12-2017

Ecology of Greater Sage-Grouse Inhabiting the Southern Portion of the Rich-Morgan-Summit Sage-Grouse Management Area

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ECOLOGY OF GREATER SAGE-GROUSE INHABITING THE SOUTHERN PORTION OF THE RICH-MORGAN-SUMMIT SAGE-GROUSE MANAGEMENT AREA

by

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A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Wildlife Biology

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UTAH STATE UNIVERSITY
Logan, UT

2017

ABSTRACT

Ecology of Greater Sage-Grouse Inhabiting the Southern Portion of the Rich-Morgan-Summit Sage-Grouse Management Area

by

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Utah State University, 2017

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Greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) are considered key indicators of sagebrush ecosystem health because of their dependence on sagebrush habitat throughout their life cycle. Sage-grouse populations have declined range-wide over the last century due to loss and fragmentation of sagebrush (*Artemisia* spp.) habitats from anthropogenic impacts that have been linked to changes in habitat use. Understanding the basic ecology, seasonal movements, and habitat selection patterns of individual populations throughout Utah, regardless of population size, is critical for proper conservation and management. Sage-grouse populations found in large intact sagebrush landscapes are considered to be more resilient, however, some small isolated populations persist and thrive in fragmented landscapes. I examined seasonal movement patterns, vital rates, and habitat selection of a small geographically isolated sage-grouse population in Morgan and Summit Counties in northern Utah from 2015–2016. Using generalized linear models, I examined the influence of female age, year, transmitter type (very-high frequency radio collars and platform terminal transmitters) and vegetation components on vital rates. I also compared micro-site vegetation structure at nest and brood sites with paired random sites to determine which vegetation components were important to the production of this population. This population is one of the most productive in Utah despite limited habitat space and small seasonal movements. Contrary to other research, my results demonstrated that transmitter type had no influence on vital rates, which could be a function of attachment style. Additionally, nest sites exhibited variation in vegetation structure that influenced nest success, while brood sites did not. I used a resource selection analysis framework to examine seasonal and spatial variability of habitat selection based on topographic, biological, and anthropogenic landscape features. Sage-grouse avoided trees and developed areas, especially during the breeding season and selection of other landscape variables was season-dependent. Models suggested limited differences in habitat selection by transmitter type. This information suggests that a sage-grouse population can occupy areas of limited habitat on an annual basis if seasonal habitat requirements are met. This study provides information that stakeholders can utilize to conserve critical seasonal habitats within this study area where the population could be negatively affected by anthropogenic development pressure.

(182 pages)

PUBLIC ABSTRACT

Ecology of Greater Sage-Grouse Inhabiting the Southern Portion of the Rich-Morgan-Summit Sage-Grouse Management Area

M. Brandon Flack

Greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) are sagebrush obligates and are therefore considered to be key indicators of sagebrush ecosystem health. Sage-grouse populations have declined range-wide over the last century due to loss and fragmentation of sagebrush (*Artemisia* spp.) habitats. Sage-grouse populations found in large intact sagebrush landscapes are considered to be more resilient, however, some small isolated populations persist and thrive in fragmented landscapes. Because of Utah's unique topography and geography, sage-grouse habitat is discontinuous and populations are naturally dispersed throughout the state in suitable intact blocks or in disconnected islands of sagebrush habitat. Thus, Utah populations provide the ideal place to understand how landscape attributes may influence at risk populations. Of these, the Morgan-Summit population is important because very little was known about the general ecology of this population and it experiences a high level of anthropogenic disturbances.

I examined seasonal movement patterns, habitat selection, vital rates (nest initiation rates, nest success, clutch size, breeding success, brood success, and survival probability of breeding age birds) and the influence of vegetation components on vital rates of a small geographically isolated sage-grouse population in Morgan and Summit Counties in northern Utah from 2015–2016. To collect the data, I deployed 25 very-high frequency radio collars and 10 platform terminal transmitters and completed micro-site vegetation surveys at nest, brood, and paired random sites and then made comparisons. Nest sites exhibited variation in vegetation structure that influenced nest success, while brood sites did not.

This population is one of the most productive in Utah exhibiting high nest initiation rates, hatching rates, and brood success rates despite limited habitat space and small seasonal movements. Transmitter type had no influence on vital rates, which is contrary to other studies, and limited influence on habitat selection. Sage-grouse avoided trees and developed areas, especially during the breeding season. Selection of other landscape variables was season-dependent. This information suggests that a sage-grouse population can occupy areas of limited habitat on an annual basis if seasonal habitat requirements are met. This study provides information that stake holders can utilize to conserve critical seasonal habitats within this study area where the population could be negatively affected by anthropogenic development pressure.

DEDICATION

This thesis is dedicated to my father, Dr. Marc D. Flack, who passed away on May 31, 2005. When he was a kid, he wanted to be either a marine biologist or a dentist. He ended up doing the latter but passed along his passion for the outdoors and appreciation of wild things and wild places to his children. He would have loved to share in my adventures and in this journey of becoming a wildlife biologist. It's not marine biology, but it'll have to do.

I miss you every day, Dad.

M. Brandon Flack

ACKNOWLEDGMENTS

I am here, not by my merits alone, but because other people saw something in me that I did not see in myself. My wife, Kristin, is my foundation. She has supported me through this process of starting a new career later in life and trusted in me as her husband and the provider for our family. It has not been an easy road. She is an incredible mother, an incredible wife, a wonderful friend to others, patient, kind, and my best friend. Our 4 kids have willingly come along for the ride with very little, if any, complaining. Thank you for being my partners in this journey of adventure that is our life.

My mother, Annette Flack, has always been my champion. She supports me and buoys me up even when she doesn’t feel like it because she knows that is what I need in the moment. She is selfless and an amazing example of love. Thank you, mom, for your constant support, patience, insights, positive outlook, and unwavering trust in God and His ability to bless all our lives.

This project finally came to fruition after many years of effort by the Morgan-Summit Adaptive Resource Management local working group which is made up of biologists from the Utah Division of Wildlife Resources (UDWR), local landowners, County officials, and anyone else interested in sage-grouse work. I want to thank Lorien Belton and the members of the group for their efforts and for welcoming me with open arms and sharing a lot of local knowledge that was instrumental in my work.

The support and information I received from the UDWR was awesome! I’m grateful for the opportunity to work with Scott Walker, Pam Kramer, Scott McFarlane, Chad Wilson, Dave Rich, Thayne Aubrey, Jason Robinson, and Avery Cook. Many thanks to Darren DeBloois and Frank Howe who provided camper trailers for me and my technicians to live in during the field seasons. The folks at East Canyon State Park (Chris Haramoto, Kent Cummings, Zach Alvis, Hayley Smith) were so generous to offer camp sites with water, power, and sewer hookups. They were always curious how the project was going. They treated us like family and I am happy to call them my friends.

I acknowledge Adam Brewerton for his vision and support as a friend, boss, biologist, birding expert, and colleague. Adam has an amazing ability to see the bigger picture. He hired me as a wildlife technician during my first summer as an undergraduate at USU even though I hadn't yet taken classes relevant to the work we would be doing. He took a chance on me. He taught me, and continues to teach me, many things. After working with Adam for 2 seasons, he recommended me to Dr. Messmer for this project. Thank you, Adam, for being a mentor, teacher, and friend. I owe a lot to you.

I want to thank my major advisor, Dr. Terry Messmer, for providing this opportunity to study sage-grouse in Morgan and Summit Counties. I truly appreciate his patience, guidance, trust, and example. He has been a great mentor for my project, and for my career, teaching me how to manage difficult situations and encouraging me to express myself in a unique way that touches people. Thank you for caring about me, my family, and our well-being. I'd also like to thank Dr. Tom Edwards and Dr. Dave Koons for being on my graduate committee and for the assistance they have provided along the way as teachers and experts in their fields. I acknowledge my technicians, Wayne Smith and Megan Squire. Thank you for your hard work and dedication. You put in long hours away from family and friends in all kinds of weather. I learned from both of you and I couldn't have done this without you.

My lab and office mates have been great. I leaned heavily on Charlie Sandford during my first year of grad school. We worked together in the lab, in the classroom, and in the field. Thanks for your patience and willingness to help along the way, Charlie. You made the process much easier for me. Special thanks to Dr. Dave Dahlgren, Seth Dettenmaier, Melissa Chelak, Wayne Smith, Justin Small, and Skyler Farnsworth for the insights you offered, help with trapping, and the comradery in the office and lab. It is a pleasure to know you and learn from each of you. I want to thank Michel Kohl for his time, insights, and guidance while assisting me with analyses. You never made me feel inferior and you constantly reminded me that I am capable. Thank you for that. Finally, I want to thank Rae Ann Hart who took care of the daily management and organization of the lab. You are an unsung hero who makes all of our jobs easier to do.

I also want to thank those responsible for funding this project including Summit County, the Kern River Gas Transmission Company, the Jack H. Berryman Institute, and the Utah Public Lands Policy Coordination Office, and a special thanks to the Utah State University Quinney College of Natural Resources and the Quinney Professorship for Wildlife Conflict Management for supporting me financially through this process.

Lastly, even with funding, this project would not have been possible without the cooperation, trust, generosity, and knowledge of the local landowners. You didn’t have to show interest in the project, yet you did. You didn’t have to allow me access to your properties, yet you did. You didn’t have to care about sage-grouse and other wildlife, yet you do. And because of you, this project was a success.

There are countless others who deserve praise and thanks. I can’t name all of you because it would double the size of this thesis. I know who you are and I am thankful for your love, kindness, support, friendship, and encouragement. I am inspired by those who lift others through words and actions and I have truly been blessed by many such people in my life. I am humbled to stand on the shoulders of those who have gone before me and to link arms with those who walk beside me.

M. Brandon Flack

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

HISTORY

The greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) is an iconic species of western North America. They are considered an umbrella species because of their role as an indicator of the condition of sagebrush (*Artemisia* spp.) ecosystems (Hanser and Knick 2011, Knick et al. 2013). Sage-grouse are the largest grouse species in North America and although males and females have morphological similarities with black bellies, pointed tail feathers, and cryptic coloration, they are sexually dimorphic with males being about twice as large as females (Patterson 1952, Dalke et al. 1963). Males can be easily distinguished during the mating season as they display elaborate breeding plumage and exhibit charismatic behavior while female plumage and behavior remain cryptic, even if the female is on the lek.

Sage-grouse population declines were recognized as much as a century ago when conservationist and author W. T. Hornaday (1916) called for "the people of the Far West to save the sage grouse from complete annihilation." Populations of sage-grouse have continued to decline range-wide since then (Connelly et al. 2004) with potential habitat being reduced from an estimated pre-settlement distribution of 1.2 million km^2 to 668,000 km^2 as of 2000 (Schroeder et al. 2004). These declines have been largely attributed to the degradation, alteration, and fragmentation of the sagebrush habitats that sage-grouse depend on (Schroeder et al. 2004, Connelly et al. 2011a). Urban development, excessive livestock grazing, conversion of sagebrush landscapes to agricultural production, and invasive plants are all cited as contributors to habitat loss and fragmentation (Crawford et al. 2004, Connelly et al. 2011b) and are all potential threats to sage-grouse populations in my study area (Morgan Summit Adaptive Resource Management Local Working Group [MSARM] 2006). The immediate impacts to sage-grouse include loss of forage and cover, loss or fragmentation of breeding locations (Braun et al. 1977), lost nesting and brood rearing locations (Connelly and Braun 1997), altered seasonal movements, population isolation, reduced gene flow, and increased predation risk (Coates and Delehanty 2010). Nevertheless, researchers believe that sage-grouse conservation is still possible because the species is widely distributed and there are still areas of relatively large intact and suitable sagebrush habitats (Connelly et al. 2011b) as sage-grouse are currently found in 11 states in the western United States and 2 Canadian provinces.

In recent years, the sage-grouse has been at the center of a conservation controversy. In 2005, after petitions for federal protection and a review of the species status, the U.S. Fish and Wildlife Service (USFWS) determined that the sage-grouse was not warranted for federal protection under the Endangered Species Act of 1973 (ESA; USFWS 2015a). Due to litigation and court orders, sage-grouse status was re-evaluated and in March 2010 the USFWS found the species was “warranted for listing but precluded by higher priority listing actions.” The primary reasons for a warranted listing decision were habitat loss, habitat fragmentation, and inadequate regulatory mechanisms (USFWS 2010). Another lawsuit followed challenging the “warranted but precluded” status and the USFWS agreed to review all species that fell into that category and publish proposed rules or findings by September 30, 2016 (USFWS 2015a). After this latest review, the USFWS announced in October 2015 that the sage-grouse did not warrant protection under the ESA stating that the primary threats of habitat loss, fragmentation, and lack of regulatory mechanisms had been ameliorated by conservation efforts to protect and restore habitat and by the implementation of federal and state management plans created specifically for sage-grouse (Wyoming Sage-grouse Working Group 2003, Bi-State Local Planning Group 2004, Stinson et al. 2004, Montana Sage Grouse Work Group 2005, Idaho Sage-grouse Advisory Committee 2006, Colorado Greater Sage-grouse Steering Committee 2008, Hagen 2011, State of Utah 2013, Nevada Sagebrush Ecosystem Council 2014). The collaborative effort between federal and state agencies, private land owners, and conservation groups to protect sage-grouse has been called the largest land conservation effort in U.S. history (USFWS 2015b).

Sage-Grouse in Utah

In Utah, it has been estimated that sage-grouse occupy 41% of possible historic habitats, with the largest populations inhabiting sagebrush areas in western Box Elder, western Garfield, Rich, Uintah, and Wayne Counties (Beck et al. 2003, Dahlgren et al. 2016). In response to population declines and the potential for federal protection of the species under the ESA, the Utah Division of Wildlife Resources (UDWR) developed a strategic statewide management plan in 2002 which was updated in 2009 (UDWR 2002, 2009). In April 2013, Utah Governor Gary Herbert signed the Conservation Plan for Greater Sage-Grouse in Utah (Plan; State of Utah 2013). The Utah Plan is a science-based strategy that establishes goals and measurable objectives for sage-grouse in Utah and describes how Utah will manage their habitat and populations to meet those objectives. Because of Utah's unique topography and geography, sage-grouse habitat is discontinuous and populations are therefore naturally dispersed throughout the state in intact blocks of suitable habitat in the Great Basin, or in disconnected habitat islands in the Colorado Plateau (State of Utah 2013, Dahlgren et al. 2016).

The Utah Plan emphasizes the need to understand local population dynamics, site-specific threats and research needs, and recommended management strategies to conserve sage-grouse in Utah using the best available data (State of Utah 2013). Over the past 20 years, researchers from Utah State University and Brigham Young University have completed studies which have mapped the ecology of most of Utah's sage-grouse populations. These studies were paramount to the development of the scientific basis and strategies of the Utah Plan (State of Utah 2013). Based on previous research, the state of Utah established 11 sage-grouse management areas (SGMAs) that encompass roughly 95% of the seasonal sage-grouse habitat throughout the state (Dahlgren et al. 2016). Habitat improvements and restoration work is carried out in the SGMAs which affords the greatest potential to conserve the species in Utah (State of Utah 2013, Dahlgren et al. 2016).

The willingness of private landowners in Utah to collaborate with state and federal agencies to improve habitat and conserve species like the sage-grouse provides evidence that community-based conservation programs can be effective. Because half of the sage-grouse in Utah occur on private lands, the Utah Plan relies on voluntary conservation efforts of private landowners and collaboration with government agencies to conserve sage-grouse and increase their populations throughout Utah (State of Utah 2013, Dahlgren et al. 2016). At this time, it appears the Utah Plan is working as designed with objectives being met or exceeded each year and sage-grouse population estimates in Utah increasing by 40% from 2013 to 2014 and 18% from 2014 to 2015 (UDWR 2014, 2015).

The USFWS decision in October 2015 that sage-grouse do not currently warrant federal protection under the ESA (USFWS 2015a) provides additional time for states to demonstrate that their conservation plans are working.

Morgan-Summit Sage-Grouse

The Rich-Morgan-Summit SGMA, located in northeastern Utah near the Wyoming border is inhabited by one of the state's largest sage-grouse populations (State of Utah 2013). Most of the sage-grouse in this SGMA are found in Rich County with smaller populations dispersed on mostly private lands throughout Morgan and Summit Counties. Research has been carried out on Utah's large sage-grouse populations mentioned previously but less research has been conducted on Utah's smaller populations. Thus, information is lacking regarding the ecology of the smaller populations that could be used to guide and refine conservation recommendations contained in the Utah Plan (State of Utah 2013). One such area includes a sage-grouse population in Morgan and Summit Counties. This population was described as a distinct small population separated from other populations by mountainous terrain and distances of 20–40 km (Connelly et al. 2004, Garton et al. 2011). Lek monitoring efforts in this area show fluctuation in the population size with a declining trend since 1965 (Garton et al. 2011). Aside from counting male sage-grouse on leks, no research had been conducted on this population and very little was known about survival rates, habitat use (nesting, brood rearing, and winter habitats), migration patterns, or connectivity to larger populations in this area. In their review of sage-grouse seasonal movements in Utah, Dahlgren et al. (2016) reported data from 15 years of research on many of the sage-grouse populations in Utah but did not mention the Morgan-Summit sage-grouse population at all, indicating the lack of knowledge regarding this population.

The MSARM developed a conservation plan with the goal of maintaining, and where possible, increasing sage-grouse populations and improving habitat conditions in Morgan and Summit Counties (MSARM 2006). The conservation plan identifies several strategies including, but not limited to: monitoring of leks, identification of important sage-grouse habitat use areas, and potential habitat conservation actions to improve sagebrush (*Artemisia* spp.) quality. Habitat improvement, restoration efforts, and habitat protection could provide better connectivity between populations, effectively reducing small population vulnerability and mitigating the effects of many conservation threats (Connelly et al. 2000, Schroeder and Baydack 2001, Dahlgren et al. 2016). Because Morgan and Summit Counties are made up primarily of private lands, conservation of sage-grouse depends on the voluntary cooperation and involvement of private landowners.

Dynamics of Small Populations

Most wildlife species are negatively impacted if population sizes decline too far. In a remnant population of greater prairie chickens (*Tympanuchus cupido pinnatus*), reduced fertility, reduced egg hatching rates, and reduced genetic diversity resulted as the population size decreased (Westemeier et al. 1998). An assessment of the population dynamics of northern bobwhite (*Colinus virginianus*), ring-necked pheasant (*Phasianus colchicus*), and eastern cottontails (*Sylvilagus floridanus*) in Kansas demonstrated that smaller populations were less stable and more susceptible to environmental fluctuations (Williams et al. 2003).

Small populations of sage-grouse are considered to be at increased risk of extinction because they are spatially isolated from larger populations and inhabit smaller geographic areas (Aldridge et al. 2008, Garton et al. 2011). Some studies suggest that small sage-grouse populations in fragmented landscapes travel farther to fulfill their life cycle needs than those in larger contiguous geographic areas (Hagen et al. 2001, Schroeder and Robb 2003, Beck et al. 2003, Dahlgren et al. 2016) placing them at increased risk for predation and reduced fitness. In contrast, because seasonal habitats in small geographic areas may completely overlap, individual sage-grouse may carry out their entire life cycle in the same area without migrating at all (Patterson 1952, Hulet 1983, Hagen 1999). If most or all individuals were to select this strategy, disturbance events such as wildfire, drought, or extensive urban development could lead to extirpation of the population (Williams et al. 2003). Without contiguous habitat or migratory corridors that connect populations, genetic diversity could be lost leading to limited local adaptation and decreased fitness (Westemeier et al. 1998, Oyler-McCance and Quinn 2011).

GENERAL ECOLOGY AND HABITAT CHARACTERISTICS

Sage-grouse are sagebrush obligates, meaning they require sagebrush to survive as it is used for protective cover, nesting, and food (Braun et al. 1976, Connelly et al. 2011b). Sage-grouse habitat requirements vary seasonally resulting in highly variable seasonal movements among sage-grouse populations range wide (Connelly et al. 2011b). Many populations are partially migratory, where some individuals migrate while others do not (Connelly et al. 2011a, Fedy et al. 2012, Dahlgren et al. 2016). For those who do not migrate, seasonal ranges may be integrated or overlap entirely, especially in areas where habitat may be limited (Connelly et al. 2003, State of Utah 2013). Sage-grouse exhibit high fidelity to seasonal ranges with individuals breeding on the same leks each year and females nesting in the same area each year (Connelly et al. 2011a).

Because population declines have been attributed to habitat loss, degradation, and fragmentation (Crawford et al. 2004, USFWS 2010), sage-grouse vital rates have been tied to habitat measurements and vegetation characteristics (Bergerud 1988, Connelly et al. 2011b). Sage-grouse vital rates such as adult and juvenile survival, nest success, and brood success are highly variable within populations across the species range (Connelly et al. 2011a). Nest bush species, nest bush height and width, shrub canopy cover, grass and forb height, and grass and forb cover are all factors that play a role in sage-grouse vital rates (Connelly et al. 2011b). Sage-grouse populations found in large intact sagebrush ecosystems tend to be more resilient than those found in small isolated pockets of sagebrush habitat (Garton et al. 2011). Although, Schroeder (1997) reported observations of a sage-grouse population found in a fragmented landscape in north-central Washington that not only persisted in that environment, but thrived.

Breeding

Sage-grouse engage in communal breeding behavior described both as polygamy (Scott 1942), meaning individual males and females have multiple mates, and polygyny (Wiley 1973), where one male breeds with multiple females. During the breeding season, 2 or more male sage-grouse form territories on open, flat areas called leks where they display breeding plumage and strut to attract and mate with females (Patterson 1952, Connelly et al. 2011a). A dominant male generally claims a territory on the lek where females traditionally congregate and will often mate with a majority of the females (Wiley 1973).

Leks generally occur in relatively open areas with sparse vegetation surrounded by sagebrush. Adult males typically begin congregating on leks in February and strutting behavior can last until early June in some locations (Connelly et al. 2011a). Lek attendance by females tends to peak from late March to early April and females may visit multiple leks during a breeding season (Connelly et al. 2011a, Schroeder and Robb 2003). Peak male attendance generally occurs a few weeks later when yearling males begin claiming territories on the lek (Connelly et al. 2011a). Lek locations are traditionally found in the same place year after year although they can move in response to disturbance, changes in snow cover and vegetation, or expansion (Connelly et al. 2011a). Sage-grouse may use disturbed sites such as pipeline scars or heavily grazed locations for lekking if these provide adequate visibility (Connelly et al. 1981, Duvuvuei 2013). Because leks are found in the same general location year after year, populations can be monitored on a long term basis by counting the number of males attending the leks which serves as an index of population sizes (Connelly et al. 2003, Connelly and Schroeder 2007).

Nesting

Most sage-grouse nest locations are found within 3 km of the nearest lek, but may be located 20 km or more from the nearest lek (Wakkinen et al. 1992, Hanf et al. 1994, Connelly et al. 2000, Fedy et al. 2012). Site fidelity to successful nest locations plays a role in where a female will nest in subsequent years. Females that had a successful nest in the previous year are likely to nest within 1.6 km of that location the following year

(Berry and Eng 1985, Fischer et al. 1993, Holloran et al. 2005, Schroeder and Robb 2003). Conversely, females that had an unsuccessful nest the previous year will nest an average of 5.2 km away from the previous year's failed nest location (Schroeder and Robb 2003). Gibson et al. (2016) suggested that female sage-grouse select nest habitat based on its qualities as a brood rearing habitat because nest site selection variables were more predictive of chick survival than of nest survival.

Sage-grouse nests are most often located under sagebrush (Patterson 1952, Wallestad and Pyrah 1974). Although similar shrub species have also been selected by female sage grouse as a nest location (Klebenow 1969, Gregg et al. 1994, Gruber 2012, Duvuvuei 2013), nests located under sagebrush have a higher success rate (Connelly et al. 2011b). Some research has shown that sage-grouse nest sites typically have taller and denser shrub and grass canopy cover than random sites (Gregg et al. 1994, Holloran et al. 2005, Knerr 2007) and that nests located in areas with greater sagebrush canopy cover are typically more successful (Wallestad and Pyrah 1974, Gregg et al. 1994, Kolada et al. 2009). However, Dahlgren (2006) and Guttery (2011) did not observe the same relationship for sage-grouse nesting in higher elevation sagebrush communities in Utah. Connelly et al. (2000) recommended maintaining mean sagebrush nesting canopy cover of 15–25% with mean height of nest bushes 30–72 cm, depending on site moisture conditions.

Nest initiation and nest success rates are variable depending on the hen age (Wallestad and Pyrah 1974, Peterson 1980, Hausleitner 2003, Gregg et al. 2006), habitat conditions (Coggins 1998), and environmental conditions (Schroeder 1997, Walker 2008). Connelly et al. (2011a) reported that nest initiation rates average 78% range wide.

The typical clutch size of sage-grouse is 6–9 eggs (Schroeder 1997, Connelly et al. 2011a). On average, a female will lay one egg every day and a half (Schroeder et al. 1999). Incubation begins once the clutch is complete and lasts from 25–29 days (Patterson 1952, Connelly et al. 2011a). Nest success varies widely across the species range with estimates of 15–86%. Nest success factors include habitat quality, the female's age and experience, and the abundance of nest predators (Connelly et al. 2011a). If the first nest is unsuccessful, the female may re-nest, though the second clutch will likely be smaller than the first (Schroeder 1997). Adults are more likely to re-nest than yearlings and re-nesting rates are highly variable with a 9–87% likelihood and an average of 30% likelihood across the species range (Connelly et al. 2011a).

Brood Rearing

Sage-grouse chicks are considered precocial and can move around and forage almost immediately after hatching. They are capable of weak flight at 2 weeks of age and strong flight by 5 weeks of age (Schroeder et al. 1999). Movement away from the nest location is variable and seems to be driven by stand structure and food availability (Klebenow 1969, Peterson 1970, Wallestad 1971, Drut et al. 1994, Connelly et al. 2000). Most females stay close to the nest location during early brood rearing but Gates (1983) reported one female moving 3.1 km with her brood just 2 days after hatching. During their first few weeks of life, the chicks live on a diet consisting mainly of forbs and insects (Patterson 1952, Drut et al. 1994, Gregg and Crawford 2009). Sage-grouse are only able to digest soft plant tissue and insects because they do not have a muscular gizzard (Patterson 1952). Their specialized digestive system filters toxic secondary compounds and extracts nutrients from fibrous plant material which allows them to digest sagebrush (Clench and Mathias 1995). As the brood rearing season grows longer and plants begin to dry out, the female may move her brood greater distances to find more mesic habitats that maintain dietary needs of the growing chicks (Klebenow 1969, Connelly et al. 2000).

Brood rearing areas generally have less dense shrub canopy cover than nesting sites (Thacker 2010) and broods tend to use areas of low sagebrush cover during early brood rearing (Drut et al. 1994). Broods will use areas with greater sagebrush height during late brood rearing (Wallestad 1971, Dunn and Braun 1986). Forb cover is typically greater at brood use sites than at random locations (Klebenow 1969, Schoenberg 1982, Dunn and Braun 1986) with Drut et al. (1994) reporting up to 14% forb cover and Apa (1998) reporting that brood use sites had twice as much forb cover as random locations.

The survival of young sage-grouse is influenced by gender (Swenson 1986), habitat quality (Pyle and Crawford 1996, Gregg 2006), food availability (Swenson 1986, Pyle and Crawford 1996, Holloran 1999), age of brood female (Gregg 2006), and weather (Rich 1985). Juvenile and brood survival rates vary greatly among sage-grouse populations and direct comparisons are difficult because of the differences in time periods used (18–51 days) and whether a study looked at chick or brood survival (Connelly et al. 2011a). Chicks stay with the female for 10–12 weeks at which time broods begin to break up (Schroeder et al. 1999).

Summer

Summer habitats are those areas used by sage-grouse after dessication of herbaceous vegetation (Klebenow and Gray 1968) and could be more than 80 km away from nest locations although movement patterns vary greatly among populations and among individuals of the same population (Connelly et al. 1988). As with breeding areas, sage-grouse will use traditional summer habitats even if it means moving greater distances and bypassing suitable summer habitat to get there (Wallestad 1971, Fischer et al. 1996).

Early summer is the time of year when the diet of sage-grouse chicks transitions from insects to succulent forbs (Patterson 1952, Peterson 1970). From July through September, sage-grouse will exploit different habitat types including riparian areas, wet meadows, and agricultural fields but often continue to use sagebrush dominated areas selecting for habitats based on forb availability (Patterson 1952, Wallestad 1971, Connelly et al. 1988). Sage-grouse will move up in elevation or use sites where moisture collects and forbs are available all summer (Wallestad 1971, Fischer et al. 1996). Because sage-grouse obtain moisture through the vegetation they consume, movements in summer are most likely in response to availability of succulent forbs rather than availability of free water (Connelly 1982, Connelly and Doughty 1989). Aldridge and Brigham (2002) suggested that a lack of shift in habitat selection from early to late brood rearing areas could indicate no difference of forb availability in the area.

The Utah Plan (State of Utah 2013) suggested that Utah's sage-grouse populations are space limited which could be another reason for a lack of shift in habitat selection throughout the species' yearly life cycle. Dahlgren et al. (2016) confirmed this assumption. In either case, non-migratory sage-grouse will seek out microhabitats within sagebrush dominated landscapes such as swales and ditches that hold moisture longer into the summer and where forbs are still available (Wallestad 1971).

Fall and Winter

Fall is a transitional time in the diet and habitat use of sage-grouse when birds shift from consuming a variety of forbs, insects, and sagebrush to a diet made up almost exclusively of sagebrush. The dietary shift forces sage-grouse to congregate more often in sagebrush dominated habitats and consequently form larger flocks (Patterson 1952, Savage 1969, Wallestad et al. 1975, Thacker 2010). This shift occurs because of continued vegetation desiccation and because frost kills nutritious forbs and insects as temperatures decrease (Patterson 1952, Savage 1969). Fall habitats vary based on many factors including availability, elevation, topography, water, distance between summer and winter range, and weather (Patterson 1952, Dalke et al. 1963, Wallestad 1971, Connelly 1982, Connelly et al. 1988). In Utah, sage-grouse use fall habitats from August through December with migrations to winter habitats occurring in November regardless of snow depths (Welch et al. 1990).

Winter habitat is dominated by big sagebrush (*A. tridentata* spp) which is used for food and cover (Patterson 1952, Connelly et al. 2000, Crawford et al. 2004) but can also include little sagebrush (*A. arbuscula*) and black sagebrush (*A. nova*) if it can be found above the snow (Schroeder et al. 1999). Habitat selection is influenced by snow depth and hardness, topography, vegetation height and cover (Connelly 1982, Schoenberg 1982, Robertson 1991, Schroeder et al. 1999) and spatial distribution of sage-grouse depends on snow depth (Patterson 1952, Welch et al. 1990) and sagebrush height above the snow (Schoenberg 1982, Connelly 1982). Because of snow depth, sage-grouse will likely be found at relatively low elevations during the winter (Connelly et al. 2011b). They tend to use areas with south or southwest facing slopes of less than 5%

slope where snow is directly exposed to the sun and melts more quickly providing more exposed sagebrush (Beck 1977, Crawford et al. 2004). Sagebrush canopy cover in winter habitat areas varies from 6–43% (Schroeder et al. 1999).

In Utah, Homer et al. (1993) found that sage-grouse preferred medium to tall shrubs (40–60 cm) and moderate canopy cover (20–30%). For management purposes, Connelly et al. (2000) recommend a sagebrush canopy cover of 10–30% with shrubs tall enough to protrude 25–35 cm above the snow. Sage-grouse fidelity to specific winter range habitat is not well studied (Connelly et al. 2011b) and in Utah, Welch et al. (1990) found that sage-grouse exhibited less fidelity to winter range than to other seasonal ranges.

STUDY AREA

This research focuses on sage-grouse populations located in the southern portion of the Rich-Morgan-Summit SGMA in northern Utah (Fig. 1-1) which was defined in the Utah Plan (State of Utah 2013). This area is within the Southern Great Basin Sage-Grouse Management Zone identified in the Greater Sage-Grouse Comprehensive Conservation Strategy (Stiver et al. 2006). It is generally bounded by the Rich-Morgan-Summit SGMA boundary and is made up mostly of portions of Morgan and Summit Counties. The study area encompassed approximately 2,150 km^2 although most sage-grouse monitoring occurred in an area of approximately 100 km^2 where the core population was located.

Vegetation in the study area included big sagebrush (*Artemisia* spp.) communities at lower elevations transitioning to mountain brush communities, Gambel oak (*Quercus* spp.), maple (*Acer* spp.), juniper (Juniperus spp.), aspen (*Populous tremuloides*) and mixed coniferous (*Picea* spp. and *Pseudotsuga menziesii*) forests as elevation increases. Elevation ranges from 1500–2800 meters above sea level.

Average annual precipitation is 44.5 cm. The area receives an average of 152.4 cm of snowfall that primarily occurs from December through February. Average monthly temperatures range from a high of 31.9° C in July to a low of -11.6° C in January (Western Regional Climate Center 2016). During this study, monsoon-like rain fell in May 2015, however, the area still received below average precipitation. Steady amounts of rain and snow fell during the spring of 2016, however, the summer returned to below average precipitation. During this study, winters were mild with lower than normal precipitation (Utah Climate Center 2017).

RESEARCH PURPOSE

The Utah Plan emphasized the need to understand local population dynamics using the best available data (State of Utah 2013). Completion of this study will provide information about habitat-use patterns and vital rates for the sage-grouse population in Morgan and Summit Counties, Utah. It will also identify potential migratory corridors, distinct seasonal habitats, and habitat fragmentation by tracking and documenting inter-seasonal movements of sage-grouse in these counties. Acquiring these data is important to inform management actions that will achieve the goals of the conservation plan in Morgan and Summit Counties and the Rich-Morgan-Summit SGMA (MSARM 2006). This information could also refine conservation recommendations in the Utah Plan.

Chapter 2 examines the nesting and brood rearing habitats used by this sage-grouse population as well as the factors affecting production. I examine the influence of micro-site vegetation characteristics and other factors like sex, age, year, and transmitter type on sage-grouse vital rates. I also report the average distance moved between seasonal ranges. Chapter 3 incorporates resource selection function analyses to investigate the spatial and seasonal variation exhibited by this sage-grouse population. I compared location data acquired from both very-high frequency transmitters and global positioning system enabled platform terminal transmitters to determine if habitat selection predictions vary by transmitter type. I determined the spatial scale at which sage-grouse were selecting for resources and analyze the influence of landscape variables on habitat selection across seasons. The Appendix contains supplemental information describing seasonal migration patterns, home range estimates, and comparisons of migratory and non-migratory individuals.

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FIGURES

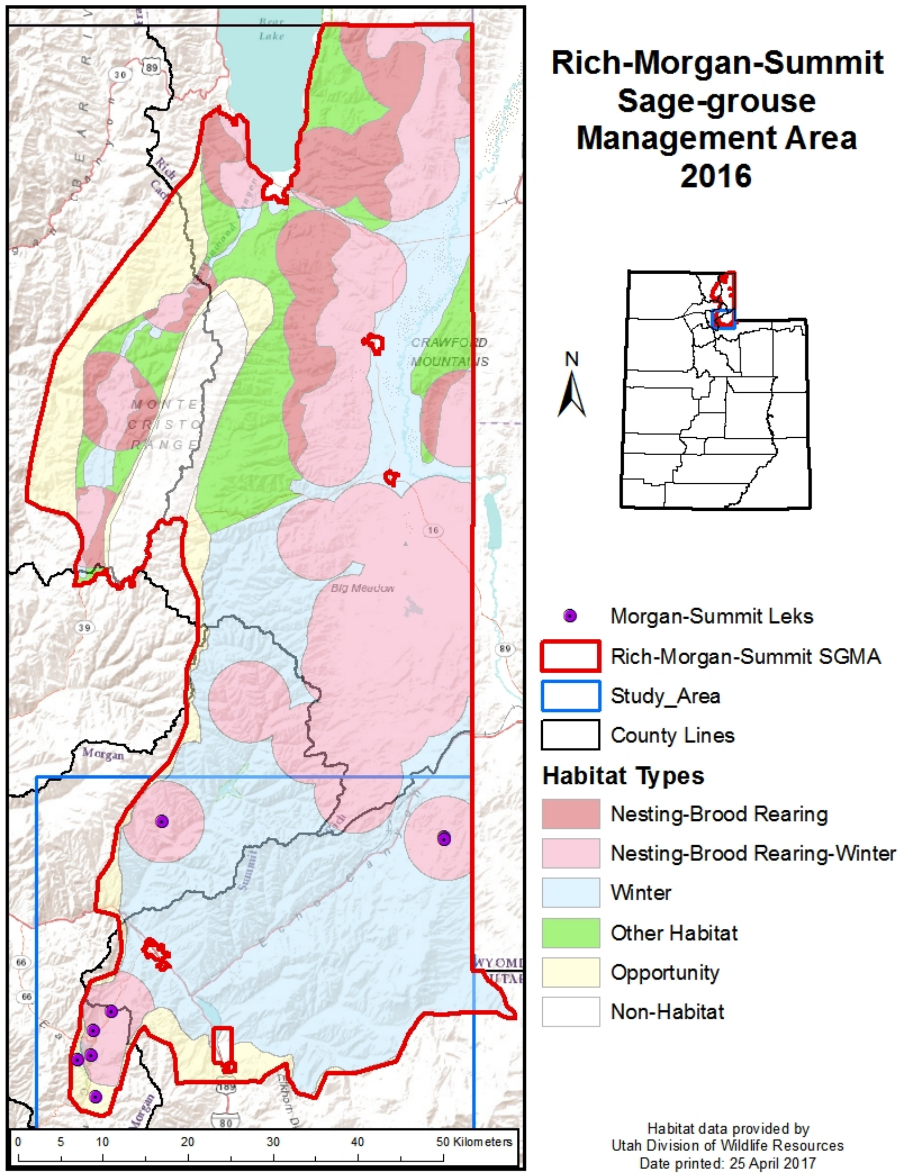

Figure 1-1. Morgan-Summit study area of greater sage-grouse (*Centrocercus urophasianus*) within the Rich-Morgan-Summit Sage-grouse Management Area (SGMA) as defined by the Conservation Plan for Greater Sage-grouse in Utah (State of Utah 2013), 2015–2016. This map represents the most current habitat delineations determined by the Utah Division of Wildlife Resources (UDWR 2016). The areas within the SGMA are classified as habitat, non-habitat, and opportunity areas with further classification of habitat into nesting-brood rearing, nesting-brood rearing-winter, winter, and other habitat. The core of the population in Morgan and Summit Counties in 2015 and 2016 was located in the extreme southwest portion of the SGMA where the majority of the research took place.

CHAPTER 2

BREEDING ECOLOGY, SURVIVAL RATES, AND MOVEMENT PATTERNS OF GREATER SAGE-GROUSE INHABITING THE RICH-MORGAN-SUMMIT SAGE-GROUSE MANAGEMENT AREA

ABSTRACT

Greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) are considered key indicators of sagebrush ecosystem health because of their dependence on sagebrush habitat. Sage-grouse populations have declined range-wide over the last century in response to the loss and fragmentation of sagebrush (*Artemisia* spp.) habitats. Because environmental conditions can cause variation in annual productivity and affect population numbers, researchers have focused on describing the relationship between productivity and habitat quality. Generally, sage-grouse populations found in large intact sagebrush landscapes are considered to be more resilient than smaller populations inhabiting smaller isolated areas. Still, smaller isolated populations persist and even thrive in fragmented landscapes. One such population occurs on private lands in Morgan and Summit Counties (MS) in northern Utah. The Conservation Plan for Greater Sage-grouse in Utah emphasized the need to understand local population dynamics and site-specific threats. Therefore, it is important for managers to understand the basic ecology and seasonal movement patterns of individual populations throughout the state, regardless of population size. I examined seasonal movement patterns and vital rates (nest initiation rates, nest success, clutch size, breeding success, brood success, and survival probability of breeding age birds) of this geographically isolated sage-grouse population from 2015–2016. Using generalized linear models, I examined the influence of female age, year,

transmitter type (very-high frequency radio collars and platform terminal transmitters) and vegetation components on vital rates. I also compared vegetation structure at nest and brood sites with paired random sites and made comparisons between vegetation structure at successful nest and brood sites with unsuccessful sites to determine which vegetation components were important to the production of this population. These analyses confirmed that the MS population is highly productive despite limited space and limited seasonal movements. My research also demonstrated that transmitter type and female age had no influence on vital rates contrary to what other research has shown and that rump-mounted platform terminal transmitters can provide excellent information regarding sage-grouse ecology. There was no significant variation in vegetation structure between used and paired random sites in this area. This information suggested that a sage-grouse population can occupy areas of limited habitat on an annual basis if seasonal habitat conditions are met and critical habitat areas are protected from further degradation or fragmentation.

INTRODUCTION

Greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) are considered key indicators of sagebrush (*Artemisia* spp.) ecosystem health because of their dependence on sagebrush habitat (Lyon and Anderson 2003, Knick et al. 2013). Hence, sage-grouse may be particularly vulnerable to changes in habitat conditions and availability. Sage-grouse populations have declined range-wide over the last century in response to the loss and fragmentation of sagebrush habitats (Connelly et al. 2004, Connelly et al. 2011a). Distribution of sage-grouse was estimated at 668,000 km^2 as of 2000, a decrease of 43% from the estimated pre-settlement distribution (Schroeder et al.

2004). In 2015, in response to petitions to protect the sage-grouse under the Endangered Species Act of 1973 (ESA) and after an extensive review of the current range wide status of sage-grouse, the U.S. Fish and Wildlife Service (USFWS) determined sage-grouse did not warrant protection under the ESA (USFWS 2015). Another review of the species' status will be completed in 2020.

Environmental conditions can cause variation in annual productivity and affect population numbers (Bergerud 1988). Concomitantly, researchers have focused on relationships between productivity and habitat quality, predation pressures, and demography (Bergerud 1988, Schroeder 1997). Sage-grouse population vital rates (i.e., nest initiation rates, nest success, clutch size, breeding success, brood success, and survival probability of breeding age birds) are affected by environmental variability, population structure and past reproductive efforts (Guttery et al. 2013, Caudill et al. 2014, Caudill et al. 2016a, Caudill et al. 2016b). Additionally, when compared to other upland game bird species, sage-grouse exhibit a relatively low probability of nesting, and re-nesting is unusual (Connelly et al. 1993). However, Connelly et al. (2011a) reported a wide range of nesting and re-nesting probabilities among sage-grouse populations across the species range.

Sage-grouse populations found in large intact sagebrush ecosystems tend to be more resilient than those found in small isolated pockets of sagebrush habitat (Aldridge et al. 2008, Garton et al. 2011). Populations in Wyoming, Montana, southern Idaho, and northern Nevada are large, and therefore persistent, partly because they occupy larger intact sagebrush landscapes whereas peripheral populations experience greater rates of extirpation (Aldridge et al. 2008, Garton et al. 2011). However, some peripheral populations persist despite being located in fragmented or less suitable habitats. Schroeder (1997) reported observations of a sage-grouse population found in a fragmented landscape in north-central Washington that not only persisted in that environment, but thrived.

In Utah, it has been estimated that sage-grouse occupy 41% of historic habitats, with the largest populations inhabiting sagebrush areas in western Box Elder, western Garfield, Rich, Uintah, and Wayne Counties (Beck et al. 2003). Because of Utah's unique topography and geography, sage-grouse habitat is discontinuous and populations are therefore naturally dispersed throughout the state in suitable intact blocks of sagebrush habitat in the Great Basin, or in disconnected islands in the Colorado Plateau (State of Utah 2013, Dahlgren et al. 2016). Thus, Utah populations provide the ideal situation to understand how landscape attributes may influence at risk populations. Of these, the Morgan-Summit (MS) population is important because very little is known about the general ecology of this population and it experiences a high level of anthropogenic disturbances (Morgan-Summit Adaptive Resource Management Local Working Group [MSARM] 2006). Of particular conservation interest are the vital rates and movement patterns of breeding-age birds that includes identification of important seasonal habitat use areas and possible connectivity with other nearby populations (MSARM 2006). Although considered a small and geographically isolated population (Garton et al. 2011), long-term lek count data suggests the population is stable (Utah Division of Wildlife Resources [UDWR], unpublished data).

In this chapter, I examined seasonal movements and vital rates and the variation associated with age, year, transmitter type, and vegetation structure for a geographically isolated sage-grouse population (UDWR 2002, 2009, Garton et al. 2011). I compared productivity between the MS sage-grouse population to other Utah populations and across the species range with an emphasis on the highly productive population studied in north central Washington (Schroeder 1997). This research provided new information to help guide sage-grouse conservation strategies of the MSARM, the state of Utah, and private landowners.

STUDY AREA

The study area was located in the southern portion of the Rich-Morgan-Summit Sage-grouse Management Area (SGMA) in northern Utah (Fig. 2-1). This area is within the Southern Great Basin Sage-Grouse Management Zone identified in the Greater Sage-Grouse Comprehensive Conservation Strategy (Stiver et al. 2006). The study area was generally bounded by the Rich-Morgan-Summit SGMA boundary and was made up mostly of portions of Morgan and Summit Counties. Geographically, the core of the study area is located within 8 km of East Canyon State Park (lat. 40°54’4”N, long. 111°35’14”W) in the Wasatch mountain range in Morgan County. The study area encompassed approximately 2,150 km^2 although the majority of sage-grouse monitoring occurred in an area of approximately 100 km^2 where the core population was located.

Land ownership in the study area is mostly private with some public lands which consist of US Forest Service, UDWR wildlife management areas, and Utah State Parks. Because of its proximity to the heavily populated areas of Salt Lake City and Ogden, the area is a popular year-round tourism destination providing recreational opportunities including camping, fishing, hunting, hiking, cycling, and water sports. Livestock grazing occurs from April through July on most properties. A natural gas pipeline bisects the core sage-grouse area, and although habitat restoration occurred post installment, a scar is clearly visible. Because of its location adjacent to (and sometimes on) state Highway 65, the Henefer Divide lek is one of the most visited leks in the entire sage-grouse range. During the mating season, high numbers of tourists drive from the Salt Lake metropolitan area to view the mating display of male sage-grouse.

Sagebrush habitat in the core area has remained intact. Vegetation included big sagebrush (*A. tridentata* spp.) communities at lower elevations transitioning to mountain brush communities, Gambel oak (*Quercus* spp.), maple (*Acer* spp.), juniper (*Juniperus* spp.), aspen (*Populous tremuloides*) and mixed coniferous (*Picea* spp. and *Pseudotsuga menziesii*) forests as elevation increases. A complete list of shrub, forb, and grass species observed in the study area is found in Table A-1.

Elevation ranges from 1540–2836 m above sea level. Average annual precipitation is 44.5 cm. The area receives an average of 152.4 cm of snowfall that primarily occurs from December through February. Average monthly temperatures range from a high of 31.9° C in July to a low of -11.6° C in January (Western Regional Climate Center 2016). During this study, monsoon-like rain fell in May 2015, however, the area still received below average precipitation. Steady amounts of rain and snow fell during the spring of 2016, however, the summer returned to below average precipitation. During this study, winters were mild with lower than normal precipitation (Utah Climate Center 2017).

METHODS

Capture and Marking

Sage-grouse were trapped on or near 3 different lek sites in early spring during the breeding season and before the onset of nesting (March 5 to April 15 in 2015, and March 31 to April 5 in 2016) so as to minimize negative impacts on nest initiation. Trapping occurred at night using all-terrain vehicles, spotlights, and dip nets following protocols described by Giesen et al. (1982), Wakkinen et al. (1992), and Connelly et al. (2003). Each captured bird received a numbered aluminum leg band (National Band Company, Newport, KY). Birds were fitted with either a 22g necklace style very-high frequency (VHF) radio-collar (Advanced Telemetry Systems, Isanti, MN, Fig. A-1; n = 25), or a 22g global positioning system (GPS) equipped rump-mounted personal terminal transmitter (PTT; 22g Solar Argos/GPS PTT-100, Microwave Telemetry, Inc., Columbia, MD, Fig. A-2; n = 10). At time of capture, we recorded leg band size and number, sex, age (Crunden 1963, Eng 1955), weight, behavior during handling, cloud cover, wind speed (Beaufort scale), temperature, time from capture to release, and GPS coordinates (Universal Transverse Mercator [UTM], NAD 1983, Zone 12N). All birds were processed at the capture site and released as quickly as possible to mitigate capture related mortality. Research and handling protocols were approved by the Utah State University Institutional Animal Care and Use Committee under permit #2419, and UDWR Certificate of Registration #2BAND9483.

Nest Monitoring

I determined the start of nest initiation for VHF radio-collared birds when a female was found in the same location on 2 consecutive visits during or following the breeding season. For birds marked with PTT transmitters, nest incubation was ascertained when spatial locations recorded and uploaded by the PTT were similar over several consecutive days during or following the mating season. Nesting was verified by visually locating all nesting females by slowly circling the estimated nest location. Care was taken not to disturb or flush nesting females to mitigate nest abandonment.

Following confirmation of incubation, nest observation locations were marked using a hand-held GPS unit, distance and bearing to the nest were recorded, and a discreet physical marker was placed at the observation point to aid researchers in returning to the observation location for ongoing nest monitoring. Actively nesting females were observed 3–5 times per week from a distance of 5–30 m until the nest hatched or failed. A successful hatch was determined when egg halves were found intact in or near the nest bowl, and/or the inner membrane of the eggs was separated from the shell (Wallestad and Pyrah 1974). A failed nest was determined when no eggs or egg halves were found at the nest site, if egg halves were not intact, or if only egg fragments remained at or near the nest site (Patterson 1952). Every effort was made to verify nest fate by locating the marked hen as quickly as possible to observe her behavior and/or by visually observing chicks with the female. If nest failure was determined, monitoring frequency of that female was reduced to 1–2 times per week. In the event a female re-nested, the above protocol was repeated. A GPS location was recorded at each nest after fate was determined and the female was no longer present.

Brood Monitoring

After hatching, females with broods were located twice per week until the brood reached 50 days of age or until the brood failed. We used radio-telemetry equipment to locate marked females with broods and circled the female's location until the female or a chick was seen. Once the brood location was confirmed, a GPS location was recorded. A failed brood was determined if the female flushed with one or more females and no chicks were seen on 2 consecutive location attempts. Once it was determined that the brood had failed, we reduced monitoring frequency to 1–2 locations per week.

For successful broods, each brood was flushed and counted 50 days after hatching (Schroeder 1997). The observer walked directly toward the radio signal until the female flushed. Once the female's exact location was determined, a thorough search of the area was performed by walking an outward spiral pattern with 5–10 m spacing for 20 minutes (Dahlgren et al. 2010a). All birds that flushed, or were seen walking, or were seen roosted during the location effort or during the spiral search were counted and classified as either females or chicks.

Fall and Winter Monitoring

I listened for live VHF signals from 4 different locations in the study area during fall which allowed me to ascertain survival of most VHF marked birds. I also completed 3 telemetry flights in a small fixed-wing aircraft during the winter months of the study; January 2016, December 2016, and January 2017. These flights allowed verification of survival and general location of VHF birds from the air.

Vegetation Surveys

Vegetation surveys were completed at all nest and brood locations to determine the micro-site habitat characteristics. We completed vegetation surveys at nest sites within a few days of the nest hatching if successful or within a few days of the estimated hatch date if unsuccessful. This method allowed for more meaningful comparisons of vegetation at the time of nest hatch (Gibson et al. 2016a). We also attempted to complete surveys at brood sites within a few days of locating the female and her brood at that location. In addition, surveys were completed at paired random sites to compare used nest and brood sites to available habitat. Random sites were determined by selecting random distances between 100–500 m and random bearings from 0–359 degrees from used nest and brood sites. I used a random number generator smartphone application to generate the distance and bearing numbers (Random Number by Saranomy, v 1.0.11). The paired random surveys were performed on the same day as the nest or brood surveys, but if that was not possible they were performed within 2 days of the nest or brood surveys.

Vegetation surveys consisted of a single transect in each cardinal direction from the nest bowl or brood site. Nest and brood site transects were each 15 and 12 m in length, respectively (Connelly et al. 2003). A longer transect at brood sites accounts for separation between chicks and females during foraging, especially as chicks age and grow larger. Brood site vegetation surveys were performed at locations temporally spaced at least one week apart.

I used the line intercept method to determine percent shrub canopy cover and shrub height, and the Daubenmire frame technique to evaluate species composition (percent cover and height) of forbs and grasses as well as percent bare ground, percent litter, and percent rock (Connelly et al. 2003). The Daubenmire frames measured 50 cm long x 20 cm wide. Five frames were placed along each nest survey transect at 3 m intervals. Four frames were placed on each brood survey transect, also at 3 m intervals. Visual obstruction readings (VORs) were determined by using Robel poles to measure the height in decimeters of vegetation 4 m out and 1 m above ground level at nest, brood, and random locations at the 4 different transects (Robel et al. 1970). The VORs were also measured looking out to 4 m from the nest bowl.

Because of the large number of nests and broods relative to the sample size of marked females, and that I was limited to only 2 observers to complete field work in each year of the study, it was difficult to complete all the vegetation surveys in a timely manner as described above. For example, in 2016, there were 16 failed nests before the first successful nest hatched. Because of the timing of incubation and the estimated hatch dates of the failed nests, that meant 32 vegetation surveys (16 nest surveys, 16 random surveys) needed to be done in a matter of a few days. With other nests hatching and failing over the following few weeks it was not possible for 2 observers to perform that many surveys and continue to track and monitor birds. Consequently, vegetation surveys were performed as quickly as possible considering the limitations of time and manpower.

Data Variables and Analyses

I performed 14 different analyses to quantify the general ecology of sage-grouse in this seemingly isolated population. I used variables established by Schroeder (1997) and added vegetation components collected during my study as predictor variables. To understand the effects of vegetation structure on sage-grouse demography, I evaluated the influence of vegetation components on nest success and brood success (Bergerud 1988). I also compared vegetation components between used sites and paired random sites. Furthermore, I quantified the seasonal survival rates of breeding age females and examined how the influence of year, female age, transmitter type, nest order, and various vegetation components affected vital rates. Lastly, I compared mean distances between breeding areas and summer and winter locations to provide a better understanding of how a space-limited population was using the landscape. I used program R (R version 3.3.1, www.r-project.org, accessed 1 Oct 2016) for all data analyses. Results were considered significant at $\alpha \leq 0.05$.

Breeding Vital Rates

Following Schroeder (1997), I used generalized linear models (GLMs) to evaluate the influence of year, female age (adult or yearling), transmitter type (VHF or PTT), nest order (first nest or re-nest), and various vegetation components on breeding vital rates. To evaluate the influence of the aforementioned variables on brood success, I used generalized linear mixed models (GLMMs). The incorporation of a random effect of bird identification number accounted for autocorrelation among locations obtained for the same female during a given brooding season (Gillies et al. 2006).

Nest incubation start date and date of nest fate were estimated as the midpoints between consecutive observations. Nesting and re-nesting likelihood were calculated as the percent of females that started incubating a first nest and the percent of females that started incubating a second or third nest after the failure of their previous nest. This information was based on female movements and direct observations of nests. Clutch size was estimated by counting egg shells or fragments following hatch or failure within

5 days of the female leaving the nest location. Breeding success was estimated as the percent of females that hatched at least one chick (regardless of the number of nest attempts) during the breeding season. Brood success was estimated as the percent of females that produced at least one chick that lived to be 50 days old (Schroeder 1997). Brood mixing can occur with sage-grouse but was not accounted for in this study because we did not mark individual chicks. Therefore, brood success estimates in this population could be underestimated (Dahlgren et al. 2010a).

Nest Success

Nest success was calculated as the percent of nests that hatched at least one egg. Because apparent nest success can be biased high, I used the Mayfield Method (Mayfield 1961, Mayfield 1975) to estimate nest survival probability based on a daily survival rate (DSR). Blomberg et al. (2015) recommend using a DSR that accounts for nest exposure during egg laying (initiation period), and incubation which minimizes bias across a broad range of situations. For sage-grouse, a nest exposure period of 37 days (27 days for incubation and 10 days for egg laying) is recommended and supported in other research (Coates and Delehanty 2010, Blomberg et al. 2015). For this analysis I used a nest exposure period of 36.3 days which represents an incubation period of 27 days (Schroeder 1997, Blomberg et al. 2015) and an initiation period of 9.3 days. The initiation period was comprised of 1.5 days per egg laid (Schroeder et al. 1999) and the average clutch size of successful nests in my study (6.2 eggs). Because nest success is a nonlinear function of daily survival rates, I used the delta method to estimate the standard error of nest survival probability in order to calculate confidence intervals (Seber 1982).

Micro-site Vegetation

To determine differences in vegetation components at nest and brood sites, I used two sample, two tailed t-tests. Because multiple t-tests were performed on dependent vegetation variables, I adjusted the α-value that would be considered significant with a Bonferroni correction by dividing the original α-value of $\alpha < 0.05$ by the number of parameters used in each set of analyses. Comparisons were made between nest locations and random nest locations, and successful and unsuccessful nest locations. Data from 15 vegetation components were collected at nest locations. Therefore, t-tests would need to produce a P-value of $\alpha < 0.003$ after the Bonferroni correction to be considered significant. I also analyzed differences between used brood sites and random brood sites as well as sites used by successful broods and sites used by broods that were ultimately unsuccessful. I used data collected from 12 vegetation components at brood locations which would require a significant P-value of $\alpha < 0.004$ after the Bonferroni correction.

Adult Survival

I evaluated the influence of season, year, sex, age, and transmitter type on the survival of breeding age birds using GLMs. To simplify analysis by year, I defined year to coincide with the annual sage-grouse life cycle that begins with the breeding season on 1 March and ends with the winter season at the end of February, hereafter referred to as grouse year. I performed a seasonal survival analysis by dividing the grouse year into the 4 seasons that are important to the sage-grouse life cycle: Spring (Mar.–May), Summer (June–Aug.), Fall (Sept.–Nov.), and Winter (Dec.–Feb.). The months for each season were selected based on Dahlgren et al. (2016) and were meant to coincide roughly with the breeding/nesting period (Spring), the brood rearing period (Summer), the fall transition period (Fall), and the winter period (Winter). I was unable to estimate monthly survival because I was not able to observe survival in regular intervals during the non-breeding season. Seasonal survival probability and standard error estimates were obtained from GLMs by using the predict function in program R. I calculated annual survival estimates by multiplying seasonal survival rates together. Annual survival standard errors were calculated using the delta method in the msm package in program R (Jackson 2011).

Seasonal Movements

I analyzed movements between leks, nests, summer range, and winter range following Dahlgren et al. (2016). I calculated the maximum distances that female sage-grouse moved from the lek of capture to nests, lek of capture to brooding locations, and lek of capture to winter locations. Maximum distances between nests and summer locations and between nests and winter locations were also calculated. The lek of capture was defined as the nearest lek to the original capture location of the bird (Dahlgren et al. 2016).

RESULTS

Thirty-five female sage-grouse were captured and fitted with transmitters during the study: 19 adults (6 PTT, 13 VHF) and 12 yearlings (4 PTT, 8 VHF) in 2015, and 3 adults and 1 yearling in 2016 (all VHF). I completed 477 vegetation surveys at nest (n = 63), brood (n = 183), and random locations (n = 231). Vegetation surveys were performed from 6 May to 28 July in 2015 and from 17 May to 12 August in 2016.

Nesting and Re-nesting Likelihood

Nest data were obtained for 27 and 30 females in 2015 and 2016, respectively. Two females were never observed nesting and 2 females were on inaccessible property during the nesting period in 2015. One of the inaccessible females from both years was marked with a PTT transmitter. The location data retrieved from the transmitter indicated that she was incubating a nest, but it was not possible to locate the female for visual verification and those data were excluded from the analyses. This female appeared to have initiated incubation of a nest on the same inaccessible property in 2016. That nest appeared to have failed, after which the female initiated and incubated a second nest on accessible property. Because I could not visually verify the first nest, it was also excluded from analysis and her second nest was treated as a first nest in the analysis.

Twenty-seven of 31 marked females (87%) were observed on nests in 2015. All adult females (n = 18) and 75% of yearling females (n = 9) nested. Of the 21 females marked with VHF radio collars, 90% (n = 19) were observed on nests while 80% (n = 8) of females marked with PTTs were verified nesters. I was unable to visually verify that one PTT female and one VHF female nested because they were on inaccessible properties. No re-nest attempts were observed during that year.

In 2016, 30 of 31 marked females (97%) were recorded as initiating incubation of at least one nest. I was unable to visually verify that one VHF female nested because she was on inaccessible property. All adult (n=29) and yearling (n=1) females nested with 5 of the adult females nesting a second time after their first nest failed and one adult female nesting a third time after her first 2 nests failed. Of the 22 females marked with VHF radio collars, 95% (n = 21) were found on nests while 100% (n = 9) of PTT marked females were located on nests.

Initiation of Incubation

The mean date of initiation of nest incubation for all nests was 23 April (range 6 April–28 May) for 63 nest attempts. The average date of initiation of incubation was 19 April (range 6 April–11 May) in 2015 (n = 27) and 26 April (range 13 April–28 May) in 2016 (n = 36). The larger range of initiation of incubation in 2016 can be attributed to 6 re-nest attempts that year. There were no documented re-nest attempts in 2015. Based on these observations, I analyzed the incubation start date of first nests only. When comparing all nests to first nests, the average date of incubation initiation for first nests was 3 days earlier (20 April) in 2015 and the range of incubation initiation decreased by 2 days (range 6 April–26 May).

There was no difference in average date of initiation of incubation from 2015 to 2016 ($t = -1.435$, $P = 0.157$) or between adult females and yearling females ($t = 1.152$, $P = 0.266$). Date of initiation of incubation based on nest order (first nests or re-nests) was different ($t = -7.997$, $P \leq 0.001$).

Clutch Size

In my preliminary analyses, clutch size differed by nest fate ($t = 3.126$, $P = 0.003$) which is likely an artifact of the methodology I used for estimating clutch size. We did not flush females off their nests to count clutches because sage-grouse often abandon a nest once they have been flushed (Connelly et al. 2003, Gibson et al. 2015). We waited until nest fate was determined before approaching the nest bowl to count clutches. Six out of 25 failed nests had zero eggs, likely due to predation or scavenging, and failed nests averaged a smaller clutch size (4.4 eggs, n = 25) than successful nests (6.2 eggs, n = 38; t = 2.8196, P = 0.008). Therefore, all further analyses of clutch size were performed on successful nests only. Clutch size ranged from 2–9 eggs for 38 successful nests. Female age (t = 1.798, P = 0.118), nest order (t = 0.187, P = 0.879), and transmitter type (t = 0.453, P = 0.656) did not influence clutch size of successful nests.

Nest Success

There were 38 successful nests during the study: 19 in each year. Overall, 60.3% of 63 nests hatched at least one egg with a nest survival probability of 58.8%. In 2015, 70.4% of 27 nests hatched an egg with a nest survival probability of 67.8%, while in 2016, 52.8% of 36 nests hatched an egg with a nest survival probability of 52.7% (Table 2-1).

Most nests were located under live big sagebrush (n = 53) however, some were located under dead big sagebrush (n = 7), low sagebrush (n = 1), snowberry (n = 1), and rabbitbrush (n = 1). Successful nests were located under big sagebrush (n = 38), dead big sagebrush (n = 4), low sagebrush (n = 1), and rabbitbrush (n = 1). Nest success was not related to year (β = -1.109, P = 0.109), female age (β = -0.757, P = 0.370), nest order (β = -3.294, P = 0.062), incubation start date (β = 0.702, P = 0.163), or transmitter type (β = -1.052, P = 0.123). Table 2-2 summarizes the mean, standard deviation, and range of the vegetation components at nest sites.

In addition to the variables examined above, I examined other variables that may influence nest success such as nest shrub diameter, live shrub cover and height, grass and forb cover, slope, and litter. Several variables were moderately significant at the $\alpha \leq 0.10$

level including nest shrub diameter (β = 0.781, P = 0.062), percent forb cover (β = -0.716, P = 0.092), and percent litter (β = -0.891, P = 0.082).

My evaluation of vegetation components at nest sites and paired random sites suggested that there was no difference in vegetation at nest sites versus paired random sites, keeping in mind the Bonferroni corrected α-value (Table 2-2, Table 2-3). When comparing vegetation variables between successful and unsuccessful nests, there were no differences in vegetation at successful nest sites versus unsuccessful nest sites, remembering again the Bonferroni corrected α-value (Table 2-4, Table 2-5).

Breeding Success

Breeding success was 66.7% for 35 marked females that were monitored across both years of the study. Twenty-seven females attempted at least one nest in 2015 and 30 females attempted at least one nest in 2016 with 70.3% (n = 19) and 63.3% (n = 19) of marked females successfully hatching at least one egg in 2015 and 2016 respectively. With no re-nest attempts in 2015 and 6 re-nest attempts in 2016, re-nesting accounted for 5.3% of the overall breeding success (n = 2). Year (β = -0.657, P = 0.327), female age (β = -0.659, P = 0.428), transmitter type (β = -1.299, P = 0.067), and incubation start date (β = 0.042, P = 0.889) did not influence breeding success.

Brood Success

Overall brood success was 60.5% for 38 marked females that hatched at least one egg and were monitored throughout the breeding season. In 2015, 13 of 19 (68.4%) females produced a successful brood while 10 of 19 (52.6%) produced successful broods in 2016. No vegetation variables differed at sites used by broods compared to random sites or at sites used by successful broods compared to sites used by failed broods (Table 2-6, Table 2-7). Brood success was not influenced by year (β = -0.724, P = 0.379), female age (β = -0.347, P = 0.751), transmitter type (β = 1.034, P = 0.186), or incubation start date (β = -0.277, P = 0.469). However, percent shrub cover (β = -1.374, P = 0.051) may negatively affect brood success.

Adult Survival

Survival of breeding age birds (males and females) showed that summer season (β = -1.533, P = 0.022) and the second year (β = -0.979, P = 0.033) were significant factors, while age (β = 0.6353, P = 0.321) and transmitter type (β = 0.609, P = 0.247) were not. Sex was marginally significant (β = -1.175, P = 0.058). Because of the low sample size of males (n = 5) during this study, and because all were marked with VHF radio-collars, and 4 of the 5 died in the first year of the study, I also completed a survival analysis of breeding age females only to understand how sex influenced the results.

The survival of breeding age females was influenced by the second year (β = -1.452, P = 0.025) and summer season (β = -1.542, P = 0.025), but not by age (β = -0.384, P = 0.627) or transmitter type (β = -0.441, P = 0.432). Nine of 18 females died in July or August in 2016. Seasonal and annual survival probabilities with associated standard error and 95% confidence intervals are shown in Table 2-8.

Seasonal Movements

The average distance moved by female sage-grouse from lek of capture to nests was 1.2 km (SE = 0.13) while the maximum distance moved from lek of capture to summer locations was 2.4 km (SE = 0.25). Resident individuals moved 6.3 km (SE =

1.16) from capture lek to winter locations and 5.7 km (SE = 1.16) from nests to winter locations while migratory individuals moved 38.2 km (SE = 6.03) and 37.6 km (SE = 5.96) from capture leks and nests to winter locations. Average maximum distance moved from nests to summer locations was 2.2 km (SE = 0.23). A comparison of movement metrics can be found in Table 2-9.

DISCUSSION

Schroeder (1997) documented similarities and differences between sage-grouse in north-central Washington and other populations. The major differences were that sage-grouse in north-central Washington laid more eggs and were more likely to nest and re-nest (Schroeder 1997). The MS sage-grouse population is a habitat limited population that also exhibited high production rates. Although the MS sage-grouse population had a smaller average clutch size (6.2 eggs), the probability of nesting was higher than most populations. Additionally, all marked females initiated at least one nest during the study. Re-nesting, which had been rarely reported in Utah (Dahlgren 2009, Gruber 2012, Duvuvuei 2013, Graham 2013), was observed in this study and the 6 re-nest attempts in 2016 are the highest amount reported during one breeding season in Utah.

Nest Related Vital Rates

Nest initiation rates, re-nest rates, and nest survival rates were all higher in the Morgan-Summit population than in other Utah populations. All radio-marked females initiated at least one nest during this study which sharply contrasts with some populations in Utah with estimated nesting likelihoods of 63–82% (Connelly et al. 2011a).

Nest success varies widely for sage-grouse with estimates of 15–86% across the species range (Connelly et al. 2011a). The nest survival probability of 58.8% in this study is higher than the reported range wide average of 52.1% (Connelly et al. 2011a). However, it is difficult to compare nest survival probabilities across studies because of methodological differences in data collection and analysis (Schroeder 1997, Connelly et al. 2011a). In any case, it is likely that I observed one of the more productive populations across the sage-grouse range despite being space limited.

In my study, re-nesting was only observed in 2016 and accounted for 5.3% of overall breeding success which is minimal when compared to other studies (Connelly et al. 2011a). Schroeder (1997) reported a high re-nesting rate of 87% in central Washington and suggested that re-nesting may be under-estimated in other regions due to estimates of nest failure, rates of nest discovery, secondary peak of female lek attendance, and other factors (Dalke et al. 1963, Eng 1963). Because of sporadic monitoring during March and early April 2015 in this study, it is possible that re-nesting did occur in 2015 and that some nests we considered first nests were actually re-nests. However, when analyzing first nests only, we found a very similar date range for initiation of incubation from one year to the next and we only observed statistical differences when comparing first nests to verified re-nests. It is noteworthy to mention that one persistent hen initiated 3 separate nests in 2016 with her third nest hatching successfully. Sveum (1995) and Schroeder (1997) both observed females re-nesting twice in different areas of Washington and Graham (2013) observed re-nesting twice from 1 female in Utah. Although re-nesting is rare in Utah (Dahlgren 2009, Gruber 2012, Duvuvuei 2013, Graham 2013), several other studies show that re-nesting does occur at a relatively high rate throughout the species range (Peterson 1980, Young 1994, Sveum 1995, Connelly et al. 2011a).

Brood Success

Brood success was within the range of rates reported in Utah and throughout the species range. Although data are collected on brooding females in many studies, brood success is not always calculated or reported (Perkins 2010, Graham 2013, Sandford 2016). This could be due to low nest success rates which leads to a small number of monitored broods (Graham 2013, Perkins 2010). One study in Utah reported brood survival rates of 71% in west Box Elder County and 30.5% in Rich County (Cook 2015). In my study, the brood success rate of 60.5% fell between the rates reported by Cook (2015) and was higher than the 49.5% reported by Schroeder (1997) in north-central Washington. Similar to Schroeder (1997), brood success was not influenced by year or female age. In addition, I found that incubation start date, transmitter type, nor any of the vegetation variables influenced brood success even though some vegetation components have been shown to be important in other studies (Connelly et al. 2000, Connelly et al. 2011b).

These results could be an artifact of the methodology used to select random locations, or a result of the limited habitat availability restricting females to the same areas for brooding, or a combination of the two. Visually, the habitat used by brooding sage-grouse in the MS study area appeared to be homogeneous, and the data support that observation. Females with broods were observed in the same group with other marked brooding hens several times throughout the breeding season each year. A possible instance of “chick-sitting” was also observed (Dahlgren et al. 2010b). During a 50 day brood count, as I approached the marked female's location, an unmarked female flushed followed by 4 chicks. The marked female was located nearby and the flush count was performed but no chicks flushed during the count, however a subsequent night search resulted in the observation of 4 chicks with the marked female suggesting that brood switching may be occurring in this population.

Although brood-mixing was likely occurring in this population, I could not verify it because I did not mark and track individual chicks. Dahlgren et al. (2010b) reported that brood-mixing occurred in 43% of monitored broods and suggested that brood-mixing may be a strategy leading to increased production in a population which could be a reason for the higher production in the Morgan-Summit population (Dahlgren et al. 2010b). Estimates of brood success in a study may vary depending on monitoring methods, habitat size, female density, and chick density.

Clutch Size

Clutch size ranged from 2–9 eggs in this study. The range was larger than the 6–9 eggs reported range wide. Mean clutch size of 6.2 eggs for this study was slightly lower than the range wide average of 7.1 (SD = 1.1; Connelly et al. 2011a). Other researchers have predicted age-based differences in clutch size (Wallestad and Pyrah 1974, Peterson 1980) but that was not observed in this study. However, clutch size analyses were only performed on successful nests and there were only 6 yearling females in 2015 that produced successful nests. This low sample size could be one reason I did not see age-based differences in clutch size. Schroeder (1997) observed a difference in clutch size between years and by nest order, however that study longevity greatly exceeded mine. Schroeder (1997) had 5 years of data that may have been a long enough period for observed differences in clutch size to manifest. However, Sveum (1995) did observe annual variation in clutch size over a 2 year period in southern Washington.

Bergerud (1988) suggested that clutch size was negatively correlated with the annual survival of breeding-age sage-grouse. That hypothesis was based on an estimated survival rate of ~ 40% and a clutch size of ~ 8 eggs. My study had a lower clutch size than Bergerud (1988) and Schroeder (1997) and an estimated survival probability of 57-85% which appears to support Bergerud's (1988) hypothesis. In contrast, Schroeder (1997) observed a clutch size of 9.1 while using estimated female survival rates of 55–75% taken from Connelly et al. (1994) and Zablan (1993) indicating that sage-grouse do not fit Bergerud's (1988) hypothesis. These differences in clutch size and annual survival probabilities of breeding age birds demonstrate the range of variability in sage-grouse populations.

Transmitter Type

Caudill et al. (2014) evaluated the effect of transmitter positioning (dorsal vs. necklace) on juvenile sage-grouse survival using a controlled experimental design with necklace-style and suture-backpack VHF transmitters. They monitored 91 juveniles captured on the Parker Mountain SGMA in south-central Utah from 2008 to 2010. Sex and transmitter type had biologically meaningful impacts on survival. The dorsally mounted transmitters negatively affected daily survival rates. In my study, transmitter type did not affect the vital rates (nest initiation rates, clutch size, nest success rates, breeding success, brood success, and seasonal survival probability) of breeding age birds. However, females with VHF radio-collars were less likely to hatch at least one egg. This result could be an artifact of sample size since there were 41 VHF nests (58.8% hatched) and only 18 PTT nests (77.8% hatched) throughout the study.

Many studies have reported negative impacts of backpack-style transmitters on birds (Small and Rusch 1985, Pietz et al. 1993, Connelly et al. 2003, Robert et al. 2006, Barron et al. 2010, Caudill et el. 2014, Kesler et al. 2014). A meta-analysis of transmitter effects on avian behavior and ecology reported that devices negatively affected every aspect considered except flying ability (Barron et al. 2010). Caudill et al. (2014) reported that the attachment style, not the dorsal positioning of the transmitter, likely affected survival rates. Neither the meta-analysis study nor the Utah study mentioned above evaluated the effect of the dorsal rump-mounted attachment style which may explain the lack of effect observed in this study.

I attached PTTs using a rump-mount method where a harness is placed around each of the bird’s legs whereas Caudill et al. (2014) evaluated a backpack attachment method where the harness is placed around the bird’s wings. The breeding success analysis indicated that females marked with VHF necklace-style collars were less likely to hatch at least one egg than females marked with PTTs. Survival probabilities were not influenced by transmitter type. This result was encouraging because the use of GPS technology continues to increase exponentially in avian research. Although units vary substantially in costs, battery life is similar, and if rump-mounted units do not affect vital rates, this suggests that the added benefit of PTT units may exceed those of VHF because the manual location of animals can be labor intensive and prohibitive during certain seasons (e.g. winter) if seasonal survival and habitat use are questions of interest.

Conversely, the costs of PTTs may limit the number of marked individuals and diminish the ability to make inferences regarding population demography. However, if nest and brood monitoring data are desired, researchers must still manually locate birds to visually verify nesting and brooding on a somewhat regular basis. This can be a challenge depending on the PTT platform or programming and requires forethought when considering which transmitter to order, which manufacturer to order from, and the programming involved for the specific needs of the research. Additionally, sage-grouse behavior in the winter months can cause location issues with solar powered PTTs. A darker colored bird on white snow is an easy target for predators so sage-grouse will seek protective cover under sagebrush or other shrubs in winter. That, combined with fewer hours of daylight and poor weather conditions, inhibits the ability of the PTT to recharge properly and transmitters can go offline for several months at a time.

Micro-site Vegetation

Female sage-grouse may use a variety of shrub species for nesting but prefer to locate nests under sagebrush species (Patterson 1952, Gill 1965, Wallestad and Pyrah 1974, Peterson 1980, Connelly et al. 2011a). In my study, 97% of nests were located under sagebrush plants with 3% located under other shrub species. In Utah, Dahlgren (2006) observed 87% of nests under big sagebrush or black sagebrush, with 13% under other shrubs or grass. Sandford (2016) observed 75% of nests under big sagebrush or black sagebrush, 18% under other shrubs or grasses, and 7% under juniper trees. Once again, these results indicate a high level of variation between sage-grouse populations, even within Utah. My comparison of nest sites and paired random sites showed no significant difference in nest shrub height or diameter, or in the percent of shrub cover when compared to random locations. This contrasts with other research carried out by Wakkinen (1990), Fischer (1994), Holloran (1999) and many others that found nest shrubs were taller and larger in diameter in addition to being surrounded by a higher percentage of shrub cover.

Connelly et al. (2000) suggest that nesting habitat should contain 15–25% canopy cover and Rasmussen and Griner (1938) reported that nesting females selected areas with sagebrush canopy cover of 15–50% in Utah. At an average of 32.1%, sagebrush canopy cover at nest sites in this study was higher than Connelly et al. (2000) recommended, similar to some areas in Utah (Sandford 2016, Wing 2014), higher than other areas in Utah (Dahlgren 2006; Duvuvuei 2013; Knerr 2007), but falls within the range reported by Rasmussen and Griner (1938). Mean sagebrush height around nest locations was 58.1 cm and within the range recommended by Connelly et al. (2000) and at the high end of sagebrush height around nests in Utah reported by Rasmussen and Griner (1938).

Connelly et al. (2000) suggested that herbaceous cover (grasses and forbs) was an important component in preferred nest locations and overall nest success. Mean forb cover of 10.2% at nest sites was higher than the 4.2–9.4% reported in west Box Elder County, Utah (Sandford 2016, Wing 2014) but lower than the 18.5% and 14.5% reported at Grouse Creek, Utah (Knerr 2007) and Anthro Mountain, Utah (Duvuvuei 2013). Mean grass cover at nest sites was observed at 15.5% which was higher than reported by Sandford (2016) but lower than other research areas in Utah (Wing 2014, Duvuvuei 2013, Knerr 2007).

Gibson et al. (2016b) reported that females selected for areas with herbaceous cover that was both taller and had a higher percentage of cover. Female sage-grouse in my study did not seem to prefer areas with taller or more herbaceous cover when compared with random locations. Percent grass cover and height were not different when comparing nest sites to random sites.

Seasonal Movements

Seasonal movements from leks to nests, summer, and winter locations were smaller than other Utah populations analyzed by Dahlgren et al. (2016). Movements from nests to summer and winter locations were also smaller supporting the idea that the Morgan-Summit population is limited by space although winter movement data from PTTs suggested population connectivity. Most of the radio-marked sage-grouse (> 90%) used habitats located within 8 km of East Canyon State Park.

The average distance moved from lek of capture to nests was half as far as reported by Dahlgren et al. (2016). Maximum distance moved from lek of capture to summer locations was also much shorter as was the distance moved from nests to summer locations. The distance moved from breeding locations to winter locations depended on whether the individuals were migratory or residents. Resident individuals averaged movements from nests to winter locations of 5.7 km while migratory individuals moved as far as 38 km. Two migratory females marked with PTTs moved south in the winter during both years of the study. They each migrated on different days during November and each went to different areas that were inhabited by other sage-grouse populations and have active leks. Each female migrated north on different dates the following March and nested near the Henefer Divide lek. The migrations were completed within 48 hours contrary to the slow, meandering movements suggested by Connelly et al. (2011a).

It is possible, given the timing of movements, that these individuals were bred on the leks found in their winter ranges and migrated north to nest and raise chicks. However, they each arrived at the Henefer Divide area several weeks before they started nesting in 2016 giving them ample time to breed at the Henefer Divide lek before nesting. During a location flight in December 2016, I observed an additional long distance migration by one VHF marked female that had moved roughly 75 km northeast to winter range. I confirmed the movement during another flight in January 2017 when I was able to re-locate the bird in the same general area. I assumed she made the same migration in the winter of 2015-2016 and she did return to the East Canyon area to nest in the spring of 2016.

Because of the limited amount of available sagebrush habitat in the core study area and the naturally discontinuous habitats in Utah, this population could be at greater risk to anthropogenic disturbances such as urban development. In the nearby Snyderville Basin, urban development has eliminated a portion of sagebrush habitat that was historically used by sage-grouse (UDWR unpublished data). Migratory sage-grouse must navigate their way around this urban landscape to reach suitable winter habitat to the south. Urban development or other high levels of anthropogenic disturbance in the core study area around East Canyon State Park could put this population of sage-grouse at great risk of extirpation.

Study Limitations

Some of the dates of initiation of incubation in 2015 could be incorrect estimates and therefore biased the analysis. Some initiation dates in 2015 were estimated after the nests had successfully hatched and we counted back 27 days from the date of hatch. This is because we were very focused on capturing and marking 36 individuals during the first year of the study. As a result, monitoring of newly marked individuals was less consistent than during the second year of monitoring when we only captured and marked 4 individuals and we had more time dedicated solely to monitoring from the beginning of March 2016. This allowed us to verify initiation of incubation with more accuracy than in 2015. Even with the possible bias of data from 2015, females initiated incubation earlier than in 2016. The difference in initiation dates from one year to the next could be due to annual variation in weather and snow levels where the winter of 2015-2016 produced more snow than the previous year and may have delayed nest initiation. Even with possibly biased data, analysis of the date of initiation of incubation showed no significant difference between years or age of females.

MANAGEMENT IMPLICATIONS

My results further validated the variability in preferences that sage-grouse exhibit in different populations based on available vegetation, habitat types, and topography in Utah (State of Utah 2013). It also highlighted the importance of continued research across the species range to better inform management decisions for locally adapted populations. Sage-grouse management is not a “one size fits all” approach because of the many conservation challenges facing sagebrush ecosystems, both natural and anthropogenic.

The movement data from this study suggested that habitat availability may be a limiting factor of this sage-grouse population. It also enhanced Utah’s knowledge of connectivity between populations despite naturally fragmented habitats and provided insights into the complexity of Utah’s sage-grouse populations. A greater understanding of seasonal movement patterns of other nearby populations can inform management decisions regarding the delineation and assessment of priority conservation areas. Making land-use decisions without this knowledge could sever existing connectivity between populations and have unintended consequences such as population extirpation. The Morgan-Summit sage-grouse population has persisted in this landscape of limited habitat even in the face of various anthropogenic disturbances and can continue to occur here as long as suitable habitat conditions persist. In areas dominated by private lands, wildlife managers should focus their efforts toward landscape conservation and preservation. This conservation strategy will require increased emphasis on developing working relationships to facilitate collaboration.

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TABLES AND FIGURES

Table 2-1. Nest daily survival rates (DSR) and overall nest survival probabilities (NSP) of greater sage-grouse (*Centrocercus urophasianus*) in Morgan and Summit Counties, Utah, 2015–2016. The DSR and NSP were calculated using the Mayfield maximum likelihood estimation method, 95% confidence intervals were calculated using the delta method. Associated standard deviation and a comparison of apparent nest survival probabilities are also included.

Nest Daily Survival Rates					
Year	n (total nests)	DSR	SD	Lower CI	Upper CI
2015	27	0.989	0.00374	0.988	0.991
2016	36	0.983	0.00420	0.981	0.984

Nest Survival Probability (Mayfield Method)						
Year	n (total nests)	NSP	SD	Lower CI	Upper CI	**Apparent NSP**
2015	27	0.678	0.09313	0.643	0.713	0.704
2016	36	0.527	0.08185	0.501	0.554	0.528

Table 2-2. Vegetation structure at greater sage-grouse (*Centrocercus urophasianus*) nest sites and paired random sites in Morgan and Summit Counties, Utah, 2015–2016. All Shrubs Cover (%) and All Shrubs Height (cm) include measurements of live shrubs and trees. Vegetation Visual Obstruction Reading (VOR) was measured in decimeters with a Robel pole (Robel et al. 1970).

	Nest Sites			Random Sites		
Parameter	Mean	SD	Range	Mean	SD	Range
Nest Shrub						
Height (cm)	94.0	18.9	54.0 to 135.0	82.8	25.1	35.0 to 139.0
Diameter (cm)	136.0	41.0	46.0 to 260.0	118.4	54.4	34.0 to 312.0
VOR in (cm)	57.1	20.0	17.5 to 105.0	48.3	17.6	12.5 to 92.5
VOR out (cm)	38.7	19.6	10 to 107.5	31.5	16.9	5.0 to 77.5
Sagebrush Cover (%)	32.1	16.3	1.5 to 62.5	24.4	13.2	1.7 to 55.0
Sagebrush Height (cm)	58.1	13.7	28.8 to 91.6	57.4	13.5	33.3 to 91.1
All Shrubs Cover (%)	38.8	16.2	23 to 78.1	32.7	14.8	7.6 to 91.7
All Shrubs Height (cm)	55.0	13.8	31.5 to 86.1	53.0	15.3	29.2 to 63.0
Forb Cover (%)	10.2	8.6	0.2 to 33.5	11.8	7.9	0.5 to 30.2
Forb Height (cm)	8.7	3.0	3.7 to 18.3	9.2	3.9	2.6 to 21.6
Grass Cover (%)	15.5	6.7	1.9 to 30.5	16.4	9.9	0.3 to 43.9
Grass Height (%)	19.5	7.5	8.0 to 37.4	19.4	7.5	7.7 to 44.9
Rock Cover (%)	5.5	5.0	0.3 to 26.2	6.0	11.4	0.0 to 85.5
Bare Ground (%)	19.5	9.4	2.7 to 44.8	17.5	10.3	4.0 to 51.7
Litter Cover (%)	44.2	16.6	15.7 to 84.1	44.1	17.2	11.4 to 76.1

Table 2-3. Statistical comparison of vegetative characteristics at greater sage-grouse (*Centrocercus urophasianus*) nest sites and paired random sites in Morgan and Summit Counties, Utah, 2015–2016. All Shrubs Cover (%) and All Shrubs Height (cm) include measurements of live shrubs and trees. Vegetation Visual Obstruction Reading (VOR) was measured in decimeters with a Robel pole (Robel et al. 1970). The significant α-value was adjusted by Bonferroni correction because multiple t-tests were performed on dependent parameters. As a result, the *P*-value was considered significant at < 0.003.

Parameter	*t*	*P*	df
Nest Shrub			
Height (cm)	2.83	0.005	115.0
Diameter (cm)	2.05	0.042	115.4
VOR In (cm)	2.62	0.010	122.0
VOR Out (cm)	2.21	0.029	121.3
Sagebrush Cover (%)	2.91	0.004	118.8
Sagebrush Height (cm)	0.25	0.801	123.0
All Shrubs Cover (%)	2.20	0.030	122.9
All Shrubs Height (cm)	0.76	0.448	122.7
Forb Cover (%)	-1.12	0.267	123.1
Forb Height (cm)	-0.82	0.416	115.8
Grass Cover (%)	-0.60	0.551	109.1
Grass Height (cm)	0.11	0.912	124.0
Rock Cover (%)	-0.31	0.757	85.4
Bare Ground (%)	1.19	0.236	123.0
Litter Cover (%)	0.03	0.975	123.8

Table 2-4. Vegetation structure at successful and unsuccessful greater sage-grouse (*Centrocercus urophasianus*) nest sites in Morgan and Summit Counties, Utah, 2015–2016. All Shrubs Cover (%) and All Shrubs Height (cm) include measurements of live shrubs and trees. Vegetation Visual Obstruction Reading (VOR) was measured in decimeters with a Robel pole (Robel et al. 1970).

	Successful Nests			**Unsuccessful Nests**		
Parameter	Mean	SD	Range	Mean	SD	Range
Nest Shrub						
Height (cm)	93.1	17.7	54.0 to 135.0	95.3	20.9	58.0 to 135.0
Diameter (cm)	144.2	45.5	46.0 to 260.0	123.7	30.0	66.0 to 212.0
VOR in (cm)	56.0	17.7	20.0 to 97.5	58.7	23.4	17.5 to 105.0
VOR out (cm)	39.9	21.1	10.0 to 107.5	37.0	17.4	10.0 to 72.5
Sagebrush Cover (%)	33.2	15.7	1.5 to 59.6	30.4	17.2	4.5 to 62.5
Sagebrush Height (cm)	57.2	12.3	33.6 to 87.1	59.4	15.9	28.8 to 91.6
All Shrubs Cover (%)	38.8	17.5	1.7 to 77.2	38.7	14.4	12.1 to 66.3
All Shrubs Height (cm)	53.8	13.0	33.0 to 87.1	56.8	15.2	30.8 to 88.4
Forb Cover (%)	8.3	7.1	0.2 to 29.6	13.0	10.0	0.9 to 33.5
Forb Height (cm)	8.6	3.1	3.7 to 18.3	8.9	2.7	5.1 to 14.4
Grass Cover (%)	16.3	7.5	2.0 to 30.5	14.3	5.2	6.0 to 23.2
Grass Height (%)	19.5	7.6	8.0 to 37.4	19.6	7.5	9.1 to 36.3
Rock Cover (%)	6.0	5.7	0.5 to 26.2	4.8	3.8	0.3 to 13.2
Bare Ground (%)	22.0	10.4	2.7 to 44.8	15.9	6.2	4.0 to 28.2
Litter Cover (%)	41.3	18.5	15.7 to 84.1	48.4	12.2	25.1 to 71.2

Table 2-5. Statistical comparison of vegetative characteristics at successful and unsuccessful greater sage-grouse (*Centrocercus urophasianus*) nest sites in Morgan and Summit Counties, Utah, 2015–2016. All Shrubs Cover (%) and All Shrubs Height (cm) include measurements of live shrubs and trees. Vegetation Visual Obstruction Reading (VOR) was measured in decimeters with a Robel pole (Robel et al. 1970). The significant α-value was adjusted by Bonferroni correction because multiple t-tests were performed on dependent parameters. As a result, the P-value was considered significant at < 0.003.

Parameter	*t*	*P*	df
Nest Shrub			
Height (cm)	-0.44	0.660	45.4
Diameter (cm)	2.15	0.036	61.0
VOR In (cm)	-0.49	0.624	41.8
VOR Out (cm)	0.59	0.556	57.8
Sagebrush Cover (%)	0.65	0.518	48.1
Sagebrush Height (cm)	-0.57	0.569	42.3
All Shrubs Cover (%)	0.02	0.981	57.8
All Shrubs Height (cm)	-0.81	0.420	45.7
Forb Cover (%)	-2.06	0.046	39.6
Forb Height (cm)	-0.31	0.761	56.6
Grass Cover (%)	1.21	0.229	60.9
Grass Height (cm)	-0.04	0.966	52.0
Rock Cover (%)	1.01	0.316	61.0
Bare Ground (%)	2.91	0.005	60.6
Litter Cover (%)	-1.84	0.071	61.0

Table 2-6. Vegetation structure and statistical comparison of vegetative components at greater sage-grouse (*Centrocercus urophasianus*) brood sites and paired random sites in Morgan and Summit Counties, Utah, 2015–2016. All Shrubs Cover (%) and All Shrubs Height (cm) include measurements of live shrubs and trees. Vegetation Visual Obstruction Reading (VOR) was measured in decimeters with a Robel pole (Robel et al. 1970). The significant α-value was adjusted by Bonferroni correction because multiple t-tests were performed on dependent parameters. As a result, the *P*-value was considered significant at < 0.004.

	Brood Sites			**Random Sites**		
Parameter	Mean	SD	Range	Mean	SD	Range
VOR in (cm)	30.0	19.9	0.0 to 132.5	29.6	24.3	0.0 to 117.5
Sagebrush Cover (%)	26.7	15.3	0.2 to 70.9	26.6	16.8	0.0 to 74.5
Sagebrush Height (cm)	57.8	17.5	20.3 to 98.9	57.0	20.4	0.0 to 133.0
All Shrubs Cover (%)	35.4	14.8	0.7 to 83.1	38.7	19.2	0.0 to 102.8
All Shrubs Height (cm)	52.4	17.4	20.3 to 124.7	52.4	19.9	0.0 to 137.3
Forb Cover (%)	10.9	6.8	0.3 to 37.7	10.8	10.8	0.1 to 77.4
Forb Height (cm)	12.2	4.9	2.6 to 28.1	13.0	7.1	3.0 to 51.6
Grass Cover (%)	18.9	12.5	0.3 to 37.7	17.8	12.1	1.1 to 91.4
Grass Height (cm)	28.4	9.5	7.1 to 56.7	29.0	9.1	4.7 to 52.1
Rock Cover (%)	4.4	4.5	0.0 to 28.8	6.5	9.2	0.0 to 80.4
Bare Ground (%)	19.3	9.0	1.3 to 44.6	21.2	10.4	0.4 to 47.2
Litter Cover (%)	43.1	17.7	6.4 to 82.7	40.5	16.4	1.4 to 88.9

Parameter	*t*	*P*	df
VOR In (cm)	0.15	0.883	319.3
Sagebrush Cover (%)	0.05	0.958	334.7
Sagebrush Height (cm)	0.37	0.715	326.1
All Shrubs Cover (%)	0.10	0.924	309.4
All Shrubs Height (cm)	-0.55	0.582	329.7
Forb Cover (%)	0.05	0.957	274.1
Forb Height (cm)	-1.24	0.216	290.8
Grass Cover (%)	0.85	0.398	344.8
Grass Height (cm)	-0.51	0.609	345.1
Rock Cover (%)	-2.70	0.008	234.5
Bare Ground (%)	-1.81	0.072	327.8
Litter Cover (%)	1.42	0.158	345.9

Table 2-7. Vegetation structure and statistical comparison of vegetative characteristics at successful and unsuccessful brood sites used by greater sage-grouse (*Centrocercus urophasianus*) in Morgan and Summit Counties, Utah, 2015–2016. All Shrubs Cover (%) and All Shrubs Height (cm) include measurements of live shrubs and trees. Vegetation Visual Obstruction Reading (VOR) was measured in decimeters with a Robel pole (Robel et al. 1970). The significant α-value was adjusted by Bonferroni correction because multiple t-tests were performed on dependent parameters. As a result, the *P*-value was considered significant at < 0.004.

	Successful Brood Sites			**Unsuccessful Brood Sites**		
Parameter	Mean	SD	Range	Mean	SD	Range
VOR in (cm)	29.3	18.6	0.0 to 132.5	33.4	26.4	5.0 to 125.0
Sagebrush Cover (%)	26.1	15.9	0.2 to 70.9	30.2	11.9	9.2 to 58.3
Sagebrush Height (cm)	57.7	17.4	23.3 to 98.9	58.7	18.6	20.3 to 93.0
All Shrubs Cover (%)	34.6	14.5	0.7 to 70.9	40.8	15.8	9.2 to 83.1
All Shrubs Height (cm)	52.9	18.0	22.0 to 124.7	50.2	14.7	20.3 to 78.1
Forb Cover (%)	11.1	7.1	0.3 to 37.7	9.5	5.7	1.1 to 24.6
Forb Height (cm)	12.3	4.9	2.6 to 28.1	11.9	5.0	5.3 to 24.6
Grass Cover (%)	19.5	13.1	1.5 to 75.4	17.1	8.1	3.8 to 43.0
Grass Height (cm)	28.6	9.2	7.1 to 56.7	27.5	11.4	10.8 to 43.0
Rock Cover (%)	4.4	4.3	0.0 to 21.8	4.5	5.4	0.5 to 28.8
Bare Ground (%)	18.9	9.1	1.3 to 44.6	22.2	7.6	8.4 to 35.9
Litter Cover (%)	43.0	17.7	6.4 to 82.7	41.2	15.7	17.9 to 72.1

Parameter	*t*	*P*	df
VOR In (cm)	-0.78	0.441	32.1
Sagebrush Cover (%)	-1.59	0.118	46.7
Sagebrush Height (cm)	-0.27	0.790	36.2
All Shrubs Cover (%)	-1.93	0.061	35.9
All Shrubs Height (cm)	0.86	0.394	43.3
Forb Cover (%)	1.34	0.186	43.7
Forb Height (cm)	0.43	0.671	37.3
Grass Cover (%)	1.28	0.205	57.0
Grass Height (cm)	0.47	0.642	33.8
Rock Cover (%)	-0.16	0.872	33.6
Bare Ground (%)	-2.01	0.051	42.6
Litter Cover (%)	0.55	0.582	40.7

Table 2-8. Seasonal and annual survival probabilities with standard error and 95% confidence intervals of breeding age female greater sage-grouse (*Centrocercus urophasianus*) in Morgan and Summit Counties, Utah, 2015–2016.

Grouse Year	Season	Survival Probability	SE	Lower CI	Upper CI
1	Spring	0.980	0.015	0.95	1.01
1	Summer	0.913	0.041	0.83	0.99
1	Fall	0.971	0.020	0.93	1.01
1	Winter	0.974	0.021	0.93	1.01
1	Annual	0.846	0.047	0.75	0.94
2	Spring	0.928	0.040	0.85	1.01
2	Summer	0.738	0.073	0.59	0.88
2	Fall	0.901	0.055	0.79	1.01
2	Winter	0.910	0.062	0.79	1.03
2	Annual	0.562	0.080	0.41	0.72

Table 2-9. Movement comparison of breeding age female greater sage-grouse (*Centrocercus urophasianus*) in Morgan and Summit Counties, Utah, 2015–2016. Summer locations are those of females with and without broods. Winter locations are those of females marked with PTTs because VHF marked birds were only located once in the winter of 2015–2016 and twice in the winter of 2016–2017 via small aircraft flights. The flights were primarily to gather survival data and not location data because the majority of birds stayed within the core study area year round.

Movement Comparison	n	$\bar{x}$ (km)	SE	Lower CI	Upper CI
Capture lek to nest	63	1.15	0.13	0.90	1.39
Capture lek to max. summer locations	54	2.38	0.25	1.89	2.86
Capture lek to max. winter locations	13	16.13	4.64	7.03	25.22
Migratory birds	4	38.24	6.03	26.42	50.05
Resident birds	9	6.30	1.16	4.02	8.58
Nest to max. summer locations	54	2.18	0.23	1.72	2.63
Nest to max. winter locations	13	15.47	4.63	6.40	24.55
Migratory birds	4	37.57	5.96	25.89	49.24
Resident birds	9	5.65	1.16	3.38	7.92

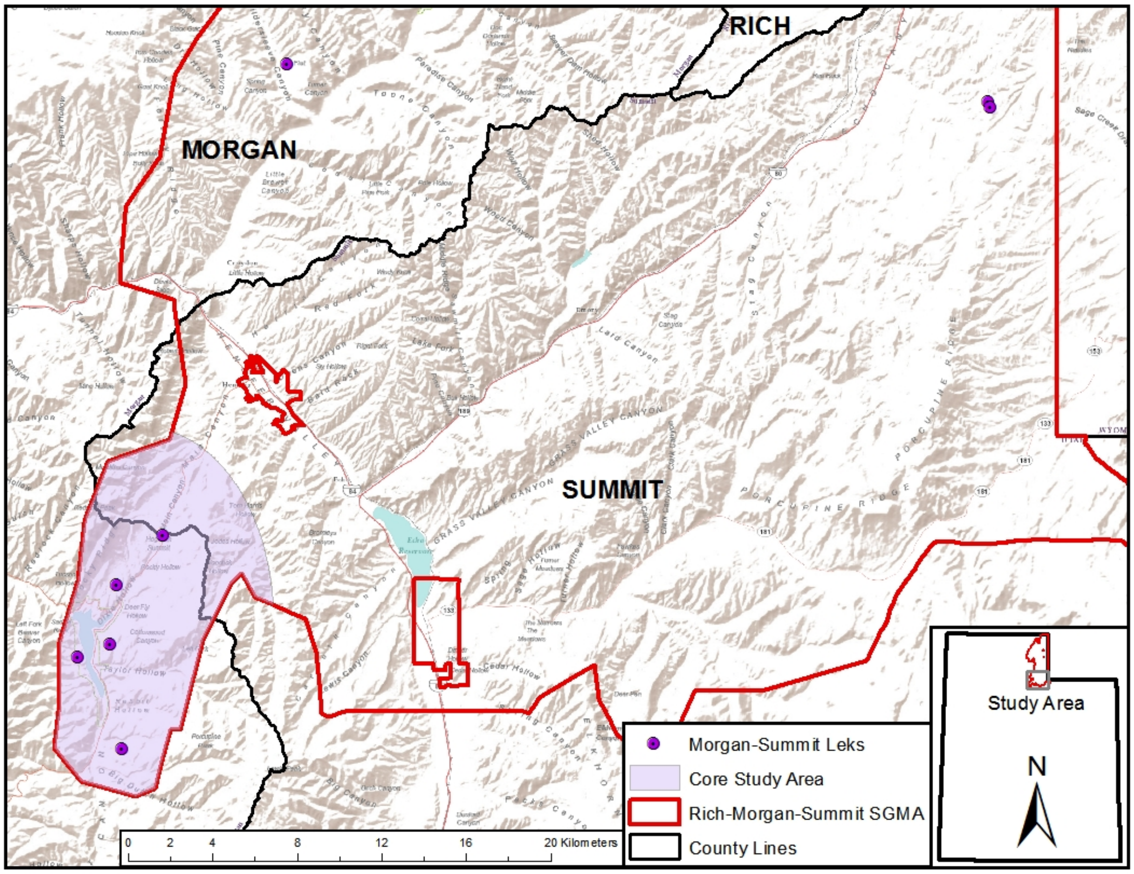

Figure 2-1. Greater sage-grouse (*Centrocercus urophasianus*) study area in Morgan and Summit Counties in the southern portion of the Rich-Morgan-Summit Sage-grouse Management Area (SGMA) in northern Utah, 2015–2016. The core study area in the extreme southwestern portion of the SGMA is where the largest portion of the population occurs and where most research took place.

CHAPTER 3

HABITAT SELECTION OF GREATER SAGE-GROUSE INHABITING THE SOUTHERN PORTION OF THE RICH-MORGAN-SUMMIT SAGE-GROUSE MANAGEMENT AREA

ABSTRACT

Resource selection by wildlife is scale dependent, both temporally and spatially. Understanding how and when animals utilize the landscape around them, and the spatial scale of both annual and seasonal habitats, are important for the proper management and conservation of a population or species. Greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) are sagebrush (*Artemisia* spp.) obligates that exhibit season-dependent habitat requirements. Populations have declined due to habitat loss, degradation, and fragmentation from anthropogenic impacts that have been linked to changes in resource use. Because sage-grouse exhibit a wide range of individual and population level variability in habitat selection, quantifying the resources and spatial scales used across all life stages is necessary to conserve populations. However, the ability to discern seasonal variability in space use and resource selection has, until recently, been hindered by monitoring limitations that typically involved the use of very-high frequency tracking devices. The use of platform terminal transmitters equipped with global positioning system technology has been increasingly common in recent years. It is unclear whether transmitter type influences habitat selection patterns. Using data from both transmitter types, I performed multiple resource selection function analyses to examine habitat selection based on season, spatial extent, and transmitter type in a small geographically isolated sage-grouse population in Morgan and Summit Counties, Utah from 2015 through 2016. I analyzed the spatial and seasonal variability of habitat selection of topographic, biological, and anthropogenic landscape features. Model results demonstrated limited differences in habitat selection by transmitter type with variation likely being a function of sampling effort. Spatially, this sage-grouse population used smaller habitat areas than reported for other populations to meet annual life cycle needs. Generally, sage-grouse avoided trees and developed areas, especially during the breeding season. Selection or avoidance of other landscape variables depended on the season and how sage-grouse used the landscape. This habitat-use information is useful to managers, policy makers, and private landowners because this sage-grouse population is already habitat limited and thus could impacted by increased development in Morgan and Summit Counties.

INTRODUCTION

Resource selection by wildlife is scale dependent, both temporally and spatially. Although ecological patterns are the result of processes that occur at multiple spatial and temporal scales, research is typically focused on habitat relationships in a single season (Wiens 1989, DeCesare et al. 2012, Fedy et al. 2012). In addition, when considering habitat use patterns that are most useful and relevant, decision-makers need to understand that different scales of inference may result in different patterns (Levin 1992, DeCesare et al. 2012). Understanding how and when animals utilize the landscape around them, and the spatial scale of both annual and seasonal habitats, are important for the proper management and conservation of a population or species (Fedy et al. 2014).

Greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) currently occur in 11 western states and 2 Canadian provinces and rely on sagebrush (*Artemisia* spp.)

habitats for their survival (Connelly and Braun 1997). Population declines of up to 47% have been observed throughout much of the species range due to habitat loss, degradation, and fragmentation from anthropogenic impacts (Connelly et al. 2004, Walker et al. 2007, Leu and Hanser 2011, Wisdom et al. 2011). Furthermore, anthropogenic disturbances and alterations to sagebrush ecosystems have been linked to changes in resource use (Walker et al. 2007). However, continued widespread distribution of sage-grouse and the relatively large areas of sagebrush habitats that remain makes conservation possible (Connelly et al. 2011a). Ultimately, the conservation of the species will depend on manager's ability to identify variability in habitat selection and use. (Jones 2001, Fedy et al. 2012, Dahlgren et al. 2016a, Dahlgren et al. 2016b). Managers and policy makers must recognize that the importance of various habitat components changes seasonally and therefore habitat selection varies throughout the year (Connelly et al. 2011b, Dahlgren et al. 2016a).

Sage-grouse are sagebrush obligates that exhibit season-dependent habitat requirements (Braun et al. 1976, Connelly et al. 2000, Connelly et al. 2011b). During the breeding season, sagebrush landscapes with relatively large shrubs, variation in shrub canopy cover, and a variety of grasses and forbs are necessary for successful nesting and brood-rearing (Gregg et al. 1994, Connelly et al. 2000, Holloran et al. 2005, Connelly et al. 2011b, Gibson et al. 2016). In summer, sage-grouse will exploit mesic areas and move up in elevation but continue to utilize sagebrush landscapes based on forb availability (Patterson 1952, Wallestad 1971, Connelly et al. 1988). In winter, sage-grouse rely almost exclusively on sagebrush for survival and congregate in sagebrush dominated areas (Patterson 1952, Savage 1969, Wallestad et al. 1975). Thus, a better understanding of how sage-grouse acquire the resources needed for survival and reproduction is a critical component in conserving meta-populations.

The conservation and management of species must operate within the appropriate spatial and temporal extents. It has been suggested that sage-grouse require intact blocks of sagebrush habitat larger than 4,000 ha for successful reproduction and overwinter survival (Connelly et al. 2011b). However, the spatial extent of habitat used by greater sage-grouse varies depending on the amount of habitat available to a population during a given season. Some migratory populations annually occupy areas exceeding 2,700 km^2, and some occupy seasonal ranges smaller than 1 km^2 (Connelly et al. 2000, Connelly et al. 2011c). This variability in spatial extent is explained in part by habitat availability, as sage-grouse in areas with large intact landscapes of sagebrush habitat can move more easily between seasonal ranges to locate necessary resources (Patterson 1952, Hagen et al. 2001, Schroeder and Robb 2003, Dahlgren et al. 2016a). Although a large proportion of the range wide population occurs in large landscapes, a sizeable portion of sage-grouse populations occur in smaller isolated habitats that prohibit large seasonal ranges, and often times require sage-grouse to live out their annual life cycle in a small geographic area (Patterson 1952, Hulet 1983, Hagen 1999, Schroeder 1997, Dahlgren et al. 2016a). Thus, quantifying the resources and spatial scales used across all life stages is necessary to adequately conserve populations and to maintain connectivity between habitats that meet all life stage requirements (Connelly et al. 2011a, Fedy et al. 2012, Dahlgren et al. 2016b).

The ability to discern seasonal variability in space use and resource selection has, until recently, been hindered by monitoring capabilities. Resource selection function

(RSF) analyses of sage-grouse populations were performed using data obtained from very-high frequency (VHF) tracking devices that require manual monitoring which produces spatially and temporally limited datasets and therefore potentially incomplete representations of habitat selection from which to make predictions (Aldridge and Boyce 2007, Carpenter et al. 2010, Baxter et al. 2017, Sandford et al. 2017). With technological advances in recent years, researchers have been able to monitor and collect movement data of sage-grouse using platform terminal transmitters (PTTs) equipped with global positioning system (GPS) technology (Fedy et al. 2014, Hansen 2016). The PTTs are more versatile than VHF transmitters in the sense that they collect movement data more frequently (several locations per day), and during periods when regularly locating VHF marked birds is difficult (e.g., winter). Therefore, PTT data may provide a more complete picture of habitat selection. Despite this, direct comparisons of VHF and PTT data to determine habitat selection predictions are not common although Hansen (2016) used independently collected VHF data to validate her PTT based RSF models. Fedy et al. (2012) compared movement distances of birds marked with VHF and PTT transmitters and found no evidence that the heavier GPS units limited movements. Because of this finding, Fedy et al. (2014) assumed both methods provide similar habitat selection predictions but they did not explicitly test it.

In Utah, because of the naturally fragmented landscapes and seemingly disconnected populations, the Conservation Plan for Greater Sage-grouse emphasized the need to understand local population dynamics and site-specific threats (State of Utah 2013). Because of Utah’s unique topography and geography, sage-grouse habitat is discontinuous and populations are dispersed throughout the state in intact blocks of suitable habitat in the Great Basin, or in disconnected habitat islands in the Colorado Plateau (State of Utah 2013, Dahlgren et al. 2016a). With naturally fragmented sage-grouse habitats in Utah, understanding habitat use and migration patterns, and effectively managing seasonal habitats and migratory corridors is important for species conservation and population persistence. The Morgan-Summit population is considered a small isolated population (Garton et al. 2011) and could be at risk for extirpation if the currently occupied habitat is altered, degraded, or lost (Wisdom et al. 2011). Management strategies should match the spatial and seasonal scales important to sage-grouse and be based on annual movements, seasonal habitats, and local components found in selected landscapes (Fedy et al. 2014).

In this chapter, I completed multiple RSFs that examine habitat selection based on transmitter type, seasonal variation, and spatial variation in a geographically isolated sage-grouse population in northern Utah (UDWR 2002, 2009, Garton et al. 2011). I compared data acquired from both VHF and PTT transmitters during the same time period and in the same geographic area to determine if habitat selection predictions varied by transmitter type. I analyzed the spatial variability of habitat selection of topographic, biological, and anthropogenic landscape features across seasons while accounting for the spatial scale that sage-grouse were selecting resources.

STUDY AREA

The study area was located in the southern portion of the Rich-Morgan-Summit Sage-grouse Management Area (SGMA) in northern Utah (Fig. 3-1). This area is within the Southern Great Basin Sage-Grouse Management Zone identified in the Greater Sage-Grouse Comprehensive Conservation Strategy (Stiver et al. 2006). The study area is bounded by the Rich-Morgan-Summit SGMA boundary and was made up mostly of portions of Morgan and Summit Counties. The study area encompassed approximately 2,150 km^2 although sage-grouse monitoring occurred in an area of approximately 100 km^2 where the core population was located (Fig. 3-1).

Land ownership in the study area is mostly private with some public lands which consist of US Forest Service, Utah Division of Wildlife Resources (UDWR) wildlife management areas, and Utah State Parks. Geographically, the core of the study area was located within 8 km of East Canyon State Park (lat. 40°54’4”N, long. 111°35’14”W) in the Wasatch mountain range in Morgan County. Because of its proximity to the heavily populated areas of Salt Lake City and Ogden City, the area is a popular year-round tourism destination providing recreational opportunities including camping, fishing, hunting, hiking, cycling, and water sports. Livestock grazing occurs from April through July on most properties. A natural gas pipeline bisects the core sage-grouse area, and although habitat restoration occurred post installment, a habitat degradation scar is clearly visible. Because of its location adjacent to (and sometimes on) state Highway 65, the Henefer Divide lek is one of the most visited leks in the entire sage-grouse range. During the mating season, high numbers of tourists drive from the Salt Lake metropolitan area to view the mating display of male sage-grouse.

Sagebrush habitat in the core area has remained intact. Vegetation in the study area includes big sagebrush (*A. tridentata* spp.) communities at lower elevations transitioning to mountain brush communities, Gambel oak (*Quercus* spp.), maple (*Acer* spp.), juniper (*Juniperus* spp.), aspen (*Populous tremuloides*) and mixed coniferous (*Picea* spp. and *Pseudotsuga menziesii*) forests as elevation increases (Table A-1).

Elevation ranges from 1540–2836 meters above sea level. Average annual precipitation is 44.5 cm. The area receives an average of 152.4 cm of snowfall that primarily occurs from December through February. Average monthly temperatures range from a high of 31.9° C in July to a low of -11.6° C in January (Western Regional Climate Center 2016). During this study, monsoon-like rain fell in May 2015, however, the area still received below average precipitation. Steady amounts of rain and snow fell during the spring of 2016, however, the summer returned to below average precipitation. During this study, winters were mild with lower than normal precipitation (Utah Climate Center 2017).

METHODS

Capture and Marking

Female sage-grouse were trapped on or near 3 different lek sites in early spring during breeding season and before the onset of nesting (March 5 to April 15 in 2015, and March 31 to April 5 in 2016) so as to minimize negative impacts on nest initiation. Trapping occurred at night using all-terrain vehicles, spotlights, and dip nets following protocols described by Giesen et al. (1982), Wakkinen et al. (1992), and Connelly et al. (2003). Each captured bird received a numbered aluminum leg band (National Band Company, Newport, KY). Birds were fitted with either a 22g necklace style very-high frequency (VHF) radio-collar (Advanced Telemetry Systems, Isanti, MN, Fig. A-1; n = 25), or a 22g rump-mounted PTT transmitter (22g Solar Argos/GPS PTT-100, Microwave Telemetry, Inc., Columbia, MD, Fig. A-2; n = 10). At time of capture, I recorded leg band size and number, sex, age (Eng 1955, Crunden 1963, Beck et al. 1975), weight, behavior during handling, cloud cover, wind speed (Beaufort scale), temperature, time from capture to release, and GPS coordinates (Universal Transverse Mercator [UTM], NAD 1983, Zone 12N). All birds were processed at the capture site and released as quickly as possible to mitigate capture related mortality. Research and handling protocols were approved by the Utah State University Institutional Animal Care and Use Committee under permit #2419, and UDWR Certificate of Registration #2BAND9483.

Monitoring and Data Collection

Sage-grouse were monitored from March 2015 through January 2017 (Fig. A-4). We manually located VHF radio-collared females 1–3 times per week from March through July in both years of the study. Once a bird was located using radio-telemetry equipment, the location was recorded with a handheld GPS unit (UTM, NAD 1983, Zone 12N). Locating VHF marked birds during the rest of the year was difficult because of access issues related to weather and land ownership. Most of the private lands in this area are managed for big game hunting which occurs in Utah from August through January and prevents regular access during that time period. In addition, snow conditions made it difficult to locate birds on foot or by ATV. We used a small fixed wing aircraft fitted with radio telemetry equipment to locate birds during the winter months. The main purpose of these flights was to collect survival information and not to pin-point the locations of marked birds so winter locations of VHF marked birds are very minimal.

Each PTT was programmed to record 6–9 locations each 24-hour period depending on the duty cycle season (Table A-3) and upload location data to the Argos system (http://www.argos-system.org/) every 3 days. Each PTT was also equipped with a ground tracking feature that transmits an ultra-high frequency radio signal during a specified period each day and allowed us to manually locate individuals or, in the case of mortalities, recover PTTs. I only located PTT marked birds manually to monitor a nesting female, or to monitor females with broods. If a female did not nest, if it was determined that her nest failed, or if it was determined that her brood failed, then efforts to manually locate PTT marked birds ceased.

After hatching, VHF marked females with broods were located twice weekly until the brood reached 50 days of age or until the brood failed. I located PTT marked females with broods once every 7–10 days to verify brood fate during that time period. To locate females with broods, I used radio-telemetry equipment and circled the estimated location of the female until the female or a chick was seen. Once a female was located, a location of her position was recorded with a handheld GPS unit (UTM, NAD 1983, Zone 12N). A failed brood was determined if the female flushed with one or more adult birds and no chicks were seen on 2 consecutive location attempts. Once it was determined that the brood had failed, we reduced monitoring frequency of the female to 1–2 locations per week.

Landscape Variables

Landscape variables were selected based on biological relevance to sage-grouse habitat use and were broadly categorized into topographic, biological, and anthropogenic factors (Connelly et al. 2011b; Table 3-1). Topographic features included elevation, slope, aspect, and ruggedness which were derived or calculated from a 30 m digital elevation model (DEM). I treated aspect as a categorical variable according to the 4 cardinal directions.

Biological factors included lek locations, riparian areas, trees, and percent sage-steppe. Lek locations were provided by the UDWR. I used LANDFIRE 2014 existing vegetation type (EVT) data to define vegetation categories present across the study area (LANDFIRE 2014). I combined EVT categories into 5 simplified vegetation classes: Agriculture, Developed, Trees, Riparian, and Sage-steppe (Table A-2). Based on my knowledge of the study area, EVT classes were unable to adequately delineate between sagebrush, grassland, and other deciduous shrubs since these 3 general groups were interwoven throughout the study area, thus they were combined into a general Sage-steppe class. Because of potential misclassification error, I combined EVT classes associated with coniferous forests, deciduous forests, and pinon-juniper woodlands into a *Trees* class.

Anthropogenic factors included agriculture, development, roads, power lines, and a natural gas pipeline scar. Agriculture and development were obtained from the aforementioned EVT categories. I classified roads into 3 categories in accordance with Sandford et al. (2017): ≤ 40 km/hr (low speed), 48–72 km/hr (moderate speed), and > 72 km/hr (high speed). I developed a representative layer for the gas pipeline scar using visual inspection of satellite imagery as a reference. The DEM, roads layer, and power lines layer were acquired from the Utah Automated Geographic Reference Center website (<www.gis.utah.gov>, accessed 10 March 2017).

Given that sage-grouse have demonstrated linear avoidance or selection preferences of many of the anthropogenic and biological landscape variables (Knick et al. 2011, Wisdom et al. 2011, Dinkins et al. 2014, Sandford et al. 2017), I estimated distance metrics from each landscape variable using the Euclidean Distance tool in ArcMap 10.3

(ESRI, Redlands, CA). I similarly estimated distance metrics for 4 of the 5 vegetation classes, however, because Sage-steppe was relatively ubiquitous across the landscape, percent Sage-steppe was deemed a more appropriate measure for quantifying sagebrush habitat use. Furthermore, because sage-grouse selection of percent sagebrush is scale-dependent (Connelly et al. 2011b), I used neighborhood statistics (i.e., moving window analysis) to summarize the Sage-steppe vegetation class at increasing spatial extents (Fedy et al. 2014). The moving window was used to calculate the proportion of Sage-steppe in each pixel which ranged from 0 to 1 (0 = no Sage-steppe, 1 = complete Sage-steppe) based on the value of neighboring pixels within the spatial extent being analyzed. The analysis comprised spatial scales ranging from a 3x3 window (0.81 ha) to a 215x215 window (4160 ha) which approximates the minimum spatial scale recommended for sage-grouse conservation (Connelly et al. 2011b). To accommodate the largest moving window scale, I used a spatial extent that expanded far enough beyond individual home ranges to permit spatial summaries. This extent covered 14,189 km^2 and encompassed the southern half of the Rich-Morgan-Summit SGMA as well as a large area that falls outside the SGMA boundary to the south (Fig. 3-2). Because no large-scale changes occurred during this study, no temporal variation in landscape variables was used.

I tested for correlation among all variables using Pearson’s correlation test with an $r > +/- 0.7$ threshold for brood locations (Hosmer et al. 2013). Ruggedness was removed because it correlated with slope (r = 0.99). No other variables were correlated.

Data Analysis

I used a resource selection function (RSF) framework to determine if female sage-grouse habitat selection differed by transmitter type and across 4 seasons in a used-available design (Manly et al. 2002). I evaluated female sage-grouse resource selection as a function of the aforementioned landscape variables using generalized linear mixed models (GLMMs). The use of GLMMs allowed me to compare year-specific use locations for each individual bird to individual-specific availability for that given year to year-specific availability (Gillies et al. 2006, Bolker et al 2009). Each RSF model was calculated as follows with $g(x)$ estimated for location *i* of individual *j*:

$$g(x) = \beta_0 + \beta_1 x_{1ij} + \beta_2 x_{2ij} + \cdots \beta_n x_{nij} + \gamma_{0j}$$

where β_0 is the mean intercept, x_n are covariates with fixed regression coefficient β_n, and γ_{0j} is the random intercept for individual *j*.

Habitat availability was estimated at the 3rd order scale (Johnson 1980) according to bird season (e.g. MS-15-0252_2015-Summer and MS-15-0252_2016-Summer were treated as 2 individuals) to account for annual variation in home range selection. I excluded any individuals with < 5 locations within a given season and estimated individual seasonal home ranges based on 95% Kernel Density Estimates (KDEs). I generated available points by systematic sampling of availability every 150 meters within each individual home range by year and season (Benson 2013). For example, a bird that survived one year of the study would have 4 seasonal home ranges while a bird that survived both years of the study would have 8 seasonal home ranges. I normalized (*m* = 0, *sd* = 1) all landscape variables to assist with convergence issues and allow interpretation of the magnitude of coefficient estimates. Because I was interested in the relative impacts of landscape variables across transmitter type and seasons, I did not use any model selection approaches since this would eliminate direct comparisons of model coefficient direction and magnitude (Kohl et al. 2013). I estimated confidence intervals (CIs) using profile likelihoods calculated within the lme4 package in R (Bates et al. 2015). If the CIs overlapped for any parameter within the transmitter model set or PTT seasonal model set, I assumed no difference between landscape variables. If CIs overlapped zero, I assumed they were not informative (Fedy et al. 2014). All analyses were performed using program R (R version 3.3.1, www.r-project.org, accessed 1 Oct 2016).

I estimated 6 RSF models to determine the role of transmitter type and seasonality on sage-grouse resource selection. To determine if data collected with different transmitter types influenced the ability to predict habitat selection, I created 2 datasets to represent females during the breeding season which I refer to hereafter as the transmitter model set (VHF breeding and PTT breeding subsample). To analyze habitat selection across seasons, I used the PTT dataset and divided it into 4 seasons which I refer to as the seasonal model set (PTT breeding, PTT summer, PTT fall, PTT winter).

Transmitter Model Set

To accurately compare resource selection between birds fitted with VHF and PTT transmitters, we subsampled PTT locations such that locations were only maintained if they fell between local sunrise/sunset times acquired from the United States Naval Observatory (<http://aa.usno.navy.mil/data/docs/RS_OneYear.php>, accessed 10 March 2017). To account for increased samples provided by PTTs, we further subsampled the daytime PTT locations so that they averaged 2 locations per week in order to approximate the number of locations obtained per week for VHF birds. This dataset is hereafter referred to as the PTT subsample dataset.

Seasonal Model Set

I defined seasons following the Sage-Grouse Habitat Assessment Framework (Stiver et al. 2015). The framework defines the breeding season as 1 March–30 June, the summer/late brood-rearing season as 1 July–30 September, and the winter season as 1 December–28 or 29 February. In addition, I added a fall season from 1 October–30 November to capture the transitional period (Connelly et al. 2011a). Other literature support these seasonal definitions (Fedy et al. 2012, Dahlgren et al. 2016a).

Percent Sage-steppe Analysis

Within all 6 RSF models, we evaluated the spatial scale of percent Sage-steppe that was best explained by the data. I ran sequential iterations of an RSF that included all landscape variables and each variation of the aforementioned Sage-steppe moving window layers (e.g., 3x3, 5x5,…215x215) for each of the 6 RSF models. This produced 107 candidate models for each season and transmitter type from which I summed the ΔAIC for each spatial scale (e.g., 3x3 breed + 3x3 summer…). I excluded the ΔAIC values for the PTT breeding subsample model when summing across models because it was redundant with the PTT breeding full sample. From these 5 model sets, I selected the spatial scale with the lowest summed ΔAIC as the most appropriate percent Sage-steppe scale to use in all analyses.

RESULTS

I monitored 35 female sage-grouse (25 VHF, 10 PTT) over 2 years resulting in 59 individual bird breeding seasons (40 VHF, 19 PTT). I used these data to compare resource selection by transmitter type. For seasonal comparisons, sample sizes varied with summer having 19 PTT bird seasons, fall having 18 PTT bird seasons, and winter having 15 PTT bird seasons. Using this information, I was able to determine that the spatial scale of percent Sage-steppe that best fit the data across transmitter type and seasons was a moving window of 19x19 pixels in size (Table 3-2). That scale was subsequently used in all 6 models (2 transmitter models, 4 seasonal models).

For any landscape variables classified as distance metrics in the model summary tables (Table A-4 through Table A-9), a positive coefficient indicated avoidance while a negative coefficient indicated selection. For example, the parameter estimate (β) for distance to development was 0.146 which indicated that as distance to development increased, probability of use increased and the inference could be made that sage-grouse selected areas farther away from development (i.e., avoided development). Because the Sage-steppe class was calculated as a percentage rather than a distance metric, a positive coefficient indicated selection for increasing proportion of Sage-steppe in all model output tables.

Transmitter Models

Resource selection did not differ for 14 of 18 landscape variables providing confidence that transmitter type did not influence habitat selection. Habitat selection did not differ by transmitter type based on topographic features during the breeding season. Sage-grouse avoided steep slopes and selected for intermediate elevation. There was no difference in selection of aspect based on transmitter type (Fig. 3-3).

Sage-grouse selected for the Sage-steppe class regardless of transmitter type. There was no statistical difference in distance to riparian and distance to leks by transmitter type. In contrast, sage-grouse differed by transmitter type in their use of distance to trees. Despite a statistical difference, general selection patterns were similar as both VHF and PTT marked sage-grouse avoided trees although the VHF CI overlapped zero indicating no selection pattern (Fig. 3-4).

Distance to agriculture, distance to power lines, distance to pipeline, and distance to high speed roads did not differ by transmitter type. Sage-grouse location distance to developed areas, low speed roads, and moderate speed roads differed by transmitter type (Fig. 3-4). Despite a statistical difference, general selection patterns were similar by transmitter type as both VHF and PTT marked sage-grouse avoided developed areas (Fig. 3-4, Tables A-4 and A-5). However, VHF marked birds avoided low speed roads and moderate speed roads (Table A-4) while PTT marked birds selected areas closer to both road types (Fig. 3-4; Table A-5).

PTT Seasonal Models

Sage-grouse habitat selection varied across seasons. Generally, sage-grouse selected intermediate elevations and avoided steep slopes. They avoided north facing aspects in every season, preferred east facing aspects in the summer, and selected south and west facing aspects during the breeding, fall, and winter seasons (Fig. 3-5; Table A-6 through A-9).

Sage-grouse selected for the Sage-steppe class regardless of the season but selected for it most in the winter. For every 5% increase in Sage-steppe habitat, the odds of use increased by as much as 820% (Table 3-3). Sage-grouse avoided trees in all seasons with the greatest avoidance occurring during the breeding season. Riparian areas were not selected for during the breeding season but were selected for during the summer and winter seasons (Table 3-3). Leks were avoided during the breeding season but favored during all other seasons (Fig. 3-6; Table A-6 through Table A-9).

Sage-grouse selected for agriculture areas in the winter and breeding seasons. Developed areas influenced sage-grouse selection during the breeding season. For every kilometer farther from developed areas, odds of use increased by 75% during the breeding season (Table 3-3). The PTT marked birds exhibited slight selection for low speed roads during all seasons but avoided moderate speed roads in the summer only. Sage-grouse avoided power lines during fall and winter but showed slight selection during the breeding and summer seasons. Sage-grouse selected areas near the pipeline during summer and fall but avoided the pipeline during the winter and breeding seasons (Fig. 3-7; Tables A-6 through A-9).

DISCUSSION

Of the 18 landscape variables I analyzed, 4 (distance to trees, distance to developed, distance to low speed roads, and distance to moderate speed roads) did not produce overlapping CIs. I detected some variation among selection patterns between the PTT breeding subsample and PTT breeding full sample datasets. This variation between VHF and PTT transmitters may be a function of sampling effort (Supplement Fig. A-3). Although researchers continue to use VHF transmitters to monitor sage-grouse, the use of PTTs is increasingly common.

Fedy et al. (2012) and Chapter 2 of this thesis reported that sage-grouse movement distances and vital rates were not influenced by transmitter type but it is still unclear whether transmitter type influences habitat selection patterns. Independently collected VHF data has been used to validate PTT based RSF models (Hansen 2016).

Although the data were collected in the same general area, they were not collected during the same time period. I found limited differences in habitat selection between birds fitted with either VHF or PTT transmitters.

My models showed selection of areas near low speed and moderate speed roads by PTT marked birds and avoidance by VHF marked birds. These results could be an artifact of sampling bias as I used an ATV to travel unpaved low speed roads to manually locate VHF birds which may have disturbed them more resulting in stronger avoidance of low speed roads (Fedy et al. 2012). The selection of moderate speed roads may be in part a function of the paved state highway that bisects the middle of the core study area. Sage-grouse were not able to move far away from the highway without moving out of desirable habitat. As a result, roads may not actually influence habitat selection in this population because there are few roads and they run through a confined area of quality habitat making avoidance difficult.

The influence of biological landscape variables on habitat selection varied depending on the season. Percent Sage-steppe influenced habitat selection during all seasons. Increased selection for Sage-steppe habitat in the winter corresponds with research showing sage-grouse rely almost exclusively on sagebrush for nutrition in the winter months (Wallestad et al. 1975, Thacker 2010, Wing and Messmer 2016). My results show that sage-grouse did not select for riparian areas during the breeding season but favored such areas during the summer season which coincides with previous research (Connelly et al. 2000, Thacker 2010). Mesic areas are thought to be important for brooding females because they hold water longer into the summer, provide areas with nutritious forbs, and attract insects that sage-grouse can feed on (Aldridge and Boyce

2007, Robinson and Messmer 2013). However, as the study area dried out in late summer, it is likely that sage-grouse sought out mesic areas because they remained relatively moist during the summer season (July 1 – Sept. 30).

My results show that female sage-grouse avoided leks during the breeding season (nesting and early brood rearing) and favored them during other seasons. This may seem counter-intuitive however, location data from my study showed that female sage-grouse spend a small proportion of their time at lek locations. After copulation, females focused on nesting and brood rearing that occurred in areas surrounding but away from the lek. As the breeding season ends, the males abandon the leks. As a result, lek locations are largely indistinct from the surrounding landscape during summer and fall. In late winter, male sage-grouse began congregating on leks, which coincides with increased visitation by females as they prepare for the breeding season (Connelly et al. 2011c).

Obligate species such as sage-grouse are at increased risk of population declines if habitat is lost, fragmented, or degraded (Baxter et al. 2017). The amount of available sagebrush habitat continues to decline due to anthropogenic disturbances and impacts (Foley et al. 2005) which have been linked to changes in resource use (Walker et al. 2007). Agriculture, development, and roads may impact sage-grouse habitat-use (Johnson et al. 2011) but it is unclear if, and to what extent, those changes have on sage-grouse as the year progresses. Connelly et al. (2011b) and Cook et al. (2017) reported that sage-grouse may use agricultural areas (i.e., irrigated hay fields) during the summer however, my results demonstrate that selection was season-dependent. Sage-grouse favored agriculture during the winter and breeding seasons and avoided it during summer and fall. Agriculture in the core study area consisted of small patches surrounded by sagebrush, which may partially explain selection patterns.

Selection during the winter and breeding seasons could be an artifact of increased movement patterns in the core area during the winter. Resident birds demonstrated increased movement around the core study area during winter with some birds moving closer to the town of Henefer where there was increased agricultural development. Additionally, the 2 PTT birds that migrated south of the core range used winter range near Kamas Valley and Heber Valley where agriculture is prevalent. Agricultural areas may also have provided sage-grouse with valuable resources during winter.

Development fragments, degrades, and eliminates sagebrush habitat and can cause sage-grouse to abandon nearby leks and the surrounding habitat (Johnson et al. 2011). Sage-grouse in my study avoided development during the breeding season but not during other seasons. The sage-grouse I studied exhibited some of the smallest home ranges reported in the literature (Connelly et al. 2011c, Dahlgren et al. 2016a; Tables B-1 and B-2). My research suggested that the MS population was limited by habitat availability. As such, they concentrated in areas of core high quality habitat during the nesting and early brood rearing season where development was limited (Ch. 2 of this thesis).

Larger home range estimates in the fall and winter (Table B-2) demonstrated that sage-grouse were moving more during these seasons and therefore were more likely to encounter developed areas as they searched for sagebrush accessible above the snow. A housing development proposed in the core study area would result in increased traffic volumes, reduce and degrade the already limited suitable sagebrush habitat, introduce additional stressors (such as noise and increased number of predators; Leu and Hanser 2011), and generally increase the cumulative effects of human activities on the landscape (Lyon and Anderson 2003, Aldridge et al. 2008). Urban development in the nearby Snyderville Basin (near Park City, UT) has eliminated sagebrush habitat and extirpated sage-grouse from the area (UDWR unpublished data).

Johnson et al. (2011) found no relationship between power lines and trends in lek counts. My results suggested that sage-grouse selected for areas near power lines during the breeding season and avoided them only during fall and winter. Although power lines were limited in the core study area, they were adjacent to suitable habitats. Over 40% of PTT birds spent time near them during the breeding season. In contrast, only 20% of PTT birds were located near power lines during the other seasons. This further suggests that population breeding habitat was space limited and already compromised by anthropogenic disturbances (e.g., power lines and roads). It may also suggest for this population, that habitat quality may outweigh the cumulative effects of existing anthropogenic disturbances (Messmer et al. 2013).

Pipelines associated with oil and gas development can negatively impact sage-grouse populations (Hanser and Knick 2011, Johnson et al. 2011) although sage-grouse may use disturbed sites such as pipeline scars or heavily grazed areas for lekking if they provide adequate visibility (Connelly et al. 1981, Duvuvuei 2013). A natural gas pipeline bisects the core study area that sage-grouse selected for during summer and fall but avoided during the winter and breeding seasons. These results could be a sampling artifact due to the locations of transmitter deployment. There was an active lek located in quality habitat near the pipeline route (Pioneer Camp lek). No PTTs were deployed there due to inaccessibility issues. Six PTTs were deployed near the Henefer Divide lek which is around 2.5 km away from the pipeline route however, I found that sage-grouse in this area did not move far from their lek of capture for nesting and brood rearing (see Chapter 2). As a result, few marked sage-grouse were located near the pipeline route (1 PTT during breeding, 1 PTT during fall, 2 VHF during summer, ≥ 2 VHF during winter). Thus, my ability to make inferences based on location data is limited. However, male sage-grouse at the Pioneer Camp lek were observed from a distance displaying on the pipeline route during the breeding season in 2016 indicating a preference for the pipeline route as a lek site during that season.

Sage-grouse are a landscape species and as such they requires large intact blocks of habitat to carry out all stages of their life cycle (Connelly et al. 2011a). However, Schroeder (1997) reported on a productive isolated population found in fragmented habitat in Washington. In Utah, the topography and geography creates naturally fragmented sage-grouse habitats and space-limited populations, regardless of anthropogenic influence. The MS population, considered small and isolated (Garton et al. 2011), is highly productive with some of the highest breeding vital rates found in Utah (Ch. 2 of this thesis) and yet, small isolated populations tend to be more at risk of extirpation (Aldridge et al. 2008, Garton et al. 2011). The MS population occupied less area than most sage-grouse populations (Thacker 2010, Fedy et al. 2014, Cook 2015, Dahlgren et al. 2016a, Sandford 2016). Sage-grouse in this population exhibit very small seasonal and annual home ranges (Tables B-1 and B-2) and they select for sagebrush at a much smaller scale (~ 40 ha.) than suggested by Connelly et al. (2011b; ~ 4,000 ha.).

Home range estimates for the MS population indicate limited available habitat (Tables B-1 and B-2). Seasonal movement patterns indicated the existing habitat in the core study area was able to support this population throughout its annual life cycle (See Chapter 2). This observation suggested that all of the seasonal habitat requirements were met despite the lack of large intact landscapes. The small area occupied by this population also suggests it may be at high risk of extirpation if existing habitat is lost or fragmented further (Aldridge et al. 2008, Garton et al. 2011).

MANAGEMENT IMPLICATIONS

Different scales of inference may not carry equal weights in driving patterns most relevant to decision makers (DeCesare 2012). In many areas occupied by sage-grouse, management to improve habitat at one scale (e.g., breeding habitat) may be limited and may not benefit sage-grouse at another scale (e.g., winter habitat) if populations are migratory (Doherty et al. 2010). Dahlgren et al. (2016a) suggested that increasing usable space could increase habitat availability that would in turn allow for population expansion. However, increasing sagebrush habitat availability in the Morgan-Summit area will be difficult due to topography and the resulting vegetation communities that occur at higher elevations (State of Utah 2013, Dahlgren et al. 2016a). It is a mountainous region with pockets of sagebrush habitat surrounded by naturally occurring deciduous and coniferous forests. Successful conservation of this potentially important population is far more likely and feasible by preserving the current habitat in the core study area.

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Table 3-1. Predictor variables selected *a priori* and used in the 6 resource selection function models to understand the influence of transmitter type and seasonal variation on habitat selection by greater sage-grouse (*Centrocercus urophasianus*) in Morgan and Summit Counties, Utah, USA in 2015 and 2016.

Variable	Type	Resolution	Category	Description (units)
elev_km	Continuous	30 m	Topographic	Extracted from 30 m DEM (km)
elev_km^2	Continuous	30 m	Topographic	Squared term for elevation
aspect_catN	Categorical	30 m	Topographic	Extracted from 30 m DEM and categorized into cardinal directions
aspect_catS	Categorical	30 m	Topographic	Extracted from 30 m DEM and categorized into cardinal directions
aspect_catW	Categorical	30 m	Topographic	Extracted from 30 m DEM and categorized into cardinal directions
slope	Continuous	30 m	Topographic	Extracted from 30 m DEM (radians)
slope^2	Continuous	30 m	Topographic	Squared term for slope
dist_ag_km	Continuous	30 m	Anthropogenic	Distance to agriculture in kilometers. Derived from LANDFIRE 2014 Existing Vegetation Type data.
dist_developed_km	Continuous	30 m	Anthropogenic	Distance to developed areas in kilometers. Derived from LANDFIRE 2014 Existing Vegetation Type data.
dist_pipeline_km	Continuous	30 m	Anthropogenic	Distance to Kern River Pipeline scar in kilometers
dist_powerlines_km	Continuous	30 m	Anthropogenic	Distance to power lines in kilometers
dist_roads40_km	Continuous	30 m	Anthropogenic	Distance to roads ≤ 40 km/hr in kilometers (Low speed roads)
dist_roads48-72_km	Continuous	30 m	Anthropogenic	Distance to roads 48-72 km/hr in kilometers (Moderate speed roads)
dist_roads72_km	Continuous	30 m	Anthropogenic	Distance to roads > 72 km/hr in kilometers (High speed road)
dist_leks_km	Continuous	30 m	Biological	Distance to leks in kilometers
dist_riparian_km	Continuous	30 m	Biological	Distance to riparian areas in kilometers. Derived from LANDFIRE 2014 Existing Vegetation Type data.
dist_trees_km	Continuous	30 m	Biological	Distance to trees in kilometers. Derived from LANDFIRE 2014 Existing Vegetation Type data.
sagesteppe_19x19	Continuous	30 m	Biological	Percent cover in sage-steppe areas. Derived from LANDFIRE 2014 Existing Vegetation Type classes (sagebrush, grasslands, other shrubs) and moving window analysis resulting in a 19x19 pixel area.

Table 3-2. Spatial scale differences in percent Sage-steppe by transmitter type and season based on location data of greater sage-grouse (*Centrocercus urophasianus*) in Morgan and Summit Counties, Utah, USA. Season corresponds to those described by Stiver et al. 2015 (Breeding = Mar.1–Jun. 30, Summer = Jul. 1–Sept. 30, Fall = Oct. 1–Nov. 30, Winter = Dec. 1–Feb. 28 or 29). VHF and PTT correspond to very-high frequency necklace style transmitters or rump-mounted personal terminal transmitter telemetry units. Spatial Scale corresponds to the size of neighborhood statistics (i.e. moving window analysis; range = 3x3 to 215x215) performed around a 30m x 30m raster. Akaike Information Criterion (AIC) scores are the result of model fits for identical models that differed only in the size of spatial scale. ΔAIC values of 0 are highlighted in bold and identify the best fitting model for each season. ΔAIC Sum is the sum of all season specific ΔAIC values and was used to identify the most appropriate spatial scale to use in all subsequent RSF analyses. A 19x19 window approximates an area of 324,900 m^2 or 32.49 ha. Data were collected in 2015 and 2016.

Spatial Scale	VHF Breeding		PTT Breeding		PTT Summer		PTT Fall		PTT Winter		ΔAIC Sum
	AIC	ΔAIC	AIC	ΔAIC	AIC	ΔAIC	AIC	ΔAIC	AIC	ΔAIC	
9x9	4323.45	32.05	14350.38	258.22	10772.72	86.98	12493.66	319.191	7350.67	29.58	726.02
11x11	4314.11	22.72	14299.22	207.06	10753.27	67.52	12329.79	155.33	7321.09	**0**	452.63
13x13	4305.31	13.91	14246.60	154.44	10742.56	56.81	12329.79	155.33	7327.23	6.14	386.64
15x15	4295.62	4.22	14206.57	114.41	10726.68	40.94	12267.39	92.93	7348.11	27.02	279.52
17x17	4291.40	**0**	14172.25	80.09	10694.29	8.55	12225.16	50.70	7393.82	72.73	212.06
19x19	4295.56	4.17	14130.97	38.81	10685.74	**0**	12199.24	24.78	7454.15	133.06	**200.82**
21x21	4305.49	14.09	14097.93	5.77	10692.92	7.18	12180.04	5.58	7502.34	181.25	213.87
23x23	4319.69	28.29	14092.16	**0**	10701.83	16.09	12174.46	**0**	7557.28	236.19	280.57
25x25	4332.91	41.51	14100.44	8.28	10714.57	28.83	12175.90	1.44	7604.17	283.08	363.14
27x27	4349.68	58.28	14116.58	24.42	10739.70	53.96	12175.27	0.80	7644.17	323.08	460.54
29x29	4366.02	74.63	14129.68	37.52	10785.89	100.15	12176.72	2.26	7688.13	367.04	581.59

Table 3-3. Expected change in the odds of use by female greater sage-grouse (*Centrocercus urophasianus*) in Morgan and Summit Counties, Utah, USA in 2015 and 2016. For example, the odds that a female greater sage-grouse will use area around agricultural development decrease by 16 percent for every 1 km moved away from agricultural development indicating a preference for agricultural areas during the breeding season. Bolded values were derived from coefficients that were statistically different from zero.

Parameter	Units of Change	Breeding	Summer	Fall	Winter
Distance to Agriculture	1 km	**-16.2**	**32.5**	**21.4**	**-50.2**
Distance to Developed	1 km	**74.5**	0.9	10.0	7.9
Distance to Pipeline	1 km	**2907.9**	**-90.9**	**-36.0**	**408.7**
Distance to Powerlines	1 km	**-26.5**	-28.2	**25.0**	**66.8**
Distance to Roads ≤ 40 km/hr	1 km	**-26.2**	-8.2	**-30.4**	**-33.2**
Distance to Roads 48-72 km/hr	1 km	-8.1	**233.0**	14.0	2.5
Distance to Roads > 72 km/hr	1 km	15.9	**-38.7**	**-33.6**	13.8
Distance to Leks	1 km	28.1	**-80.0**	**-71.7**	**-63.9**
Distance to Riparian	1 km	**80.1**	**-22.0**	1.9	**-21.5**
Distance to Trees	1 km	**86.0**	**26.9**	**40.4**	**47.3**
Percent Sage Steppe	5%	**323.6**	**395.3**	**202.2**	**820.7**

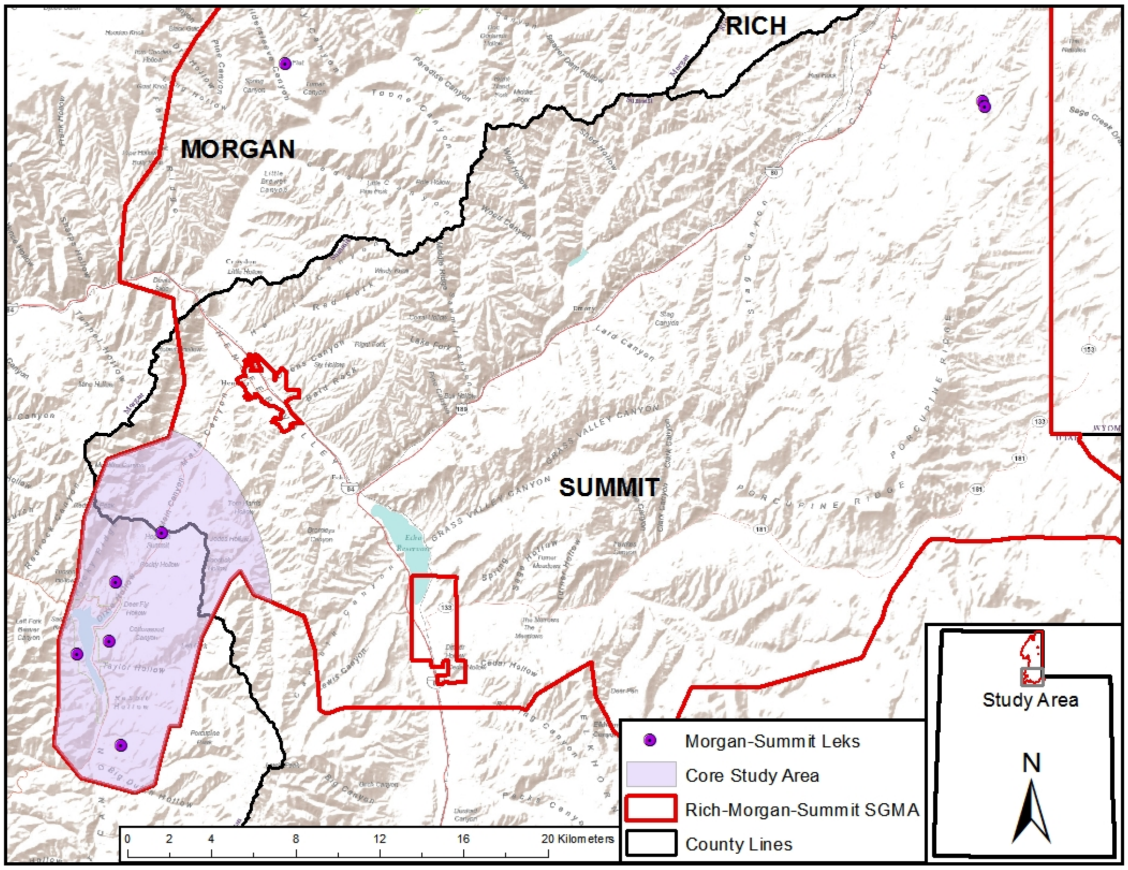

Figure 3-1. Greater sage-grouse (*Centrocercus urophasianus*) study area in Morgan and Summit Counties, Utah, USA in the southern portion of the Rich-Morgan-Summit Sage-grouse Management Area (SGMA) in northern Utah, 2015–2016. The core study area in the extreme southwestern portion of the SGMA is where the largest portion of the population occurs and where most research took place.

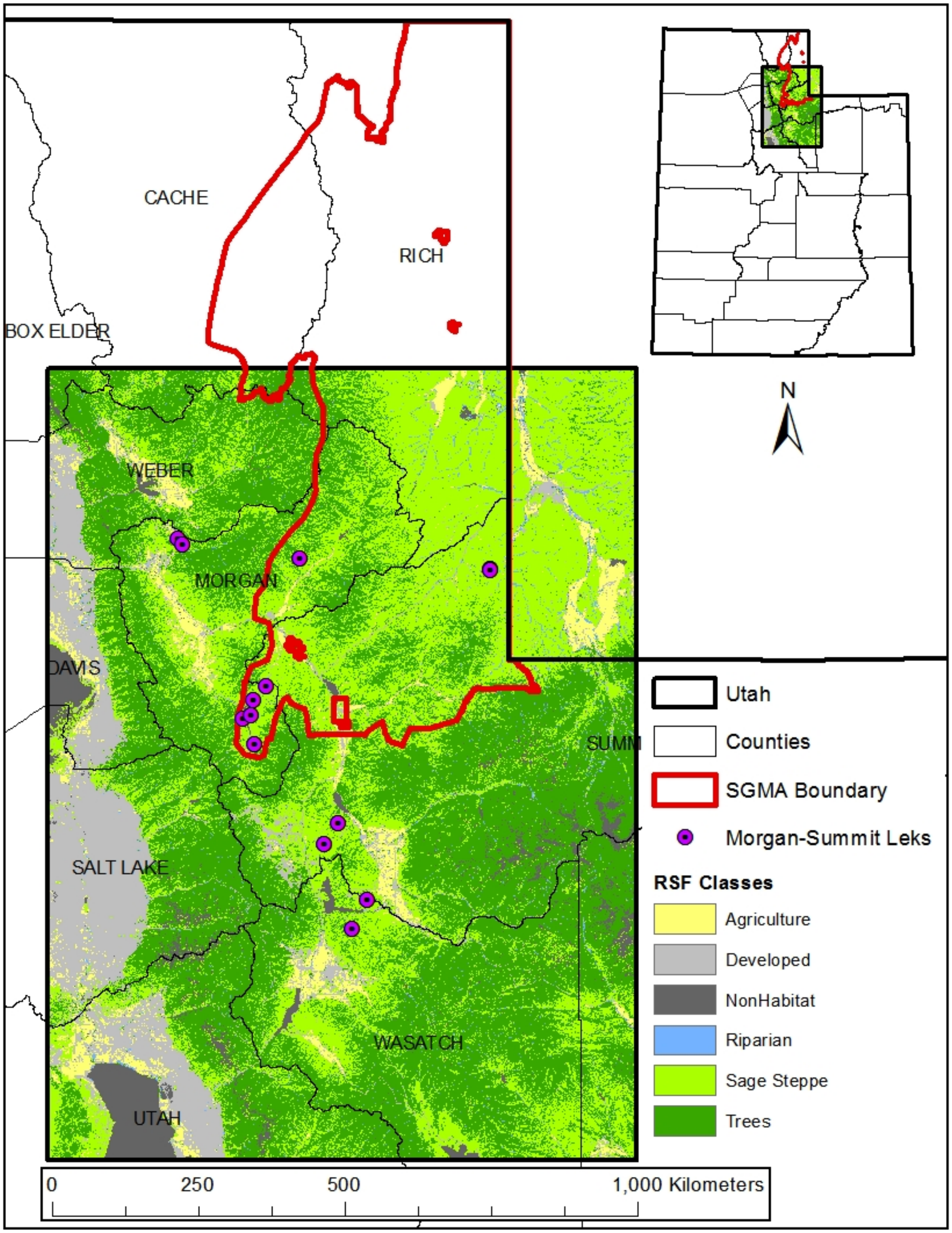

Figure 3-2. Spatial extent used for neighborhood statistics around and within the southern portion of the Rich-Morgan-Summit Sage-grouse Management Area in Morgan and Summit Counties, Utah, USA, 2015–2016. The 5 vegetation classes (plus non-habitat) were derived from LANDFIRE 2014 Existing Vegetation Type data.

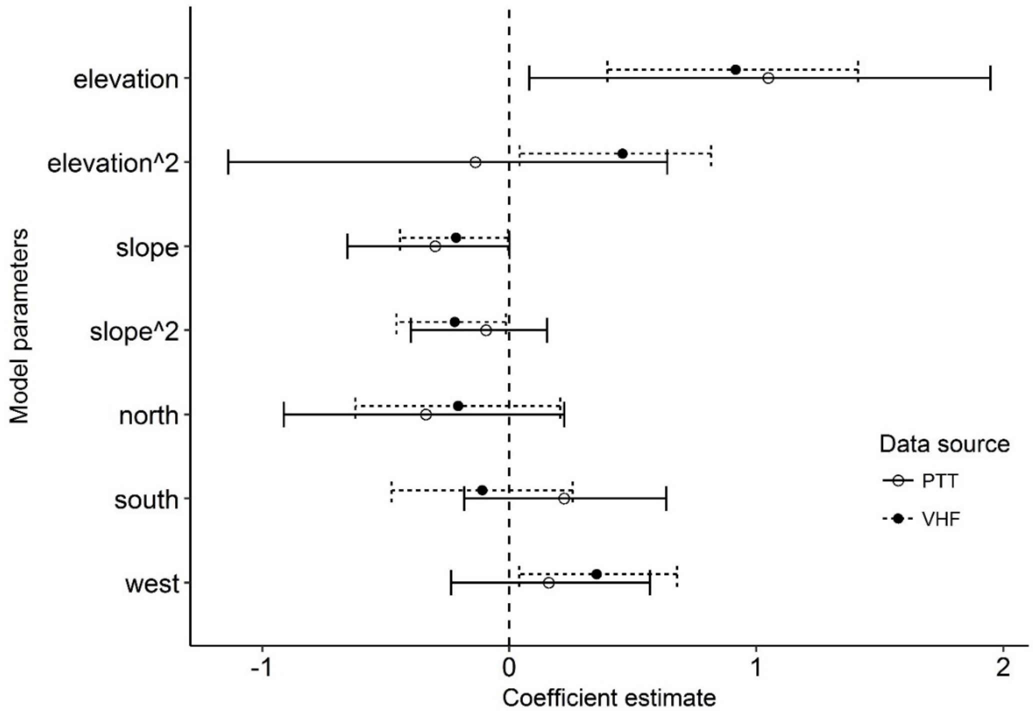

Figure 3-3. Comparison of model estimates and confidence intervals of topographic landscape variables by transmitter type during the breeding season (1 Mar.–30 June). Data were collected using very-high frequency (VHF) necklace style transmitters and rump-mounted platform terminal transmitter (PTT) telemetry units deployed on greater sage-grouse (*Centrocercus urophasianus*) in Morgan and Summit Counties, Utah, USA in 2015 and 2016. Overlapping confidence intervals indicate no statistical difference in selection between transmitter types based on topographic landscape variables. A parameter was not considered informative if the confidence interval overlapped zero. Confidence intervals were calculated using profile likelihoods.

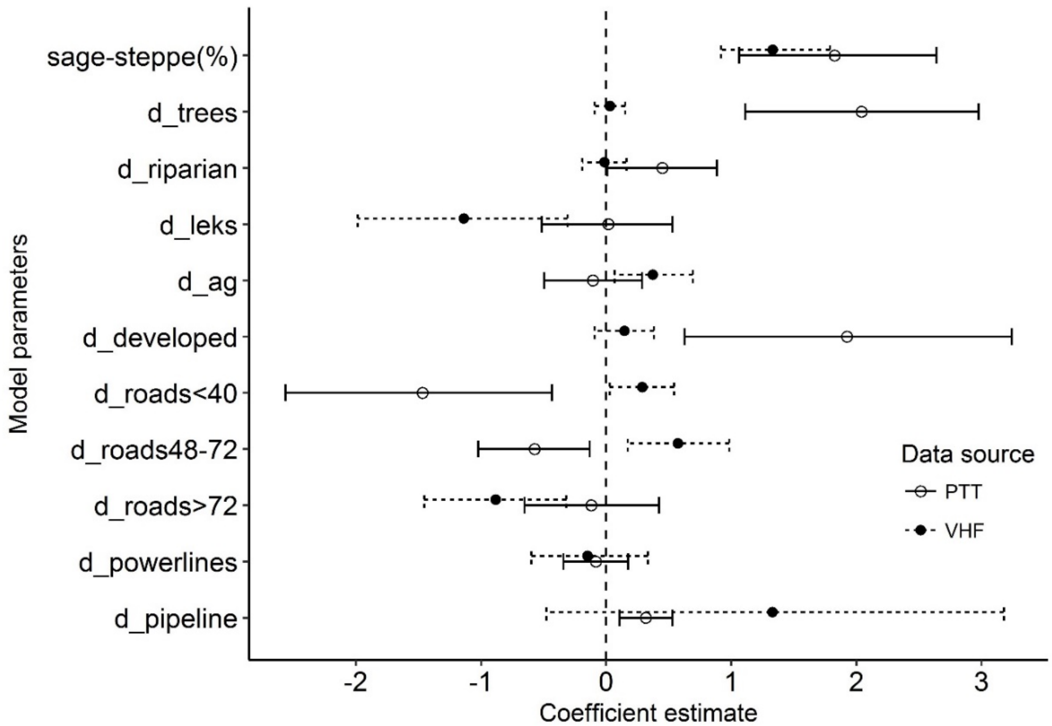

Figure 3-4. Comparison of model estimates and confidence intervals of biological and anthropogenic landscape variables by transmitter type during the breeding season (1 Mar.–30 June). Data were collected using very-high frequency (VHF) necklace style transmitters and rump-mounted platform terminal transmitter (PTT) telemetry units deployed on greater sage-grouse (*Centrocercus urophasianus*) in Morgan and Summit Counties, Utah, USA in 2015 and 2016. Landscape variables with "d" indicate distance metrics (e.g., a positive coefficient for d_trees suggests that sage-grouse selected for areas far from trees). If confidence intervals overlapped, I inferred there was no difference in selection between transmitter types. A parameter was not considered informative if the confidence interval overlapped zero. Confidence intervals were calculated using profile likelihoods.

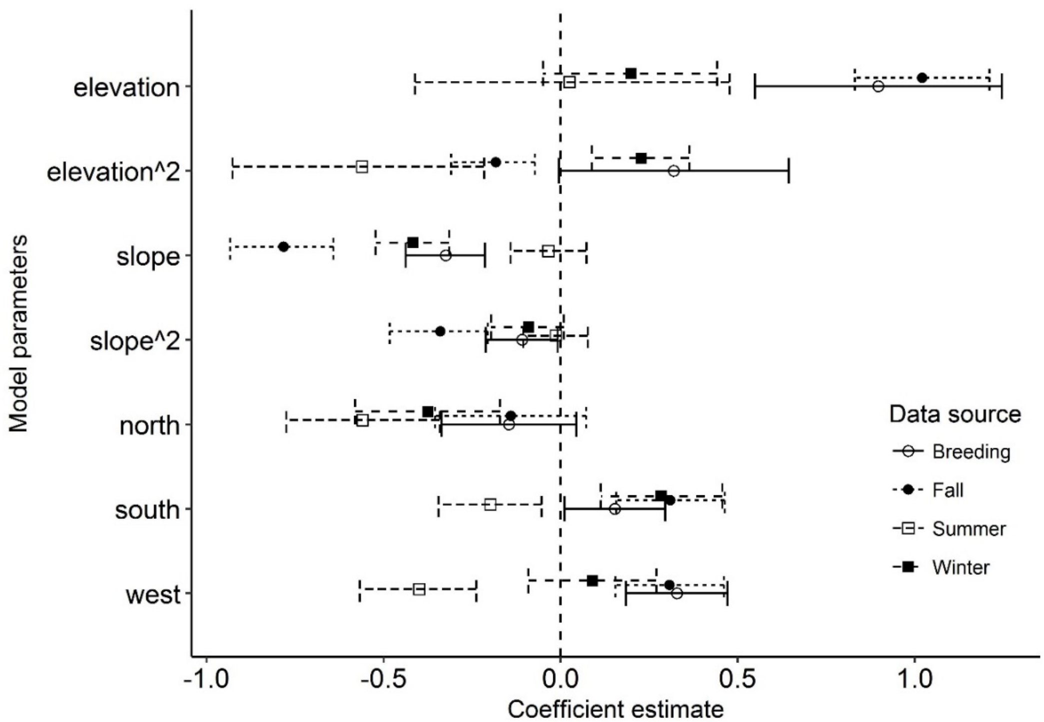

Figure 3-5. Comparison of model estimates and confidence intervals of topographic landscape variables by season. Data were collected using rump-mounted platform terminal transmitter (PTT) telemetry units deployed on greater sage-grouse (*Centrocercus urophasianus*) in Morgan and Summit Counties, Utah, USA in 2015 and 2016. Positive coefficients should be interpreted as selection (e.g., a positive coefficient for west suggests that PTT marked sage-grouse select for west facing aspects). If confidence intervals overlapped, I inferred there was no difference in selection by season. A parameter was not considered informative if the confidence interval overlapped zero. Confidence intervals were calculated using profile likelihoods.

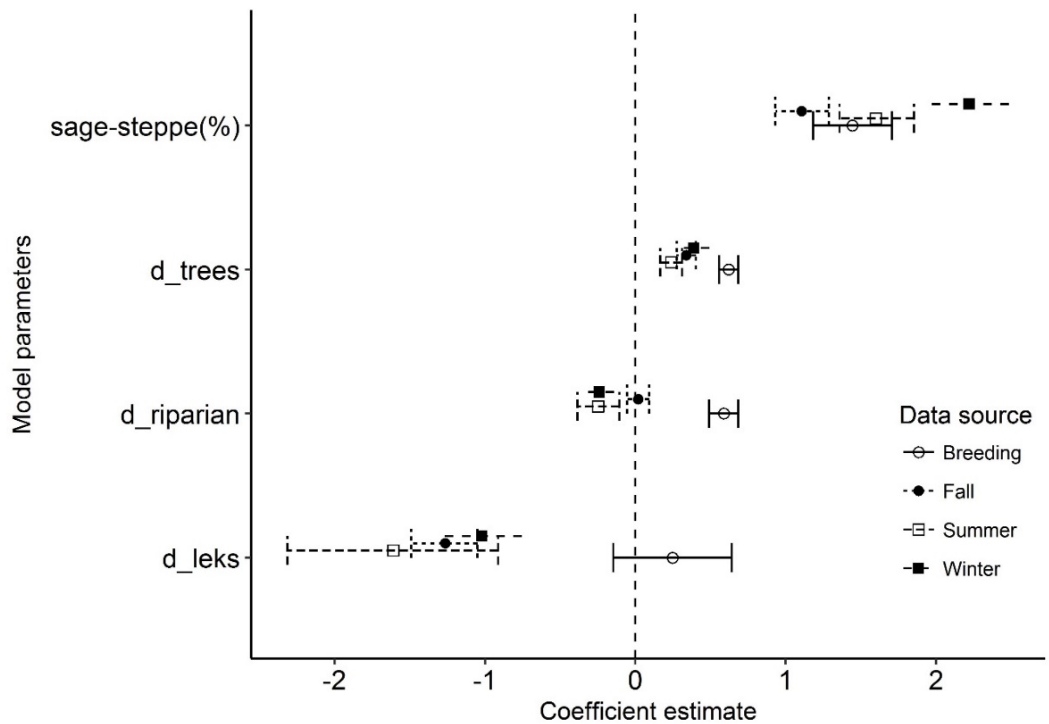

Figure 3-6. Comparison of model estimates and confidence intervals of biological landscape variables by season. Data were collected using rump-mounted platform terminal transmitter (PTT) telemetry units deployed on greater sage-grouse (*Centrocercus urophasianus*) in Morgan and Summit Counties, Utah, USA in 2015 and 2016. Landscape variables with "d" indicate distance features (e.g., a positive coefficient for d_trees suggests that PTT marked sage-grouse selected for areas far from trees). If confidence intervals overlapped, I inferred there was no difference in selection by season. A parameter was not considered informative if the confidence interval overlapped zero. Confidence intervals were calculated using profile likelihoods.

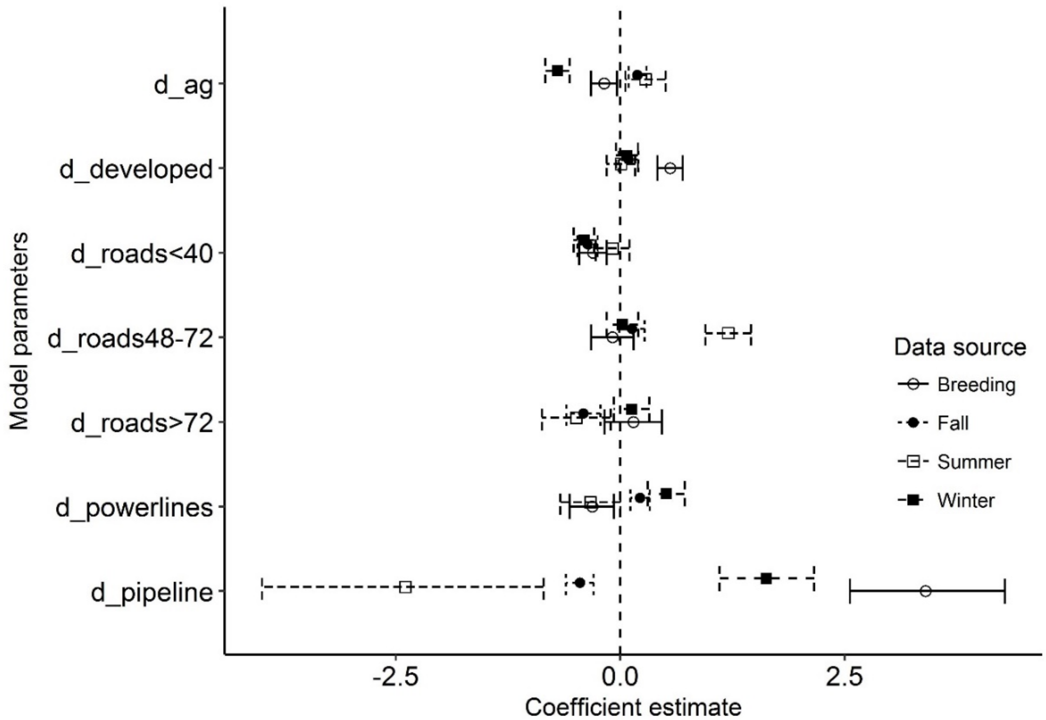

Figure 3-7. Comparison of model estimates and confidence intervals of anthropogenic landscape variables by season. Data were collected using rump-mounted platform terminal transmitter (PTT) telemetry units deployed on greater sage-grouse (*Centrocercus urophasianus*) in Morgan and Summit Counties, Utah, USA in 2015 and 2016. Landscape variables with "d" indicate distance features (e.g., a positive coefficient for d_developed suggests that PTT marked sage-grouse selected for areas far from developed areas). If confidence intervals overlapped, I inferred there was no difference in selection by season. A parameter was not considered informative if the confidence interval overlapped zero. Confidence intervals were calculated using profile likelihoods.

CHAPTER 4

CONCLUSIONS

The greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) is an iconic species of western North America and is considered an umbrella species because of its role as an indicator of the condition of sagebrush (*Artemisia* spp.) ecosystems (Hanser and Knick 2011, Knick et al. 2013). Sage-grouse population declines were recognized a century ago (Hornaday 1916) and populations have continued to decline range-wide (Connelly et al. 2004). These declines have been largely attributed to the degradation, alteration, and fragmentation of sagebrush habitats upon which sage-grouse depend (Schroeder et al. 2004, Connelly et al. 2011a) and have put sage-grouse in the middle of a conservation controversy as the species was petitioned for federal protection under the Endangered Species Act of 1973 (ESA). In 2015, the U.S. Fish and Wildlife Service (USFWS) determined that sage-grouse did not warrant listing after range wide conservation effort and the advent of federal and state management plans designed specifically to protect, improve, and restore sage-grouse habitats (USFWS 2015).

In Utah, sage-grouse populations have also declined and occupy less than half of historic habitats (Beck et al. 2003). The Utah Division of Wildlife Resources (UDWR) responded by developing statewide management plans (UDWR 2002, 2009). The state of Utah subsequently developed a statewide conservation plan with measurable objectives to ensure sage-grouse conservation in the state (State of Utah 2013). Because of Utah's unique topography and geography, sage-grouse habitat is discontinuous and populations are dispersed throughout the state in intact blocks of suitable habitat in the Great Basin, or in disconnected habitat islands in the Colorado Plateau (State of Utah 2013, Dahlgren et al. 2016). Therefore, it is critical for managers to understand local population dynamics and site-specific threats (State of Utah 2013).

Most of Utah's large sage-grouse populations have been studied but very little is known about some of the smaller isolated populations (Dahlgren et al. 2016). One such population occurs on private lands within the Rich-Morgan-Summit Sage-grouse Management Area in Morgan and Summit Counties in northern Utah (State of Utah 2013). This population is located in an area with high levels of human recreation and potential for urban development. The Morgan-Summit Adaptive Resource Management Local Working Group (MSARM) identified several strategies to maintain and increase sage-grouse populations in this area including identification of important sage-grouse habitat use areas, and potential habitat conservation actions to improve sagebrush quality (MSARM 2006).

This thesis provides new information regarding sage-grouse habitat use and demographic data including survival rates, nest success rates, and brood success rates that can be used by managers and private landowners to ensure sage-grouse conservation in this area. To obtain these data, I deployed 30 very-high frequency (VHF) necklace style radio-collars (n = 25 females, n = 5 males) in 2015 and 2016. I also deployed platform terminal transmitters (PTTs) equipped with global positioning system (GPS) technology on 10 female sage-grouse in 2015. These data were used to develop resource selection functions (RSFs) to quantify habitat selection and the influence of topographic, biological, and anthropogenic landscape variables across seasonal ranges.

In Chapter 2, I examined seasonal movements and vital rates and the variation associated with age, year, transmitter type, and vegetation structure. I compared productivity between the sage-grouse population found in Morgan and Summit Counties, Utah with other populations in Utah and across the species range with an emphasis on the highly productive population studied in north central Washington (Schroeder 1997). I used the analytical framework established by Schroeder (1997) and added transmitter type and vegetation components to generalized linear models to determine their influence on sage-grouse vital rates. I found this sage-grouse population was very productive with all marked females initiating at least one nest during the study and an overall brood success of 60.5%. In 2016, 6 females re-nested after their first nests failed and one female re-nested a second time after her first 2 nests failed. These findings provided support that this is a highly productive population because re-nesting is rare in Utah. I also found that this population uses a very small home range year round. Only 3 marked females were observed migrating > 10 km to winter ranges and all 3 females returned to the study area to for the breeding season.

Chapter 3 focused on temporal and spatial variation in this sage-grouse population. I performed 6 RSFs that examined habitat selection based on transmitter type, seasonal variation, and spatial variation. I compared data acquired from both VHF and PTT transmitters during the same time period and in the same geographic area to determine if habitat selection predictions vary by transmitter type. I analyzed the spatial variability of habitat selection of topographic, biological, and anthropogenic landscape features across seasons while accounting for the spatial scale at which sage-grouse are selecting resources. Connelly et al. (2011b) suggested that sage-grouse require large (> 4,000 ha) areas of sagebrush habitat for successful production and overwinter survival. Contiguous sagebrush landscapes of this size are not available for many sage-grouse populations in Utah because of the nature of the topography that naturally fragments suitable habitat into smaller blocks or islands (State of Utah 2013). I used a moving window analysis to quantify the amount of habitat this sage-grouse population requires. The Morgan-Summit sage-grouse population selected for sagebrush habitat at a 40 ha scale, not 4,000 ha. My results confirmed that a one-size-fits-all approach to managing sage-grouse is not feasible in Utah because the spatial extent of habitat used by sage-grouse depends on the amount of habitat available to a population in a given season.

I found that transmitter type did not influence habitat selection and any variation in selection patterns was likely a function of sampling effort. I verified this by comparing data from the PTT breeding subsample and the PTT breeding full sample. I also found that the influence of landscape variables on habitat selection varied by season. However, some patterns of habitat selection across all seasons did emerge. Sage-grouse selected for sagebrush habitat in every season, especially in the winter. They avoided development and trees during every season, especially during the breeding season.

Transmitter type did not influence sage-grouse vital rates. This is novel because many studies report that transmitters, especially dorsally mounted transmitters, negatively affect vital rates of birds (Small and Rusch 1985, Pietz et al. 1993, Connelly et al. 2003, Robert et al. 2006, Barron et al. 2010, Caudill et el. 2014, Kesler et al. 2014). However, it appeared that attachment style, not the dorsal positioning of transmitters, that affects vital rates (Caudill et al. 2014). I utilized a rump-mounted attachment style that was not evaluated by the studies mentioned above. My results suggested that a dorsal rump-mounted attachment style does not negatively impact vital rates any more than a standard VHF necklace-style attachment method would.

This research provided new information to help guide sage-grouse conservation strategies for MSARM, the state of Utah, Morgan and Summit Counties, and private landowners. It enhanced Utah's knowledge of connectivity between populations previously thought to be isolated and provided insights into the complexity of Utah's sage-grouse populations. The moving window analysis I performed could be used to analyze each sage-grouse population in Utah to understand the extent at which each population selects for sagebrush habitat. Although it has been suggested that increasing usable space could increase habitat availability which would in turn provide sage-grouse a larger annual home range and allow for population expansion (Dahlgren et al. 2016), that is not possible in some areas of Utah, namely Morgan and Summit Counties. Small isolated populations of sage-grouse can be productive if all seasonal habitat requirements are met. A more productive and viable approach would be to protect and conserve existing habitat. In areas dominated by private lands, this requires working relationships and collaboration between many stakeholders.

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APPENDICES

APPENDIX A

SUPPLEMENTARY TABLES AND FIGURES FOR CHAPTERS 2 AND 3

Table A-1. List of shrub, tree, forb, and grass species observed at nest sites, brood sites, and random sites in the greater sage-grouse (*Centrocercus urophasianus*) study area located in Morgan and Summit Counties, Utah, USA, 2015–2016.

SHRUBS/TREES

Common Name	Scientific Name	Common Name	Scientific Name
Utah serviceberry	*Amelanchier utahensis*	Chokecherry	*Prunus virginiana*
Low sagebrush	*Artemisia arbuscula*	Antelope bitterbrush	*Purshia tridentata*
White sagebrush	*Artemisia ludoviciana*	Gambel oak	*Quercus gambelii*
Mt. Big sagebrush	*Artemisia tridentata vaseyana*	Wood's rose	*Rosa woodsii*
Yellow rabbitbrush	*Chrysothamnus viscidiflorus*	Common snowberry	*Symphoricarpos albus*
Oregon grape	*Mahonia repens*	Mountain snowberry	*Symphoricarpos oreophilus*
Narrowleaf cottonwood	*Populus angustifolia*		

FORBS

Common Name	Scientific Name	Common Name	Scientific Name
Common yarrow	*Achillea millafolium*	Common sunflower	*Helianthus annuus*
Pale agoseris	*Agoseris glauca*	Showy goldeneye	*Heliomeris multiflora*
Tapertip onion	*Allium acuminatum*	Pink alumroot	*Huechera rubescens*
Desert madwort	*Alyssum desertorum*	Oneflower sunflower	*Helianthella uniflora*
Common fiddleneck	*Amsinckia menziesii*	Ballhead waterleaf	*Hydrophyllum capitatum*
Western ragweed	*Ambrosia psilostachya*	Owl's claws	*Hymenoxys hoopesii*
Low pussytoes	*Antennaria dimorpha*	Prickly lettuce	*Lactuca serriola*
Spreading dogbane	*Apocynum androsaemifolium*	pea	*Lathyrus spp*
Spearleaf arnica	*Arnica Longifolia*	Fernleaf licorice-root	*Ligusticum filicinum*
Looseflower milkvetch	*Astragalus tenellus*	Slender woodland star	*Lithophragma tenella*
Cutleaf balsamroot	*Balsamorhiza macrophylla*	Giant biscuitroot	*Lomatium dissectum*
Willow baccharis	*Baccharis salicina*	Foothill biscuitroot	*Lomatium grayi*
Shepherd's purse	*Capsella bursa-pastoris*	Silvery lupine	*Lupinus argenteus*
Nodding thistle	*Carduus nutans*	Mountain tarweed	*Madia glomerata*
Indian paintbrush	*Castilleja spp*	Horehound	*Marrubium vulgare*
Diffuse knapweed	*Centaurea diffusa*	Sweetclover	*Melilotus officinalis*
Curveseed butterwort	*Ceratocephala testiculata*	Bluebell spp	*Mertensia spp*
Canada thistle	*Cirsium arvense*	Spotted beebalm	*Monarda punctata*

Bull thistle	*Cirsium vulgare*	Needleleaf navarretia	*Navarretia intertexta*
Miner's lettuce	*Claytonia perfoliata*	Scotch thistle	*Onopordium acanthum*
Field bindweed	*Convolvulus arvensis*	Prickly pear	*Opuntia polyacantha*
King's bird's-beak	*Cordylanthus kingii*	Yellow owl's-clover	*Orthocarpus luteus*
Blue eyed Mary	*Collinsia parviflora*	Lobeleaf groundsel	*Packera multilobata*
Diffuse collomia	*Collomia tenella*	Spiny phlox	*Phlox hoodii*
Tapertip hawksbeard	*Crepis acuminate*	Longleaf phlox	*Phlox longifolia*
Torrey's cryptantha	*Cryptantha torreyana*	Slender cinquefoil	*Potentilla gracilis*
Springparsley	*Cymopterus spp*	Lambstongue ragwort	*Senecio intergerrimus*
Hound's tongue	*Cynoglossum officinale*	Tall tumblemustard	*Sisymbrium altissimum*
Alaska draba	*Draba stenoloba*	Desert globemallow	*Sphaeralcea ambigua*
Western tansymustard	*Descurainia pinnata*	Western aster	*Symphyotrichum ascendens*
Tall annual willowherb	*Epilobium brachycarpum*	Common dandelion	*Taraxacum officinale*
Redstem stork's bill	*Erodium cicutarium*	Hoary Townsend daisy	*Townsendia incana*
Shaggy fleabane	*Erigeron pumilus*	Yellow salsify	*Tragopogon dubius*
Aspen fleabane	*Erigeron speciosus*	Jack-go-to-bed-at-noon	*Tragopogon pratensis*
Sticky willy	*Galium aparine*	3 leaf clover	*Trifolium repens*
Geranium	*Geranium richardsonii*	Common mullein	*Verbascum thapsus*
American Licorice	*Glycyrrhiza lepidota*	American vetch	*Vicia americana*
Curlycup gumweed	*Grindelia squarrosa*	Nuttall's violet	*Viola nuttallii*
Manyflower stickseed	*Hackelia floribunda*	Mule-ears	*Wyethia amplexicaulis*
Jessica sticktight	*Hackelia micrantha*	Foothill deathcamas	*Zigadenus paniculatus*

GRASSES

Common Name	**Scientific Name**	**Common Name**	**Scientific Name**
Letterman's needlegrass	*Achnatherum lettermanii*	Needle and thread	*Hesperostipa comata*
Columbia needlegrass	*Achnatherum nelsonii*	Foxtail barley	*Hordeum jubatum*
Crested wheatgrass	*Agropyron cristatum*	Mouse barley	*Hordeum murinum*
Redtop	*Agrostis gigantea*	Little barley	*Hordeum pusillum*
Japanese brome	*Bromus japonicus*	Rushes	*Juncus spp*
Smooth brome	*Bromus inermis*	Prairie Junegrass	*Koeleria macrantha*
Cheatgrass	*Bromus tectorum*	Perennial ryegrass	*Lolium perenne*

Geyer's sedge	*Carex geyeri*	Basin wildrye	*Leymus cinereus*
Hood's sedge	*Carex hoodia*	Oniongrass	*Melica bulbosa*
Liddon sedge	*Carex petasata*	Western wheatgrass	*Pascopyrum smithii*
Orchardgrass	*Dactylis glomerata*	Timothy	*Phleum pratense*
Squirreltail	*Elymus elymoides*	Bulbous bluegrass	*Poa bulbosa*
Common spikerush	*Eleocharis palustris*	Kentucky bluegrass	*Poa Pratensis*
Quackgrass	*Elymus repens*	Sandberg's bluegrass	*Poa secunda*
Slender wheatgrass	*Elymus trachycaulus*	Bluebunch wheatgrass	*Pseudoroegneria spicata*
Horsetail	*Equisetum arvense*	Intermediate wheatgrass	*Thinopyrum intermedium*
Fowl mannagrass	*Glyceria striata*		

Table A-2. Re-classification of LANDFIRE vegetation categories for final land cover predictor variables utilized in seasonal resource selection analysis of the greater sage-grouse (*Centrocercus urophasianus*) population in Morgan and Summit Counties, Utah, USA, 2015–2016.

RSF Category	LANDFIRE CLASSNAME Category
Agriculture	Western Cool Temperate Close Grown Crop, Western Cool Temperate Orchard, Western Cool Temperate Row Crop, Western Cool Temperate Row Crop - Close Grown Crop, Western Cool Temperate Fallow/Idle Cropland, Western Cool Temperate Pasture and Hayland, Western Cool Temperate Wheat, Western Warm Temperate Row Crop, Western Warm Temperate Close Grown Crop, Western Warm Temperate Fallow/Idle Cropland, Western Warm Temperate Pasture and Hayland, Western Warm Temperate Wheat
Developed	Developed-High Intensity, Developed-Low Intensity, Developed-Medium Intensity, Developed-Roads, Quarries-Strip Mines-Gravel Pits, Western Cool Temperate Developed Ruderal Deciduous Forest, Western Cool Temperate Developed Ruderal Evergreen Forest, Western Cool Temperate Developed Ruderal Grassland, Western Cool Temperate Developed Ruderal Mixed Forest, Western Cool Temperate Developed Ruderal Shrubland, Western Cool Temperate Undeveloped Ruderal Deciduous Forest, Western Cool Temperate Undeveloped Ruderal Evergreen Forest, Western Cool Temperate Undeveloped Ruderal Grassland, Western Cool Temperate Undeveloped Ruderal Shrubland, Western Cool Temperate Urban Deciduous Forest, Western Cool Temperate Urban Evergreen Forest, Western Cool Temperate Urban Herbaceous, Western Cool Temperate Urban Mixed Forest, Western Cool Temperate Urban Shrubland, Western Warm Temperate Developed Ruderal Evergreen Forest, Western Warm Temperate Developed Ruderal Grassland, Western Warm Temperate Developed Ruderal Shrubland, Western Warm Temperate Undeveloped Ruderal Grassland, Western Warm Temperate Urban Deciduous Forest, Western Warm Temperate Urban Evergreen Forest, Western Warm Temperate Urban Herbaceous, Western Warm Temperate Urban Mixed Forest, Western Warm Temperate Urban Shrubland
NonHabitat	Barren, Inter-Mountain Basins Sparsely Vegetated Systems, Inter-Mountain Basins Sparsely Vegetated Systems II, North American Warm Desert Sparsely Vegetated Systems II, Open Water, Rocky Mountain Alpine/Montane Sparsely Vegetated Systems, Rocky Mountain Alpine/Montane Sparsely Vegetated Systems II, Snow-Ice

Riparian	Inter-Mountain Basins Montane Riparian Forest and Woodland, Inter-Mountain Basins Montane Riparian Shrubland, Introduced Riparian Forest and Woodland, Introduced Riparian Shrubland, Rocky Mountain Montane Riparian Forest and Woodland, Rocky Mountain Montane Riparian Shrubland, Rocky Mountain Subalpine/Upper Montane Riparian Forest and Woodland, Rocky Mountain Subalpine/Upper Montane Riparian Shrubland, Rocky Mountain Wetland-Herbaceous, Western Great Plains Depressional Wetland Systems, Western Great Plains Floodplain Forest and Woodland, Western Great Plains Floodplain Herbaceous, Western Great Plains Floodplain Shrubland
Sage Steppe	Arctostaphylos patula Shrubland Alliance, Artemisia tridentata ssp. vaseyana Shrubland Alliance, Coleogyne ramosissima Shrubland Alliance, Colorado Plateau Mixed Low Sagebrush Shrubland, Columbia Plateau Low Sagebrush Steppe, Columbia Plateau Steppe and Grassland, Grayia spinosa Shrubland Alliance, Great Basin Semi-Desert Chaparral, Great Basin Xeric Mixed Sagebrush Shrubland, Inter-Mountain Basins Big Sagebrush Shrubland, Inter-Mountain Basins Big Sagebrush Steppe, Inter-Mountain Basins Greasewood Flat, Inter-Mountain Basins Mat Saltbush Shrubland, Inter-Mountain Basins Mixed Salt Desert Scrub, Inter-Mountain Basins Montane Sagebrush Steppe, Inter-Mountain Basins Semi-Desert Grassland, Inter-Mountain Basins Semi-Desert Shrub-Steppe, Introduced Upland Vegetation-Annual and Biennial Forbland, Introduced Upland Vegetation-Annual Grassland, Introduced Upland Vegetation-Perennial Grassland and Forbland, Mogollon Chaparral, Mojave Mid-Elevation Mixed Desert Scrub, Northern Rocky Mountain Lower Montane-Foothill-Valley Grassland, Northern Rocky Mountain Montane-Foothill Deciduous Shrubland, Northwestern Great Plains Mixedgrass Prairie, Quercus gambelii Shrubland Alliance, Quercus turbinella Shrubland Alliance, Rocky Mountain Alpine Dwarf-Shrubland, Rocky Mountain Alpine Turf, Rocky Mountain Gambel Oak-Mixed Montane Shrubland, Rocky Mountain Lower Montane-Foothill Shrubland, Rocky Mountain Subalpine-Montane Mesic Meadow, Sonora-Mojave Semi-Desert Chaparral, Southern Colorado Plateau Sand Shrubland, Southern Rocky Mountain Montane-Subalpine Grassland, Wyoming Basins Dwarf Sagebrush Shrubland and Steppe
Trees	Abies concolor Forest Alliance, Colorado Plateau Pinyon-Juniper Woodland, Great Basin Pinyon-Juniper Woodland, Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland, Inter-Mountain Basins Curl-leaf Mountain Mahogany Woodland, Inter-Mountain Basins Juniper Savanna, Inter-Mountain Basins Subalpine Limber-

	Bristlecone Pine Woodland, Middle Rocky Mountain Montane Douglas-fir Forest and Woodland, Northern Rocky Mountain Subalpine Woodland and Parkland, Rocky Mountain Aspen Forest and Woodland, Rocky Mountain Bigtooth Maple Ravine Woodland, Rocky Mountain Foothill Limber Pine-Juniper Woodland, Rocky Mountain Lodgepole Pine Forest, Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland, Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland, Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland, Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland, Southern Rocky Mountain Ponderosa Pine Savanna, Southern Rocky Mountain Ponderosa Pine Woodland

Table A-3. Seasonal duty cycles and location collection times for 10 platform terminal transmitters (PTTs) attached to female greater sage-grouse (*Centrocercus urophasianus*) in Morgan and Summit Counties, Utah, USA in 2015–2016. PTTs were manufactured by Microwave Telemetry, Inc., Columbia, Maryland, USA, and were programmed to collect 9 GPS locations per day from 1 March through 31 October and 6 locations per day from 1 November through 28 February. The reduced number of locations collected in the winter was to conserve battery power during the time of year when the weather is poor and the PTTs have a difficult time charging properly and fully.

Season:	**March 1-May 15**	**May 16-Oct 31**	**Nov 1-Feb 28**
Location Collection Times	1:00 AM	2:00 AM	2:00 AM
	6:00 AM	6:00 AM	8:00 AM
	7:00 AM	8:00 AM	11:00 AM
	8:00 AM	10:00 AM	1:00 PM
	10:00 AM	12:00 PM	3:00 PM
	12:00 PM	2:00 PM	5:00 PM
	3:00 PM	4:00 PM	
	5:00 PM	6:00 PM	
	7:00 PM	8:00 PM	

Table A-4. Model output of Resource Selection Function (RSF) analysis of habitat selection of female greater-sage-grouse (*Centrocercus urophasianus*) during the breeding season (1 Mar. – 30 June) in Morgan and Summit Counties, Utah, USA, 2015–2016. Data locations were collected with very-high frequency (VHF) necklace style transmitters. A positive coefficient for “Distance to” landscape variable suggests that sage-grouse selected for areas far from that particular landscape variable). A P-value < 0.05 is considered significant and is bolded.

VHF Breeding Season				
Parameter	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-4.101	0.558	-7.355	< **0.001**
Elevation	0.916	0.254	3.610	< **0.001**
Elevation^2	0.458	0.193	2.367	**0.018**
North Aspect	-0.207	0.208	-0.999	0.318
South Aspect	-0.110	0.185	-0.597	0.550
West Aspect	0.353	0.162	2.187	**0.029**
Slope	-0.216	0.110	-1.962	**0.050**
Slope^2	-0.222	0.112	-1.981	**0.048**
Distance to Agriculture	0.374	0.158	2.373	**0.018**
Distance to Development	0.146	0.120	1.222	0.222
Distance to Pipeline	1.328	0.921	1.442	0.149
Distance to Powerlines	-0.149	0.217	-0.686	0.493
Distance to Roads ≤ 40 km/hr	0.288	0.130	2.216	**0.027**
Distance to Roads 48-72 km/hr	0.573	0.205	2.797	**0.005**
Distance to Roads > 72 km/hr	-0.882	0.287	-3.077	**0.002**
Distance to Leks	-1.137	0.422	-2.692	**0.007**
Distance to Riparian	-0.013	0.088	-0.151	0.880
Distance to Trees	0.031	0.062	0.493	0.622
Sage-Steppe (%)	1.332	0.216	6.164	< **0.001**

Table A-5. Model output of a Resource Selection Function (RSF) analysis of habitat selection of female greater-sage-grouse (*Centrocercus urophasianus*) with a subsample of data during the breeding season (1 Mar. – 30 June) in Morgan and Summit Counties, Utah, USA, 2015–2016. Data locations were collected with rump-mounted platform terminal transmitters (PTTs). A positive coefficient for "Distance to" landscape variable suggests that sage-grouse selected for areas far from that particular landscape variable). A P-value < 0.05 is considered significant and is bolded.

PTT Breeding Season Subsample				
Parameter	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-4.272	1.334	-3.204	**0.001**
Elevation	1.048	0.474	2.209	**0.027**
Elevation^2	-0.138	0.473	-0.292	0.770
North Aspect	-0.338	0.287	-1.177	0.239
South Aspect	0.221	0.207	1.068	0.286
West Aspect	0.159	0.204	0.780	0.436
Slope	-0.301	0.165	-1.826	0.068
Slope^2	-0.095	0.140	-0.679	0.497
Distance to Agriculture	-0.106	0.197	-0.539	0.590
Distance to Development	1.925	0.662	2.909	**0.004**
Distance to Pipeline	0.318	0.107	2.977	**0.003**
Distance to Powerlines	-0.081	0.131	-0.621	0.535
Distance to Roads ≤ 40 km/hr	-1.466	0.540	-2.713	**0.007**
Distance to Roads 48-72 km/hr	-0.571	0.226	-2.532	**0.011**
Distance to Roads > 72 km/hr	-0.119	0.272	-0.436	0.663
Distance to Leks	0.017	0.263	0.063	0.950
Distance to Riparian	0.448	0.222	2.023	**0.043**
Distance to Trees	2.042	0.473	4.320	**< 0.001**
Sage-Steppe (%)	1.825	0.399	4.571	**< 0.001**

Table A-6. Model output of Resource Selection Function (RSF) analysis of habitat selection of female greater-sage-grouse (*Centrocercus urophasianus*) with the full sample data set during the breeding season (1 Mar. – 30 June) in Morgan and Summit Counties, Utah, USA, 2015–2016. Data locations were collected with rump-mounted platform terminal transmitters (PTTs). A positive coefficient for "Distance to" landscape variable suggests that sage-grouse selected for areas far from that particular landscape variable). A P-value < 0.05 is considered significant and is bolded.

PTT Breeding Season Full Sample				
Parameter	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.105	0.274	4.030	< **0.001**
Elevation	0.897	0.178	5.050	< **0.001**
Elevation^2	0.319	0.165	1.929	0.054
North Aspect	-0.146	0.097	-1.505	0.133
South Aspect	0.153	0.072	2.110	**0.035**
West Aspect	0.329	0.073	4.493	< **0.001**
Slope	-0.325	0.057	-5.692	< **0.001**
Slope^2	-0.109	0.052	-2.100	**0.036**
Distance to Agriculture	-0.177	0.074	-2.406	**0.016**
Distance to Development	0.557	0.071	7.814	< **0.001**
Distance to Pipeline	3.404	0.439	7.759	< **0.001**
Distance to Powerlines	-0.308	0.126	-2.440	**0.015**
Distance to Roads ≤ 40 km/hr	-0.304	0.078	-3.903	< **0.001**
Distance to Roads 48-72 km/hr	-0.085	0.120	-0.706	0.480
Distance to Roads > 72 km/hr	0.148	0.163	0.903	0.367
Distance to Leks	0.247	0.201	1.232	0.218
Distance to Riparian	0.588	0.050	11.835	< **0.001**
Distance to Trees	0.621	0.032	19.146	< **0.001**
Sage-Steppe (%)	1.444	0.134	10.780	< **0.001**

Table A-7. Model output of Resource Selection Function (RSF) analysis of habitat selection of female greater-sage-grouse (*Centrocercus urophasianus*) during the summer season (1 July – 30 Sept.) in Morgan and Summit Counties, Utah, USA, 2015–2016. Data locations were collected with rump-mounted platform terminal transmitters (PTTs). A positive coefficient for "Distance to" landscape variable suggests that sage-grouse selected for areas far from that particular landscape variable). A P-value < 0.05 is considered significant and is bolded.

PTT Summer Season				
Parameter	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-1.345	0.581	-2.313	**0.021**
Elevation	0.025	0.243	0.101	0.920
Elevation^2	-0.562	0.182	-3.088	**0.002**
North Aspect	-0.560	0.111	-5.025	**< 0.001**
South Aspect	-0.199	0.074	-2.677	**0.007**
West Aspect	-0.400	0.085	-4.707	**< 0.001**
Slope	-0.035	0.054	-0.639	0.523
Slope^2	-0.014	0.047	-0.297	0.766
Distance to Agriculture	0.282	0.114	2.464	**0.014**
Distance to Development	0.009	0.082	0.113	0.910
Distance to Pipeline	-2.394	0.803	-2.980	**0.003**
Distance to Powerlines	-0.332	0.171	-1.937	0.053
Distance to Roads ≤ 40 km/hr	-0.085	0.096	-0.886	0.375
Distance to Roads 48-72 km/hr	1.203	0.129	9.318	**< 0.001**
Distance to Roads > 72 km/hr	-0.489	0.195	-2.505	**0.012**
Distance to Leks	-1.610	0.357	-4.506	**< 0.001**
Distance to Riparian	-0.248	0.073	-3.402	**< 0.001**
Distance to Trees	0.238	0.037	6.476	**< 0.001**
Sage-Steppe (%)	1.600	0.127	12.639	**< 0.001**

Table A-8. Model output of Resource Selection Function (RSF) analysis of habitat selection of female greater-sage-grouse (*Centrocercus urophasianus*) during the summer season (1 Oct. – 30 Nov.) in Morgan and Summit Counties, Utah, USA, 2015–2016. Data locations were collected with rump-mounted platform terminal transmitters (PTTs). A positive coefficient for "Distance to" landscape variable suggests that sage-grouse selected for areas far from that particular landscape variable). A P-value < 0.05 is considered significant and is bolded.

PTT Fall Season				
Parameter	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-3.829	0.426	-8.991	< **0.001**
Elevation	1.022	0.097	10.556	< **0.001**
Elevation^2	-0.183	0.061	-3.017	**0.003**
North Aspect	-0.140	0.109	-1.291	0.197
South Aspect	0.310	0.078	3.965	< **0.001**
West Aspect	0.307	0.078	3.924	< **0.001**
Slope	-0.783	0.074	-10.542	< **0.001**
Slope^2	-0.340	0.071	-4.811	< **0.001**
Distance to Agriculture	0.194	0.050	3.841	< **0.001**
Distance to Development	0.095	0.055	1.730	0.084
Distance to Pipeline	-0.447	0.079	-5.687	< **0.001**
Distance to Powerlines	0.223	0.055	4.051	< **0.001**
Distance to Roads ≤ 40 km/hr	-0.362	0.058	-6.209	< **0.001**
Distance to Roads 48-72 km/hr	0.131	0.072	1.816	0.069
Distance to Roads > 72 km/hr	-0.409	0.097	-4.230	< **0.001**
Distance to Leks	-1.263	0.112	-11.244	< **0.001**
Distance to Riparian	0.019	0.038	0.512	0.609
Distance to Trees	0.339	0.033	10.426	< **0.001**
Sage-Steppe (%)	1.106	0.090	12.232	< **0.001**

Table A-9. Model output of Resource Selection Function (RSF) analysis of habitat selection of female greater-sage-grouse (*Centrocercus urophasianus*) during the winter season (1 Dec. – 28 or 29 Feb.) in Morgan and Summit Counties, Utah, USA, 2015–2016. Data locations were collected with rump-mounted platform terminal transmitters (PTTs). A positive coefficient for "Distance to" landscape variable suggests that sage-grouse selected for areas far from that particular landscape variable). A P-value < 0.05 is considered significant and is bolded.

PTT Winter Season				
Parameter	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-4.609	0.628	-7.336	< **0.001**
Elevation	0.198	0.125	1.582	0.114
Elevation^2	0.227	0.070	3.239	**0.001**
North Aspect	-0.375	0.104	-3.595	< **0.001**
South Aspect	0.284	0.088	3.225	**0.001**
West Aspect	0.090	0.092	0.977	0.329
Slope	-0.418	0.053	-7.889	< **0.001**
Slope^2	-0.091	0.052	-1.736	0.083
Distance to Agriculture	-0.698	0.069	-10.091	< **0.001**
Distance to Development	0.076	0.063	1.216	0.224
Distance to Pipeline	1.627	0.271	6.010	< **0.001**
Distance to Powerlines	0.512	0.104	4.919	< **0.001**
Distance to Roads ≤ 40 km/hr	-0.403	0.059	-6.854	< **0.001**
Distance to Roads 48-72 km/hr	0.025	0.090	0.276	0.783
Distance to Roads > 72 km/hr	0.129	0.101	1.273	0.203
Distance to Leks	-1.020	0.137	-7.450	< **0.001**
Distance to Riparian	-0.242	0.052	-4.674	< **0.001**
Distance to Trees	0.387	0.055	7.069	< **0.001**
Sage-Steppe (%)	2.220	0.133	16.673	< **0.001**

Figure A-1. Female greater sage-grouse (*Centrocercus urophasianus*) captured in Morgan County, Utah, USA in 2015 and marked with a 22 g very-high frequency (VHF) necklace style transmitter produced by Advanced Telemetry Systems, Inc., Isanti, Minnesota, USA.

Figure A-2. Female greater sage-grouse (*Centrocercus urophasianus*) captured in Morgan County, Utah, USA in 2015 and marked with a camouflaged 22 g rump-mount style solar-powered platform terminal transmitter (PTT) equipped with global positioning system (GPS) technology and an ultra-high frequency (UHF) radio signal. Attached with custom harnesses made from ¼" tubular Teflon ribbon and copper crimps adding 8 g of weight for a total overall transmitter weight of 30 g. Harness construction and attachment protocols provided by Brett Walker with Colorado Parks and Wildlife. PTT manufactured by Microwave Telemetry, Inc., Columbia, Maryland, USA.

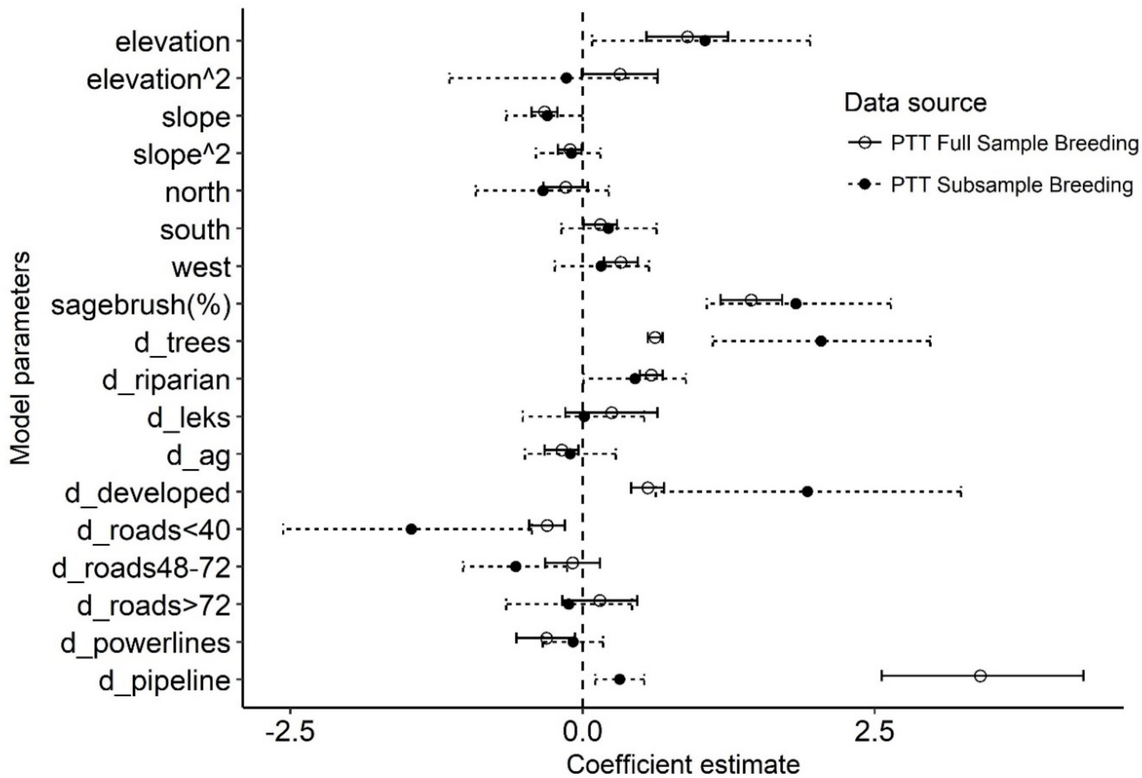

Figure A-3. Comparison of model estimates and confidence intervals of landscape variables by transmitter type during the breeding season (1 Mar. – 30 June). Data were collected using rump-mounted platform terminal transmitter (PTT) telemetry units deployed on greater sage-grouse (*Centrocercus urophasianus*) in Morgan and Summit Counties, Utah, USA in 2015 and 2016. Overlapping confidence intervals indicate no statistical difference in selection between transmitter types based on topographic landscape variables. A parameter was not considered informative if the confidence interval overlapped zero. Confidence intervals were calculated using profile likelihoods. This figure compares the PTT breeding season subsample data set with the PTT breeding season full sample data set.

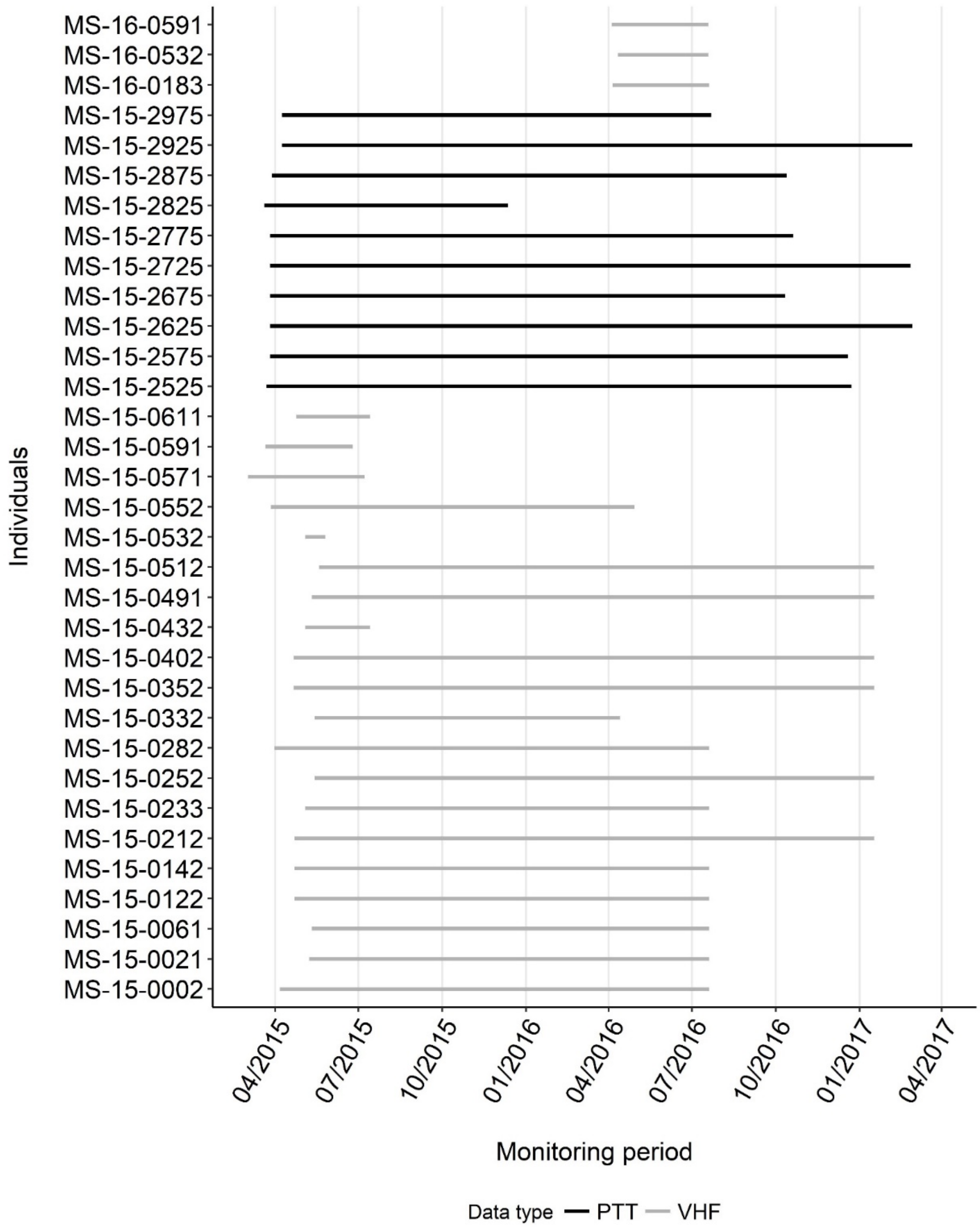

Figure A-4. Data collection timeline of greater sage-grouse (*Centrocercus urophasianus*) in Morgan and Summit Counties, Utah, USA, 2015–2016 indicating when a bird was captured and marked and the period of time each bird was monitored. Sage-grouse were marked with either a 22 g very-high frequency (VHF) necklace style transmitter or a 22 g rump-mounted platform terminal transmitter (PTT) equipped with global positioning system technology and an ultra-high frequency radio signal.

APPENDIX B

SUPPLEMENTAL HOME RANGE INFORMATION

Supplement B-1: Home range information

The results from this study support the idea that sage-grouse populations vary significantly range wide. The Morgan-Summit population does not use as much space as other populations in Utah in part because they have limited area to use (Thacker 2010, Garton et al. 2011, Cook 2015, Dahlgren et al. 2016, Sandford 2016). Urban development near Park City in Summit County, Utah has reduced the amount of available habitat for this population (UDWR unpublished data). The population occurs in the core study area because of quality sagebrush habitat even though the area is relatively small. Home range sizes indicate that this population could be space limited (Supplement Table A-1 and A-2). When comparing home range estimates between transmitter types, PTT data produced a smaller home range size than VHF data. This is because of the several daily locations a PTT can collect which allows the KDE to produce a more accurate home range estimate. For home range estimates based on a 95% KDE, PTT data should be used over VHF data if available. The home range estimates were very small for the breeding and summer seasons indicating that birds did not move far between nesting and brood rearing habitat which again supports the idea of space limitations. Most of the marked birds in this study (36 of 39) were year-round residents in the core study area. Of the three that migrated, two were marked with PTTs and, as a result, their migration movements and winter ranges were captured. Although their migrations were more than 30 km, their winter ranges were smaller than some of the resident PTT birds.

Seasonal Home Range Estimates

The Morgan-Summit sage-grouse population exhibited varying home range sizes depending on the season and type of location data used to calculate the 95% KDE.

Estimated home range sizes varied by year as well (Supplement Table A-1 and A-2). During the breeding season, an average home range estimate of 5.9 km^2 for VHF marked birds (n = 40) is comparable to the 6.9 km^2 home range estimate for the PTT subsample dataset (n = 19).

Because PTTs collect data year-round, I estimated seasonal home ranges based on the full PTT dataset. The average PTT breeding season and summer season home ranges were 4.6 km^2 (n = 19), and 3.5 km^2 (n = 19) respectively. The average fall home range expanded to 80.3 km^2 (n = 18) but is skewed by two individuals who migrated south for the winter (Supplement Table A-2). For resident PTT birds, the average fall home range was 18.7 km^2 (n = 14). The average winter home range was 26.4 km^2 (n = 15) for all PTT marked birds regardless of whether they spent the winter in the core study area or on winter range to the south.

Table B-1. Breeding season (1 Mar. – 30 June) home range estimates based on a 95% kernel density estimate calculated from locations of female greater sage-grouse (*Centrocercus urophasianus*) marked with very high frequency (VHF) necklace style radio transmitters in Morgan and Summit Counties, Utah, USA, 2015–2016.

VHF Birds (Breeding Season)			
BIRD_ID_2015	Home Range Area (km^2)	BIRD_ID_2016	Home Range Area (km^2)
MS-15-0002_2015	1.2	No Data	
MS-15-0021_2015	3.5	MS-15-0021_2016	5.2
MS-15-0061_2015	5.1	MS-15-0061_2016	7.9
MS-15-0122_2015	4.0	MS-15-0122_2016	1.1
MS-15-0142_2015	4.2	MS-15-0142_2016	4.9
MS-15-0212_2015	5.9	MS-15-0212_2016	1.2
MS-15-0233_2015	3.4	MS-15-0233_2016	1.8
MS-15-0252_2015	1.9	MS-15-0252_2016	7.8
MS-15-0282_2015	1.2	MS-15-0282_2016	5.2
MS-15-0312_2016	4.3	No Data	
MS-15-0332_2015	2.9	No Data	
MS-15-0352_2015	8.6	MS-15-0352_2016	8.2
MS-15-0402_2015	11.8	MS-15-0402_2016	25.3
MS-15-0432_2015	13.4	MS-15-0432_2016	0.9
MS-15-0491_2015	6.8	MS-15-0491_2016	0.3
MS-15-0512_2015	2.4	MS-15-0512_2016	2.2
MS-15-0532_2015	1.1	No Data	
MS-15-0552_2015	3.5	MS-15-0552_2016	0.4
MS-15-0571_2015	32.6	MS-15-0571_2016	7.8
MS-15-0591_2015	2.1	No Data	
MS-15-0611_2015	7.3	MS-15-0611_2016	1.9
No Data		MS-16-0183_2016	16.7
No Data		MS-16-0532_2016	7.5
No Data		MS-16-0591_2016	3.1
Average Home Range Area: 5.9 km^2			

Table B-2. Seasonal home range estimates of female greater sage-grouse (*Centrocercus urophasianus*) marked with rump-mounted platform terminal transmitters (PTTs) in Morgan and Summit Counties, Utah, USA, 2015 and 2016. Home range estimates are based on a 95% kernel density estimate calculated from locations gathered by the PTTs. Calculations for the fall and winter seasons include average home range estimates for the population and for resident individuals only.

	PTT Birds: Home Range Areas (km^2)				
BIRD ID YEAR	Breeding Full dataset	Breeding Subsample	Summer	Fall	Winter
MS-15-2525_2015	9.3	16.6	1.4	16.2	61.2
MS-15-2525_2016	16.8	34.5	3.8	5.5	43.1
MS-15-2575_2015	1.2	0.6	2.4	1.8	No Data
MS-15-2575_2016	3.1	3.7	1.2	2.1	6.3
MS-15-2625_2015	1.5	1.5	3.1	551.8	2.0
MS-15-2625_2016	5.3	5.3	1.6	4.7	7.0
MS-15-2675_2015	2.0	3.1	1.3	625.6	27.6
MS-15-2675_2016	2.6	2.3	3.6	0.4	28.6
MS-15-2725_2015	0.6	0.3	1.7	60.4	172.0
MS-15-2725_2016	5.4	0.7	0.8	20.0	3.8
MS-15-2775_2015	1.1	1.7	3.9	5.7	No Data
MS-15-2775_2016	11.7	34.8	3.4	5.4	8.4
MS-15-2825_2015	4.4	5.2	2.0	16.6	No Data
MS-15-2875_2015	6.6	4.4	25.2	12.7	0.1
MS-15-2875_2016	7.3	9.0	1.3	101.6	12.5
MS-15-2925_2015	1.3	1.5	2.1	9.5	7.2
MS-15-2925_2016	4.2	4.8	3.5	3.1	11.0
MS-15-2975_2015	0.6	0.3	1.8	1.4	No Data
MS-15-2975_2016	2.6	1.8	2.8	No Data	5.5
Average Area	4.6	6.9	3.5	80.3	26.4
		Residents only		18.7	30.1