surveyed in 2006. The highest recorded count during this time period was 329 birds in 1989 when six leks were counted (Fig. 2-5). From 1985 to the present lek counts in the area were >300 birds in two years, 200–300 birds in five years, 100–200 birds in 8 years, and <100 bird in 13 years. Average birds per lek was >10 in 5 years, 10-20 in 10 years, 25-50 in 10 years, and 50-130 in 4 years (Fig. 2-6). All Utah leks in the area had birds observed during at least one year from 2007 to the present.

From 1966 to the present, natural resource agencies have counted leks in Idaho. From 1967–1981, one lek was monitored in the BLPV. Counts ranged from 12–105 with the highest count in 1975 (Fig. 2-5). In the period of 1982–1990, between one and four leks were counted in the area each year. Counts ranged from 11–98 and average birds per lek ranged from 11-70 (Figs. 2-5 and 2-6). No leks were counted in 1991. From 1992–2000, four of the leks that had been monitored long term became unoccupied. During this time period, 16 new leks were discovered. The recorded counts ranged from 6 to 259 during this period with the high count in 2000 (Fig. 2-5). Average birds per lek ranged from 2-12 (Fig. 2-6). From 2001–2013, at least three leks were counted consistently, with a maximum of 22 leks counted in 2007. The counts ranged from 54–221 with the highest count in 2010 when 16 leks were counted (Fig. 2-5). Average birds counted per lek ranged from 12-36 (Fig. 2-6). From 2001 to the present there were seven years when >100 birds were counted.

Prior to 1985, <5 leks were counted across the BLPV each year. Utah increased monitoring efforts in 1985, and all Utah leks on the BLPV were monitored each year to the present. Idaho also increased lek monitoring efforts in 1988, and ≥2 leks have been consistently monitored each year to the present (except in 1990 when no Idaho leks were counted). From 1985 to the present, total BLPV lek counts have ranged from 71-479 birds (Fig. 2-7), with average birds counted per lek ranging from 8-64 (Fig. 2-8). As of 2011, 33 leks (57.9%) were of unknown status, 17 leks (29.8%) were active, and 7 leks (12.3%) were classified as inactive (Fig. 2-4).

Nest Success and Brood Survival

In 2010, hens were not monitored on a regular basis, so nesting success was not recorded. In 2011, 11 of 24 radio-marked hens were recorded with nests (45.8% observed). It was a late snow melt year, and discovery dates ranged from 18 May–7 June. Clutch size ranged from 3–6 eggs with an average of 5 eggs. Of the 11 observed attempts, three hens had successful nests (apparent success=27.3%). Of the three broods, one failed within one week of hatching and one failed within three weeks of hatching. The third brood was recorded for 14 days with at least 3 chicks still alive, but the hen's radio-transmitters failed and I was not able to locate the brood again.

In 2012, 17 of 28 radio-marked hens were recorded with nests (60.7% observed). Nest discovery dates ranged from 19 April–26 May. Clutch size ranged from 4–7 eggs, with an average of 6 eggs. Of the 17 attempts, 7 nests survived until hatching (apparent success=41.2%). Of those seven broods, one failed 3 weeks after hatching. The six other hens which hatched broods had at least one chick that survived until 50 days (85.7% brood success rate).

Using the Delta method (Seber 1982) to calculate nest success, the most parsimonious AIC model for predicting nest success was the null model (Table 2-2). Two models ranked higher than the null model, VOR measurements, and distance to the nearest tall anthropomorphic structure, but there was no credible evidence that these models were better than the most parsimonious model (ΔAICc <2). The daily nest survival rate using the null model was 95.9% (SE=0.94%). Using the Delta method to calculate nest success, the probability of any nest surviving for the full 36 days from beginning of laying to hatch was 22.3% (95% CL=6.9–37.8%). The mean probability of nest success varied widely among years, with success rates recorded in 2011 as 9.8% (95% CL=0.0–25.6%) and 2012 as 31.1% (95% CL=8.6–53.6%). High inter-annual variability both years could be caused by low sample sizes. Nest survival by age also had very different mean values with a high amount of noise likely due to low sample sizes. Yearling nest survival was 9.5% (95% CL=0.0–31.5%) and adult nest survival was 25.7% (95% CL=7.4–44.0%).

Nest and Brood Site Selection

I recorded vegetation variables at 25 of 28 nest sites. Three nests could not be located after the conclusion of nesting attempts. Of the 25, 80% (n=20) were located under big sagebrush, 12% (n=3) were located under low sage, and 8% (n=2) under rabbitbrush or crested wheatgrass. The most parsimonious model for predicting nest success was the null model (Table 2-2). No temporal or habitat factors were found to influence nest success more than the null model, but this may have been due to small sample sizes. Models of VOR measurement and distance to the nearest anthropogenic structure ranked higher than the null model, but not with significant weight. Shrub height within 15 m of nests ranged from 11.7–69.2 cm with a mean of 36.4 cm. Nest VORs ranged from 19.3–89.5 cm. Nest sites were found in both big sagebrush and low sagebrush areas. Percentage of sagebrush within 15 of nests sites ranged from 0.4–59.4%, with heights ranging from 11.6–81.6 cm with a mean of 40.1 cm.

I also measured vegetation at random locations (Table 2-3) and analyzed it for differences from nest site vegetation using logistic regression. Vegetation variables including VOR, nest shrub diameter, and total grass percent and height differed between nest and random sites ($P<0.05$). Site VOR measurements averaged 43.7 cm (SE=7.6 cm) at nest sites, and 23.5 cm (SE=8.7 cm) at random sites. At random sites the average center shrub diameter was 66.4 cm (SE=14.7 cm) and at nest sites the nest shrub averaged 118.9 cm (SE=20.4 cm). Total grass cover at nest sites averaged 14.1% (SE=2.5%) with average heights of 16.3 cm (SE=1.9 cm), and at random sites total grass cover averaged 18.9% (SE=2.8%) with average heights of 20.0 cm (SE=3.1 cm). Nest sites had slightly higher forb levels than random sites ($p=0.058$) with nest sites averaging

17.5% (SE=4.1%) and random sites averaging 12.1% (SE=3.6%). The random points were selected in areas within 5 km of a lek, and were located in sagebrush habitat.

The average distance from a nest site to the nearest lek was 2.7 km (SE=0.9 km), ranging from 0.2–11.4 km. Average distance from the lek of capture was 3.5 km (SE=1.3 km) with distances ranging from 0.5–13.4 km. Two hens were observed nesting in subsequent years. They nested in relatively similar areas with one having subsequent nests 1.4 km apart, and the other having subsequent nests 0.1 km apart.

Three and seven hens had successful nests in 2011 and 2012, respectively. The average distance of a brood from its nest in the first 60 days was 1581 m (SE=348 m), with maximum distances of 6508 m. The average distance of a brood to its nest location was 747 m (SE=283 m) from 0–14 days, 1528 m (SE=557 m) from 15–28 days, and 2082 m (SE=624 m) from 29–60 days. The average distance of marked and unmarked broods from a lek from hatch to 60 days was 2241 m (SE=508 m). From the radio-marked hens and unmarked hens with broods, 24 vegetation sites were measured and compared to 9 random sites (Table 2-4). Brood site selection vegetation variables were analyzed using logistic regression. The site variable that differed between brood sites and random sites was slope ($P<0.05$). Slope at random sites averaged 12.4° (SE=6.8°) and the average slope at a brood site was 3.8° (SE=1.4°). Vegetation cover did not differ between brood and random sites ($P=0.05$). Shrub cover at brood sites averaged 23.3% (SE=6.4%) with average heights of 37.2 cm (SE=9.7 cm). Average grass cover at brood sites was 16.9% (SE=3.0%) with heights of 21.9 cm (SE=3.8 cm). Average forb cover at brood sites was 11.3% (SE=2.7%) with heights of 9.0 cm (SE=2.9 cm).

Survival

Monthly survival estimates were obtained for 150 radio-marked sage-grouse (males, n=93, females n=57) and seasonal survival estimates were obtained for 145 radio-marked sage-grouse (males n=89, females n=56). Sixty-four individuals were discovered after the radio-transmitters signal changed to mortality. By assessing the remains of the carcasses, I attempted to determine cause of morality. Predation was the leading cause of mortality. Mammalian predation accounted for 26.6% (n=17) of the mortalities, avian predation accounted for 37.5% (n=24) of the mortalities, 3.1% (n=2) of the mortalities were caused by fence collision, and 32.8% (n=21) of the carcasses were unidentifiable.

The average annual survival rate for all birds across the study was 52.8% (95% CL=49.4–56.2%; n=195). The most parsimonious model for predicting survival was a model that assessed survival in the different seasons (Table 2-5). The other top models for predicting survival were a model with a combination of variation in capture area and season, and a model with a combination of bird age and season. Seasonal survival estimates for sage-grouse on the BLPV were spring 84.7% (95% CL=78.5–89.4%), summer 79.3% (95% CL=71.3–85.6%), fall 94.3% (95% CL=87.1–97.6%), and winter 83.4% (95% CL=n/a).

Annual survival rates for males was 49.7% (95% CL=38.3–61.1%), and annual survival rate of females was 57.4% (95% CL=43.7–71.0%). Yearling and adult survival varied, with adults survival of 48.8 (95% CL=38.9–58.7%; n=102) and yearling survival of 66.9% (95% CL=49.3–84.5%; n=43). There was a small amount of annual variation during the study, in 2010 annual survival was 52.2% (95% CL 35.0–69.4%), in 2011 survival was 66.4% (95% CL=52.6–80.1%), and in 2012 survival was 40.2% (95%

CL=26.3–54.0%). In 2010 annual female survival was 65.0% (95% CL=40.5–89.6%), in 2011 female survival was 67.5% (95% CL=46.2–88.7%), and in 2012 female survival was 40.1% (95% CL=17.4–62.9%). In 2010 annual male survival was 41.8% (95% CL=19.1–64.4%), in 2011 male survival was 63.8% (95% CL=46.0–81.6%), and in 2012 male survival was 40.2% (95% CL=22.7–57.7%).

I also assessed the effect of migration on survival for sage-grouse monitored over an entire year. I found no significant differences in annual survival between sage-grouse that were observed to migrate 75.1% (95% CL=61.0–89.1%, n=38), and sage-grouse that were not observed to be migratory 73.0% (95% CL=60.4–85.5%, n=51).

Movement

Location data were obtained for 153 radio-marked sage-grouse (males, n=94; females, n=59). Radio failure (n=2), capture related mortality (<5 days after capture; n=4), and inadequate sampling (n=24) resulted in a sample size of 123 (males, n=74, females, n=49). Incidental locations were taken for 272 unmarked sage-grouse.

The average location distance to lek of capture was 4414 m (SE=193 m, n=3083). Average distance from the lek of capture differed by season and by capture lek ($p<0.05$), but not by age or sex. Average distance to capture lek in spring was 3359 m (SE=233 m; n=1559), summer was 4873 m, (SE=228 m; n=1235), fall was 4961 m (SE=563 m; n=191), and winter was 14341 m (SE=3069 m; n=98). The average distance to capture leks (Fig. 2-4) were 2B002=1594 m (SE=452 m; n=21), 2B003=10146 m (SE=4399 m; n=26), 2B015=5270 m (SE=425 m; n=954), 2B025=3883 m (SE=437 m; n=226), 2B032=3903 m (SE=415 m; n=425), or 2B043=4016 m (SE=255 m; n=1431).

The average location distance to the nearest lek was 1775 m (SE=51 m, n=3133). The distance to the nearest lek differed by season ($p<0.05$), but not by sex or age. The average distance from nearest lek in the spring was 1462 m (SE=68 m, n=1501), summer was 2115 m (SE=73 m, n=1353), fall was 1557 m (SE=205 m, n=152), and winter was 2292 m (SE=469 m, n=86).

Each individual shapefile was assessed for migratory seasonal movements ≥10 km. Twenty-eight percent (n=43) of the marked individuals moved <10 km seasonally, 23.5% (n=36) marked individuals moved ≥10 km seasonally, and 48.4% (n=74) of individuals were undetermined due to lack of annual location data. Of the 36 individuals who made movements >10 km to distinct seasonal ranges 97.2% showed one-stage migratory behavior (n=35; 16 females and 19 males), and 2.8% showed two-stage migratory behavior with three distinct ranges. Of these 35 one-stage migratory individuals, 2.9% (n=1) had a unique spring range, 5.7% had unique summer ranges (n=2), 11.4% (n=4) had unique fall ranges, and 80% (n=28) had unique winter ranges. Migration timing and seasonal habitat use duration varied by year and individual bird. The average distance between each seasonal range was 24915 m (SE=4981 m). Average movement bearing between seasonal ranges was 153° (SE=29°). Seasonal path metrics did not differ related to grouse sex, age, or between season.

Home Range

I calculated home range size for individual sage-grouse with ≥10 locations using MCP, LoCoH, and KDE. I used one nesting location, due to the slightly larger utilization distribution measurements from KDE outputs.

I reported the KDE values in this section because they are commonly used for wildlife studies (Sheather and Jones 1991, Seaman et al. 1999, Lichti and Swihart 2011, Rudeen 2012). The MCP and LoCoH home ranges were also generated for referencing BLPV home ranges to other studies (Table 2-6). Average annual KDE home range area was 100.7 km^2 (SE=15.4 km^2, n=99). There were differences between average annual male and female KDE home ranges (p<0.01). The average female annual KDE home range area was 59.4 km^2 (SE=12.5 km^2, n=42), and the average annual male KDE home range area was 131.8 km^2 (SE=24.5 km^2, n=57). There were also differences between average annual adults and yearlings KDE home ranges (p=0.05). The average annual yearling KDE home range area was 138.5 km^2 (SE=43.3 km^2, n=28), and the average annual adult KDE home range area was 85.7 km^2 (SE=12.6 km^2, n=71). Average annual KDE home range area for the different capture areas (Fig. 2-4) were 2B015=120.8 km^2 (SE=24.3 km^2, n=23), 2B025=80.4 km^2 (SE=28.6 km^2, n=12), 2B032=92.9 km^2 (SE=18.8 km^2, n=16), 2B043=50.6 km^2 (SE=15.4 km^2, n=33), off lek (Fall)=112.6 km^2 (SE=38.5 km^2, n=12). There were no differences between birds captured at different leks.

I tested for a relationship between the number of locations and the size of the home range using linear regression in SAS. There was no significant relationship (p=0.05) between the number of points used in the calculation and the home range areas of MCP, LoCoH, KDE. Moreover, home range sizes peaked between 10–30 points (Fig. 2-9). Home range size did not appear to increase with additional points, but few birds had >30 locations, so this may be biased by low sample size.

DISCUSSION

Lek Counts

Lek counts have been used as an indicator of population trend for sage-grouse by many state agencies (Connelly and Schroeder 2007, Johnson and Rowland 2007). Many states did not have standardized protocols until the 1970s, thus early lek data are difficult to interpret (Connelly and Schroeder 2007). Lek count data on the BLPV are a compilation of maximum male counts per lek, aerial survey counts, and lek route counts. As individual leks on the BLPV have not been monitored the same each year, using the data for an index of population status was not possible. The number of males per lek has remained fairly stable since 1985 when monitoring efforts increased. Since 2001, state agencies have attempted to count the same leks annually. This may provide a better index of population status (Johnson and Rowland 2007).

Nesting

Nest success is an important factor in sage-grouse population dynamics (Taylor et al. 2012). Range-wide nest success rates reported in other studies varied from 15–86% (Trueblood 1954, Gregg 1991, Schroeder et al. 1999, Connelly et al. 2011a). Both apparent hen nest success (27.3% in 2011 and 41.2% in 2012) and calculated nest success in the BLPV (9.8% in 2011 and 31.1% in 2012) were at the lower range of rates for sage-grouse populations. The BLPV clutch sizes were lower than sage-grouse clutch sizes reported from studies throughout their range (Connelly et al. 2011a). These lower clutch sizes likely result from inclusion of renests, as clutch sizes in first nest attempts tend to average 2 eggs greater than a second nest attempt (Kaczor 2008), or eggs had been removed by predators before nest investigation. During trapping, two hens were captured and noted to have brood patches. These hens were later observed to have a nesting attempt, which suggests that some sage-grouse in the BLPV may renest after early nest failure (Connelly et al. 1993, Kaczor 2008, Taylor et al. 2012).

Nest distance to nearest lek ranged widely with minimum distances of 0.2 km and maximum distances of 11.4 km. Previous research shows that female in fragmented habitats moved much farther from leks to nest sites compared to contiguous habitats (Schroeder et al. 1999, Wakkinen et al. 1992a). The distance from the nest to the hen's lek of capture was larger, which has been commonly noted in previous literature (Connelly et al. 2011b).

The BLPV contains diverse habitat types. Vegetation composition is important in nest selection and success. I assessed the small scale habitat measurements associated with nest site selection. It is critical for females to have large blocks of nesting habitat. Much like other Idaho and Utah studies, most nesting hens selected big or low sagebrush for nesting, but other shrubs and grass were used for nesting as well (Connelly et al. 1991, Dahlgren 2006, Connelly et al. 2011b, Robinson and Messmer 2013). Females selected shrubs exhibiting larger canopies for nesting than recorded at random sites, which is consistent with range-wide observations (Sveum et al. 1998, Knerr 2007, Connelly et al. 2011b). Similar to studies range-wide, the sagebrush canopy around nest sites on the BLPV averaged 25.4% (Wallestad and Pyrah 1974, Connelly et al. 2000b, Connelly et al. 2011b, Robinson and Messmer 2013). Females selected areas with higher nest bowl VOR than random sites, which has been reported other studies (Herman-Brunson 2007, Kaczor 2008, Connelly et al. 2011b). Increased vegetation cover may provide greater concealment and contribute to reduced predation (Coates and Delehanty 2010, Hagen 2011).

Nest sites showed slightly higher forb levels than random sites suggesting that hens nested near areas with greater forb number as a food source during early brood rearing. Total grass coverage was within estimates of studies range-wide, but average grass heights were lower than other nest vegetation sites (Connelly et al. 2011b).

There was no evidence that any single temporal or spatial factor provided the best model for approximating nesting success (Burnham and Anderson 2002). Temporal and spatial factors may not have been top models for approximating nesting success, but with larger sample sizes these factors may rank higher in model selection. The variation of the means of analyzed factors such as inter-annual variation, hen age, and capture area, may be identified as important factors with larger samples sizes that reduce the amount of variation associated with estimates.

Range-wide studies have found predator avoidance is an important component for nest selection site and can affect nest success (Cresswell 2008, Conover et al. 2010, Dinkins et al. 2012). For BLPV successful sage-grouse nests, VOR and distance to the nearest tall anthropomorphic structure ranked higher than the null model, but the null model was the most parsimonious model. Visual obstruction was an important nest site selection component and a factor affecting nest success (Kaczor 2008). Sage-grouse may avoid anthropomorphic structures as an indirect means of avoid avian predators which may use these structures as perches (Coates et al. 2014).

Brood Rearing

Because brood sample sizes were low in both years, my results may be biased. Low brood success in 2011 could have been affected by exposure to wet and cold weather due to the much later snowmelt. Brood survival was lower in 2011 than 2012. In 2012, the temperature was about 5 warmer on average April-July, and precipitation measured less than half of the precipitation received in 2011 during April-June (Western Regional Climate Center 2013). Precipitation in July 2012 was twice what was measured in July 2011, which could have provided additional forbs and insects for chicks and increased brood production All brood failures occurred in the first four weeks after hatching, when chicks are vulnerable because they are unable to fly (Gregg et al. 2007, Gregg and Crawford 2009).

Vegetation at brood sites did not differ from random sites. The BLPV brood sites contained similar forbs reported common in of other southern Idaho and northern Utah studies; alfalfa (*Medicago sativa*), clover (*Trifolium* spp.), yarrow (*Achillea millefolium*), lupine (*Lupinus caudatus*), and dandelion (*Taraxacum officinale*) (Klebenow 1969, Graham 2013, Robinson and Messmer 2013). Slightly higher forb composition was observed at nest sites over random sites suggesting that hens nested near areas with greater forb number as a food source during early brood rearing. Forb production is important at both early and late brood rearing sites as a food source. The forb cover at brood sites ranged from 0–24%, with an average of 11.3%, studies range-wide suggest that forb composition in brood rearing habitats be >15 % (Connelly et al. 2000b). Herbaceous cover (grass and forbs) was slightly higher at brood sites than random sites, which has been observed range-wide (Hagen et al. 2007). Sagebrush cover at brood sites was within habitat management guidelines suggestions (10–25%; Connelly et al. 2000b), with less sagebrush cover at broods sites than nest and random sites (Hagen et al. 2007).

Survival

Survival estimates vary among sage-grouse populations across the species' range (Connelly et al. 1994, Bunnell 2000, Perkins 2010). Published survival estimates range from 30–78% (Connelly et al. 2011a), and annual survival rates on the BLPV were within this range. Male survival estimates were similar to the range of what has been observed in other area studies (Connelly et al. 1994, Bunnell 2000, Robinson and Messmer 2013). Female estimates were slightly higher than male estimates, and likewise similar to what has been found in other area studies (Bunnell 2000, Dahlgren 2006). Higher female survival rates might be due to breeding season sexual dimorphism and associated predation rates of males during the breeding season. Yearling survival was slightly higher than adult, which has been noted in other sage-grouse studies (Zablan et al. 2003). There was some variation in survival based on the capture location of the grouse. Sage-grouse captured on the western side of the lake had higher survival than leks on the eastern side. Migration did not appear to affect survival of sage-grouse on the BLPV.

The most parsimonious model for predicting survival was seasonal effect. Other sage-grouse studies have shown that mortality patterns can vary by season (Connelly et al. 2000a, Wik 2002, Moynahan et al. 2006). Like many range-wide studies, sage-grouse in my study area were the most vulnerable during breeding season (Connelly et al. 2000a). Survival estimates were the lowest in summer, when males are completing lekking and females are vulnerable from nesting. Previous research has found that sage-grouse overwinter survival can be very high ranging from 85–100% (Wik 2002), but sage-grouse survival may be negatively impacted by extreme temperatures and snow depth (Anthony and Willis 2009). Winter survival in the BLPV might be lower than range wide estimates because the plateau experiences heavy snowfall and temperatures can be much colder than other areas in the sage-grouse range.

Movement

Sage-grouse exhibit high site fidelity to breeding grounds and to seasonal ranges (Dalke et al. 1963, Hagen 1999, Schroeder and Robb 2003). The BLPV sage-grouse monitored remained fairly close to lek sites. Sage-grouse had higher average distances from the nearest lek during winter than spring, suggesting that breeding habitat does not offer sufficient food and cover for sage-grouse during this time. Sage-grouse distances to the nearest lek were also smaller than to the lek of capture, suggesting sage-grouse may visit multiple leks during the breeding season, and may be caught near a lek they may not show fidelity to (Schroeder and Robb 2003).

In range-wide studies, sage-grouse have been documented to travel large distances between seasonal ranges or as dispersal in yearling individuals (Connelly et al. 1988, Bradbury et al. 1989, Schroeder and Robb 2003, Reinhart et al. 2013). Individual BLPV sage-grouse monitored also made large movements, and similar to range-wide studies most of which correlated with seasonal changes or with yearling dispersal. Though some individuals made migratory movements, not all BLPV sage-grouse were migratory. Even all individuals captured in the same lek area were not classified as a uniform migratory status. Many populations throughout the sage-grouse range cannot be completely classified as migratory or non-migratory (Fedy et al. 2012). The ability of individual sage-grouse to obtain resources on the landscape may influence migration patterns. Individual differences in migratory behavior may also be influenced by tradition (Wallestad 1971), as well as life stage and landscape composition (Fedy et al. 2012, Reinhart et al. 2013). Most of the migratory radio-marked birds in my study had unique winter ranges. Fedy et al. (2012) reported similar findings for migratory sage-grouse in Wyoming. This suggests that individuals may not uniformly select winter cover and forage at a population level. There was no uniform direction of movement between migratory ranges for BLPV sage-grouse as has been observed in other studies (Reinhart et al. 2013).

For yearlings making dispersal movements, individuals moved between known lek areas. One male (SGM3458) moved between Idaho, Utah and Wyoming. Two males, one in 2010 (SGM4252) and one in 2012 (SGM4299), moved across Bear Lake, and SGM4252 was located in the Bear Lake National Wildlife Refuge.

Several radio-marked grouse were found outside of the study area, to the far north in Caribou County, ID near the Bonneville County line and to the west in Bannock County, ID. These birds moved 70–100 km. Long distance movements have been observed in other studies (Patterson 1952, Connelly et al. 1988). The BLPV is located at the edge of the Wyoming Basin sage-grouse population (Stiver et al. 2006; Fig. 2-10), and extreme north and western movements are away from Wyoming Basin populations centers. The BLPV sage-grouse may provide an important genetic link between the Wyoming Basin and the Snake River Plain populations (Connelly et al. 2004).

Home Range

Home ranges for sage-grouse can vary widely. Previous literature has reported annual home ranges from 4–615 km^2. Sage-grouse home ranges in the BLPV were within this range, with the average LoCoH home ranges of 11.6 km^2, MCP areas of 46.3 km^2, and KDE areas of 100.8 km^2. Variation in home range size may be explained by habitat requirements and resource needs. Female and male sage-grouse had significantly different home range sizes, with males' annual home ranges almost twice the size of female home ranges. Male sage-grouse tend to make larger movements and cover more area than females (Connelly et al. 1988, Hagen 1999). Variation in home range sizes could be related to different resource needs. Differences in average home range size were also found between yearlings and adult birds. Younger individuals are known to make large exploratory movements during dispersal (Dunn and Braun 1985) which could account for these variations in size.

Different calculation techniques used to determine animal home range area may also yield very different results (Lichti and Swihart 2011, Rudeen 2012). Using VHF data can miss larger individual movements due to the time constraints of collecting data. This can lead to the underestimation of sage-grouse habitat used (Kochanny et al. 2009). Data collected are important to consider when estimating home ranges, but historical estimates are also important. Sage-grouse home ranges have been estimated using minimum convex polygon, kernel density estimators, and local convex hull. Local convex hulls are a relatively recent technique for estimating home ranges (Getz and Wilmers 2004), which uses minimum convex polygons to create a convex hull around nearest neighbors. Larger sample sizes increases the power of both KDE and LoCoH

(Lichti and Swihart 2011). Due to limited data, BLPV sage-grouse LoCoH estimates selected areas that were clustered and did not include movement corridors in the area estimate. LoCoH technique also did not estimate the probability of sage-grouse habitat use outside of the known locations. Kernel density estimation gives a better estimation of actual habitat given a smaller sample size (Lichti and Swihart 2011). Both KDE and LoCoH better define home range boundaries than MCP (Lichti and Swihart 2011). I included all three estimate types as a comparison to current and future studies of sage-grouse studies (Rudeen 2012).

MANAGEMENT IMPLICATIONS

Poor recruitment because of low nest and brood survival appear to be affecting population stability for sage-grouse on the BLPV. The variability I observed in nest and brood success may be reflective of environmental conditions and sample sizes. Given these factors, it is important to use caution when interpreting the results of short-term studies. The overall contribution of nest and brood success to upland game population dynamics can only be determined by long-term research that is able to compare the relative effects of seasonal variation on vital rates. Continued monitoring of reproductive efforts on the BLPV would lead to a better understanding of the role recruitment may play in population stability.

Stable sage-grouse populations typically occupy large landscapes that exhibit suitable sagebrush cover and limited fragmentation (Leonard et al. 2000, Aldridge et al. 2008, Knick et al. 2013). Sage-grouse may avoid nesting in areas that contain large amounts of anthropogenic edge habitat, and likewise, broods avoid human developments

(Aldridge and Boyce 2007). Preventing further fragmentation of the remaining suitable sage-grouse habitat could promote population stability by enhancing vital rates.

Habitats in Bear Lake State Park and Bear Lake National Wildlife Refuge likely serve as movement corridors for dispersing and migrating sage-grouse. Additional corridors may be identified where sage-grouse cross fragmented habitats on the BLPV. Corridors between core habitats could be protected from further development to provide viable genetic links between populations.

After the large landscape protection measures have been implemented in the BLPV, managers should consider management actions at the microhabitat scale to improve quality of habitat. Maintaining areas of relatively high sagebrush canopy in close proximity to leks may further enhance female nest success in the BLPV population (Connelly et al. 2011b). Connelly et al. (2000b) suggested managing for 80% or more sagebrush cover with 15–25% canopy and leaving adequate residual grass height and cover. Increasing grass height and composition in areas around leks may also increase nest and brood success, as found in other studies (Perkins 2010, Guttery 2011, Gruber 2012, Doherty et al. 2014). Nest success on the BLPV was slightly impacted by distance to tall structures. The effect of the placement of new tall structures in the BLPV may be mitigated if they are placed within existing transmission corridors.

Microscale habitat management could benefit broods. Forb production in my study area was also lower than recommended habitat guidelines (Connelly et al. 2000b), and improvement of high-density forb habitat could improve brooding success. In areas where sagebrush canopy may be limiting herbaceous understory in late summer habitat, shrub reduction at small scales may improve conditions for chicks (Connelly et al. 2000b, Dahlgren 2006). Improvement of brood habitat quality could also be accomplished by well managed grazing (Boyd et al. 2014).

Sage-grouse on the BLPV study area used habitat in Idaho, Utah, and Wyoming. Cooperation between state agencies and local working groups in Idaho, Utah, and Wyoming could aid in landscape and population management efforts. The East Idaho Uplands Sage-grouse Local Working Group, the Rich County Coordinated Resources Management Sage-grouse Subcommittee, and the Southwest Wyoming Local Sage-grouse Working Group prepared Sage-grouse Conservation Plans in 2011, 2006, and 2007 respectively (EIULWG 2011, RCCRM 2006, SWLWG 2007). Each plan identified threats and made conservation recommendations for local sage-grouse populations. The creation of a tri-state management plan for sage-grouse on BLPV could be beneficial for conservation of important seasonal habitats found in all three states. Additionally, a BLPV Sage-grouse Conservation Plan that addresses threats and conservation activities identified by the local working groups can direct management decisions. Long term monitoring of sage-grouse habitats in all three states will aid managers in assessing the effects of conservation efforts.

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Table 2-1. Greater sage-grouse (*Centrocercus urophasianus*) radio-transmitter deployments by sex, age class, and lek for sage-grouse on the Bear Lake Plateau and Valley (BLPV) study area, Idaho-Utah, USA. Spring capture dates ranged from 18 March-17 May across years. Fall capture dates range from 30 August-19 October in 2010 and 2011. BLPV Study, 2010–2012.

Capture Area	Season	Male Adult	Male Yearling	Male Juvenile	Female Adult	Female Yearling	Female Juvenile
2010							
2B002	Spring	-	-	-	1	-	-
2B015	Spring	9	-	-	4	4	-
2B043	Spring	8	6	-	3	4	-
Off Lek	Fall	-	-	-	6	-	1
2011							
2B015	Spring	12	2	-	-	2	-
2B025	Spring	3	4	-	-	2	-
2B032	Spring	6	-	-	-	1	-
2B043	Spring	7	1	-	6	5	-
Off Lek	Fall	7	-	2	5	2	1
2012							
2B003	Spring	-	2	-	-	-	-
2B015	Spring	5	1	-	-	-	-
2B025	Spring	4	2	-	1	-	-
2B032	Spring	7	1	-	4	1	-
2B043	Spring	3	2	-	5	1	-
TOTALS							
2B002	Spring	-	-	-	1	-	-
2B003	Spring	-	2	-	-	-	-
2B015	Spring	26	3	-	4	6	-
2B025	Spring	7	6	-	1	2	-
2B032	Spring	13	1	-	4	2	-
2B043	Spring	18	9	-	14	10	-
Off Lek	Fall	7	-	2	11	2	2
TOTAL		**71**	**21**	**2**	**35**	**22**	**2**

Table 2-2. Models assessing the impact of temporal and habitat factors on nest survival of greater sage-grouse (*Centrocercus urophasianus*), Bear Lake Plateau and Valley study area (BLPV), Idaho-Utah, USA. BLPV Study 2011–2012.

Model	**K [a]**	**AIC*c* [b]**	**Δ AIC*c* [c]**	***w* [d]**
Robel In	2	130.4242	0	0.11599
Distance to Structure	2	130.8589	0.43469	0.09333
Null	1	131.416	0.99184	0.07064
Year	2	131.4383	1.01412	0.06986
Litter Percentage	2	131.6405	1.21632	0.06314
Aspect	2	131.9829	1.55869	0.05321
Distance to Fence	2	132.424	1.99979	0.04268
Hen Age	2	132.5972	2.17301	0.03914
Total Shrub Height	2	132.9267	2.17301	0.03319
Nest Shrub Diameter	2	133.0083	2.58413	0.03186
Forb Percentage	2	133.0126	2.58845	0.03179
Grass Percentage	2	133.0464	2.62225	0.03126
Rock Percentage	2	133.0475	2.62336	0.03124
Forb Height	2	133.0532	2.62897	0.03116
Distance to Lek	2	133.1351	2.71087	0.02991
Total Shrub Height	2	133.2869	2.86267	0.02772
Nest Shrub Height	2	133.393	2.96878	0.02629
Distance to Road	2	133.4175	2.99335	0.02597
Slope	2	133.4185	2.99435	0.02595
Bare Percentage	2	133.4226	2.99839	0.0259
Artemisia spp. Percentage	2	133.4252	3.00104	0.02587
Shrub Percentage	2	133.4346	3.01037	0.02575
Grass Height	2	133.4346	3.01044	0.02575
Capture Area	4	133.7136	3.28947	0.02239

[a] K: number of parameters in each model.
[b] AICc: Akaike's Information Criterion corrected for small sample size
[c] Δ AICc: difference between a model and the best performing model

Table 2-3. Vegetation characteristics at greater sage-grouse (*Centrocercus urophasianus*) nest sites compared to random sites in the Bear Lake Plateau and Valley study area (BLPV), Idaho-Utah, USA. BLPV Study 2011–2012.

	Nest (*n*=26)		**Random (*n*=21)**	
	$\bar{x}$	*se*	$\bar{x}$	*se*
Aspect	164.5	(32.0)	159.0	(43.7)
Slope	9.4	(3.4)	9.7	(3.6)
Cover %				
Shrub	28.6	(5.9)	21.7	(6.9)
Artemisia spp.	25.4	(5.2)	15.7	(4.8)
Forb	17.5	(4.1)	12.1	(3.6)
Grass	14.1	(2.5)	18.9	(2.8)
Bare Ground	20.4	(5.3)	15.1	(3.5)
Litter	30.4	(4.9)	35.0	(6.1)
Rock	8.3	(4.3)	8.2	(3.9)
Cover Height(cm)				
Shrub	37.2	(6.3)	33.9	(6.3)
Artemisia spp.	40.1	(7.4)	35.5	(6.1)
Forb	7.0	(1.1)	6.5	(1.1)
Grass	16.3	(1.9)	20.0	(3.1)
Nest Shrub				
Height (cm)	64.2	(10.6)	49.8	(12.7)
Diameter (cm)	118.9	(20.4)	66.4	(14.7)
Robel In (dm)	43.7	(7.6)	23.5	(8.7)

(SE) Standard error found in parenthesis

Table 2-4. Vegetation characteristics at greater sage-grouse (*Centrocercus urophasianus*) brood sites compared to random sites in the Bear Lake Plateau and Valley study area (BLPV), Idaho-Utah, USA. BLPV Study 2011–2012.

	Brood (*n*=24)		**Random (*n*=9)***	
	$\bar{x}$	*se*	$\bar{x}$	*se*
Aspect	154.5	(46.5)	164.5	(70.4)
Slope	3.8	(1.4)	12.4	(6.8)
VOR (dm)	27.5	(7.3)	17.8	(11.1)
Cover %				
Shrub	23.3	(6.4)	28.3	(10.0)
Artemisia spp.	21.0	(5.9)	28.3	(13.8)
Forb	11.3	(2.7)	13.3	(6.1)
Grass	16.9	(3.0)	13.1	(4.0)
Bare Ground	15.2	(3.5)	16.5	(3.3)
Litter	38.9	(4.8)	32.0	(6.7)
Rock	5.5	(3.6)	9.3	(4.2)
Cover Height (cm)				
Shrub	37.2	(9.7)	36.4	(13.8)
Artemisia spp.	35.9	(9.6)	39.2	(18.1)
Forb	9.0	(2.9)	6.1	(2.3)
Grass	21.9	(3.8)	16.6	(2.5)

* *In the pilot year, unmarked broods were observed and vegetation was recorded, but due to time constraints, not all random matched locations were measured*

(SE) Standard error found in parenthesis

Table 2-5. Models assessing the impact of temporal and habitat factors on survival of greater sage-grouse (*Centrocercus urophasianus*), Bear Lake Plateau and Valley study area (BLPV), Idaho-Utah, USA. BLPV Study 2011–2012.

Model	**K** [a]	**AIC** [b]	**Δ AIC** [c]	***w*** [d]
Season + CapArea	8	319.2146	0	0.1822
Season + Age	5	319.2988	0.0843	0.1746
Season	4	319.72	0.5054	0.1415
CapArea + Individual Year	8	319.7214	0.5068	0.1414
Season + Individual Year	7	320.784	1.5694	0.0831
Season + Sex	5	321.0982	1.8836	0.071
Year In	3	321.5427	2.3281	0.0569
CapArea	5	322.7494	3.5348	0.0311
Age	2	323.1259	3.9113	0.0258
Age + Individual Year	5	323.5192	4.3046	0.0212
Individual Year	4	323.5849	4.3703	0.0205
Null	1	323.97	4.7554	0.0169
Year (Continuous)	2	324.1717	4.9571	0.0153
Sex + Individual Year	5	325.0558	5.8412	0.0098
Sex	2	325.2753	6.0607	0.0088

[a] K: number of parameters in each model.
[b] AIC: Akaike's Information Criterion
[c] Δ AIC: difference between a model and the best performing model

Table 2-6. Annual home range sizes for greater sage-grouse (*Centrocercus urophasianus*) on the Bear Lake Plateau and Valley (BLPV) study area, Idaho-Utah, USA. All areas were reported as km^2. Each home range measurement was included for reference to other studies, and to report the wide variation of different home range analyses. Variations in home range size were analyzed for sex using a t-test, age using a t-test, and capture area using ANOVA. BLPV Study 2011–2012.

	LoCoH		**MCP**		**KDE 95%**	
	$\bar{x}$	*se*	$\bar{x}$	*se*	$\bar{x}$	*se*
All						
Study Wide	11.5	(1.5)	46.4	(6.5)	100.8	(15.4)
Sex						
Female	7.3*	(1.4)	36.2	(8.5)	59.4*	(12.5)
Male	14.8*	(2.3)	53.8	(9.4)	131.8*	(24.5)
Age						
Yearling	12.5	(2.5)	58.4*	(15.5)	138.5*	(43.3)
Adult	11.2	(1.8)	41.6*	(6.8)	85.7*	(12.6)
Capture Area						
2B002	4.3	(n/a)	15.0	(n/a)	32.7	(n/a)
2B003	39.4*	(4.9)	294.4*	(76.2)	856.8*	(208.3)
2B015	17.7	(3.9)	51.3	(10.5)	120.8	(24.3)
2B025	9.9	(4.3)	26.8	(9.4)	80.4	(28.6)
2B032	11.1	(3.0)	43.2	(9.7)	92.9	(18.8)
2B043	6.3	(1.6)	27.7	(7.6)	50.6	(15.4)
Off Lek (Fall)	12.8	(4.1)	73.3	(28.0)	112.6	(38.5)

(*) The measurement was found to be significantly different (p>0.05) from other home range measurements

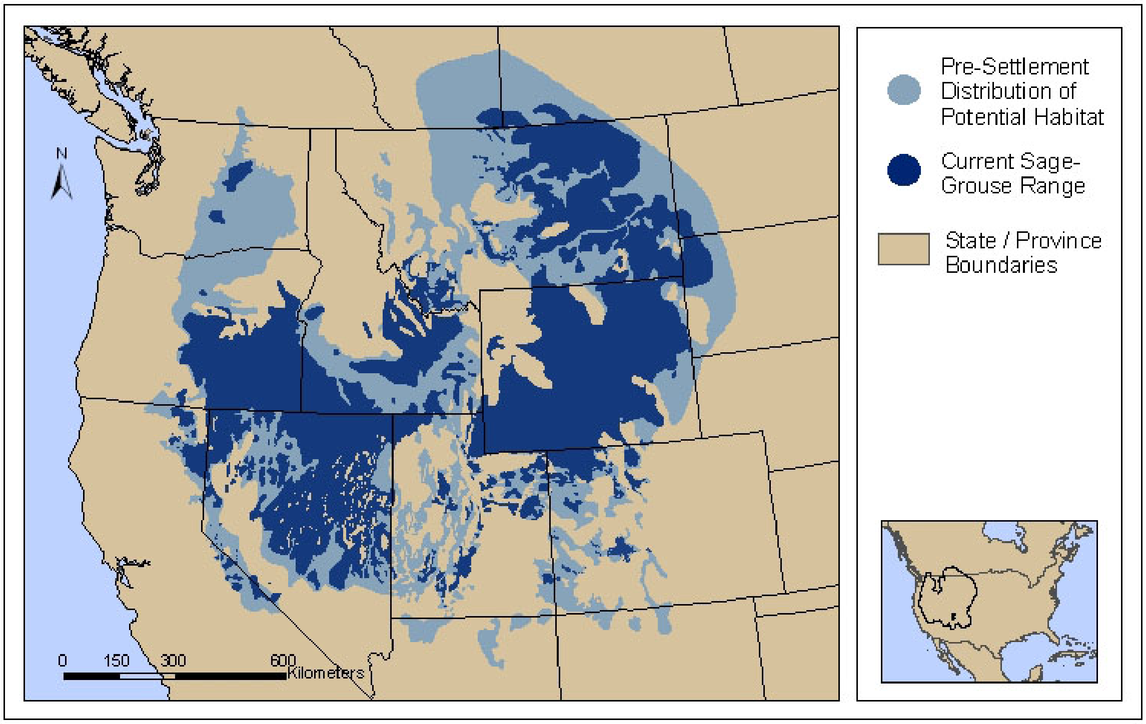


Figure 2-1. Current and estimated pre-settlement distribution of greater sage-grouse (*Centrocercus urophasianus*) habitat in North America (Schroder et al. 2004, Stiver et al. 2006).

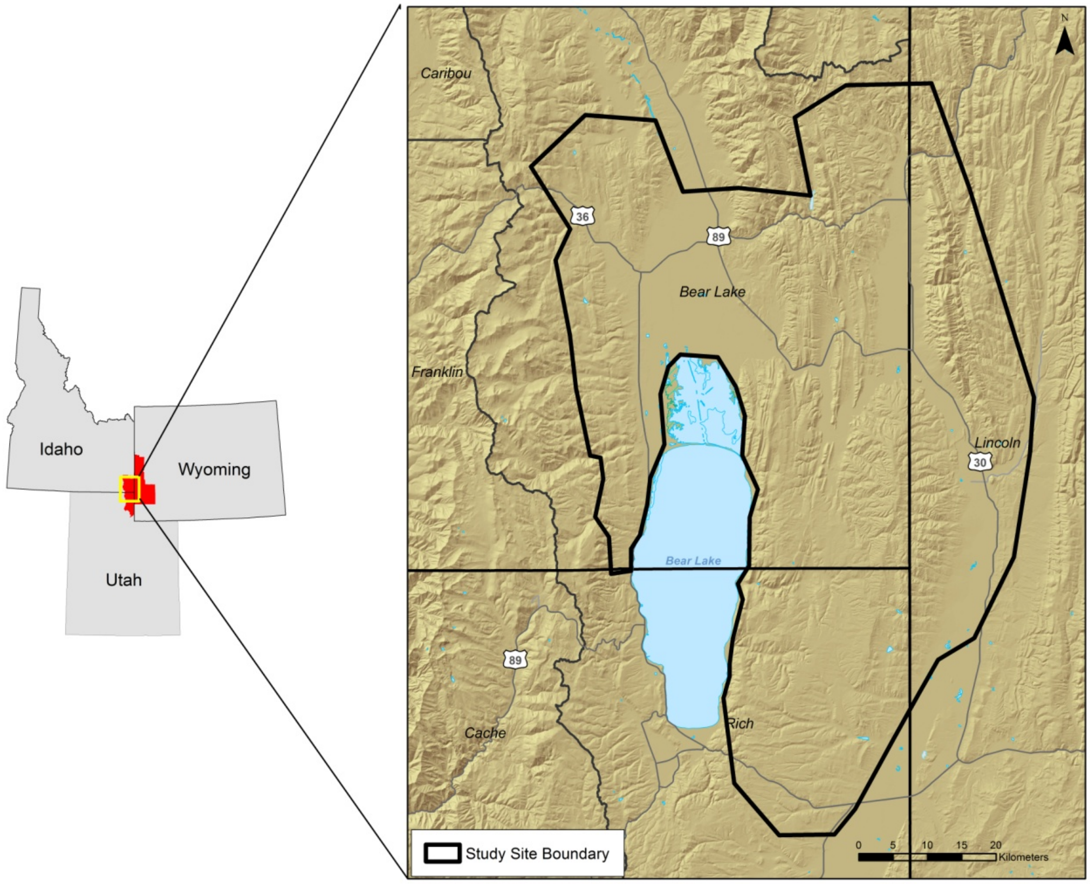


Figure 2-2. Bear Lake Plateau and Valley (BLPV) study area, Idaho-Utah-Wyoming, USA. Area included 99% of all recorded greater sage-grouse (*Centrocercus urophasianus*) locations, BLPV Study, 2010–2012.

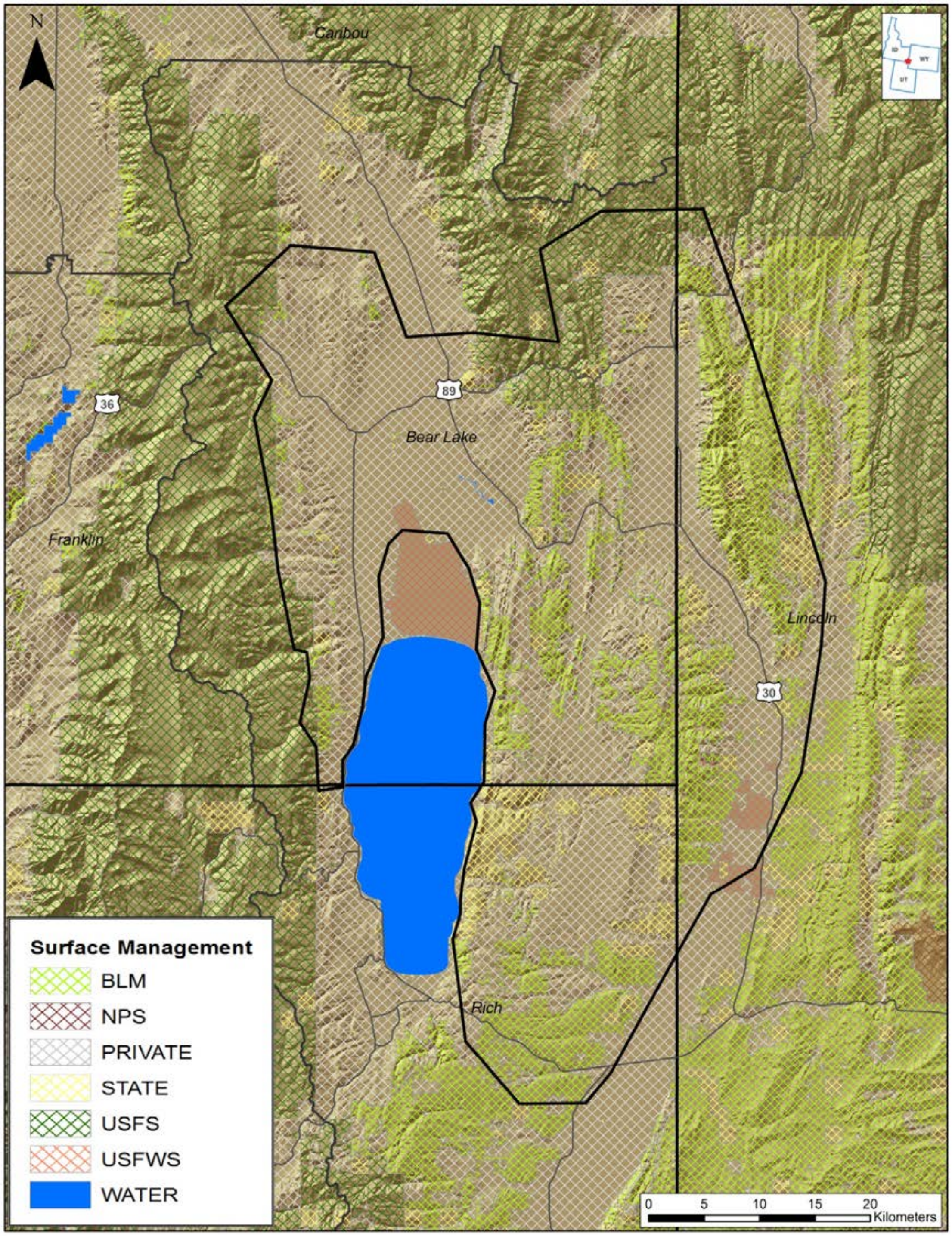


Figure 2-3. Land ownership of the Bear Lake Plateau and Valley (BLPV) study area, Idaho-Utah-Wyoming, USA. Approximately 58 % of the area was privately-owned, 8.8% state-owned land, 8.1 % managed by the U.S. Forest Service (USFS), 24.4 % managed by the Bureau of Land Management (BLM), and 0.7% managed by the U.S. Fish and Wildlife Service, BLPV Study, 2010–2012.

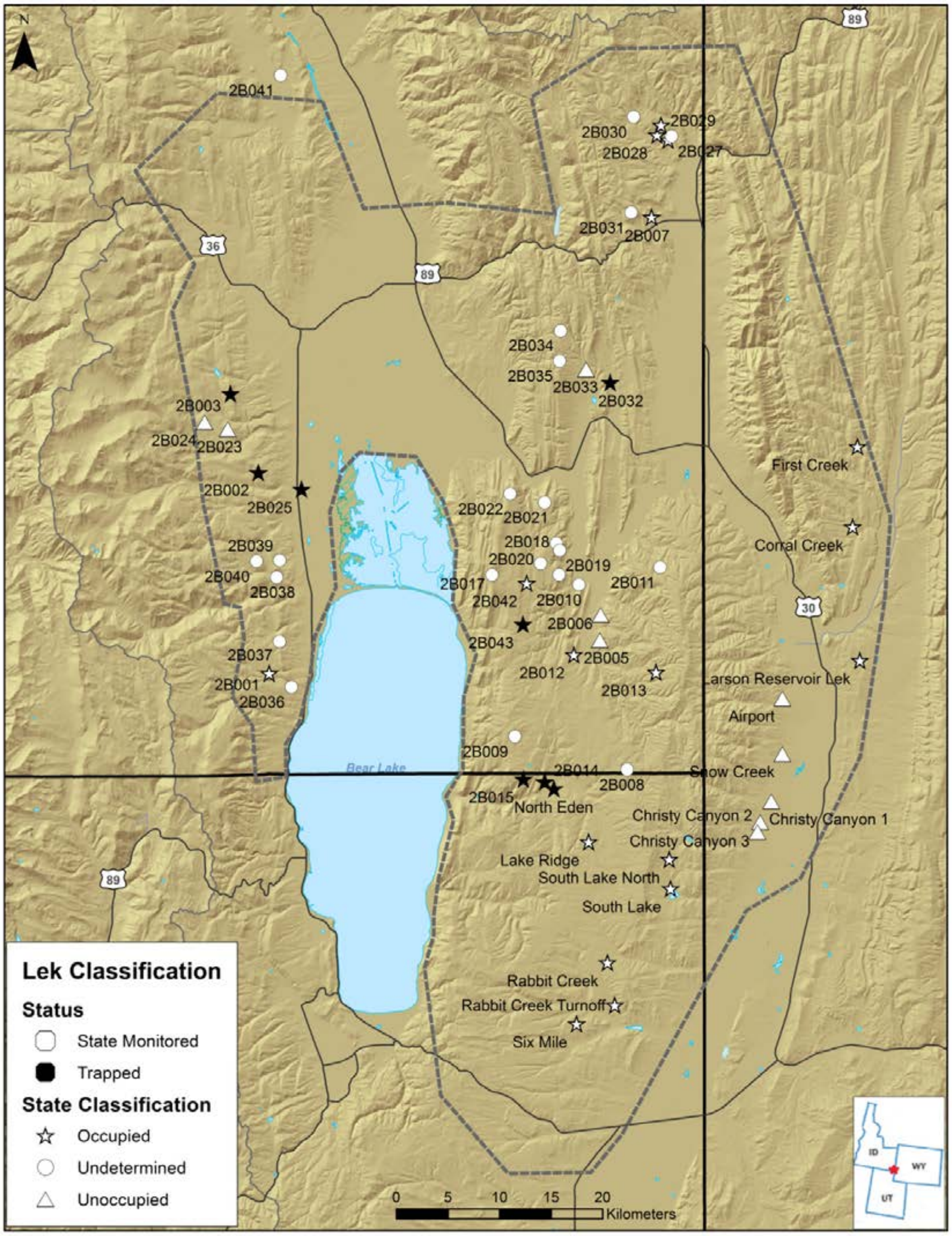


Figure 2-4. Greater sage-grouse (*Centrocercus urophasianus*) leks monitored by Idaho Fish and Game, Utah Department of Wildland Resources, and Wyoming Game and Fish Department on the Bear Lake Plateau and Valley (BLPV) study area. BLPV Study 2010–2012.

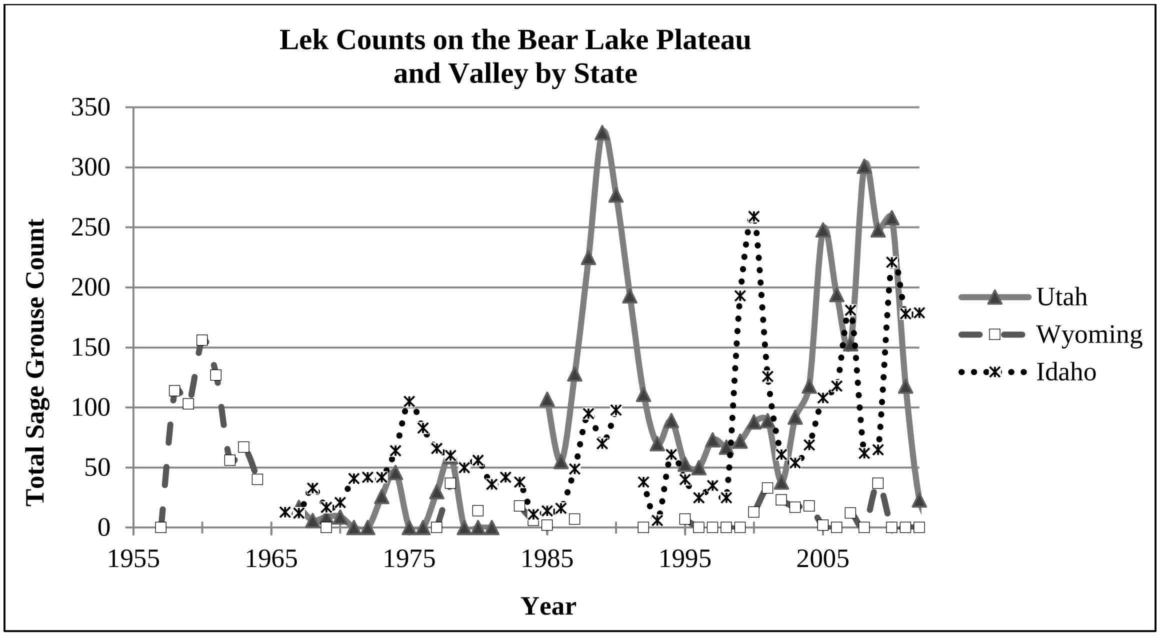


Figure 2-5. Greater sage-grouse (*Centrocercus urophasianus*) males counted by individual states during lek observations from 1955–2012 for leks present on the Bear Lake Plateau and Valley (BLPV) study area, Idaho-Utah-Wyoming, USA.

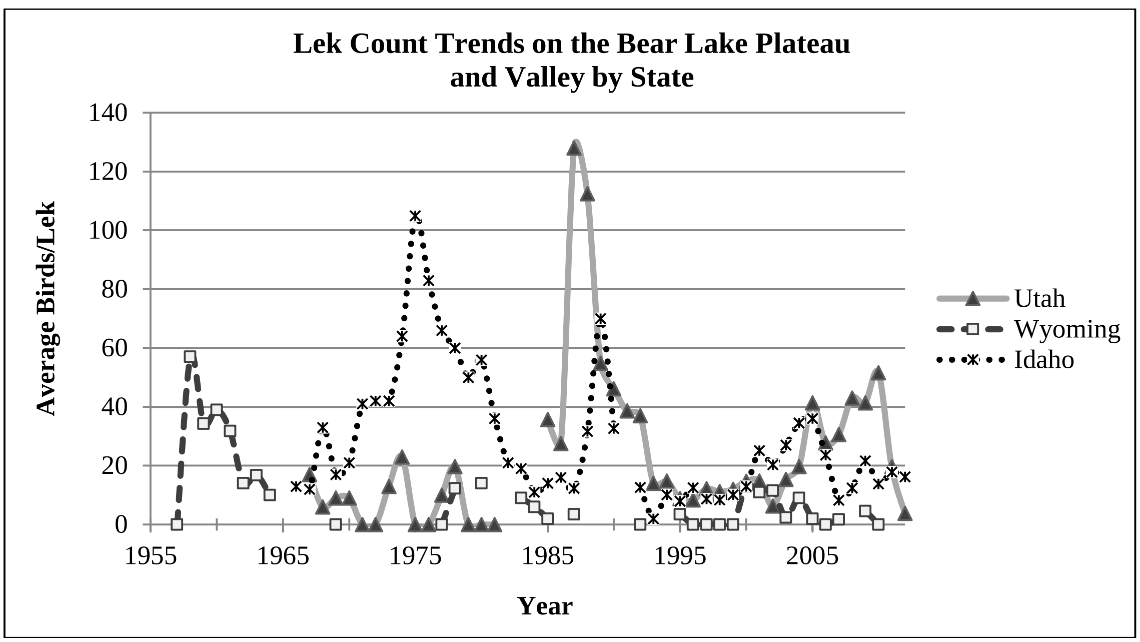
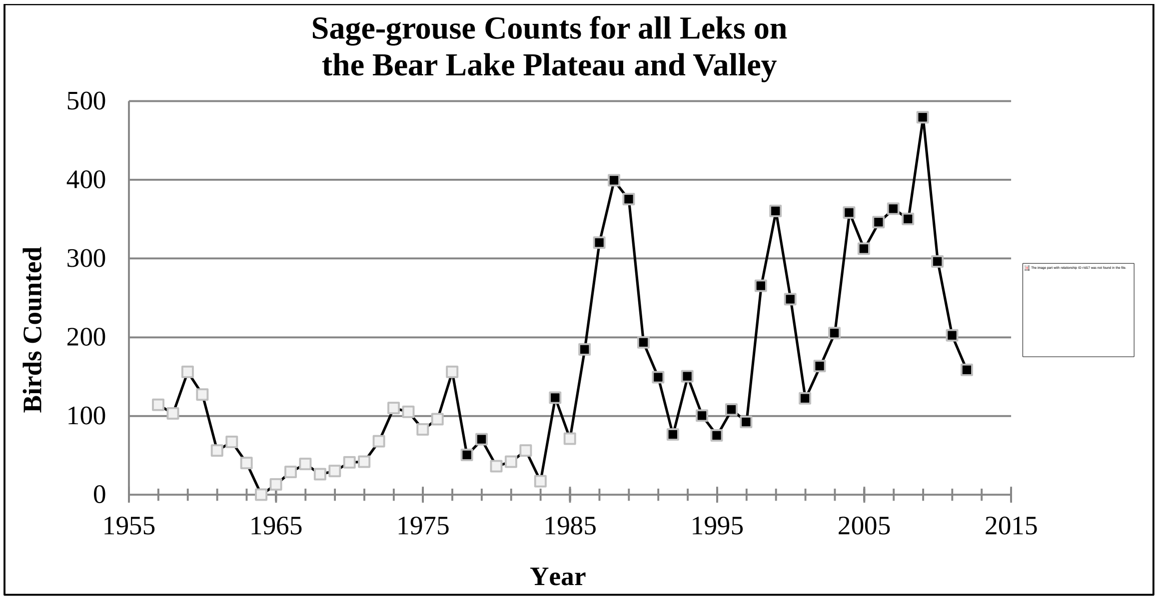
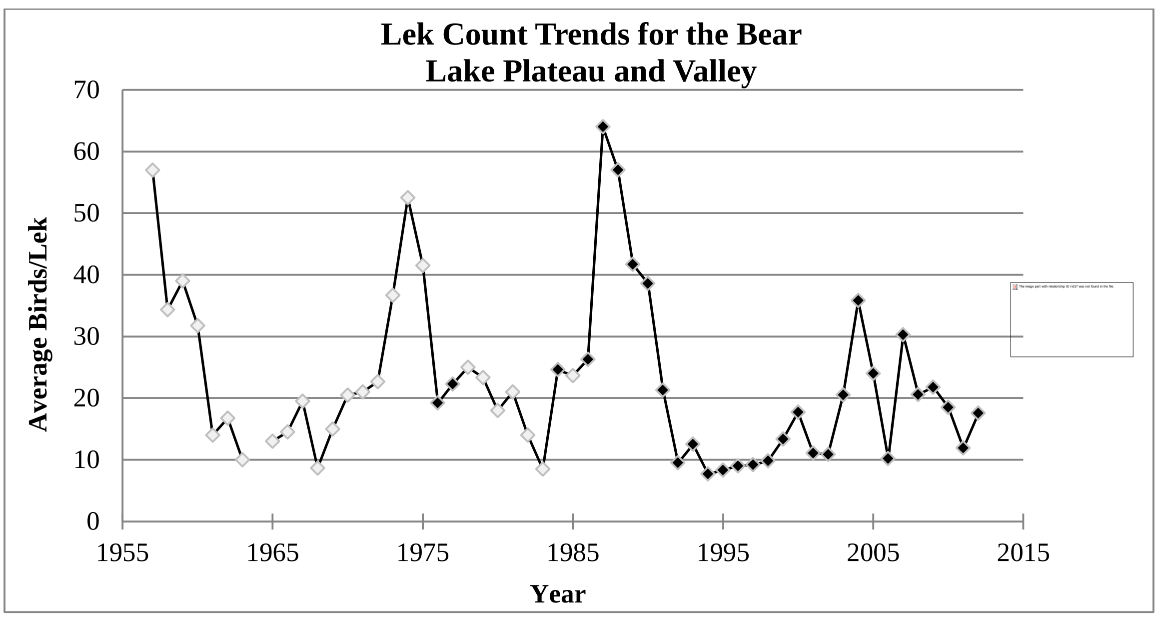


Figure 2-6. Greater sage-grouse (*Centrocercus urophasianus*) lek count averages from 1955–2012 for individual states on the Bear Lake Plateau and Valley (BLPV) study area, Idaho-Utah-Wyoming, USA. Total number of male sage-grouse counted was averaged by number of leks monitored within each state for each year.



* Black markers indicate years when ≥ 5 leks were counted

Figure 2-7. Total number of greater sage-grouse (*Centrocercus urophasianus*) males counted during lek observations from 1955–2012 across the Bear Lake Plateau and Valley (BLPV) study area, Idaho-Utah-Wyoming, USA.



* Black markers indicate years when ≥ 5 leks were counted

Figure 2-8. Average number of greater sage-grouse (*Centrocercus urophasianus*) males counted on leks from 1955–2012 on the Bear Lake Plateau and Valley (BLPV) study area, Idaho-Utah-Wyoming, USA. Total males counted was averaged by number of leks monitored each year.

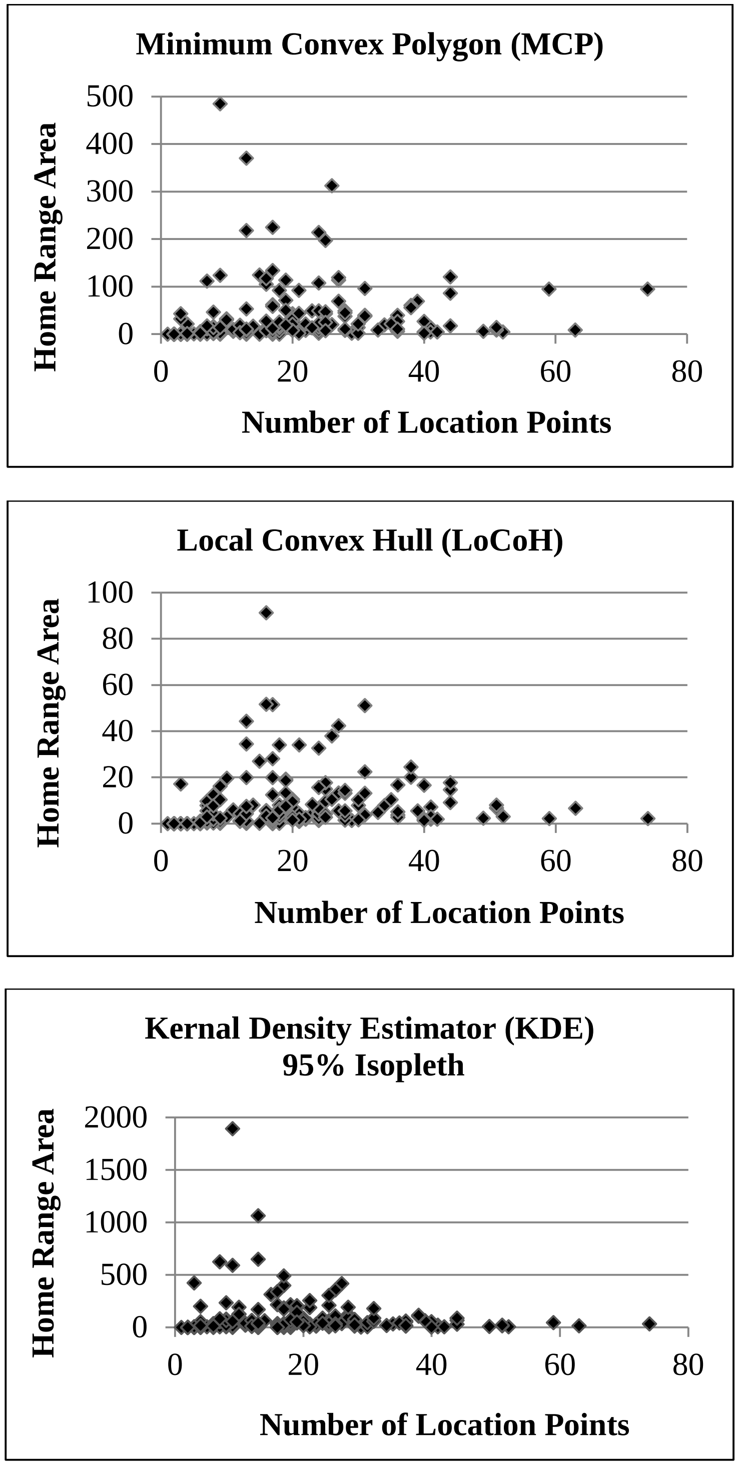


Figure 2-9. Number of location points for all individual greater sage-grouse (*Centrocercus urophasianus*) monitored that were used to calculate home range areas on the Bear Lake Plateau and Valley (BLPV) study area. Maximum areas were found between 10–30 points. BLPV Study 2010–2012.

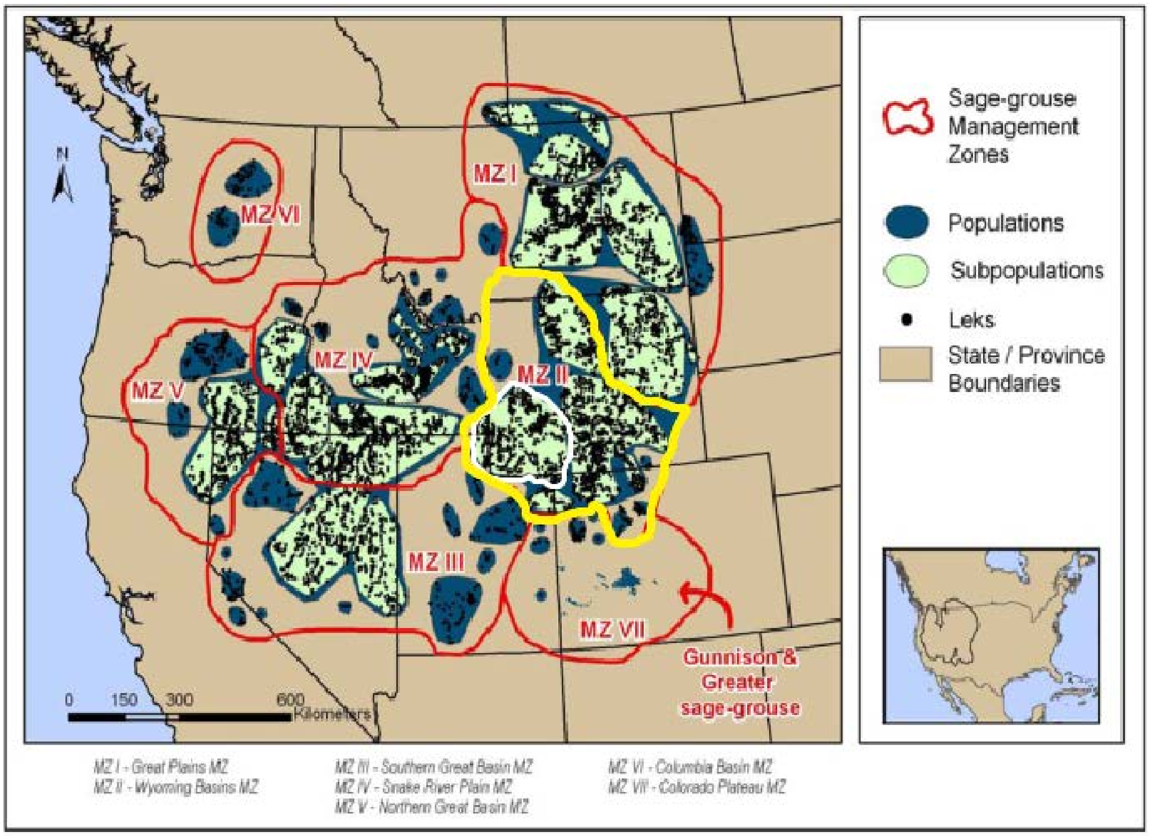


Figure 2-10. Range-wide greater sage-grouse (*Centrocercus urophasianus*) populations divided into sub-populations. Greater sage-grouse in the Bear Lake Plateau and Valley (BLPV) study area was included in the Wyoming Basin Management Zone highlighted in yellow. The southwestern Wyoming, northwestern Colorado, northeastern Utah, southeastern Idaho subpopulation was outlined in white (adapted from Connelly et al. 2004).

CHAPTER 3

GREATER SAGE-GROUSE HABITAT SELECTION IN A FRAGMENTED LANDSCAPE

ABSTRACT

The greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) is a landscape species that requires large expanses of sagebrush habitat for its annual life cycle. As such, habitat composition and connectivity at the landscape scale can impact sage-grouse seasonal movements, habitat use, and vital rates across the landscape. The landscapes used by the sage-grouse population inhabiting the Bear Lake Plateau and Valley (BLPV) in Utah, Idaho, and Wyoming exhibits both natural and anthropogenic habitat fragmentation. Habitat selection was modeled using MaxEnt. Ten landscape-extent environmental and anthropological habitat variables were included in models to predict core use and connection areas. All models were ranked with good to excellent fit (AUC ≥ 0.808). Variables with highest weight for predicting habitat selection were distance to major road, distance to habitat edge, distance to vertical structure, and land cover class. Probability of occurrence was highest with increased distance to major road. Habitat selection increased with increased distance to habitat edge. The preferred vegetation types were shrubland, grasslands, and wet meadows. Sage-grouse habitat composition and fragmentation varies across the BLPV study area with Bear Lake separating the east and western sides. The western side of the study area is bounded by Bear Lake to the east and national forest to the west. Fragmentation of habitat was greater on the west side of the study area, where both natural and anthropogenic fragmentation affected habitat

extent, resulting in slightly smaller habitat patch size ($\bar{x}$=0.2 km^2), higher edge to area ratios, and smaller proportions of habitat surrounding 10 km of leks (36.9%). The eastern portion of the study side is bounded by Bear Lake to the west, but has no habitat bounds to the east. The eastern side of the study area was characterized by more intact habitat with less fragmentation. Patch size was larger ($\bar{x}$=2.3 km^2), edge to area ratios were smaller, and there was more habitat within 10 km of leks (74.7%). Managers should focus conservation efforts on core areas with lower levels of fragmentation. Coupling state-defined habitat with MaxEnt habitat models could provide baseline data to create and implement a tri-state management plan.

INTRODUCTION

The greater sage-grouse (*Centrocercus urophasianus*; sage-grouse), is a sagebrush (*Artemisia* spp.) obligate species that requires large expanses of sagebrush habitat to complete its annual life cycle (Dalke et al. 1963, Connelly et al. 1988, Leonard et al. 2000, Connelly et al. 2000). Schroeder et al. (2004) estimated that sage-grouse currently occupy about 668,412 km^2, <60% of the estimated historic range, which currently includes 11 states and 2 Canadian Provinces (Fig. 3-1). Sage-grouse were designated as a candidate species in March 2010 by the U.S. Fish and Wildlife Service (USFWS) for protection under the Endangered Species Act (ESA) of 1973 (USFWS 2010). In the 12–month finding, the USFWS determined that sage-grouse warranted protection under the ESA range-wide, but their listing was precluded because of higher conservation priorities. Declines in sage-grouse populations have mainly been attributed to habitat loss and degradation of the sagebrush-steppe ecosystem (Braun 1998, Connelly et al. 2004, Knick and Connelly 2011).

Sagebrush ecosystem patterns, processes, and components have been altered since Euro-American settlement in the late 1800s (West and Young 2000, Bunting et al. 2003). The dominant factors that influence sagebrush habitats across sage-grouse range include: invasive species, wildfire, land use changes, and energy development (Connelly et al. 2004, Miller et al. 2011). Land use has modified sagebrush habitat due to development of anthropogenic features and large-scale conversion of sagebrush land cover to agricultural land, rural development, and energy developments (Leu and Hanser 2011). Sagebrush landscapes have been manipulated by means of prescribed fire, herbicides, and mechanical and biological treatment (Knick et al. 2003). These manipulations were used to improve forage production, reduce exotic species or woody cover, or reduce fire hazards (Knick et al. 2003, Connelly et al. 2004). In addition to manipulation of sagebrush landscapes, human populations have grown and expanded in the sagebrush biome since 1900 and removed sagebrush habitat (Connelly et al. 2004). Along with urbanization, the increase of roads may further fragment sagebrush ecosystems (Lyon and Anderson 2003).

The spatial patterns of sage-grouse on sagebrush landscapes can provide insights for managing populations and maintaining population viability (Knick and Hanser 2011). Sage-grouse respond to sagebrush landscape features, such as quantity, composition, and configuration, and these can be used to identify core areas (Wisdom et al. 2002, Doherty et al. 2011). Defining core areas of biological value represents a proactive attempt to identify conservation targets for maintaining viable and connected populations (Doherty et al. 2011). However, translating landscape structure into species response has proven elusive (Wiens and Milne 1989, Milne 1992, Wiens 2002, Calabrese and Fagan 2004) and relies on our ability understand how a species perceives its environment (Wiens et al. 1993, With et al. 1997, Baguette and Van Dyck 2007). Landscape metrics describing physical attributes of habitats and important resources can be integrated into spatial data layers using geographical information system (GIS) technology (Calabrese and Fagan 2004, Taylor et al. 2006). Taking spatial and temporal landscape dynamics into consideration during population assessment can help guide management decisions (Shugart 1998). Changes in land cover mosaic can influence the spatial and temporal dynamic of a natural system (Shugart 1998). Additionally, it is important to assess landscape metrics over broad scales, because wildlife populations do not perceive political boundaries (Stiver et al. 2006).

Modeling functional relationships of sage-grouse to their sagebrush habitat is challenging because important habitat characteristics are apparent at different spatial and temporal scales (Aldridge and Boyce 2007, Aldridge et al. 2008). Observer ability to understand important habitat characteristics depends on the scale domain used to measure and analyze selection. Extent and resolution are important to consider when assessing species habitat selection (Mayor et al. 2009, Knick et al. 2011). Large-scale attributes of sagebrush habitat may influence population dynamics (Knick and Hanser 2011). Population dynamics of sage-grouse within core components similarly may depend on the amount and quality of sagebrush or level of disturbance (Knick and Hanser 2011). Sage-grouse moving between seasonal ranges may be more sensitive to the broader-scale matrix and traverse areas that do not contain suitable habitats (Connelly et al. 1988, Leonard et al. 2000, Fedy et al. 2012). Fine-scale attributes of sagebrush habitats may influence seasonal movements and vital rates, including survival and productivity (Connelly et al. 2000, Crawford et al. 2004, Beck et al. 2006).

Species Distribution Models (SDMs) can be used to predict species distributions, characterize the natural distributions of species, and to understand species' environmental requirements (Graham et al. 2008). Species distribution models use field data including individual locations, and combine these data with landscape metrics to create mathematical predictions of species distribution throughout the environment (Elith and Leathwick 2009). Maximum Entropy (MaxEnt; Phillips et al. 2006) is a SDM with potential use for identifying distributions and habitat selection of wildlife (Baldwin 2009, Elith et al. 2011). This software makes predictions using presence-only data and GIS environmental layers (Phillips et al. 2006).

Presence-only data can be difficult to interpret because sample selection bias is affected by sampling effort, and it cannot be used to determine the prevalence of the species in the landscape (Elith et al. 2011, Hastie and Fithian 2013). MaxEnt performs post-transformation of the raw output and makes assumptions about prevalence and sampling effort in an attempt to predict species prevalence. MaxEnt is becoming more common in sage-grouse studies as a tool for modeling potential distributions and habitat selection (Yost et al. 2008, Freese 2009, Schrag et al. 2011, Burnett 2013).

The objective of my research was to create MaxEnt distribution models of sage-grouse habitat use and selection at a landscape-extent in the BLPV using location data collected through radio-telemetry. Little was known about habitat use of sage-grouse inhabiting the BLPV, apart from population trend data collected from lek counts. Landscape-extent environmental and anthropological habitat predictor attributes were included in models to predict general and core use areas sage-grouse on the BLPV. These habitat selection models were then projected to a surrounding area to identify potential habitat in the surrounding the BLPV. These projected models were then compared to current state wildlife agency sage-grouse habitat maps to assess the model and aid in refining core habitats.

STUDY AREA

The Bear Lake Plateau and Valley Study Area (BLPV) is located in Bear Lake County, Idaho, Rich County, Utah, and Lincoln County, Wyoming (Fig. 3-2). The BLPV encompasses 2450 km^2 (245,000 ha) comprised of different land ownership and management entities and constitutes the northwestern portion of the Wyoming Basin (Stiver et al. 2006). Approximately 58% of the area was privately-owned, 8.8% state-owned land, 8.1% managed by the U.S. Forest Service (USFS), 24.4% managed by the Bureau of Land Management (BLM), and 0.7% managed by the USFWS.

The BLPV differs on the east and western sides of the valley. The western side of the study area is bounded by the Caribou and Cache National Forests to the west and Bear Lake to the east. Population centers on the western side of the study area include Fish Haven, St. Charles, Bloomington, Paris, and Ovid, all in Idaho. On the plateau west of Bloomington, Idaho, a mining corporation has been exploring for phosphate. The corporation has placed exploration equipment and established roads to test sites in this area. More recreational homes and USFS roads are located on the western plateau compared to the eastern plateau. The eastern portion of the study side is bounded by Bear Lake to the west, but has no discernible habitat bounds to the east. Population centers on the east side of the study area include Montpelier, Geneva, and Raymond in Idaho, Laketown in Utah, and Cokeville, in Wyoming. The eastern side of the study area was characterized by more intact habitat with less fragmentation than the western side of the study area.

Topography

The elevation of the study area ranged from 1800–2500 m above mean sea level. The structural basins consist of north-south plateaus that parallel one another. The valley contains Bear Lake, a 282 km^2 surface area lake, and the 77 km^2 USFWS Bear Lake National Wildlife Refuge comprised mainly of bulrush (*Scripus* spp.) marsh, open water, and flooded meadows of sedges (*Carex* spp.), and grass-type species (Palacios et al. 2007, USFWS 2013). The plateau is dominated by sagebrush steppe.

Climate

The climate of the study area is typical of intermountain highlands with cold winters and hot summers. Temperatures range from average lows of -14.2°C in January, and highs of 28.8°C in July. The area receives between 25.4 and 43.2 cm of precipitation annually most which occurs between September and June as snow in winter and rain in summer. The average annual snowfall varies through the site varying between 83 and 235 cm, most of this occurs from October to March (Western Regional Climate Center 2013).

Vegetation

Vegetation was dominated by sagebrush steppe communities. The dominant shrubs included Wyoming big sagebrush (*A. tridentata. wyomingensis*), mountain big sagebrush (*A. t. vaseyana*), basin big sagebrush (*A. t. tridentata*), black sagebrush (*A.*

nova), serviceberry (*Amelanchier utahensis*), snowberry (*Symphoricarpos* spp.), and rabbitbrush (*Chrysothamnus* spp.). Common grasses included wheatgrasses (*Agropyron* and *Pseudoroegneria* spp.), bromegrass (*Bromus* spp.), bluegrass (*Poa* spp.) and wild rye (*Elymus* spp.). Common forbs included: *Phlox* spp., Redtop (*Agoseris glauca*), Hawksbeard (*Crepis acuminata),* groundsel (*Baccharis salicina*), rosy pussytoes (*Antennaria rosea*) milk vetch (*Astragalus* spp.), penstemon (*Penstemon* spp.) and daisy (*Erigeron* spp.). Cache and Caribou National Forests are characterized by high elevation tree stands consisting of lodgepole pine (*Pinus contorta*), spruce (*Picea* spp.), fir (*Abies* spp.), and aspen (*Populus tremuloides*) and sage-brush steppe in lower elevations (O'Brien and Pope 1997).

The primary land use was grazing by domestic livestock. Some grazing areas have been manipulated by brush removal and reseeded with introduced grasses. Because of the presence of Bear Lake, the BLPV is a major seasonal recreation area, with most of the use occurring in summer. Residential development is occurring at the base of Bear Lake on both the east and west sides of the study area.

METHODS

Captures

Sage-grouse were trapped at leks and roost sites throughout the study area in the spring and fall from March 2010–April 2012. Spotlights and binoculars were used to locate roosting grouse, and grouse were captured using a dip net (Wakkinen et al. 1992, Connelly et al. 2003). Sage-grouse were handled according to procedures approved under the Utah State University Institutional Animal Care and Use Committee permit

#1463, and with a Certificate of Registration from the Utah Division of Wildlife Resources (UDWR) #3BAND8430, and a Wildlife Collection Permit from Idaho Department of Fish and Game (IDFG) #100419. Sage-grouse were classified by sex (male or female) and age (juvenile, yearling or adult) using size and plumage (Dalke et al. 1963). Males and females were fitted with 18–26g necklace style very high frequency (VHF) radio-transmitters (Advanced Telemetry Systems, Insanti, MN; American Wildlife Enterprises, Monticello, FL; Wildlife Materials, Murphysboro, IL; Sirtrack, Havelock North, New Zealand). Radio frequencies ranged from 148.000–152.999 MHz, and they were checked with other wildlife projects in the area to insure no frequency overlap.

Fragmentation

Habitat fragmentation was described as habitat subdivision, loss, and degradation, and level of landscape connectivity (Lindenmayer and Fischer 2007). I delineated habitat using the United States Geological Survey (USGS) 2011 National Land Cover Data (NLCD) set (Homer et al. 2012, Gergely and McKerrow 2013), and USGS ortho-imagery (Mauck et al. 2009). The NLCD program was created to provide generalized and seamless land-cover data for the United States (Wardlow and Egbert 2003). It contains 20 classes of land cover data derived from Landsat imagery data, ancillary data including digital elevation models, and derivatives including slope and aspect (Table 3-1). Using the classified habitats in NLCD, I selected habitat as shrub and grassland/herbaceous cover. I classified non-habitat as developed areas, wetlands, water, major roads, forested areas, and cultivated agriculture. Because NLCD environmental covariates were defined at a 30 x 30 m scale, I used this information as the patch size for the basis of my delineation. Using classified habitat, I analyzed the study area for landscape patch area, length of edge, perimeter-area ratio, and number of disjunct core areas in ArcGIS. I defined core areas as contiguous habitat with a total area over 100 km^2. I used a 10 km buffer around each lek and clipped delineated habitat in this area to analyze differences in percentage of habitat surrounding leks, average habitat patch size, and edge-to-area ratios between different leks. Because leks are often within 10 km of each other, I also dissolved the lek buffers to compare the differences between habitat composition and fragmentation on east side buffered leks and west side buffered leks.

Habitat Selection

Sage-grouse Locations

Sage-grouse were located using radio-telemetry. Triangulation was used to calculate locations obtained using bearings collected in the field. All sage-grouse spatial locations were recorded using the geographic coordinate system Universal Transverse Mercador (UTM) Zone 12 T. Triangulation locations were calculated using Locate 3.18 (Nams 2006). Locate calculates an ellipse of confidence regions for each location. I removed locations that had error ellipses over 500,000 m^2 (0.5 km^2) in an attempt to removed bias of sage-grouse possibly selecting more than one type of habitat. I separated the locations by season: spring (15 March-14 June), summer (15 June-14 September), fall (15 September-15 December), and winter (15 December-14 March). Sage-grouse nesting activity was confirmed by carefully approaching hens that had confined their movements to specific areas and observing from at least 10 m away with binoculars. A hen was considered nesting when it was under the same bush for 3 consecutive days. Hens with broods were approached during the day by walking up or were spotlighted at night to count the number of chicks (Dahlgren et al. 2010).

MaxEnt

Maximum entropy was used to predict areas of habitat selection using presence-only locations (Phillips et al. 2006). Environmental covariates selected for the model were GIS raster data, and pixels of the rasters made up the scale at which each prediction was defined (Table 3-2). Environmental data were supplied in the form of grids of covariates covering a pixilation of the landscape. Predictions were made throughout a landscape of interest (Elith et al. 2011). Each covariate was clipped to the landscape of interest. MaxEnt first estimated the ratio of the conditional density of the covariates over the marginal density of covariates across the study area (Elith et al. 2011). The MaxEnt distribution probability was predicted using the equation:

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

where λ was a vector of n real-valued coefficients or attribute weights, $f(x)$ denoted the vector of all n attributes, and Z_{λ} was a normalizing constant ensuring that q_{λ} summed to 1 (Phillips et al. 2006). MaxEnt imposes constrains on the model so the output reflects information from the collected locations by attempting to minimize the conditional density of the covariates at the presence sites, compared to the marginal density of covariates across the study area (Baldwin 2009, Elith et al. 2011). MaxEnt avoids overfitting models by setting an error bound that reflects variation by feature class-specific tuned parameters (Yost et al. 2008). In addition, likelihood calculations are done simply at presence sites in an attempt to avoid over extrapolating habitat selection preference across the landscape (Elith et al. 2011). MaxEnt models a target distribution across a defined area by estimating a probability distribution that is closest to uniform, subject to a set of constraints that represent incomplete information about the target distribution (Phillips et al. 2006, Yost et al. 2008). The probability defined for each variable in the model can be extrapolated to estimate likelihood of species occurrence across a landscape (Phillips et al. 2006). MaxEnt randomly sampled 10,000 background locations from covariate grids (Elith et al. 2011, Burnett 2013), and extracted the predictor values at those sites. Predictor variables were also extracted at sage-grouse locations (Smith 2012). MaxEnt randomly selected 70% of the location data points for model training, and 30% of the location data points to test the model (Smith 2012). For nest and brood models, I used cross-validation techniques due to small sample size. MaxEnt replicated the model 10 times and averaged the results from all model replicates. A function was created that maximized the entropy between predictor variables extracted at sage-grouse locations and the background data points (Elith et al. 2011, Smith 2012). The output prediction values range from 0 to 1 based on the probability of species occurring in a specific location based on predictor variables. Top indicator variables were assessed for their impact on probability of sage-grouse occurrence. Using the model created from the study area, the probability of habitat selection can be projected onto a larger landscape.

Landscape of Interest

Picking an appropriate landscape of interest in which to create the MaxEnt model is very important (VanDerWal et al. 2009). If the selected landscape of interest is too small, there will be excessive overlap of background locations and presence points. A model with this excessive overlap will result in a low fit, as the model will not be able to select out which variables are important for predicating locations (Barbet-Massin et al. 2012). In a landscape of interest that is too large, background locations will show differences based on environmental conditions that are very different from the presence data (Barbet-Massin et al. 2012). This will overfit the model, and predicted distributions will be clustered around the points (Baldwin 2009). The original study area encompassed 99% of the locations and was 2,450 km^2. Several locations collected through aerial telemetry were 23–57 km outside the study site. In an attempt to include additional active leks in the area and other potential habitat near the edge of the study area, I buffered the study area by 5 km, for a landscape of interest of 4,025 km^2 (Fig. 3-2). I clipped each environmental covariate to the landscape of interest. All covariates needed the same geographic bounds and cell size to run the MaxEnt model. To identify potential habitats in the surrounding area (projection landscape), I projected the MaxEnt model 25 km south of the study area, 53 km to the east and west, and 75 km to the north. The projection landscape encompassed the entirety of sage-grouse locations collected during the study and known leks in the area. The projection landscape totaled 28,200 km^2 (Fig. 3-2).

Environmental Variables

Environmental variables included aspect, elevation, NLCD canopy cover, NLCD vegetation type, and distance to habitat edge (Fig. 3-4). Elevations were obtained from a 30–m digital elevation model (DEM) from the geospatial data gateway from the USGS

(Gesch et al. 2002, Gesch 2007). The National Elevation Dataset (NED) was created by integrating 10–m imagery, and then resampling at one arc-second (Gesch et al. 2002). Elevation on the BLPV ranged from 1795–2945 m. Using the 30–m DEM and spatial analyst tools in GIS, I created rasters of slope and aspect. Slope ranged from 0–57°. Slope was a continuous variable. Using spatial analyst tools in GIS, I divided aspect data into 8 cardinal and ordinal directions categories.

Land cover classes were defined using NLCD. The NLCD program was created to provide generalized and seamless land-cover data for the United States (Wardlow and Egbert 2003). It contains 20 classes of land cover data derived from Landsat imagery data, ancillary data including digital elevation models, and derivatives including slope and aspect (Table 3-1). A measurement of forest canopy cover was also used. The USFS cartographic canopy product was created by NLCD, and measures percent of tree canopy cover from 0 to 100 percent.

I added landscape composition distance from patch edge for the analysis as well. I created Euclidean distance rasters from the edge of the patch inward and outward. There may be limitations to the model by using the distance from habitat edge due to how habitat was defined. I classified habitat as shrub and grassland/herbaceous cover using NLCD. Shrubland habitat delineated in NLCD is of varying quality, some of which may not be suitable for sage-grouse use. Habitat quality and landscape condition are also important to assess when considering conservation of sage-grouse (Aldridge et al. 2008).

Anthropogenic Variables

Anthropogenic variables included developed land, distance to tall structures, and distance to primary and secondary roads (Fig. 3-4). Developed lands were defined using ortho-imagery, NLCD impervious surface data, and field observations. Developed lands included populated areas and lands that contained buildings (Connelly et al. 2004, Wickham et al. 2013). Distance from developed land was a continuous variable, calculated with spatial analyst tools in GIS. Distance to development ranged from 0–9687 m. I created a tall structures shapefile of high voltage, long distance transmission lines, communication towers, antennas, and wind turbines. I used the energy structure shapefile produced by USGS through the Interior Columbia Basin Ecosystem Management Project, tall structures data reported to the FAA and FCC, and field observations to create this shapefile. Using the spatial analyst tools in GIS, I created Euclidean distance rasters for distances to structure. Distance to the nearest tall structure ranged from 0–10,000 m, and was a continuous variable.

I obtained a road layer through Natural Resources Conservation Services Geospatial Gateway. Using the data in this road layer, field observations, and ortho-imagery, I classified roads as minor or major. Minor roads had slower vehicle speeds and lower levels of maintenance. Minor roads included: trails and 4 wheel drive trails, paved roads with speed limits less than 45 mph, and secondary roads which included local neighborhood streets. Major roads were classified by higher speeds and greater level of maintenance. Major roads included: county roads with speed limits greater than 45 mph, state highways, and interstates. Additionally, railroads were included in the major road classification. I compared the road layer to a 2011 ortho-imagery map to correctly assess the classification of road type. I created Euclidean distance rasters from the roads using the spatial analyst tools in GIS. Distance from the nearest minor road ranged from 0–

5,022 m, and distance to the nearest major road ranged from 0–16,687 m. Both distance variables were continuous.

Wildlife Agency and Sage-grouse Habitat Model Comparison

I projected the models obtained through MaxEnt to compare modeled sage-grouse habitat to core sage-grouse habitat determined by state agencies, field biologists, local working groups, USFS, and the BLM (Rodemaker et al. 2009, Inside Idaho 2012, Utah Automated Geographic Reference Center (ARGC) 2012). Sage-grouse habitat areas were found in State Geospatial Data Websites: Inside Idaho (2012), Utah AGRC (2012), and Wyoming Geospatial Hub (Rodemaker et al. 2009). State selected sage-grouse habitat was defined as core areas and general habitat by Idaho (Inside Idaho 2012). Utah state agencies created maps of occupied habitat, brood habitat, and winter habitat. I selected Utah's winter habitat to estimate core habitat, because it was the only seasonal habitat that was separated from the total occupied range. Wyoming Governor's sage-grouse conservation initiative classified Wyoming's sage-grouse range as overall habitat and core habitat (Rodemaker et al. 2009). I overlayed the MaxEnt predicted models on the state determined habitat boundaries. The MaxEnt model outputs a probability of habitat selection, and I used probability of occurrence of 0.1 to 1 as the sage-grouse general habitat. I utilized this range to capture all habitats with probability of sage-grouse occurrence. I defined core habitat as MaxEnt predicted probability of occurrence of >0.4. Using spatial analyst tools in GIS, I was able to calculate the difference in self modeled versus state modeled habitat.

Data Analysis

Fragmentation

Using ArcGIS, I obtained landscape patch area, length of edge, perimeter-area ratio, and number of disjunct core areas. I analyzed differences in average patch size and differences between perimeter-area ratios surrounding different leks using analysis of variance (ANOVA) (PROC GLM, SAS® System for Windows 9.3, Cary, NC). Variance was noted in comparing habitat patch size around lek, as patch size varied widely around leks. I compared the differences between east side buffered leks and west side buffered leks using a Satterthwaite's t-test for unequal variance (PROC TTEST, SAS).

Habitat Selection

MaxEnt contains statistical analysis in the model software (Elith et al. 2011). Probabilities were given from 0 (absence) to 1 (presence). To divide the predicted habitat into habitat/non-habitat, I chose a threshold probability of 0.1 and classified everything below 0.1 as non-habitat, and everything above it as habitat. I defined core habitat as MaxEnt predicted probability of occurrence of >0.4. Variable influence on the model was determined by providing a percent contribution of each variable on the final model, or by using a jackknife approach to exclude one variable at a time while running the model (Phillips et al. 2006). Model performance was evaluated using the test data to test against the training data used to create the model. Receiver operating characteristic (ROC) analysis evaluated model performance for areas under the ROC curve (AUC) (Deleo 1993, Phillips et al. 2006). The ROC analysis assigned a threshold to classify each sampled unit as positive or negative for species presence. The AUC ranged between

0.5 and 1.0, with the value 0.5 indicating the model was no better than random prediction (Wiley et al. 2003). For presence-only data, the AUC will always be less than 1.0 (Phillips et al. 2006). Categories for AUC classification were defined by Swets (1988) and Smith (2012).

RESULTS

Captures

I used location data from 153 radio-marked sage-grouse (71 adult males, 21 yearling males, 2 juvenile males, 35 adult females, 22 yearling females, and 2 juvenile females). In 2010, 39 sage-grouse were captured and radio-marked near leks 2B002, 2B015, and 2B043 (Fig. 3-3; 17 adult males, 6 yearling males, 8 adult females, and 8 yearling females). I captured and radio-marked an additional 7 sage-grouse on fall roosting areas (6 adult females and 1 juvenile female). In 2011, I captured and radio-marked 51 sage-grouse at leks: 2B015, 2B025, 2B032, 2B043 (Fig. 3-3; 28 adult males, 7 yearling males, 6 adult females, 10 yearling females). From August-October an additional 17 sage-grouse were captured and radio-marked at fall brooding locations (7 adult males, 2 juvenile males, 5 adult females, 2 yearling females, and 1 juvenile female). In 2012, I captured and radio-marked 39 sage-grouse at leks: 2B003, 2B015, 2B025, 2B032, and 2B043 (Fig. 3-3; 19 adult males, 8 yearling males, 10 adult females, and 2 yearling females). In addition, 272 incidental unmarked sage-grouse locations were recorded while traversing the study area.

Fragmentation

I validated my selection of habitat cover by comparing sage-grouse use of different vegetation classes in the NLCD. By extracting NLCD vegetation class data from each sage-grouse location, I determined that 92.9% of locations occurred in shrubland habitat, and 1.8% of locations occurred in grassland/herbaceous habitat. Only 5.3% of locations occurred in other habitat types. The average habitat patch size was 0.34 km^2 with areas ranging from 0.0007–933.01 km^2 (Fig. 3-3). The average amount edge per patch was 1.41 km, with edge length ranging from 0.02–2392.95 km. The perimeter-area ratio was largely dependent on patch size with the average edge-area ratio of 107 with the lowest ratio at 1.8 and the highest of 5072.6. There were four main disjunct core areas across the study area, with three on the east side of the study area, and one on the west side.

Areas surrounding different leks (Fig. 3-3) had varying levels of fragmentation, with leks on the west side of the lake showing much greater fragmentation than leks on the east side (Table 3-5). The average patch area surrounding different leks differed (p=0.025). Patch size variability within 10 km surrounding leks was very (Table 3-5). There was much more overlap in the leks in the western portion of the study area, because several leks were within 10 km of each other. The average patch area surrounding leks was similar on the east ($\bar{x}$=2.3 km^2; SE=1.69 km^2; n=791), and west side ($\bar{x}$=0.20 km^2; SE=0.17 km^2; n=791). The proportion of habitat in the 10 km buffer of east side leks was 74.7% compared to 36.9% on the west side.

Habitat Selection

Locations

Location data were obtained for 153 radio-marked sage-grouse (males, n=94; females, n=59) and 272 unmarked sage-grouse. I recorded 5,245 sage-grouse locations were recorded throughout the course of the study. Removing duplicates of birds in flocks or at leks yielded 2,314 locations (Fig. 3-5). Twenty-eight nest locations and 70 brood locations were recorded throughout the study.

MaxEnt

To model sage-grouse habitat use on the BLPV, MaxEnt used 1624 locations to train the model, and 695 locations to test model accuracy. The training run AUC was 0.872 and the AUC from the test run was 0.863 (SD=0.006). The annual model for sage-grouse habitat selection ranked as good (Swets 1988). The model for spring habitat selection used 684 training locations and 293 test locations. The training run AUC was 0.918, and the AUC from the test run was 0.908 (SD=0.008). The model for spring sage-grouse habitat selection ranked as excellent (Swets 1988). The model for summer habitat selection used 759 locations for training, and 324 locations for testing. The training run AUC was 0.909, and the AUC from the test run was 0.897 (SD=0.008). The model for summer sage-grouse selection ranked between good and excellent (Swets 1988). The model for fall habitat selection used 106 locations for training and 45 locations for testing. The training run AUC was 0.975, and the AUC from the test run was 0.953 (SD=0.013). The model for fall sage-grouse habitat selection ranked excellent (Swets 1988). The model for winter habitat selection used 61 locations for model training and

25 locations for testing. The training run AUC was 0.901, and the AUC from the test run was 0.808 (SD=0.045). The model for winter sage-grouse habitat selection ranked as good (Swets 1988). The model for nest habitat selection used 27 training locations, and 3 test locations. The training run AUC was 0.95, and the AUC from the test run was 0.886 (SD=0.064). The model for sage-grouse nest habitat selection ranked as good (Swets 1988). The model for brood habitat selection used 69 training locations, and 8 test locations. The training run AUC was 0.975, and the AUC from the test run was 0.956 (SD=0.025). The model for sage-grouse brood habitat selection ranked as excellent (Swets 1988).

Environmental Variables – Land cover class was an important variable in modeling annual, summer, fall, winter, and nesting habitat selection models (Table 3-4). When analyzed by MaxEnt as the only variable for habitat selection, sage-grouse primarily selected shrub/scrub habitats for all models. When combined with all of the landscape variables, different land cover classes became important in the habitat selection models. Nesting habitat was the one exception, and even when analyzed with all other variables, shrub habitat was the only land cover class with a high probability of occurrence for nest habitat selection (Fig. 3-17). Probability of sage-grouse occurrence in emergent herbaceous wetlands was high in annual, spring, summer, fall, and brood habitat selection models (Figs. 3-7, 3-9, 3-11, 3-13, and 3-19). Woody wetlands had high probability of occurrence for sage-grouse in annual and winter habitat selection models (Figs. 3-7 and 3-15). Probability of sage-grouse occurrence was higher for cultivated crops in summer (Fig. 3-11). Developed open space had an increased probability of occurrence in spring habitat models (Fig. 3-9). Probability of occurrence was elevated in pasture/hay habitat for brood habitat selection models (Fig. 3-19).

Elevation was an important variable in modeling annual, summer, fall, and brood habitat selection (Table 3-4). For all models probability of species occurrence was highest when elevation was between 1,800-2,300 m. Probability of occurrence peaked at 2,200 m in annual, summer, fall, brood, and nest habitat selection models (Figs. 3-7, 3-11, 3-13, 3-17, and 3-19). Probability of occurrence had peaks at 1,900 m and 2,200 m for spring habitat selection models (Fig. 3-9). Peak probability of occurrence for winter habitat models was at 1,900 m, with decreasing occurrence probability with increasing elevation (Fig. 3-15).

Distance to habitat edge was an important variable in the annual, spring, and summer models (Table 3-4). For all models except fall, probability of occurrence was highest within the habitat patch, and in non-habitat. For summer and brood rearing habitat, probability of occurrence was highest at farthest point within the habitat patch at about 3,000 m from the habitat edge (Figs. 3-11 and 3-19). For annual and spring habitat selection, probability of occurrence peaked at 500 m in a habitat patch (Figs. 3-7 and 3-9). Probability of occurrence peaked at 1,000 m into a habitat patch for winter and nesting habitat selection (Figs. 3-15 and 3-17). For fall habitat selection, probability of occurrence peaked in both non-habitat and within habitat patches near the edge (Fig. 3-13).

Slope was an important variable for winter habitat selection models, and a minor component in all other models (Table 3-4). Winter habitat models had peak probability of occurrence on slopes ranging 3-13º (Fig. 3-15). Slope in nest habitat selection models was also unique, as probability of occurrence was greatest at 5-45º (Fig. 3-15). All other habitat selection models had peak probability of occurrence at 3º (Figs 3-7, 3-9, 3-11, 3-13, and 3-19).

Forest canopy was a minor component in all habitat selection models ranging between 0.4-6.4% of variable contribution to the models (Table 3-4). For all models, except summer, probability of occurrence was highest at 0% canopy cover and dropped as canopy cover increased (Figs. 3-7, 3-9, 3-13, 3-15, 3-17, and 3-19). For summer habitat selection models, probability was highest at 0% but also had a minor peak at 35-40% canopy cover (Fig. 3-11).

Aspect was a minor component in all habitat selection models ranging between 0.5–5.6% of variable contribution to the models (Table 3-4). Nest models showed slightly higher probability of occurrence for E-SE and W-NW than other aspects (Fig. 3-17). There were no notable differences in probability of occurrence for different aspects for all other models (Figs. 3-7, 3-9, 3-11, 3-13, 3-15, and 3-19).

Anthropogenic variables – Distance to major road was an important contributor to all models (Table 3-4). Probability of occurrence was lowest near a major road, and increased as the distance to major road increased (Fig. 3-6). For all models, expect nest habitat, probability of occurrence was highest at 15,000 m from nearest major road (Figs. 3-7, 3-9, 3-13, 3-11, 3-15, and 3-19). For nest habitat selection models, probability of occurrence peaked at 7,000 m from a major road (Fig. 3-17).

Distance to tall structure was an important variable in the annual, spring, summer, fall, winter, and nest models (Table 3-4). For all models, probability of occurrence was highest at 1,000-3,000 m to tall structure. Probability of occurrence decreased as distance to structure increased beyond 3,000 m (Figs. 3-7, 3-9, 3-13, 3-11, 3-15, 3-17, and 3-19).

Distance to development was an important variable for spring and nest habitat selection models (Table 3-4). For all habitat selection models, except winter, probability of occurrence peaked between 200-2,000 m from a development, and then declined as distance to building increased (Figs. 3-7, 3-9, 3-13, 3-11, 3-17, and 3-19). Probability of occurrence in winter habitat selection models peaked at 3,000 m from a development, and then remained high as distance to development increased (Fig. 3-15).

Distance to minor road was an important variable for brood habitat selection models, and a minor component in all other habitat selection models (Table 3-4). Probability of occurrence was highest from 0-200 m to a minor road for brood habitat selection (Fig. 3-19). A high probability of occurrence close to minor roads is likely due to the number of incidental broods recorded while traversing the study. For annual, spring, fall, and winter habitat models, probability of occurrence was highest between 0-1,000 m to a minor road (Figs. 3-7, 3-9, 3-13, and 3-15). For summer and nesting habitat selection models, probability of occurrence increased as distance to a minor road increased and peaked at 5,000 m from a minor road (Figs. 3-11 and 3-17).

Wildlife Agency and Sage-grouse Habitat Model Comparison

Within the projection landscape (28,200 km^2) Idaho, Utah, and Wyoming state wildlife agencies estimated 10,926 km^2 of occupied area and 4,978 km^2 of core habitat (Fig. 3-20). The occupied area predicted by MaxEnt was 5,640 km^2, and the core habitat area predicted by the MaxEnt model was 1,291 km^2 (Fig. 3-20). Within the projection landscape, Idaho identified 2,151 km^2 of potential sage-grouse habitat and 885 km^2 of core habitat. MaxEnt modeled 2,510 km^2 of potential habitat and 605 km^2 of core habitat within the projection landscape in Idaho. Within the projection landscape, UDWR identified 1,611 km^2 of potential sage-grouse habitat. Because UDWR winter habitat was restricted to a smaller area, I considered this core habitat. The UDWR estimated there was 789 km^2 of winter habitat in the projection landscape. MaxEnt modeled 961 km^2 of potential habitat and 266 km^2 of core habitat within the state of Utah. Wyoming Governor's Sage-grouse Conservation Initiative identified 7,163 km^2 of potential sage-grouse habitat and 3304 km^2 of core habitat within the projection landscape. MaxEnt modeled 2,168 km^2 of potential habitat and 420 km^2 of core habitat in the projection landscape in Wyoming.

DISCUSSION

Fragmentation

Habitat loss and fragmentation influence population dynamics, and high levels of habitat loss often results in increased probability of species extinction (Fahrig 2003, Aldridge et al. 2008). Sage-grouse vital rates, movements, and habitat use are influenced by fragmentation, though effects of fragmented landscapes have shown mixed results on populations (Schroeder 1997, Lyon and Anderson 2003, Shepherd 2006, Perkins 2010). Habitat loss and fragmentation varied across the BLPV.

Anthropogenic-caused habitat loss was highest on the west side of the study area along the base of the plateau. Towns and vacation homes range along the west side of Bear Lake with human-footprint-intensity ranging from intermediate to high (Leu and

Hanser 2011). Human-footprint-intensity on the east side of the study area consisted mostly of vacation homes near the lake edge, plus several towns including Montpelier, Idaho and Cokeville, Wyoming (Leu and Hanser 2011). Natural fragmentation also occurred across the study area. Bear Lake and the Bear Lake National Wildlife Refuge comprise large areas of non-habitat, as do the national forests on the west and north sides of the study area (O'Brien and Pope 1997, USFWS 2013). Leks on the west side of the study area are separated from leks on the east side by ≥ 15 km, with large blocks of non-habitat in this distance (Fig. 3-3). Movement corridors between breeding habitats can reduce the effect of fragmentation on populations (Fahrig and Merriam 1985, Fahrig 1997, Fahrig 2003, Taylor et al. 2006, Knick and Hanser 2011, Knick et al. 2013). Sage-grouse on the BLPV are likely using small patches of habitat as movement corridors to cross non-habitats between the east and west sides of the study area (Fig. 3-3).

The differing levels of habitat loss and fragmentation across the Bear Lake Plateau and Valley may account for some of the variation found in BLPV sage-grouse vital rates (Beck et al. 2006, Perkins 2010, see Chapter 2). Leks on the west side of the study area were associated with less habitat and smaller patch sizes within 10 km of active leks, compared to 10 km areas surrounding east side leks. Additionally, leks on the west side had higher edge to area ratios in the surrounding area compared to those on the east side. MaxEnt modeled nest habitat selection was influenced by distance to edge, and probability of nest occurrence was greatest farther from habitat patch. Lyon and Anderson (2003) noted that hens in disturbed areas had lower nest initiation rates than hens in undisturbed areas. West side leks did not have as much predicted breeding habitat as leks on the east side of the lakes, which may result in lower recruitment.

Habitat Selection

All MaxEnt models ranked with good to excellent fit for predicting sage-grouse probability of occurrence in the landscape, though land cover and sagebrush habitats were not the primary factor for probability of occurrence. A key factor in sage-grouse occurrence and persistence is the presence of sagebrush habitat (Aldridge et al. 2008, Johnson et al. 2011, Wisdom et al. 2011, Knick et al. 2013). Sage-grouse are a sagebrush obligate, and they require sagebrush for cover, food, and nesting (Schroeder et al. 1999, Aldridge et al. 2008, Connelly et al. 2011). MaxEnt models are a technique to model potential habitat, and when land cover class was assessed as the only variable for habitat selection, shrub/scrub was primarily selected by sage-grouse. When the model contained all ten variables, some variables ranked higher than land cover class. Additionally, when assessed as a full model, the importance of shrub/scrub for predicting probability of occurrence also decreased. Though other variables and land cover types were important in the MaxEnt models, a critical missing component in the models was sagebrush quantity and quality. Including measurement of habitat quality may have increased the model fit for predicting sage-grouse habitat selection. Microscale features (i.e., sagebrush quantity and quality, grass height, forb composition) could not be modeled using MaxEnt, but they are important in sage-grouse habitats (Connelly et al. 2011). Collecting microscale vegetation information will help better delineate core areas, which could then be targeted for conservation efforts.

Environmental Variables- MaxEnt modeled habitat types that were important for BLPV sage-grouse included emergent herbaceous wetlands, shrub/scrub, woody wetlands, cultivated cropland, pasture/hay, and developed open space. Range wide studies have found that sage-grouse use mesic areas for pre-nesting and early brood rearing (Connelly et al. 2000, Jensen 2006, Shepherd 2006, Kaczor 2008). Emergent herbaceous wetlands offer mesic habitat with a greater proportion of forbs, and are used by BLPV in spring, summer, fall and brood rearing (Connelly et al. 2011). Emergent herbaceous wetlands may be a limiting land cover type on the BLPV. It is a disproportionately picked habitat during much of the year, and it has low frequency across the BLPV study area. Pasture/hay habitats also offer areas of higher forb concentration and can be used in brood rearing (Connelly et al. 2011). Sage-grouse may also utilize agricultural lands during the summer (Connelly et al. 1988), and probability of sage-grouse occupancy in agriculture land cover was higher during summer. The probability of occurrence of sage-grouse in developed open habitat in spring is likely associated with lek attendance. Sage-grouse on the western plateau of BLPV used developed open space outside of the town of Bloomington to lek, which could have created an emphasis on developed open space as spring habitat.

On the BLPV, elevation was associated with habitat types. Forested habitats are found on elevations greater than 2,300 in the BLPV. Low level elevations are associated with Bear Lake and wetlands. Sagebrush habitats are bounded by these elevation barriers on the BLPV, leading to higher probabilities of sage-grouse occurrence in mid-level elevation. Sage-grouse lek trends were highest at 2,100 m in the Wyoming Basin (Johnson et al. 2011), which is comparable to sage-grouse elevation selection on the BLPV.

Summer habitat selection had a small peak in sage-grouse occurrence probability in areas with forest canopy cover. In limited numbers of studies, sage-grouse in have been found to seek refuge in lightly forested areas during the summer (Burnett 2013, Duvuvuei 2013), though this is likely due to limited other habitats available. Sage-grouse on the western edge of the BLPV may be seeking refuge in less desirable forested areas due to limited habitats available.

Winter sage-grouse habitat was associated with slopes ranging 3-13º. Sage-grouse winter habitat selection is influenced by snow depth, topography, and available vegetation (Patterson 1952, Dalke et al. 1963, Beck 1977). The BLPV receives a large proportion of snow, and sage-grouse may be using windswept ridges with open sagebrush cover (Beck 1977).

Interior habitat in patches could be a limiting habitat variable on the BLPV. Sage-grouse on the BLPV avoided non-habitats and preferred habitat patch interiors. More suitable protective cover may occur in the interior of a habitat patch. Edges area often associated with mixing of habitat type (Harris 1988, Yahner 1988), and sage-grouse may be more susceptible to increased predation near an edge (Shepherd 2006, Perkins 2010). Additional fragmentation of habitats on the BLPV could further limit habitat use by sage-grouse, leading to population decline (Perkins 2010, Knick et al. 2013).

Anthropogenic variables- Probability of sage-grouse habitat occupancy increased with increasing distance from nearest major road. Major roads are often associated with river valleys and low elevations (Knick et al. 2011), exotic plant invasions (Gelbard and Belnap 2003), high volume of traffic (Trombulak and Frissell 2000), and an area of impervious surface cover. Avoidance of major roads has been found in previous studies (Braun 1986, Trombulak and Frissell 2000, Holloran 2005). Lek count trends tend to be lower on leks near federal and state highways (Johnson et al. 2011). Additional construction of major roads in the study area could negatively impact sage-grouse on the BLPV.

Vertical structures provide perches for raptors, and sage-grouse avoid avian predators, especially during nesting and brood rearing (Coates et al. 2014). Probability of sage-grouse occurrence decreased beyond 3 km of a vertical structure, though this was likely observed because there are few structures in areas of non-habitat (i.e. forested habitats, wetlands; Baruch-Mordo et al. 2013). In heavily forested and mountainous areas, there are fewer structures due to low anthropogenic need and inaccessibility for maintenance. These areas are also avoided by sage-grouse. In other studies, sage-grouse had variable reactions to vertical structure based on structure type (Johnson et al. 2011). Powerlines did not have an apparent effect on lek trend, but communication towers were associated with negative lek count trends within 18 km (Johnson et al. 2011). This may be a function of human activity near communication towers, whereas powerlines are located in more remote areas.

Probability of brood occurrence was highest in close proximity to minor roads, though this is likely biased due to a number of incidental observations made while traversing the study area on minor roads. Gravel roads and two-tracks offer an area of sparse vegetation easier for brood movement, especially during the first few weeks of life when chicks have low mobility (Hannon and Martin 2006), and this was captured in incidental observations.

All MaxEnt models ranked with good to excellent fit for predicting sage-grouse probability of occurrence in the landscape. There was a large amount of overlap in predicted seasonal habitats (Figs. 3-6, 3-8, 3-10, 3-12, 3-14, 3-16, amd 3-18). This overlap was likely the result of overlap in importance of predictor variables. Variables that were important in multiple models included: distance to major road, distance to vertical structure, land cover class, elevation, and distance to habitat edge. Combined with information on the importance of sagebrush to sage-grouse habitat (Aldridge et al. 2008, Connelly et al. 2011, Knick and Hanser 2011), MaxEnt identified variables can be used for targeted conservation efforts in the BLPV and surrounding areas.

The most limiting habitats modeled by MaxEnt were fall, nesting, and brood-rearing habitats (Figs. 3-12, 3-16, and 3-18). These are important habitats for sage-grouse on the BLPV. Breeding season habitats are critical for sage-grouse production (Connelly et al. 2011). Using MaxEnt model habitats models, areas used as breeding habitat can be identified and then assessed at a smaller scale. Information on microscale vegetation needs at nest and brood-rearing habitats could then be used for to improve these identified breeding habitats. It could also be beneficial to sage-grouse on the BLPV to preserve fall habitats. Seasonal survival of sage-grouse on the BLPV was highest during the fall (see Chapter 2). The habitats utilized by sage-grouse during the fall are able to supply food and cover for sage-grouse survival, and preservation of these habitats could help to maintain high fall survival rates.

Wildlife Agency and Sage-grouse Habitat Model Comparison

The occupied habitats estimated by state wildlife management agencies encompassed a much larger area than predicted by the MaxEnt habitat models (Fig. 3-20). State estimates were obtained through analysis of sagebrush habitats and knowledge of sage-grouse past and present distributions (Rodemaker et al. 2009, Inside Idaho 2012, Utah AGRC 2012). MaxEnt modeled habitat was based on locations collected during the study and selected environmental covariates, and some aspects of habitat selection by sage-grouse may have been missed by the model. MaxEnt models for the BLPV did not calculate land cover as the most critical component, and presence of sagebrush is vital to sage-grouse presence (Aldridge et al. 2008). The NLCD land cover database includes habitats of varying quality, some of which may not be suitable for sage-grouse use. Habitat quality is important to assess when considering conservation of sage-grouse habitats (Aldridge et al. 2008).

However, there were several areas modeled as general habitat through MaxEnt that could be added to state general habitats for conservation efforts. Areas with noted differences of habitat between MaxEnt modeled habitat and state defined habitats include areas of Bannock, Bingham, Franklin, and Caribou Counties, Idaho. Several sage-grouse captured on the BLPV used seasonal habitats in these counties during the winter (Fig. 3-5). MaxEnt overestimated the amount of potential habitat in Idaho, and included many areas where sage-grouse have not been documented. These habitats could be used by sage-grouse as seasonal movement corridors to connect populations. Wyoming and Utah defined a large selection of general habitat, encompassing most of the MaxEnt modeled habitat (Fig. 3-20). Core areas selected by states were defined using additional information on the habitat requirements of sage-grouse including defined key habitat from previous studies, winter and breeding habitat as defined by local biologists, included migratory pathways, and excluded non-habitat (Rodemaker et al. 2009, Inside Idaho 2012, Utah AGRC 2012). Core habitats defined by state agencies encompassed most of the core habitat defined using MaxEnt models (Fig. 3-20).

MANAGEMENT IMPLICATIONS

Both anthropogenic and natural fragmentation occurs across the BLPV. Preservation of current contiguous blocks of habitat could be beneficial on the BLPV, as sage-grouse occurrence was less likely near habitat edge. Maintenance of important habitat types, particularly emergent herbaceous wetlands could be valuable for sage-grouse on the BLPV. Emergent herbaceous wetlands provide valuable forb producing habitat, and were disproportionately selected by sage-grouse in MaxEnt models. Forb production around nest and broods sites was lower than recommended habitat guidelines (see Chapter 2), and improvement of high-density forb habitat could improve breeding and brood-rearing success. Keeping vertical structures out of core sage-grouse habitats could reduce avian predation, particularly during the breeding season. Construction of vertical structures could be targeted to areas that sage-grouse avoid, such as near human developments.

Maintenance of connectivity habitat could increase probability of population persistence, particularly for populations at the edge of a range (Crooks and Sanjayan 2006, Noss and Daly 2006). Sage-grouse in the BLPV could provide a genetic connection between the Wyoming Basin population and the Snake River Plain populations. Sage-grouse are likely using small patches of habitat as movement corridors to cross the potential non-habitat barriers (Fig. 3-3). Protection of movement corridors could benefit individuals that make migratory and dispersal movements between habitat patches. MaxEnt modeled habitat outside of the bounds of the study area could be maintained for sage-grouse use in dispersal movements to other populations. Potential habitat mitigation techniques could involve conservation easements, or cost-share programs to maintain and enhance native rangeland.

State defined habitats encompassed a majority of the MaxEnt predicted habitat. By selecting larger areas than modeled habitat, states are safeguarding both current and potential future habitat for sage-grouse. Cooperation between state agencies and local working groups in Idaho, Utah, and Wyoming could aid in landscape and population management efforts. Sage-grouse on the BLPV readily move between Idaho and Utah, and occasionally into Wyoming. Predicted habitat modeled using locations collected during the study identified sage-grouse habitat in all three states. Additional studies in Wyoming could help define important habitats on the eastern edge of the BLPV. As sage-grouse were not trapped in Wyoming during this study, comparison and inference for the BLPV sage-grouse habitat selection model in Wyoming is limited.

The creation of a tri-state management plan for sage-grouse on BLPV would be advantageous for conservation of important seasonal habitats found in all three states. These general and core habitat could be identified by MaxEnt models, local working groups, and state agencies. Because approximately 58% of the BLPV sage-grouse habitat occurred on private land, it is important that wildlife managers work with private landowners to maintain native range and avoid division of contiguous habitat.

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Table 3-1. National Land Cover Database (NLCD) land types identified by U.S. Geological Survey present on the Bear Lake Plateau and Valley (BLPV) study area and projection landscape, Idaho-Utah-Wyoming, USA. BLPV Study, 2010–2012.

Value	Class Name
11	Open Water
12	Perennial Ice/ Snow
21	Developed, Open Space
22	Developed, Low Intensity
23	Developed, Medium Intensity
24	Developed, High Intensity
31	Barren Land (Rock/Sand/Clay)
41	Deciduous Forest
42	Evergreen Forest
43	Mixed Forest
52	Shrub/Scrub
71	Grassland/Herbaceous
81	Pasture/Hay
82	Cultivated Crops
90	Woody Wetlands
95	Emergent Herbaceous Wetlands

Table 3-2. Predictor variables for species distribution modeling for greater sage-grouse (*Centrocercus urophasianus*) on the Bear Lake Plateau and Valley (BLPV) study area, Idaho-Utah, USA. BLPV Study, 2010–2012.

Variable	**Type**	**Description**
Environmental		
Aspect	Categorical	Obtained from 30–m digital elevation model from USGS, and classified into 8 categories
Elevation	Continuous	Obtained from a 30–m digital elevation model from USGS
Distance to Edge	Continuous	Distance to the edge of a shrub/grassland habitat patch defined by 2006 National Land Cover Database
NLCD Canopy Cover	Continuous	Forest canopy cover obtained from the United State Geological Survey 2006 National Land Cover Database
NLCD Vegetative Cover	Categorical	Vegetation categories obtained from the United State Geological Survey 2006 National Land Cover Database
Slope	Continuous	Obtained from 30–m digital elevation model from USGS
Anthropogenic		
Distance to Primary Road	Continuous	Distance to dirt roads and county roads with speed limits <45 mph
Distance to Secondary Road	Continuous	Distance to paved roads with speed limits of >45 mph
Distance to Development	Continuous	Distance to the nearest human development
Distance to Structure	Continuous	Distance to nearest tall structure defined by FAA and FCC and nearest high voltage transmission line

Table 3-3. Proportion of habitat and average area of habitat patches within a 10-kilometer buffer of greater sage-grouse (*Centrocercus urophasianus*) leks trapped on the Bear Lake Plateau and Valley (BLPV) study area, Idaho-Utah, USA. BLPV Study, 2010–2012.

Lek	*n*	Proportion of Habitat (%)	Average Patch Area (km^2)	Variance	SD	SE
2B002	1476	40.7	0.31	103.8	10.2	0.27
2B003	1473	44.0	0.29	103.3	10.2	0.26
2B025	1290	37.2	0.3	38809.7	197.0	0.30
2B032	519	68.8	6.74	188.8	10.9	4.95
2B042	1047	70.9	2.84	12726.5	112.8	2.41
2B043	791	72.4	3.18	6057.2	77.8	3.13
North Eden	158	89.8	15.68	7753.0	88.1	15.67

Table 3-4. Percent contribution of predictor variables to MaxEnt models for greater sage-grouse (*Centrocercus urophasianus*) species distribution models on the Bear Lake Plateau and Valley (BLPV) study area, Idaho-Utah, USA. BLPV Study, 2010–2012.

					Contribution %									
Model	Train *N*	Test *N*	Train AUC	Test AUC	Aspect	Dist. to Develop	Dist. to Edge	Elevation	Major Road	Minor Road	NLCD	NLCD Canopy	Slope	Structure
All	1624	695	0.872	0.863	0.77	8.31	**16.21**	12.68	**31.42**	0.80	**13.11**	0.60	0.85	**15.65**
Spring	684	293	0.918	0.908	0.53	11.48	**16.32**	**16.23**	**28.71**	0.26	7.24	0.48	1.09	**17.35**
Summer	759	324	0.909	0.897	1.50	7.35	12.34	**15.63**	**32.61**	2.82	**12.42**	0.65	1.38	**13.31**
Fall	106	45	0.975	0.953	2.03	8.62	10.26	**14.97**	**32.10**	1.09	**10.93**	0.82	1.32	**17.86**
Winter	61	25	0.901	0.808	2.49	1.63	0.48	3.68	**48.73**	3.25	**22.18**	1.80	**5.35**	**10.41**
Nest	27	3	0.951	0.886	5.65	14.33	1.89	**7.63**	**32.05**	0.323	**24.75**	1.00	1.15	**11.31**
Brood	69.3	7.7	0.975	0.957	1.71	3.25	0.02	**10.54**	**25.36**	**41.90**	3.43	**6.44**	2.87	4.49

Top four predicator variables for each model in bold

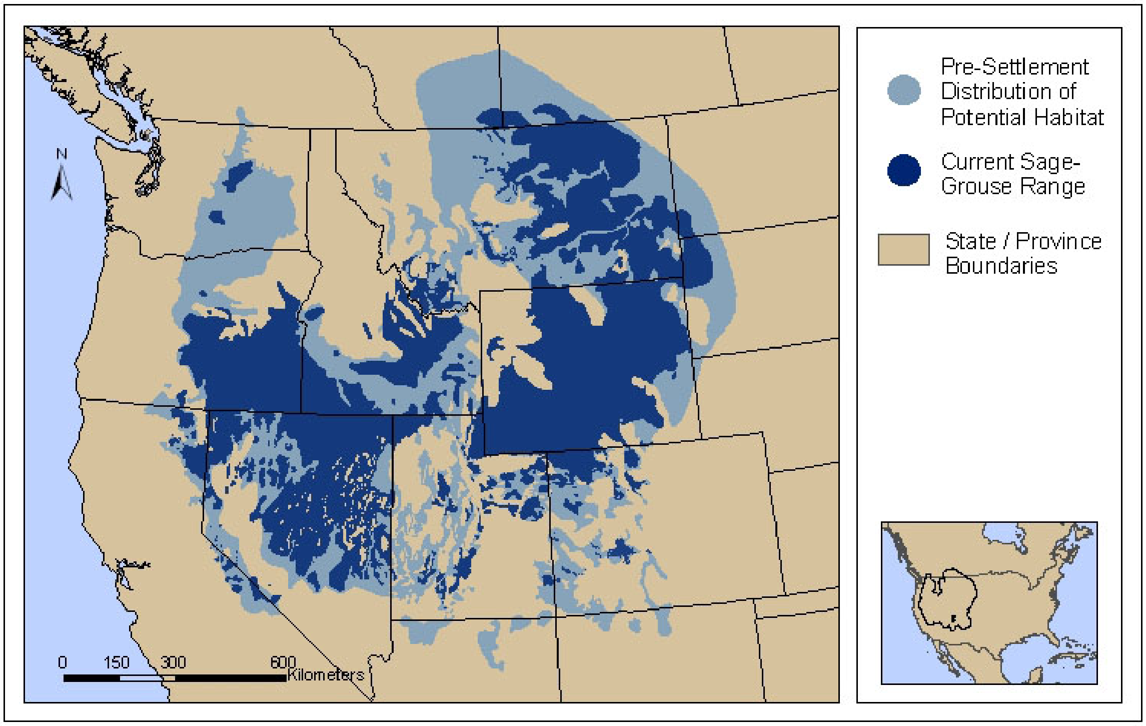

Figure 3-1. Current and estimated pre-settlement distribution of greater sage-grouse (*Centrocercus urophasianus*) habitat in North America (Schroder et al. 2004, Stiver et al. 2006).

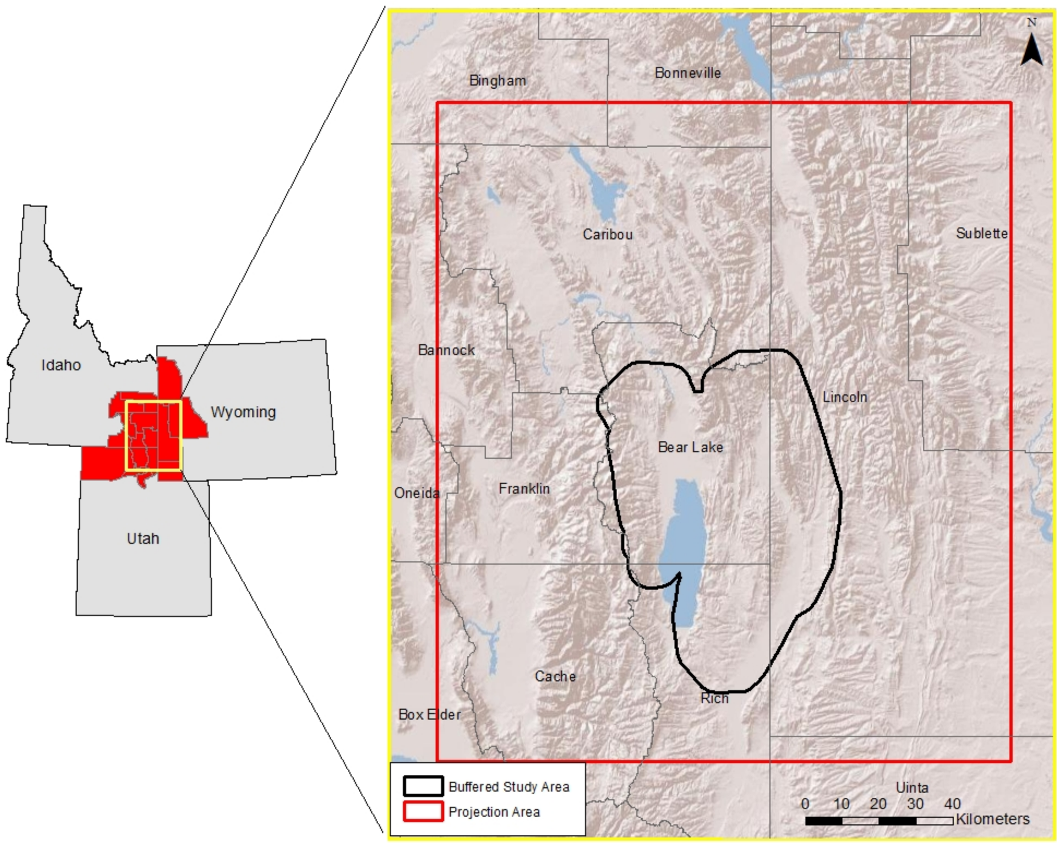

Figure 3-2. Buffered Bear Lake Plateau and Valley (BLPV) study area, Idaho-Utah-Wyoming, USA. The landscape of interest selected for the MaxEnt model included the study area buffered by 5 km. The projection landscape encompassed 100% of greater sage-grouse (*Centrocercus urophasianus*) locations and 18 surrounding leks. BLPV Study, 2010–2012.

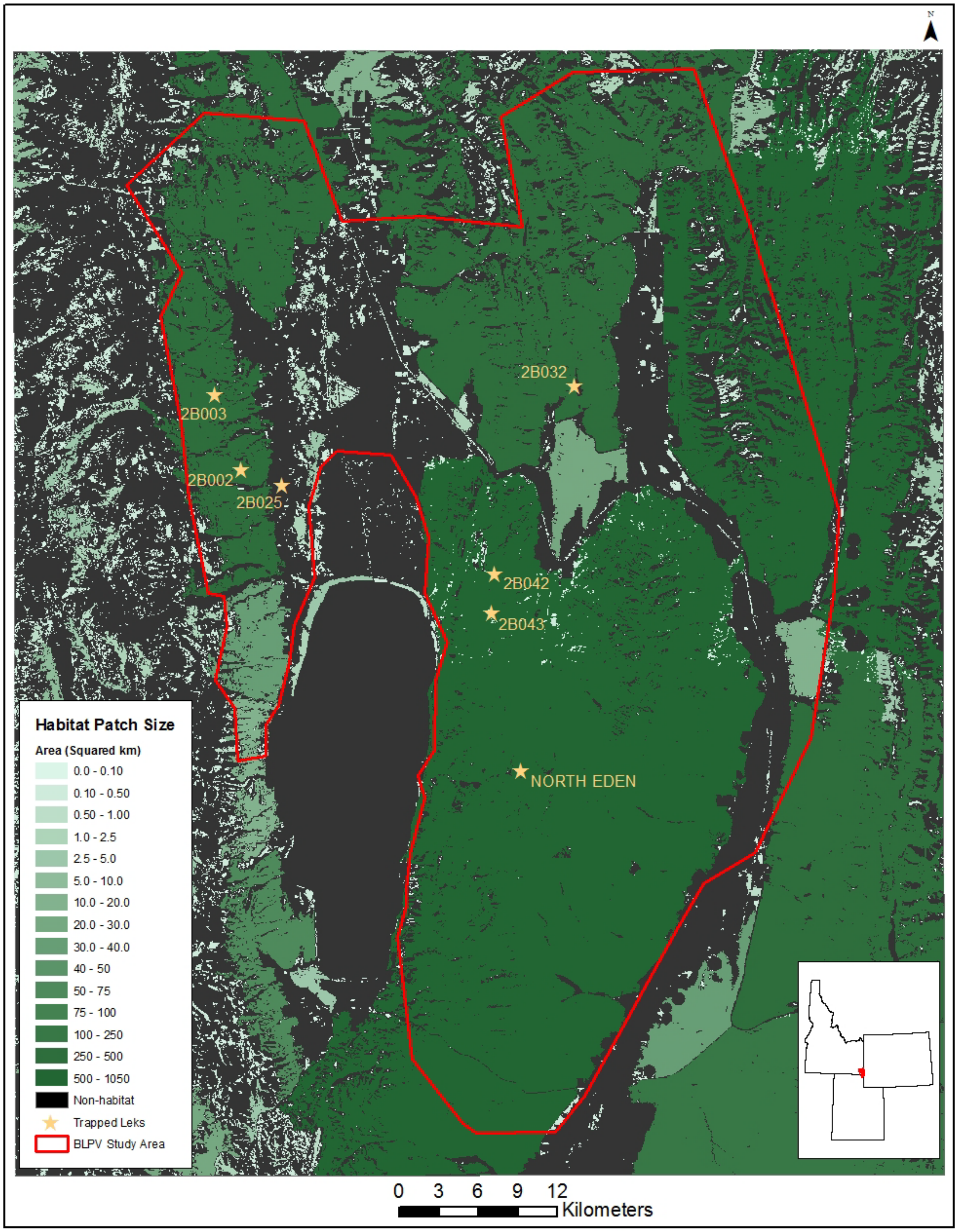

Figure 3-3. Fragmentation of habitat across the Bear Lake Plateau and Valley (BLPV) study area, Idaho-Utah-Wyoming, USA. BLPV Study, 2010–2012.

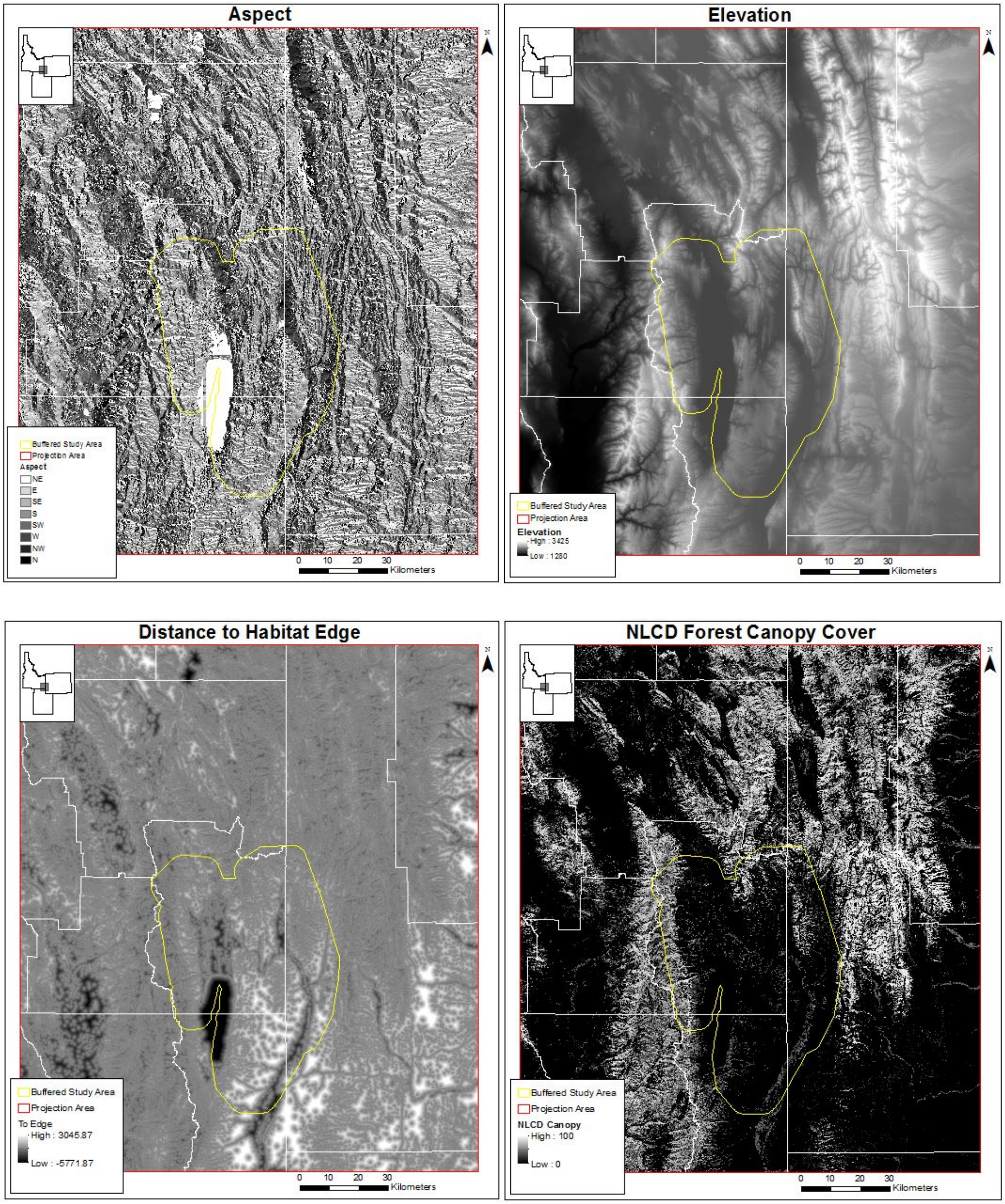

Figure 3-4. Predictor variables for species distribution modeling for greater sage-grouse (*Centrocercus urophasianus*) on the Bear Lake Plateau and Valley (BLPV) study area, Idaho-Utah, USA. BLPV Study, 2010–2012.

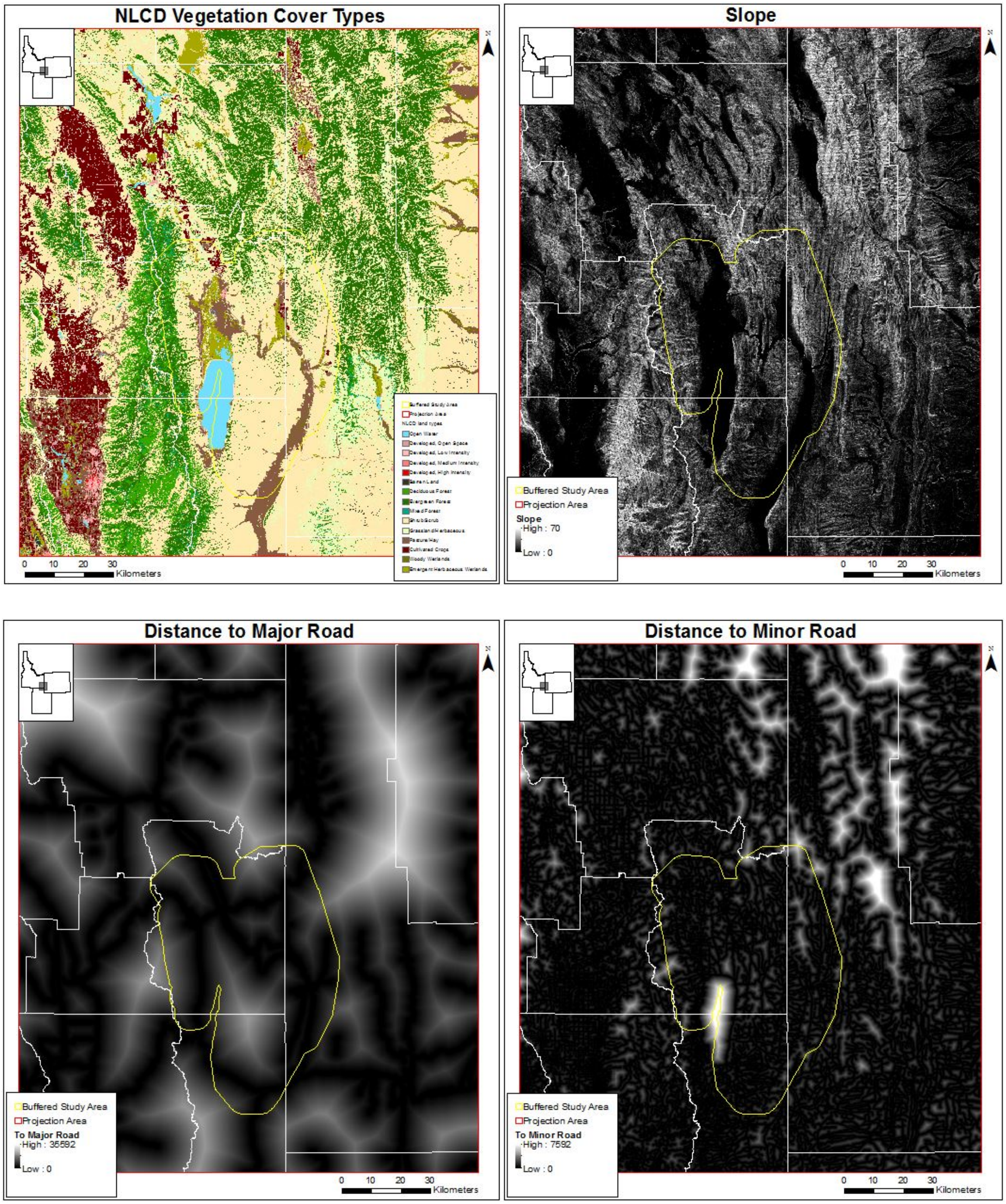

Figure 3-4. Continued.

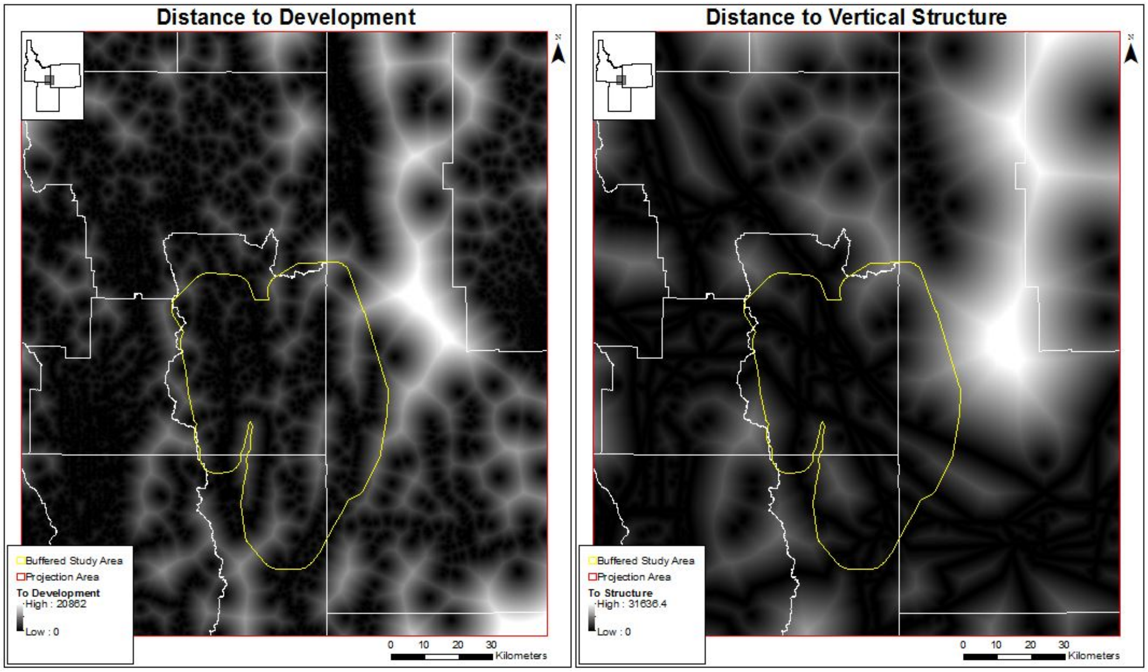

Figure 3-4. Concluded.

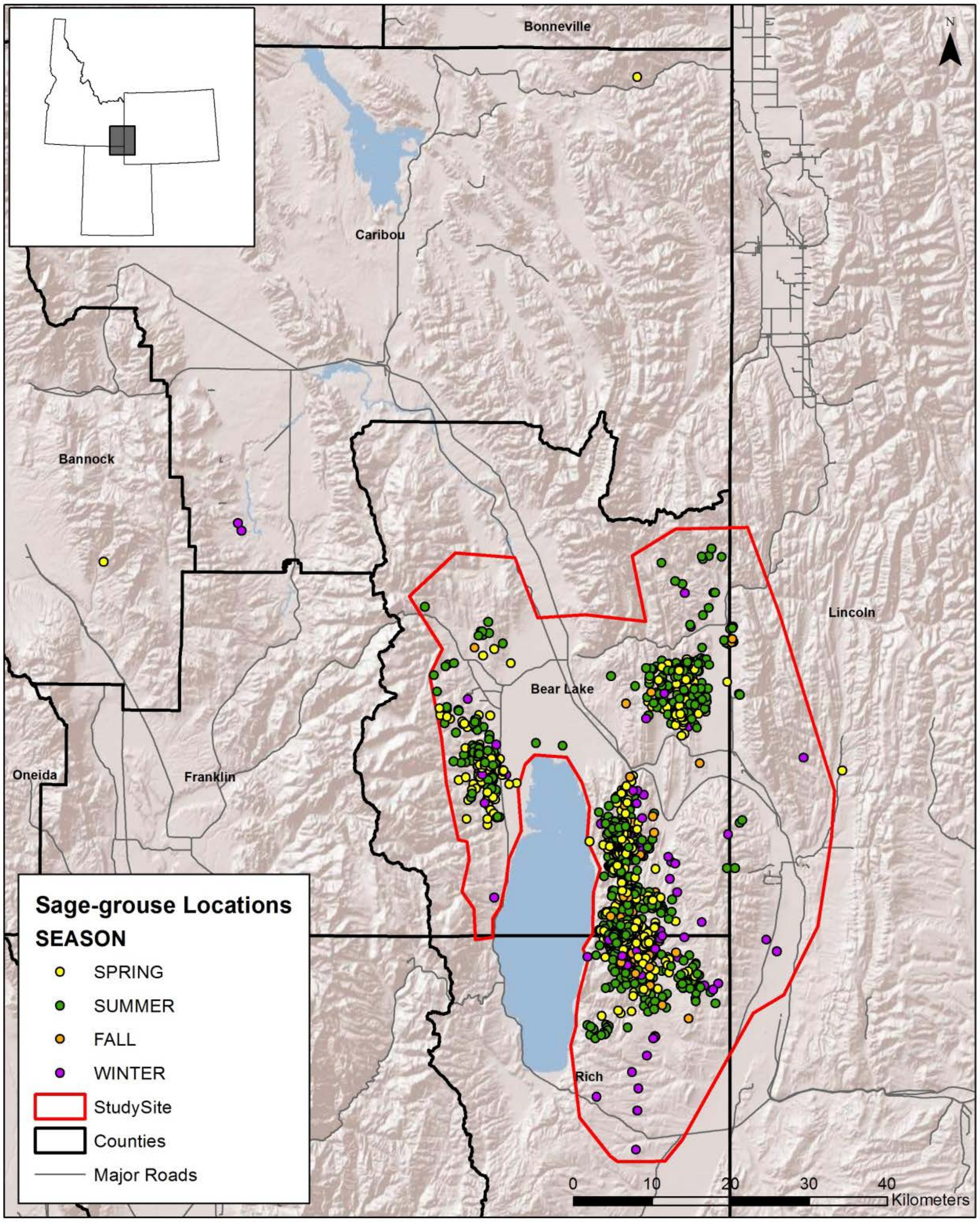

Figure 3-5. Greater sage-grouse (*Centrocercus urophasianus*) recorded locations on the Bear Lake Plateau and Valley (BLPV) study area and surrounding areas, Idaho-Utah-Wyoming, USA. BLPV Study, 2010–2012.

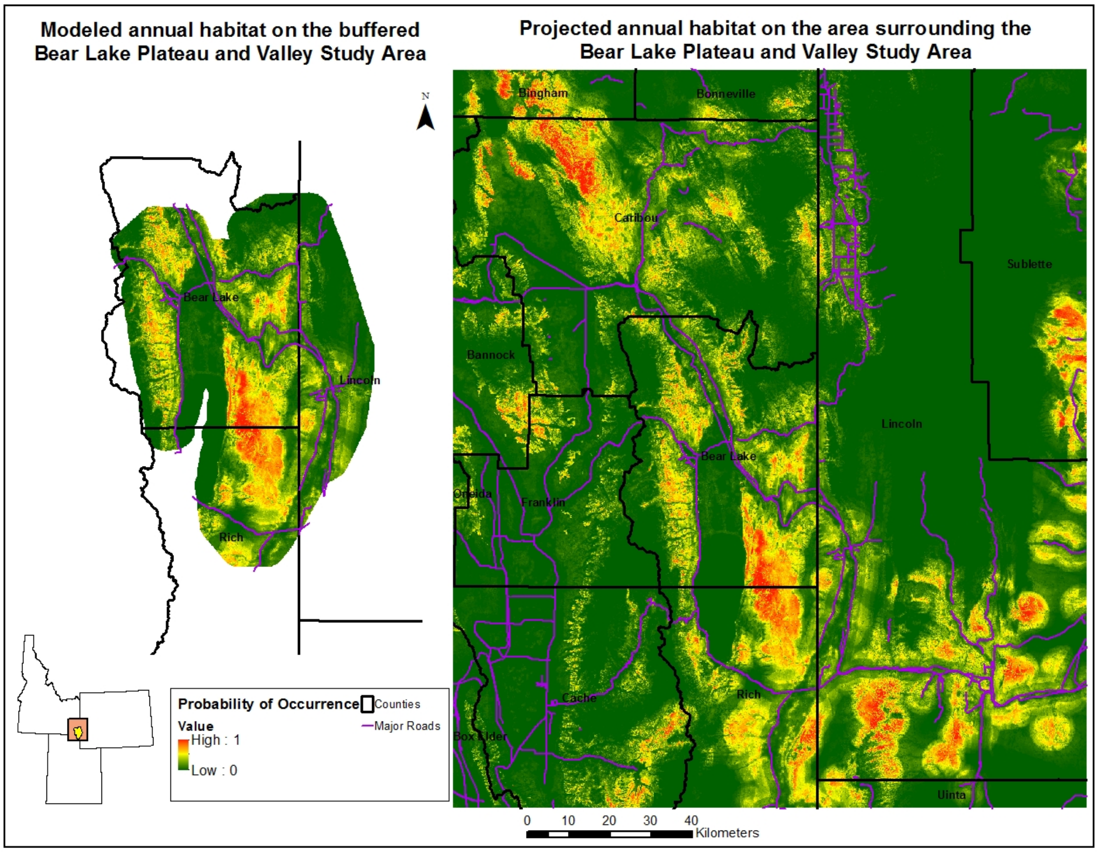

Figure 3-6. Annual predicted and projected MaxEnt habitat selection models for greater sage-grouse (*Centrocercus urophasianus*) on the buffered Bear Lake Plateau and Valley (BLPV) study area and surrounding areas, Idaho-Utah-Wyoming, USA. BLPV Study, 2010–2012.

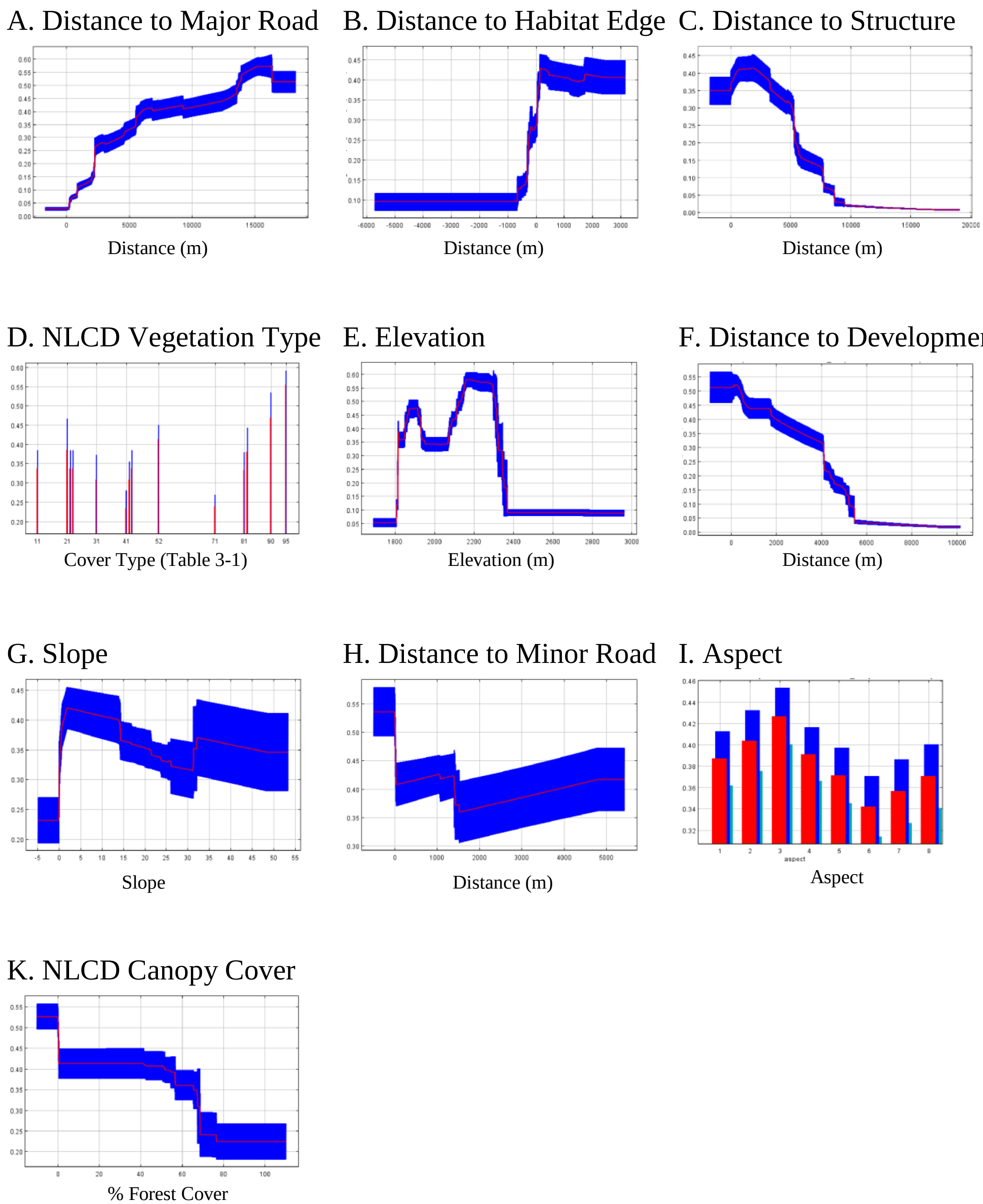

Figure 3-7. Response curves for contributing variables analyzed in the MaxEnt model for annual greater sage-grouse (*Centrocercus urophasianus*) habitat selection on the buffered Bear Lake Plateau and Valley (BLPV) study area, Idaho-Utah-Wyoming, USA. BLPV Study, 2010–2012.

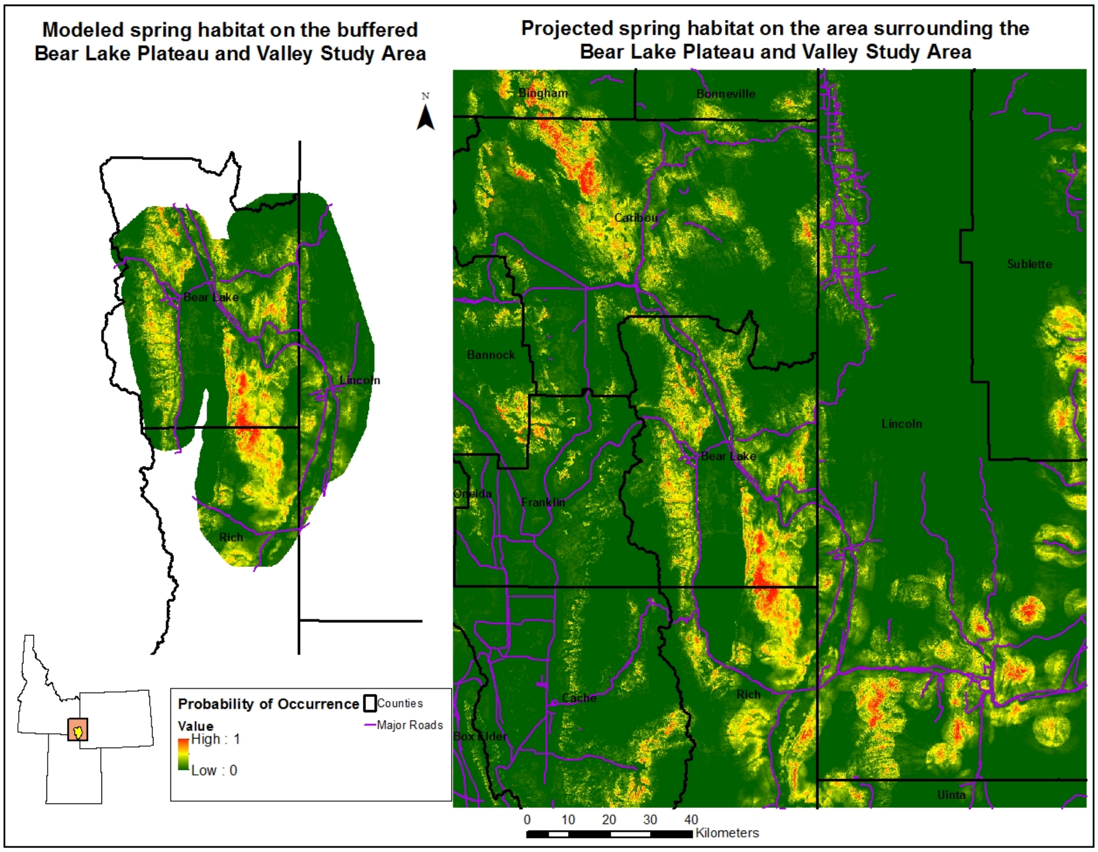

Figure 3-8. Predicted and projected MaxEnt models for spring habitat use of greater sage-grouse (*Centrocercus urophasianus*) on the buffered Bear Lake Plateau and Valley (BLPV) study area and surrounding areas, Idaho-Utah-Wyoming, USA. BLPV Study, 2010–2012.

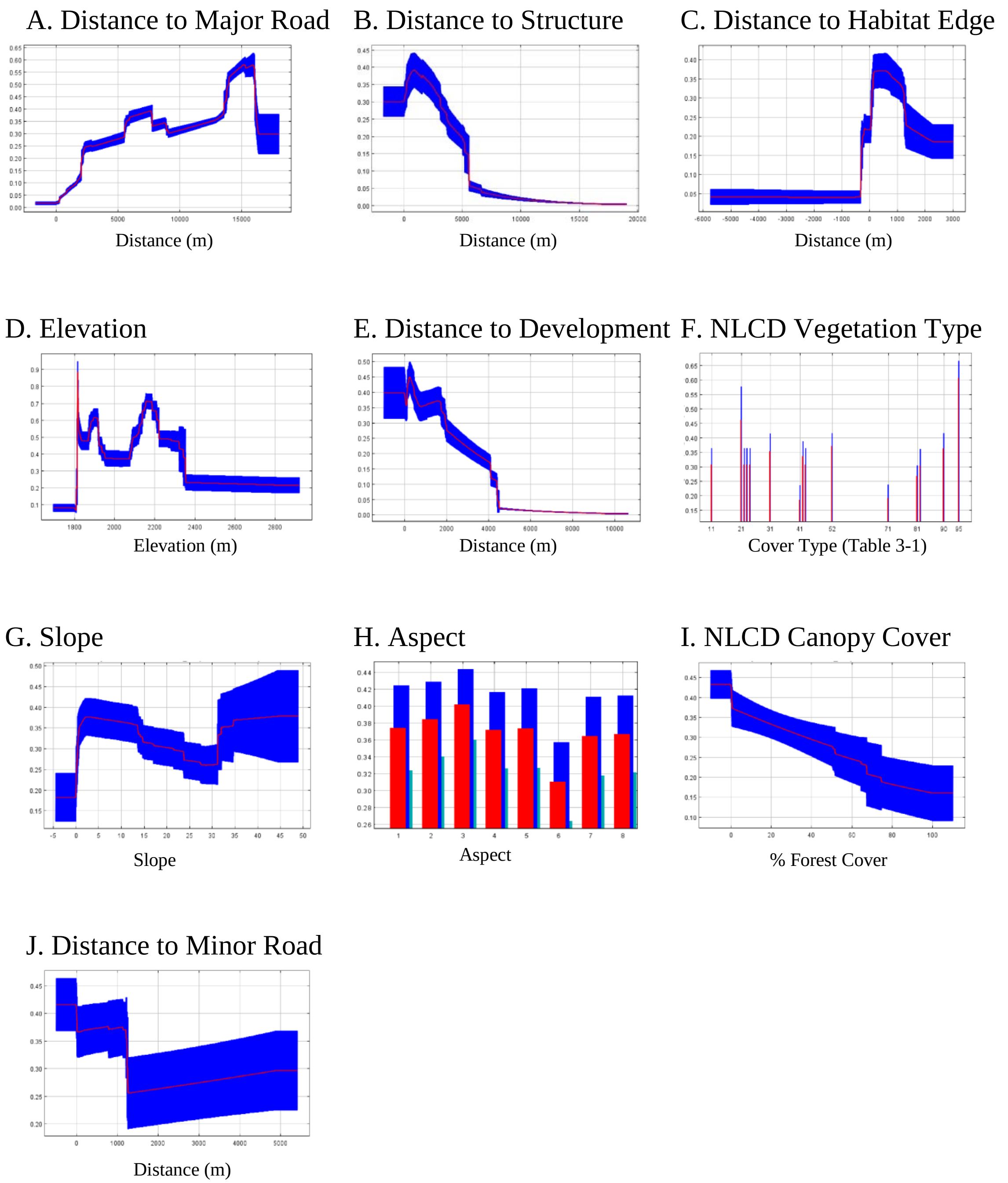

Figure 3-9. Response curves for contributing variables analyzed in MaxEnt for greater sage-grouse (*Centrocercus urophasianus*) spring habitat selection on the buffered Bear Lake Plateau and Valley (BLPV) study area, Idaho-Utah-Wyoming, USA. BLPV Study, 2010–2012.

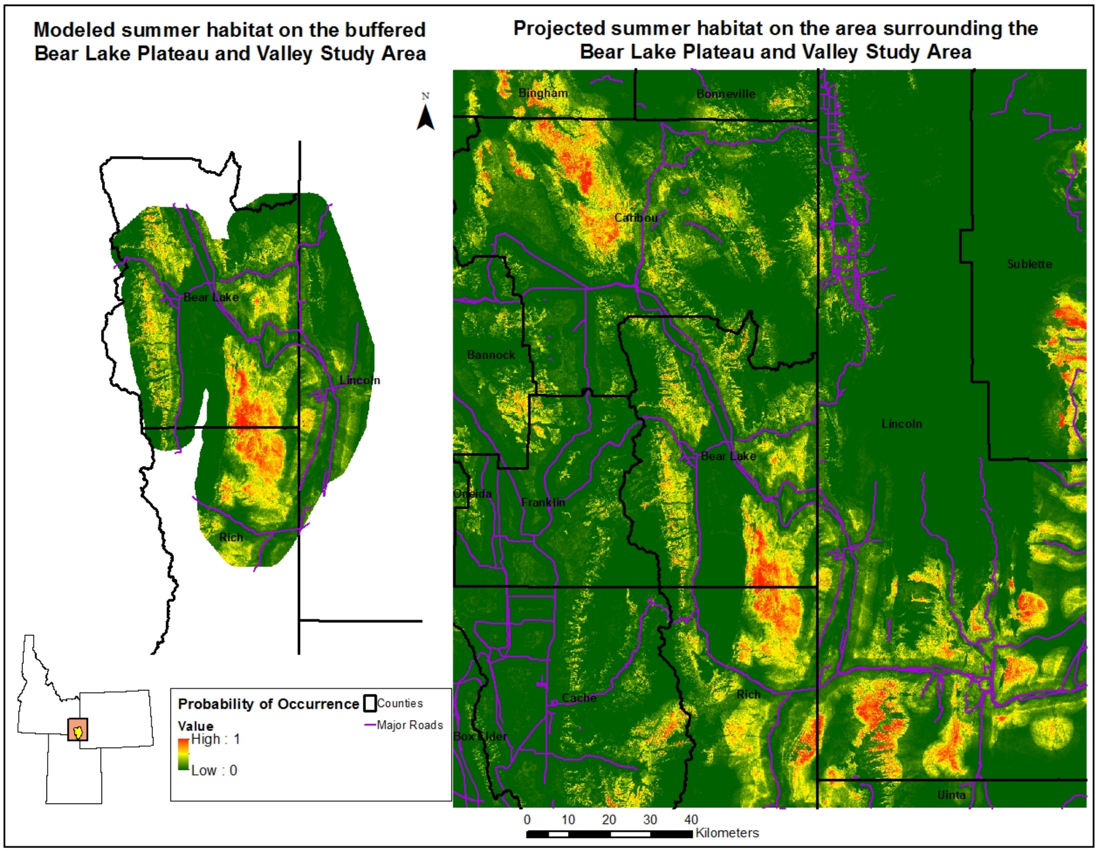

Figure 3-10. Predicted and projected MaxEnt habitat selection model of summer habitat for greater sage-grouse (*Centrocercus urophasianus*) on the buffered Bear Lake Plateau and Valley (BLPV) study area and surrounding areas, Idaho-Utah-Wyoming, USA. BLPV Study, 2010–2012.

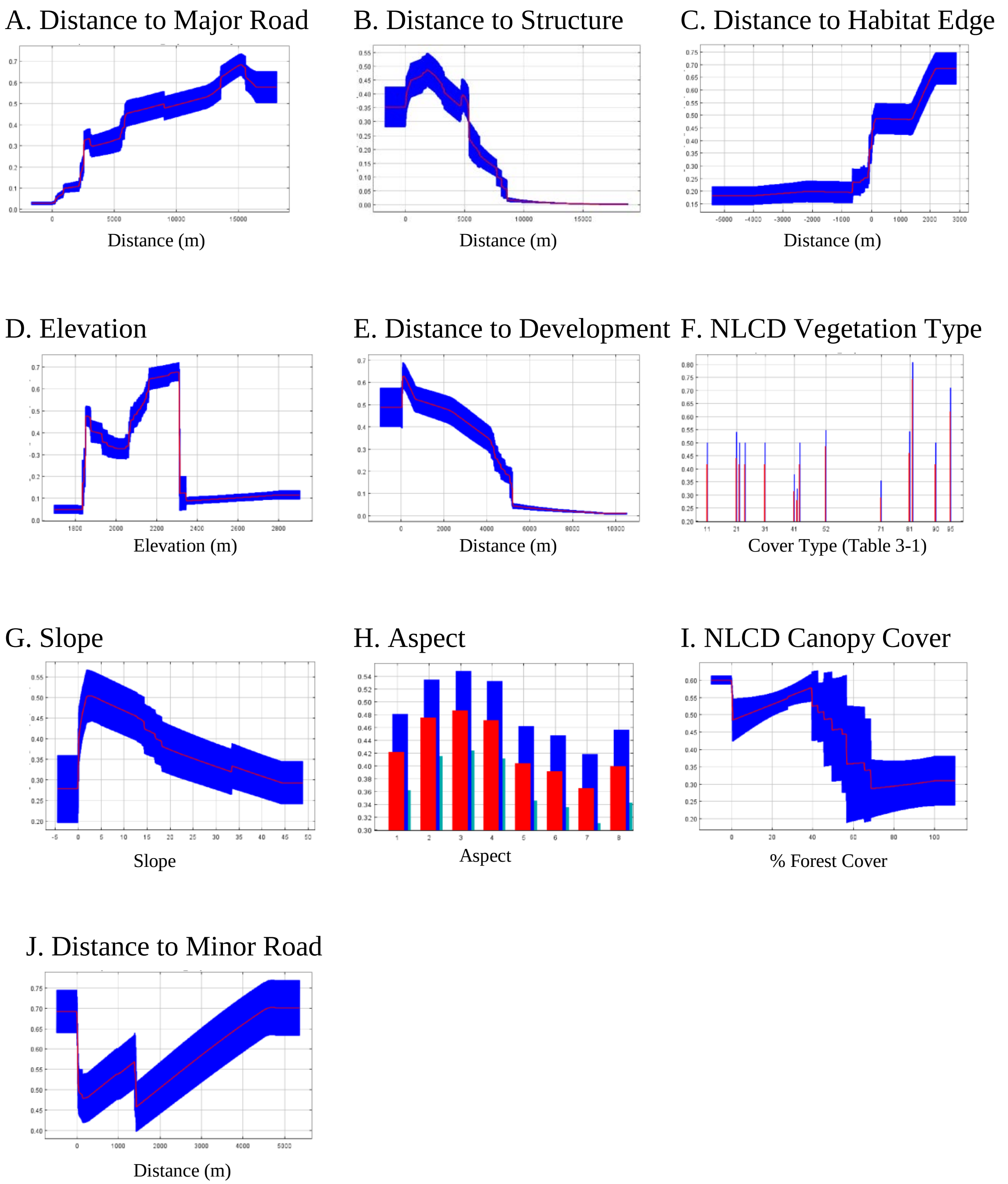

Figure 3-11. Response curves for contributing variables analyzed in the MaxEnt model of greater sage-grouse (*Centrocercus urophasianus*) summer habitat selection on the buffered Bear Lake Plateau and Valley (BLPV) study area, Idaho-Utah-Wyoming, USA. BLPV Study, 2010–2012.

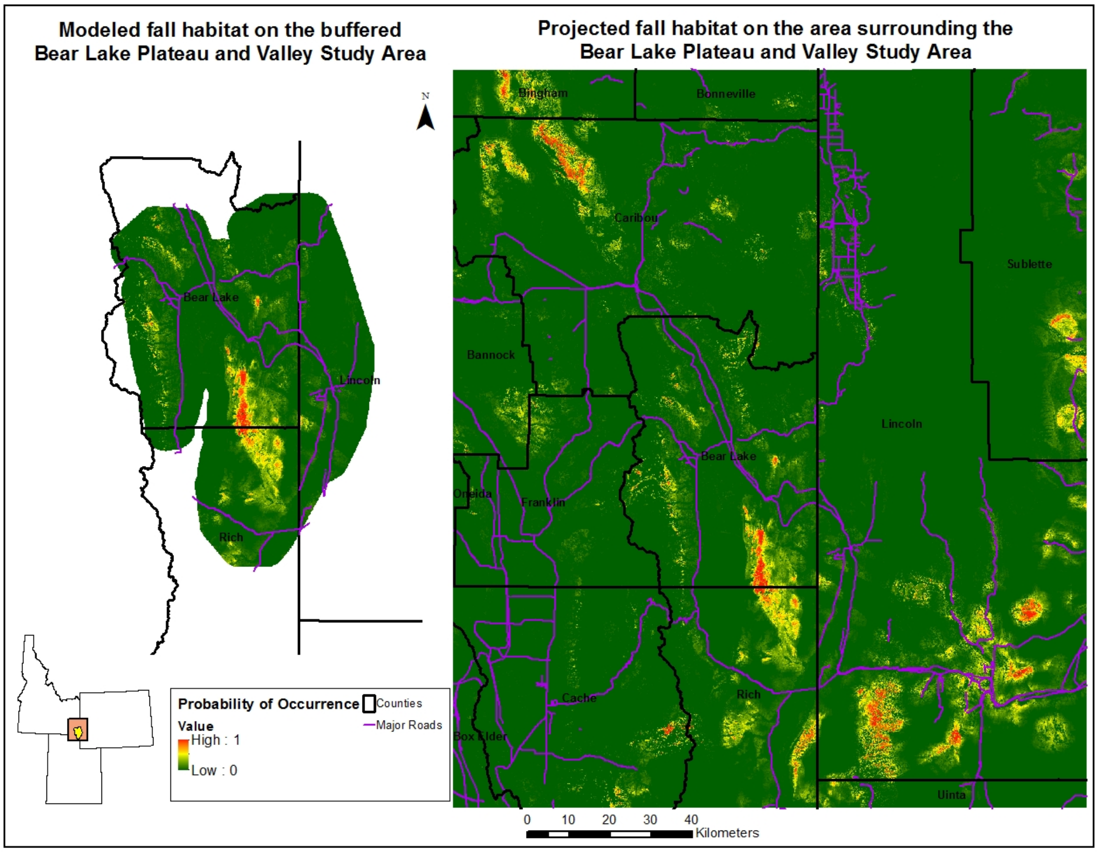

Figure 3-12. Predicted and projected MaxEnt models of fall habitat selection for greater sage-grouse (*Centrocercus urophasianus*) on the buffered Bear Lake Plateau and Valley (BLPV) study area and surrounding areas, Idaho-Utah-Wyoming, USA. BLPV Study, 2010–2012.

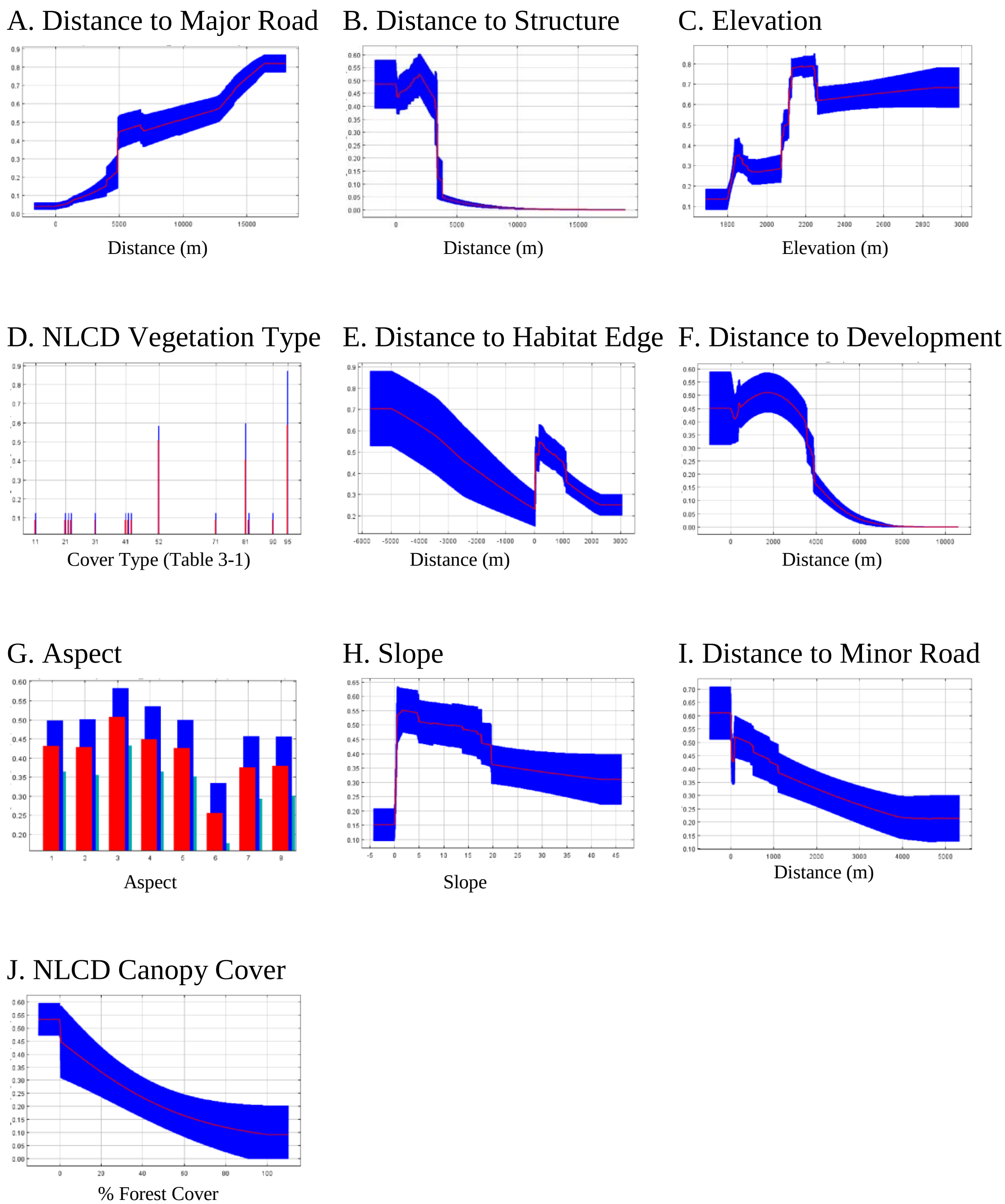

Figure 3-13. Response curves for contributing variables analyzed in the MaxEnt model for greater sage-grouse (*Centrocercus urophasianus*) fall habitat selection on the buffered Bear Lake Plateau and Valley (BLPV) study area, Idaho-Utah-Wyoming, USA. BLPV Study, 2010–2012.

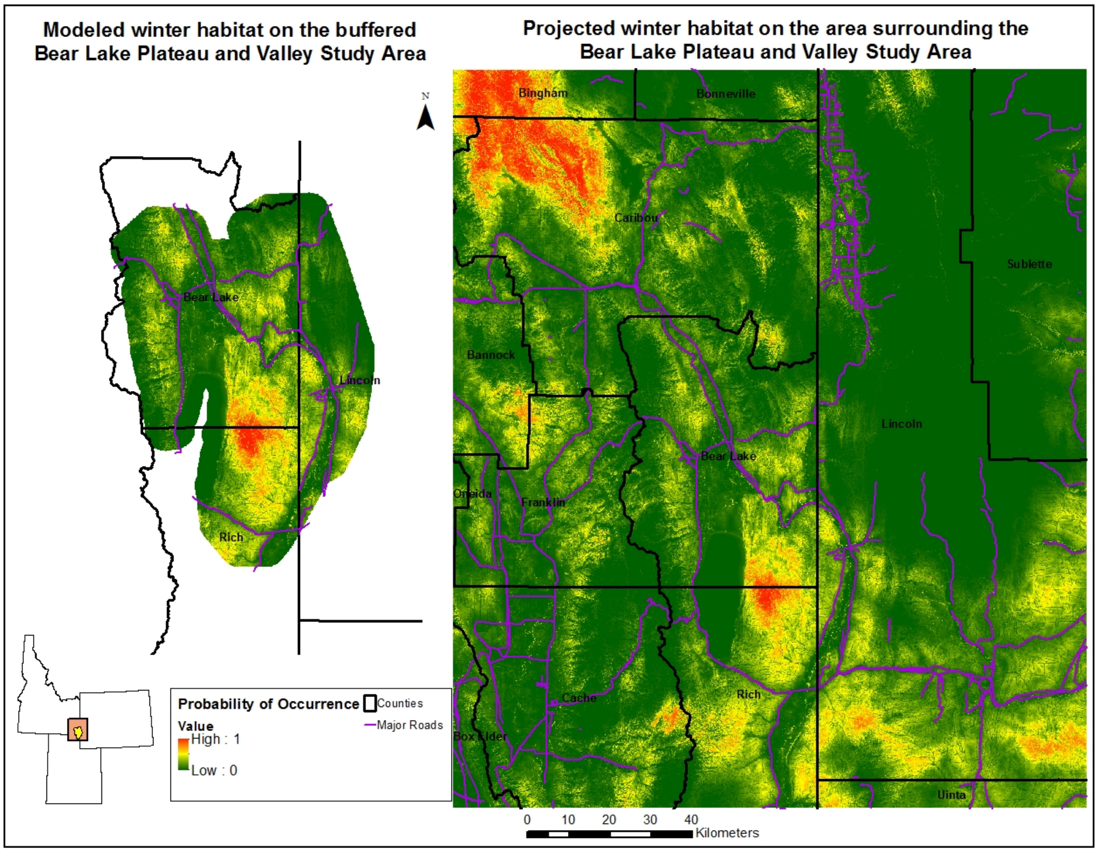

Figure 3-14. Predicted and projected MaxEnt models of winter habitat selection for greater sage-grouse (*Centrocercus urophasianus*) on the buffered Bear Lake Plateau and Valley (BLPV) study area and surrounding areas, Idaho-Utah-Wyoming, USA. BLPV Study, 2010–2012.

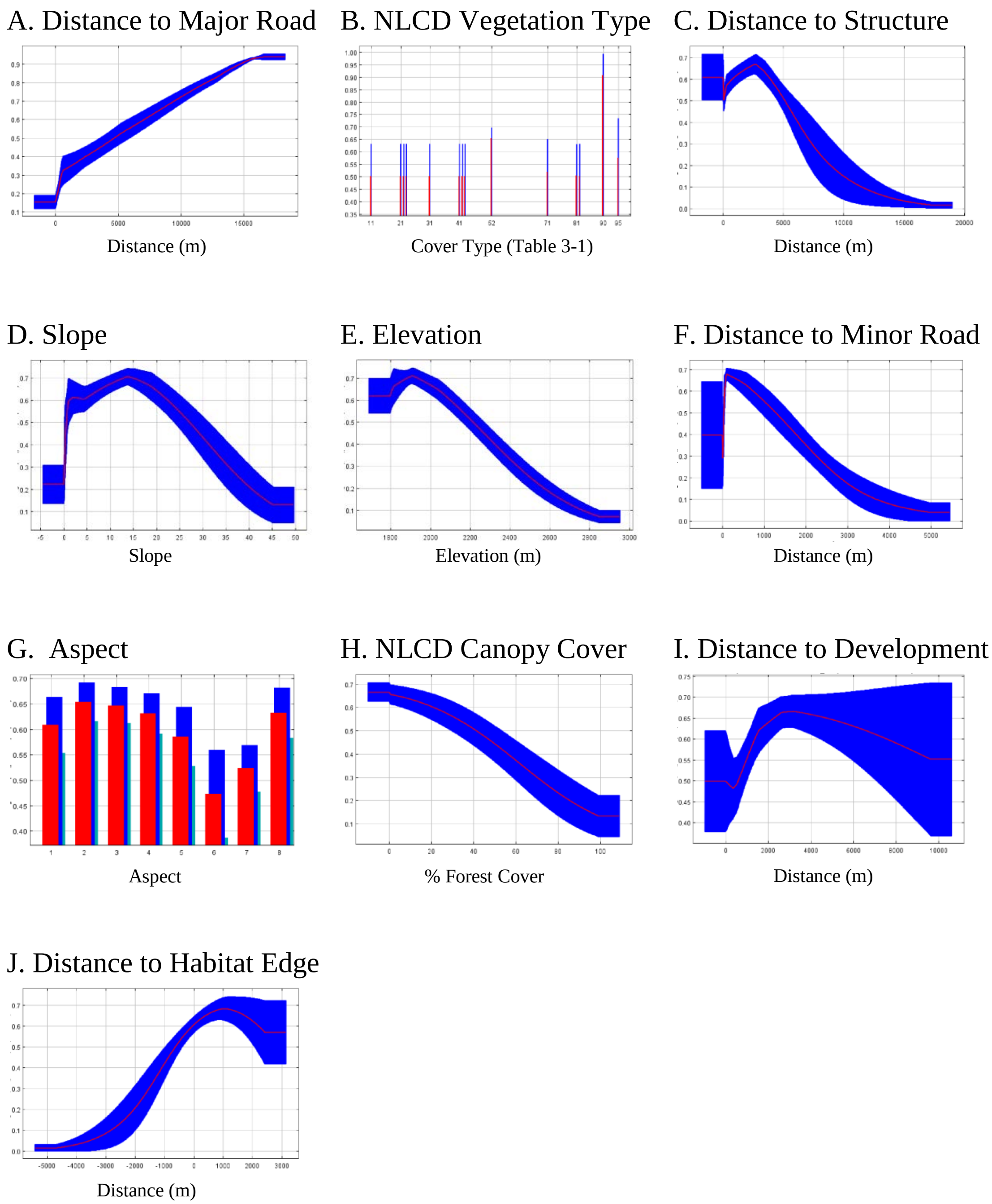

Figure 3-15. Response curves for contributing variables analyzed in the MaxEnt model for winter greater sage-grouse (*Centrocercus urophasianus*) habitat selection on the buffered Bear Lake Plateau and Valley (BLPV) study area, Idaho-Utah-Wyoming, USA. BLPV Study, 2010–2012.

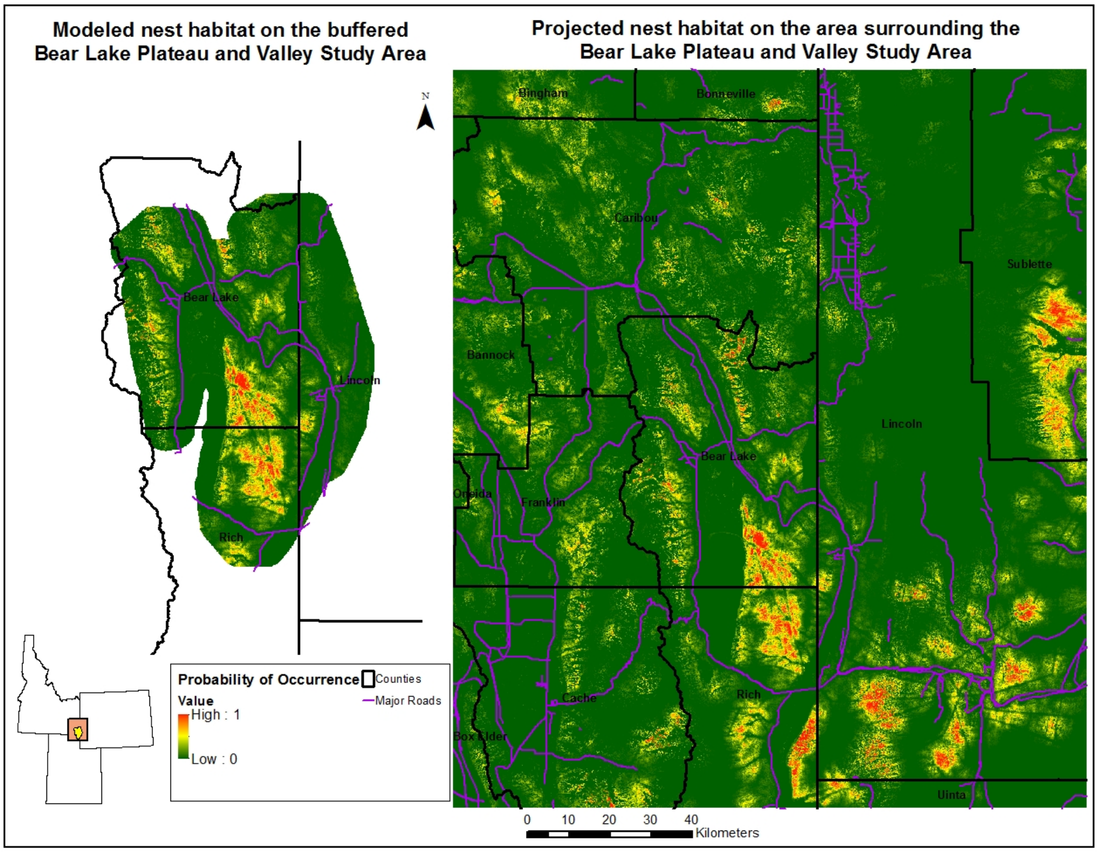

Figure 3-16. Predicted and projected MaxEnt models of nest habitat selection for greater sage-grouse (*Centrocercus urophasianus*) on the buffered Bear Lake Plateau and Valley (BLPV) study area and surrounding areas, Idaho-Utah-Wyoming, USA. BLPV Study, 2010–2012.

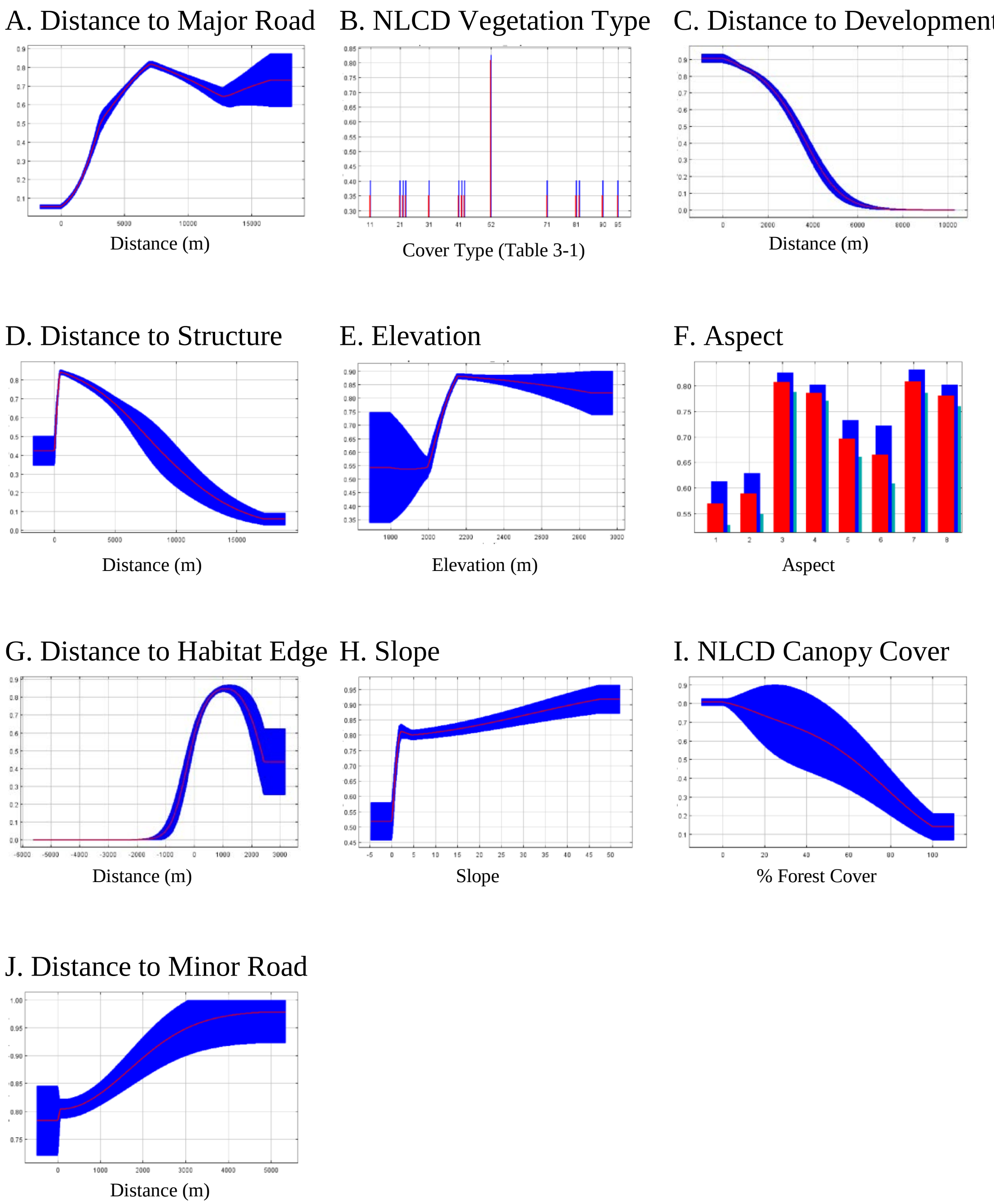

Figure 3-17. Response curves for contributing variables analyzed in the MaxEnt model of nesting habitat for greater sage-grouse (*Centrocercus urophasianus*) on the buffered Bear Lake Plateau and Valley (BLPV) study area, Idaho-Utah-Wyoming, USA. BLPV Study, 2010–2012.

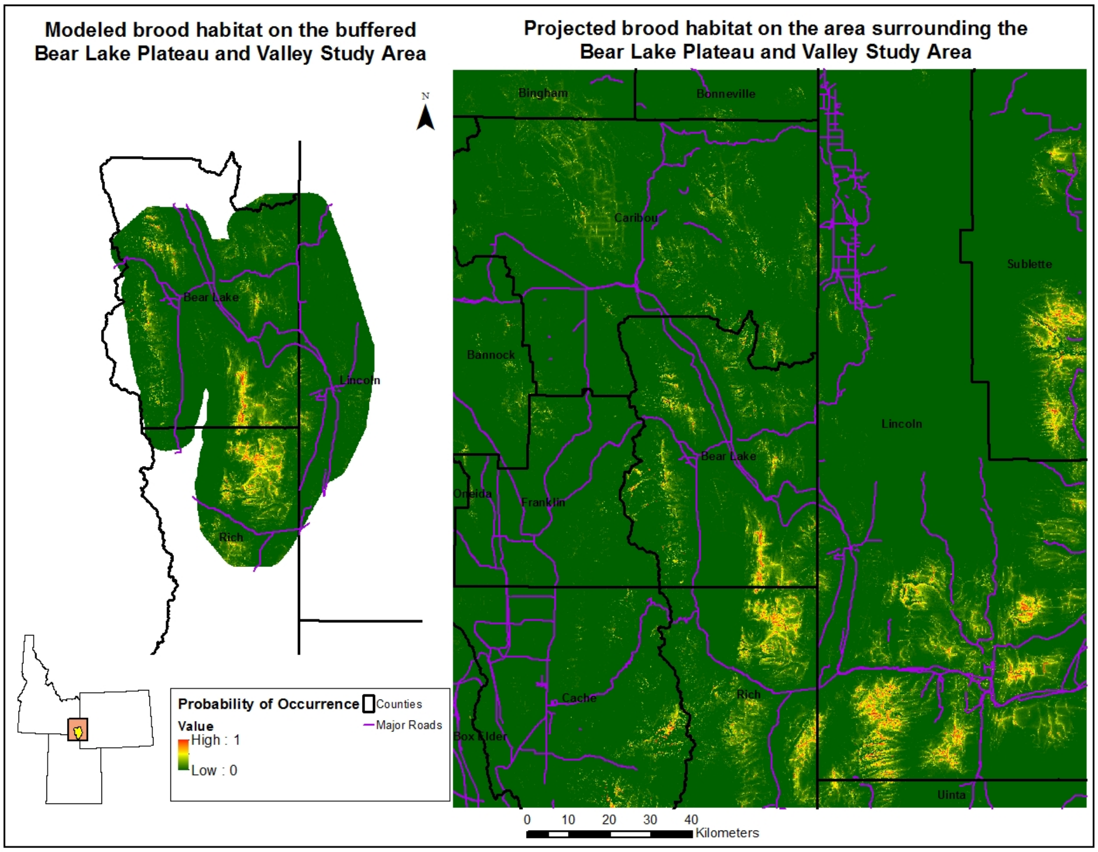

Figure 3-18. Predicted and projected MaxEnt models of brooding habitat selection for greater sage-grouse (*Centrocercus urophasianus*) on the buffered Bear Lake Plateau and Valley (BLPV) study area and surrounding areas, Idaho-Utah-Wyoming, USA. BLPV Study, 2010–2012.

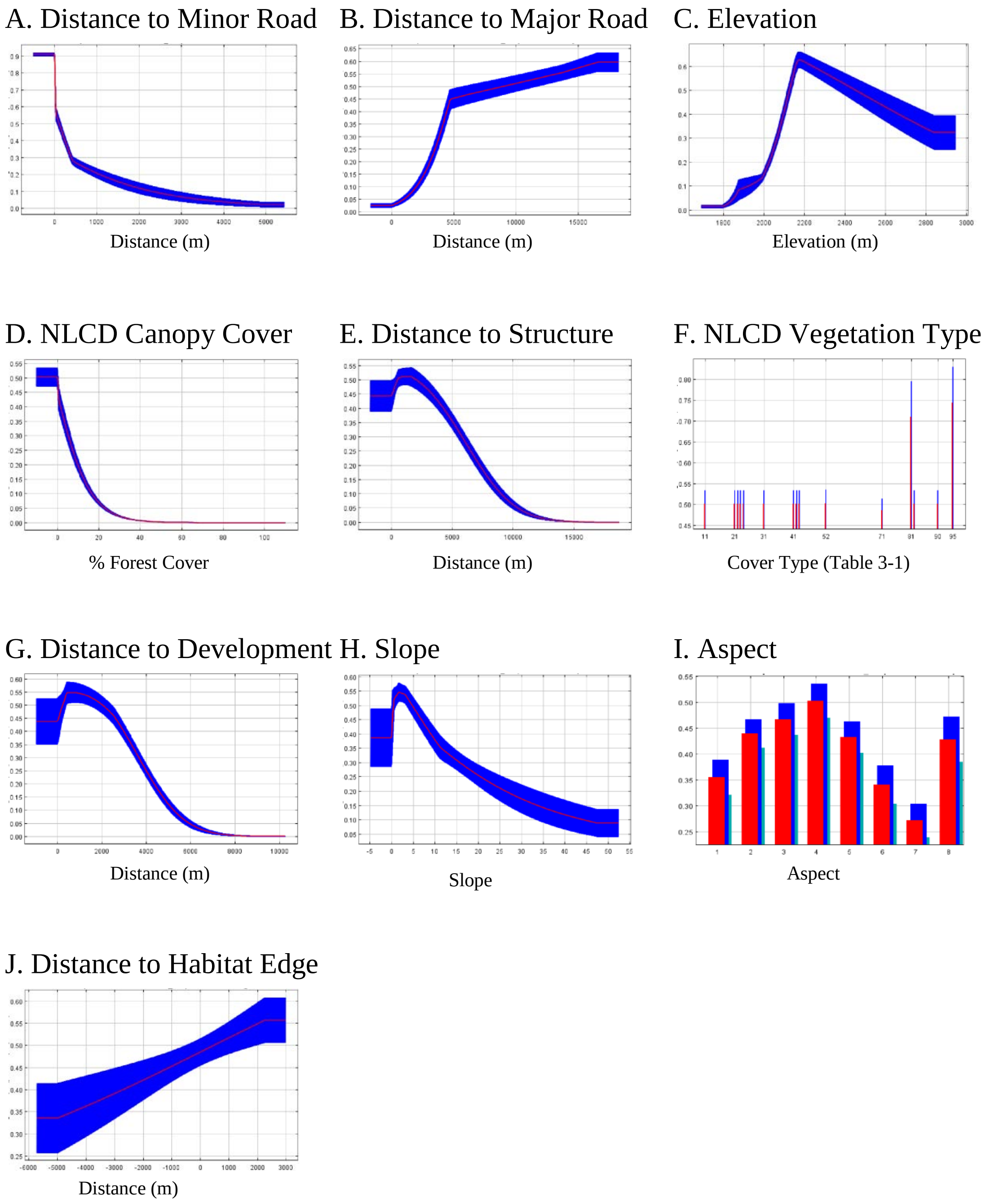

Figure 3-19. Response curves for the contributing variables analyzed in the MaxEnt model of brood habitat for greater sage-grouse (*Centrocercus urophasianus*) on the buffered Bear Lake Plateau and Valley (BLPV) study area, Idaho-Utah-Wyoming, USA. BLPV Study, 2010–2012.

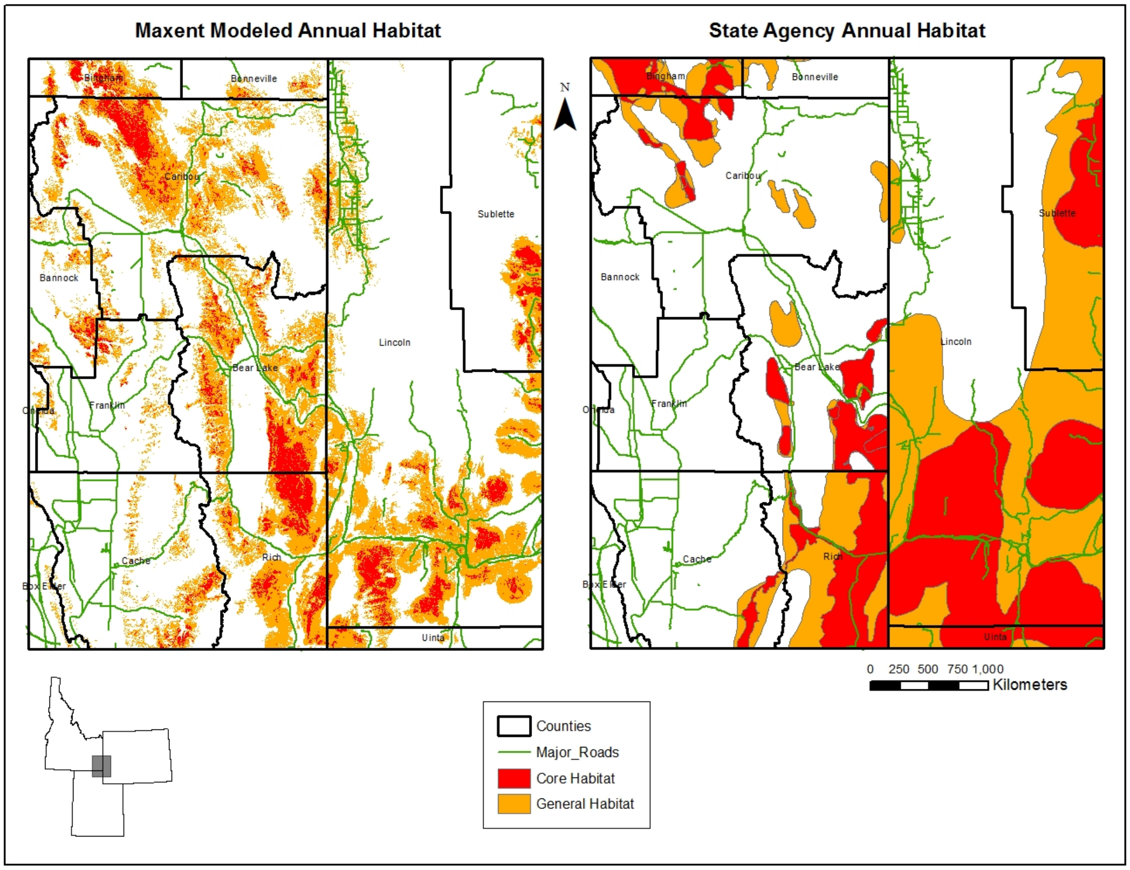

Figure 3-20. Greater sage-grouse (*Centrocercus urophasianus*) habitat predicted by state agencies compared to projected MaxEnt habitat selection models for sage-grouse on the Bear Lake Plateau and Valley (BLPV) study area and surrounding areas, Idaho-Utah-Wyoming, USA. BLPV Study, 2010–2012.

CHAPTER 4

CONCLUSIONS

Greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) populations occupy <56% of their historical range across western North America, and are a candidate species for listing under the Endangered Species Act (Schroeder et al. 2004, USFWS 2010). Reduction of sage-grouse populations and their habitats have Federal, state, and private entities creating management plans for conservation of the species. To best create management plans, it is important to understand local threats, ecological factors, and habitat use of individual populations. Populations that cross jurisdictional boundaries require collaborative management between agencies to implement the best conservation actions for population persistence.

The purpose of this research was to better understand the ecology of sage-grouse on the Bear Lake Plateau and Valley (BLPV), and to map distributions of sage-grouse habitat. My research assessed factors affecting production and survival, habitat-use patterns, and predicted potential habitat in the surrounding areas. Because the Bear Lake Plateau and Valley is subject to both natural and anthropogenic barriers and fragmentation, defining population vital rates, seasonal movement and habitat-use relative to land use and jurisdictional boundaries of this population is important as the basis for management cooperation among Idaho, Utah, and Wyoming. This research could be used to provide state agencies and local working groups in the area with information to guide management for this population.

Sage-grouse monitored during this study had vital rates that fell within the population wide estimates. Production appeared to be the limiting factor for population growth for sage-grouse in the Bear Lake Plateau and Valley. Nesting success rates in the BLPV (17.6–28.8%) were at the low range of rates for sage-grouse populations. Hens on the BLPV choose shrubs exhibiting larger canopies and higher nest bowl VOR than random sites (Sveum et al. 1998, Knerr 2007, Herman-Brunson 2007, Kaczor 2008). Nest success may increase with the promotion of larger sagebrush with high visual obstruction especially 0–11 km from known leks. Additionally, nest success was slightly impacted by distance to tall structures, suggesting that it could be beneficial to sage-grouse productivity if tall structures in the area are kept to a minimum or strategically constructed in the future. Brood success was also lower than estimates found range-wide, though sample sizes were too small to make inferences. Increasing grass height and composition in areas around leks may also increase nest and brood success, as found in other studies (Perkins 2010, Guttery 2011, Gruber 2012, Doherty et al. 2014). Forb production on the site was lower than recommended habitat guidelines (Connelly et al. 2000b), and improvement of high-density forb habitat could improve brooding success.

No reproductive attempts were observed for hens captured on the western side of the lake, and when hens were flushed later in the summer they were not observed with broods, though very few hens were caught in these areas. The amount of habitat was limited due to development on the eastern edge of the plateau, and national forest on the western edge of the plateau. Additionally, the western plateau had greater proportion of edge habitat, which nesting hens tended to avoid (Perkins 2010). Hens in disturbed areas have lower nest initiation rates that hens in undisturbed areas (Lyon and Anderson 2003), and further disturbance of habitat on the east side could further reduce reproduction. It is important that managers work with local ranchers to maintain intact habitats and mitigate against additional fragmentation. Promoting habitat quality around leks with lower levels of surrounding disturbance could preserve populations on the western edge of the study area.

Published survival estimates range from 30–78% (Connelly et al. 2011), and annual survival rates on the BLPV ranged from 47.7–64.2% and were within this range. Survival was highly dependent on season, with high fall survival rates and lowest in summer. Winter survival in the BLPV was on the low end of range wide estimates (Connelly et al. 2011), likely because the plateau experiences heavy snowfall and colder temperatures than other areas in the sage-grouse range. Sage-grouse survival was higher in 2011 than 2012, suggesting that in a year when productivity is lower, survival is higher. Sage-grouse tend to be vulnerable to predation in the breeding season, with a surge of morality often found from March through June (Connelly et al. 2000a). There was also some variation in survival based on the capture location of the grouse. Sage-grouse captured on the western side of the lake had higher survival than sage-grouse on the eastern side of the lake. Migration did not appear to affect survival of sage-grouse on the BLPV. Female estimates of survival were slightly higher than male estimates, and yearling survival was slightly higher than adult survival which also has been noted in other sage-grouse studies (Bunnell 2000, Zablan et al. 2003, Robinson and Messmer 2013).

The average sage-grouse home range in the BLPV was 100.8 km^2. Variation in home range sizes is explained by habitat requirements and resource needs. Female and male sage-grouse had significantly different home range sizes, with males' annual home ranges almost twice the size of female home ranges. Male sage-grouse tend to make larger movements and cover more area than females (Connelly et al. 1988, Hagen 1999). Variation in home range sizes could be related to different resource needs. Differences in average home range size were also found between yearlings and adult birds. Younger individuals are known to make large exploratory movements during dispersal (Dunn and Braun 1985) which could account for these variations in size.

Though some individuals made migratory movements, not all BLPV sage-grouse were migratory. Even all individuals captured in the same lek area were not classified to a uniform migratory status. The ability of individual sage-grouse to obtain resources on the landscape affects the birds' need to migrate. Managers could benefit sage-grouse populations by preserving current habitats that fulfill annual cycle resource needs. Individual differences in migratory behavior may be influenced by tradition (Wallestad 1971), as well as life stage and landscape composition (Fedy et al. 2012, Reinhart et al. 2013). Sage-grouse on the BLPV study area used habitat in Idaho, Utah, and Wyoming. Sage-grouse captured on lek 2B015 moved readily across the Idaho-Utah border. Yearling males made tri-state dispersal movements, and adults made seasonal migratory movements between Idaho, Utah, and Wyoming. Additionally, several grouse made migratory movements across Bear Lake. Several birds were found outside of the study area, to the far north in Caribou County, ID near the Bonneville County line and to the west in Bannock County, ID. These birds moved 70–100 km. Habitats outside of the BLPV study area could be important for winter habitat, or as dispersal corridors. BLPV sage-grouse may provide an important genetic link between the Wyoming Basin population and the Snake River Plain population (Connelly et al. 2004).

Habitat loss and fragmentation varied across the Bear Lake Plateau and Valley study area. Anthropogenic caused habitat loss was highest on the west side of the study area along the base of the plateau, though there was human development found all around the edge of Bear Lake and in several towns in the area (Leu and Hanser 2011). Natural fragmentation occurred from Bear Lake, the Bear Lake National Wildlife Refuge, and national forests (O'Brien and Pope 1997, USFWS 2013). Leks on the west side of the study area were separated from leks on the east side by ≥ 15 km, with large blocks of non-habitat in between. Sage-grouse on the BLPV were likely using small patches of habitat as a movement corridor to cross the potential non-habitat barrier between the east and west sides of the study area. Protection of movement corridors could benefit individuals that make movements between habitat patches (Fahrig 1997, Fedy et al. 2012, Smith 2013).

There were several covariates that were important BLPV MaxEnt habitat models. Principle characterizations of MaxEnt modeled sage-grouse habitat included increased distances from major roads, land cover supporting shrublands, emergent herbaceous wetlands, and pasture/hay lands, and vertical structures being located 3 km away. These common variables of importance in predicting sage-grouse occurrence during multiple seasons will allow targeted conservation. Seasonal habitats had a large amount of overlap, which was likely a result of overlap in importance of predictor variables. Vertical structures were avoided by sage-grouse, with highest probability of occurrence of sage-grouse at 3 km from the nearest vertical structure. Keeping vertical structures out of core sage-grouse habitats could reduce avian predation, particularly during the breeding season (Coates et al. 2014). Populations may benefit from targeting construction of vertical structures to areas that sage-grouse avoid, such as near human developments.

Interior habitat in patches could be the limiting habitat variable on the BLPV. Sage-grouse on the BLPV avoided non-habitats and preferred habitat patch interiors. Edges area often associated with mixing of habitat type (Harris 1988, Yahner 1988), and sage-grouse may be more susceptible to increased predation (Shepherd 2006, Perkins 2010). Additional fragmentation of habitats on the BLPV could further limit habitat use by sage-grouse, leading to population decline (Perkins 2010, Knick et al. 2013).

Cooperation between state agencies and local working groups in Idaho, Utah, and Wyoming could aid in landscape and population management efforts. Sage-grouse on the BLPV readily travel between Idaho and Utah, and occasionally into Wyoming. Additional studies in Wyoming could help define important habitats on the eastern edge of the BLPV. As sage-grouse were not trapped in Wyoming during this study, comparison and inference for the BLPV sage-grouse habitat selection model in Wyoming is limited. State agency defined habitat encompassed a majority of the MaxEnt predicted habitat. By selecting larger areas than modeled habitat, states are safeguarding both current and potential future habitat for sage-grouse. Predicted habitat modeled using locations collected during the study identified sage-grouse habitat in all three states. The creation of a tri-state management plan for sage-grouse on BLPV could be beneficial for conservation of important seasonal habitats found in all three states. These general and core habitat could be identified by MaxEnt models, local working groups, and state agencies. Continual surveys for new leks and enchantment of habitat surround leks could benefit sage-grouse in the area. Additionally, if the BLPV Sage-grouse Conservation Plan addresses threats and conservation activities identified by the local working groups, the plan can direct management decisions. Because a large proportion of sage-grouse habitat is located on private land, it is important that wildlife managers work with private landowners to maintain habitat in native range, and to avoid division of contiguous habitat. Long term monitoring of sage-grouse habitats in all three states will aid managers in assessing the effects of conservation efforts.

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