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Greater Sage-Grouse Seasonal Habitat Models, Response to Juniper Reduction and Effects of Capture Behavior on Vital Rates, in Northwest Utah

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GREATER SAGE-GROUSE SEASONAL HABITAT MODELS, RESPONSE TO
JUNIPER REDUCTION AND EFFECTS OF CAPTURE BEHAVIOR ON
VITAL RATES, IN NORTHWEST UTAH

by

Avery Cook

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

of

MASTER OF SCIENCE

in

Wildlife Ecology

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Logan, Utah

2015

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ABSTRACT

Greater Sage-Grouse Seasonal Habitat Models, Response to Juniper Reduction and
Effects of Capture Behavior on Vital Rates, in Northwest Utah

by

Avery Cook, Master of Science
Utah State University, 2015

Major Professor: Dr. Terry A. Messmer
Department: Wildland Resources

The greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) is a species of conservation concern in Utah and range-wide due to declines in populations and threats to sagebrush habitat on which they depend. To effectively conserve the species, detailed site-specific knowledge of ecology and distribution is needed. To expand knowledge of local populations within the West Box Elder Sage Grouse Management Area (SGMA) and gain insights into the effectiveness of vegetation treatments intended to benefit sage-grouse, I radio marked and tracked 123 (68 female, 55 male) sage-grouse and conducted sage-grouse pellet surveys on 19 conifer removal projects.

Widespread habitat restoration measures designed to benefit sage-grouse have highlighted the need for prioritization tools to optimize placement of sage-grouse habitat projects. I generated seasonal habitat models to predict sage-grouse habitat use within the West Box Elder SGMA using a suite of vegetation and topographical predictors and known sage-grouse locations. Model fit was good with brood, early summer, late

summer, lekking (early spring), and non-breeding models reporting an AUC of >0.90; nest and winter models reported an AUC of 0.87 and 0.85, respectively. A vegetation disturbance history was built for the study area from 1985 to 2013; however, the vegetation disturbances mapped were not a strong predictor of sage-grouse seasonal habitat-use.

To evaluate effectiveness of conifer reduction treatments I used fecal pellet and in concert with radio-telemetry data. Increased sage-grouse use of conifer treatments was positively associated with sage-grouse presence in adjacent habitats ($P = 0.018$), percent shrub cover ($P = 0.039$), and mesic environments within 1000 m of treatments ($P = 0.048$). Sage-grouse use of conifer treatments was negatively associated with conifer canopy cover ($P = 0.048$) within 1000 m of treatments.

To investigate sample bias related to individual bird behavior or capture trauma I monitored 204 radio-marked sage-grouse within the West Box Elder and Rich-Morgan-Summit SGAs in Utah between January 2012 and March 2013. Sage-grouse that flushed one or more times prior to capture had higher brood ($P = 0.014$) and annual survival ($P = 0.027$) than those that did not. Sage-grouse that experienced more capture trauma had decreased annual survival probabilities ($P = 0.04$).

(175 pages)

PUBLIC ABSTRACT

Greater Sage-Grouse Seasonal Habitat Models, Response to Juniper Reduction and Effects of Capture Behavior on Vital Rates, in Northwest Utah

Avery Cook

The greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) is a species of conservation concern in Utah and across their range throughout the western US and southern Canada. Sage-grouse decline is primarily a result of declines in sagebrush habitat on which sage-grouse depend for winter, summer, nesting, and brood habitat. Detailed site-specific knowledge of sage-grouse ecology and distribution is needed to effectively conserve the species. To expand knowledge of local populations within the West Box Elder Sage Grouse Management Area (SGMA) in NW Utah and gain insights into the effectiveness of vegetation treatments intended to benefit sage-grouse, I radio marked and tracked 123 (68 female, 55 male) sage-grouse and conducted pellet surveys on 19 conifer reduction projects.

I generated seasonal habitat models to predict seasonal habitat use within the West Box Elder SGMA using vegetation and topographical data coupled with radio telemetry locations to aid in prioritization and optimal placement of sage-grouse habitat improvement projects. Output maps were generated from models that indicated probability of sage-grouse use during brood, nesting, early summer non-breeding, late summer non-breeding, winter and lekking (early spring) periods. In addition, a vegetation disturbance dataset was generated from satellite imagery and available maps

for the period from 1985 to 2013. However, disturbance at the above temporal and spatial scale was not an influential predictor of sage-grouse distribution.

Conifer reduction projects are thought to be a cost effective method of restoring habitat to a state useable by sage-grouse in areas that have been invaded by pinyon pine (*Pinus* spp.) and juniper (*Juniperus* spp.). However, little information specific to sage-grouse on the effectiveness of conifer reduction is available. I evaluated sage-grouse use of conifer reduction treatments using radio telemetry and fecal pellet surveys within conifer reduction projects. Sage-grouse use was detected in 12 of 19 treatments surveyed. Use was positively associated with sage-grouse presence in adjacent habitat, mesic areas surrounding treatments, and higher shrub cover within treatments. Higher conifer density surrounding a treatment was associated with less use of conifer reduction projects.

Biologists have expressed concerns that differences in individual bird behavior or effects of capture could affect capture probability and bias reported vital rates. I monitored 204 radio-marked sage-grouse within the West Box Elder and Rich-Morgan-Summit SGMA in Utah between January 2012 and March 2013 to evaluate effects of individual behavior and capture stress on survival and reproductive success. Sage-grouse that flushed one or more times prior to capture had higher brood and annual survival rates than those that did not. Sage-grouse that were handled longer or experienced more capture trauma had decreased survival probabilities. My results suggest researchers need to consider the effects of capture and handling when reporting sage-grouse vital rates obtained through radio-marking.

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I would like to thank Terry Messmer, my major advisor, for being on the forefront of Utah's sage-grouse research and the driving force enabling this research to be accomplished. As a student of Terry, I have learned a great deal about both the ecology of sage-grouse, and how ecology fits into a broader management context. I would also like to thank my committee members, Doug Ramsey for his help in all things GIS, and Jack Connelly for support in planning and execution of the project.

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Without the many landowners of West Box Elder letting us capture and track sage-grouse across their property there would not have been a project, and there would be fewer grouse without their stewardship. The landowners of West Box Elder are a shining example of good stewardship, with healthy and productive rangelands supporting wildlife and livestock. Ken Spackmen was exceedingly generous and helpful, helping me get my feet under me, putting up with persistent phone calls, and helping me figure out who owned each section of ground.

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CONTENTS

	Page
ABSTRACT	iii
PUBLIC ABSTRACT	v
ACKNOWLEDGMENTS	vii
LIST OF TABLES.....	xii
LIST OF FIGURES	xiv
 CHAPTER	
1. INTRODUCTION AND LITERATURE REVIEW	1
SEASONAL MOVEMENTS	3
Lekking.....	4
Nest.....	5
Brood	6
Winter.....	8
CONSERVATION STATUS AND THREATS.....	9
HISTORIC LAND USE AND MANAGEMENT	11
IMPACTS OF CAPTURE AND HANDLING	13
HABITAT MODELING.....	15
STUDY SITE	16
RESEARCH OBJECTIVES	17
LITERATURE CITED	18
2. EVALUATING A GREATER SAGE-GROUSE (<i>CENTROERCUS UROPHASIANUS</i>) HABITAT SUITABILITY MODEL FOR BOX ELDER COUNTY, UT.....	31
ABSTRACT	31
INTRODUCTION	32
STUDY AREA	37
METHODS	39
RESULTS	44
Vegetation Disturbance	44
Predictive Models.....	44

DISCUSSION	46
MANAGEMENT IMPLICATIONS	53
LITERATURE CITED	54
3. FACTORS INFLUENCING GREATER SAGE-GROUSE USE OF CONIFER REDUCTION TREATMENTS: IMPLICATIONS FOR RANGE-WIDE CONSERVATION	84
ABSTRACT	84
INTRODUCTION	85
STUDY AREA	88
METHODS	89
RESULTS	93
DISCUSSION	96
MANAGEMENT IMPLICATIONS	99
LITERATURE CITED	100
4. GREATER SAGE-GROUSE SURVIVAL AND REPRODUCTIVE SUCCESS RELATIVE TO ENVIRONMENTAL CONDITIONS AND BEHAVIOR	110
ABSTRACT	110
INTRODUCTION	111
STUDY AREA	114
METHODS	115
Capture and Handling	115
Telemetry	117
Data Analysis	119
RESULTS	121
Nest Survival	122
Brood Survival	123
Annual Survival	125
DISCUSSION	127
Nest Survival	127
Brood Survival	131
Adult Survival	133
MANAGEMENT IMPLICATIONS	134
LITERATURE CITED	136

5. CONCLUSIONS.....	155
LITERATURE CITED	158

LIST OF TABLES

Table	Page
2-1. Hectares and number of vegetation changes (parenthetical) mapped by year and type of vegetation change from 1985 to 2013 within Box Elder Sage-grouse Management Area Box Elder County, Utah	64
2-2. Sample size of greater sage-grouse (<i>Centrocercus urophasianus</i>) telemetry locations within the Box Elder Sage-grouse Management Area, Box Elder County, Utah collected between 2005 and 2013 with associated model evaluation metrics	66
2-3. Variables used in Random Forest models predicting sage-grouse distribution, and influence of vegetation change on sage-grouse distribution in the Box Elder Sage-grouse Management Area, Box Elder County, Utah	67
3-1. Grouped LANDFIRE land cover classifications (USGS 2010) present in buffers surrounding conifer reduction projects in West Box Elder County, Utah evaluated in 2013 for greater sage-grouse (<i>Centrocercus urophasianus</i>) use	107
4-1. Covariates used to evaluate the effects of capture, handling, and behavior on survival and reproduction of greater Sage-grouse (<i>Centrocercus urophasianus</i>) captured between January 2012 and March 2013 in northern Utah.....	143
4-2. Sample sizes of individual covariates examined while investigating capture and handling effects on nest, brood, and annual survival of greater sage-grouse (<i>Centrocercus urophasianus</i>) during calendar years 2012 and 2013 in northern Utah.....	145
4-3. Model ranking of greater sage-grouse (<i>Centrocercus urophasianus</i>) nest daily survival rate of in northern Utah during the 2012 and 2013 breeding seasons.	146
4-4. Top models showing 27 day nest survival estimates and associated 95% confidence intervals derived from modeled greater sage-grouse (<i>Centrocercus urophasianus</i>) daily survival rates.....	147
4-5. Top models showing greater sage-grouse (<i>Centrocercus urophasianus</i>) 35 day nest survival estimates and associated 95% confidence intervals derived from modeled daily survival rates....	148

4-6. Model ranking of greater sage-grouse (<i>Centrocercus urophasianus</i>) daily brood survival rates in northern Utah during the 2012 and 2013 breeding seasons	149
4-7. Top models showing 50 day greater sage-grouse (<i>Centrocercus urophasianus</i>) brood survival estimates and associated 95% confidence intervals.....	150
4-8. Model ranking of greater sage-grouse (<i>Centrocercus urophasianus</i>) quarterly survival rates of in northern Utah from Jan 2012 to Sept 2013.....	151
4-9. Top annual known fate survival models for greater sage-grouse (<i>Centrocercus urophasianus</i>) data aggregated over the West Box Elder and Rich County study sites from Jan 2012 to Sept 2013.	152

LIST OF FIGURES

Figure	Page
1-1. West Box Elder County study area as defined by the 2002 BARM Greater Sage-grouse Management Area and the 2013 Utah Box Elder Sage-grouse Management Area.....	30
2-1. Overview of the greater sage-grouse (<i>Centrocercus urophasianus</i>) seasonal habitat modeling area within the West Box Elder Sage-grouse Management Area in Box Elder County, Utah, containing 94% of the SGMA's active Leks.....	69
2-2. Vegetation changes mapped by year and type of disturbance from 1985 to 2013 within the Box Elder Sage-grouse Management Area, Box Elder County, Utah.....	70
2-3 Percent LANDFIRE Existing Vegetation Type within the modeling area (% True Count) relative to percent LANDFIRE Existing Vegetation Type for greater sage-grouse (<i>Centrocercus urophasianus</i>) use points (% SAGR Use) collected from 2005 to 2013 within the Box Elder modeling area, Box Elder County, Utah	71
2-4. Receiver Operator Characteristic (ROC) plot of sensitivity (true positives) and specificity (false positives) for greater sage-grouse (<i>Centrocercus urophasianus</i>) non-breeding models of the Box Elder Sage-grouse Management Area, Box Elder County, Utah, based on telemetry locations collected from 2005-2013.....	72
2-5. Receiver Operator Characteristic (ROC) plots of sensitivity (true positives) and specificity (false positives) for greater sage-grouse (<i>Centrocercus urophasianus</i>) seasonal habitat models of West Box Elder County Utah based on telemetry locations collected from 2005-2013.	73
2-6. Variable importance plots for greater sage-grouse (<i>Centrocercus urophasianus</i>) Random Forest seasonal habitat models of the Box Elder Sage-grouse Management Area, Box Elder County, Utah, based on telemetry locations collected from 2005-2013.....	74
2-7. Variable importance plot for the greater sage-grouse (<i>Centrocercus urophasianus</i>) random forest seasonal habitat model for the Box Elder Sage-grouse Management Area, Box Elder County, Utah based on non-breeding telemetry locations collected from 2005-2013	75

2-8. Mapped vegetation changes within the Box Elder Sage-grouse Management Area, Box Elder County, Utah from 1985 to 2013.....	76
2-9. Predicted probability of greater sage-grouse (<i>Centrocercus urophasianus</i>) nest occupancy within the Box Elder Sage-grouse Management Area Box Elder County, Utah, based on vegetative and topographical model inputs and greater sage-grouse telemetry locations collected between 2005 and 2013.....	77
2-10. Predicted probability of greater sage-grouse (<i>Centrocercus urophasianus</i>) brood occupancy within the Box Elder Sage-grouse Management Area Box Elder County, Utah, based on vegetative and topographical model inputs and greater sage-grouse telemetry locations collected between 2005 and 2013.....	78
2-11. Predicted probability of greater sage-grouse (<i>Centrocercus urophasianus</i>) early summer non-breeding occupancy within the Box Elder Sage-grouse Management Area Box Elder County, Utah, based on vegetative and topographical model inputs and greater sage-grouse telemetry locations collected between 2005 and 2013.....	79
2-12. Predicted probability of greater sage-grouse (<i>Centrocercus urophasianus</i>) late summer non-breeding occupancy within the Box Elder Sage-grouse Management Area Box Elder County, Utah, based on vegetative and topographical model inputs and greater sage-grouse telemetry locations collected between 2005 and 2013.....	80
2-13. Predicted probability of greater sage-grouse (<i>Centrocercus urophasianus</i>) winter occupancy within the Box Elder Sage-grouse Management Area Box Elder County, Utah, based on vegetative and topographical model inputs and greater sage-grouse telemetry locations collected between 2005 and 2013.....	81
2-14. Predicted probability of greater sage-grouse (<i>Centrocercus urophasianus</i>) lekking season occupancy within the Box Elder Sage-grouse Management Area Box Elder County, Utah, a based on vegetative and topographical model inputs and greater sage-grouse telemetry locations collected between 2005 and 2013.....	82
2-15. Predicted probability of greater sage-grouse (<i>Centrocercus urophasianus</i>) non-breeding occupancy within the Box Elder Sage-grouse Management Area Box Elder County, Utah, based on vegetative and topographical model inputs and greater sage-grouse telemetry locations collected between 2005 and 2013.....	83

3-1 Conifer removal projects with treatment and reference plots surveyed in 2013 evaluating greater sage-grouse (<i>Centrocercus urophasianus</i>) use and habitat characteristics in Utah's West Box Elder Sage-grouse Management Area.....	109
4-1. West Box Elder and Rich County study areas used for evaluating effects of behavior, capture and handling on greater sage-grouse (<i>Centrocercus urophasianus</i>) in 2012 and 2013 with the encompassing Sage Grouse Management Areas	153
4-2. Estimated survival probabilities of all groups of monitored greater sage-grouse (<i>Centrocercus urophasianus</i>) in West Boxed Elder County by quarter from January 2012 to December 2013.	154
4-3. Estimated survival probabilities of all groups of monitored greater sage-grouse (<i>Centrocercus urophasianus</i>) in Rich County by quarter from January 2012 to September 2013.	154

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

BIOLOGY AND MANAGEMENT

The greater sage-grouse (*Centrocercus urophasianus*; sage-grouse), is well-known for its unique breeding displays, distinct breeding plumage, and reliance on sagebrush (*Artemisia* spp.) throughout its life cycle. Sage-grouse populations have been declining range-wide for the last century (Connelly et al. 2004, Schroeder et al. 2004, Garton et al. 2011). Their estimated occupied range has declined from a historical pre-settlement distribution of 1.2 million km² to 668,000 km² by the year 2000 (Schroeder et al. 2004). These declines have been largely attributed to the deterioration, loss, and fragmentation of sagebrush habitats (Connelly et al. 2011). In Utah, sage-grouse now occupy 41% of historic habitats, with the largest remaining populations in Box Elder, Garfield, Rich, Uintah, and Wayne Counties (Beck et al. 2003).

Wildlife managers have been concerned about declines in sage-grouse populations for almost a century (Hornaday 1916). Early population declines from market hunting resulted in hunting restrictions including shrinking bag limits in Colorado through the 1910's and 1920's, with continued declines leading to a total closure of the Wyoming and Colorado sage-grouse hunting season in 1937 (Patterson 1952, Rogers 1964). However, the hunting season was reopened after there was no population response detected as a result of hunting restrictions (Patterson 1952). In response to continuing declines, wildlife managers, industry, private citizens, and nongovernmental organizations have initiated conservation planning efforts to identify and implement

conservation actions to benefit sage-grouse by protecting and restoring habitats (Stiver 2011).

The first petition requesting the U.S. Fish and Wildlife Service (USFWS) to list sage-grouse for protection under the Endangered Species Act (ESA) of 1973 was submitted in 1999. The 1999 petition was filed to protect a Washington population of sage-grouse and resulted in the USFWS determination that ESA protection was warranted but precluded by higher priority listing actions (USFWS 2001). Two additional petitions were filed in 2001 and 2005 to list the bi-state population along the Californian-Nevada border Mono Basin area. The USFWS determined that listing these populations for ESA protection was not warranted. Other petitions were filed in the early 2000's and again in 2005; the USFWS determined that listing was not warranted (USFWS 2005, Stiver 2011). The 2005 decision was challenged in court and due to errors in how the listing was handled; the USFWS was required to reopen the process. In 2010, the USFWS determined that sage-grouse warranted ESA protection, but was precluded because of higher priority species (USFWS 2010). The USFWS was sued regarding this decision and subsequently ordered by a federal judge to make a final determination regarding species status by September 2015 (Stiver 2011).

In 2002 in response to population declines and the possibility of listing under ESA, the Utah Division of Wildlife Resources (UDWR) developed a strategic statewide management plan to guide state and local conservation actions (UDWR 2002). The Utah 2002 management plan identified 13 sage-grouse management areas in the state; the boundaries for these areas were used to define local sage-grouse working group conservation areas (UDWR 2002, 2009). In 2007, the West Box Elder Adaptive

Resource Management Local Working Group (BARM) used the state plan to develop and implement a conservation plan to manage sage-grouse in northwestern Utah (BARM 2007). In 2013 the Utah Governor's office developed an updated plan that further set priority actions and guide conservation measures (Utah 2013). The BARM plan and Utah Governor's plan identified threats to the species, knowledge gaps, and conservation actions they believed could reverse regional population declines. This thesis focuses on addressing knowledge gaps identified in the 2007 BARM plan. Specifically, I answer landscape and population scale questions about large scale movements and habitat use in the resource area. The scale of study and analysis corresponds to 2nd and 3rd order habitat assessments defined by Johnson (1980), and in a sage-grouse context by Stiver et al. (2010).

SEASONAL MOVEMENTS

Sage-grouse seasonal movements may vary among populations, but can be categorized by their temporal scale and association with individual life stages. Connelly et al. (2011) placed sage-grouse movements into four categories: 1) dispersal from place of hatching to place of breeding or attempted breeding, 2) movements of individuals within a season, 3) migration between distinct and spatially separated seasonal ranges, 4) home ranges that sum all movement types seasonally or annually. Migrations can be further classified based on the extent and frequency of movement. Connelly et al. (2000) defined these movements as 1) non-migratory, grouse do not make long-distance movements (i.e., <10 km one way) between or among seasonal ranges; 2) one-stage migratory, grouse move further than 10 km between 2 distinct seasonal ranges; and 3) two-stage migratory, grouse move more than 10 km between 3 distinct seasonal ranges.

Previous research has shown greater sage-grouse in West Box Elder County to be one-stage migratory populations, moving an average of 22.6 km from breeding/winter range to summer range (Knerr 2007). However, these classifications are often overly general and populations may exhibit a high degree of individual heterogeneity ranging from no migratory movements to movements considerably further than average (Fedy et al. 2012, Reinhart et al. 2013). Season movements can vary considerably between populations with some populations showing movements of 69 km (Fischer et al. 1997), 82 km (Connelly et al. 1988), and in the longest known sage-grouse migration of 180 km in which a sage-grouse returned to summer range over the course of 18 days (Smith 2013).

Lekking

During the early spring, male sage-grouse congregate in relatively open areas, termed leks, to display and attract females with which to breed. Lek locations are generally stable through the years, but can move in response to changes in vegetation characteristics, snow cover, and disturbance (Connelly et al. 2011). Initiation of lekking behavior generally begins in late winter between late February and early March and can extend into the first weeks of June (Connelly et al. 2011). Shortly after the first males begin strutting, 50-60% of the seasonal maximum male counts will be present on leks (Eng 1963, Jenni and Hartzler 1978), with peak attendance 3 to 4 weeks after males begin strutting (Baumgardt 2011). About four weeks later there is a roughly two week peak in hen lek attendance (Eng 1963). In northwestern Utah, peak lek counts typically occur from the last week of March to the second Week of April (Knerr 2007), but lekking behavior extends from early March to the first week of June (BARM 2007). Roughly 3 weeks following peak hen attendance, there is a peak male lek attendance as yearling

males arrive at the leks (Eng 1963, Connelly et al. 2011). However, lek timing can be variable, and weather conditions can shift peak hen attendance by several days to weeks (Schroeder 1997, Connelly et al. 2011).

Nest

Hens typically initiate incubation three to four weeks after peak hen lek attendance (Connelly et al. 2011). Most hens select nest sites in the vicinity of leks (Braun et al. 1977) however the closest lek may not be the lek where the hen bred because hens may visit multiple leks during a breeding season (Schroeder and Robb 2003). Holloran et al. (2005) found that 64% of nests were located within 5 km of a lek, and Connelly et al. (2000) found that the average distance to a lek varied between 1.1 and 6.2 km, but could be greater than 20 km. Aldridge and Boyce (2007) reported that in Alberta, Canada 90% of nesting source habitat lies within 10 km of leks and that the average distance from lek to primary nesting habitat was 5.8 km. However, there is considerable variation in distance from the nearest lek, and the nearest lek is not always the lek where the hen bred (Connelly et al. 2011). In Utah nearest lek to nest distances were within 5 km for 90% of recorded telemetry locations from multiple studies between 1998 and 2012 (D. Dhalgren, Utah State University, personal communication). Hens in fragmented areas may move greater distances than hens in contiguous habitat (Lyon and Anderson 2003, Schroeder and Robb 2003). Nesting hens often return to the same area to nest in subsequent years showing strong site fidelity, usually nesting less than 1000 m from the previous year's nest (Berry and Eng 1985, Fischer et al. 1993, Holloran et al. 2005). However, Schroeder and Robb (2003) found that hens moved an average of 1.6

km from a previous year's successful nest and 5.2 km from a previous year's unsuccessful nest in fragmented habitat.

Individual nests are most often located under sagebrush, but can also be found under other shrubs (Patterson 1952, Connelly et al. 1991, Wing 2014). Typically, more successful hens nest under shrubs with greater vertical cover and have greater residual grass cover, relative to random sites or nest sites of unsuccessful hens (Gregg et al. 1994, Sveum et al. 1998, Holloran et al. 2005).

Nest initiation rates average 78% in the western portion (CA, ID, OR, NV, UT, WA) of sage-grouse's range (Connelly et al. 2011). Sage-grouse tend to lay relatively small clutches compared to other galliform species before incubating eggs for an average of 27 days (Schroeder 1997). Clutch sizes typically range from averages of 6 (Dahlgren 2006) up to 10 (Knerr 2007) with an average of 7.1 eggs per clutch for the western portion of sage-grouse range (Connelly et al. 2011). Over a range of studies, habitat conditions and locations, Connelly et al. (2011) reported studies with nest success ranging from 15-85%.

Brood

The area in the vicinity of the nesting site is typically considered early brood-rearing habitat. For the first 2-3 weeks after hatching most broods remain within 3 km of the nest site, after which some broods move farther away to late brood rearing and summer habitat in response to increasingly xeric conditions (Berry and Eng 1985). However, broods may make small movements to areas that have less sagebrush cover and increased herbaceous cover relative to the nest site while still in the early brood rearing stage (Holloran 1999). Broods are reliant on insects as a large component of their early

diet (Klebenow and Gray 1968, Johnson and Boyce 1990) and tend to use areas with structural features that facilitate increased insect abundance (Connelly et al. 2011). Fischer (1996) found ants and beetles to be more abundant at brood sites relative to nest sites, however Dahlgren (2006) did not find a relationship between insect abundance and habitat, but did find that higher insect abundance correlated with higher chick survival.

After the first 2-4 weeks, broods move to summer and late brood rearing habitat. Late brood rearing habitats are generally selected based on forb abundance, with sage-grouse seeking areas with more moisture in locally mesic areas or at higher elevation (Connelly et al. 2011). Other populations show little to no movement to summer/late brood rearing habitats when forbs are available in the nesting habitat, or there is mesic microhabitat in the area (Connelly et al. 2011).

There is considerable variation in chick and brood survival reported among studies. Aldridge and Boyce (2007) reported 12% chick survival to 51 days. Dahlgren (2006) reported a survival rate with estimated 50% of chicks surviving to 42 days, while Chi (2004) reported an average brood survival rate over 3 years of study at 70% on Parker Mountain, UT. Chick survival was shown to be greater in years with greater forb availability (Gregg et al. 2008). Local studies in Box Elder have reported brood survival of 44% ($n = 9$, success defined as at least one chick surviving to 50 days; Knerr 2007), 80% ($n = 15$, success defined as at least one chick surviving to 42 days; Thacker 2010), and 50% ($n = 8$, success defined as at least one chick surviving to 50 days; Graham 2013).

Recruitment of juveniles to the breeding population is a key demographic parameter. However, there has been relatively little research on this life stage and the

factors influencing juvenile survival through their first fall and winter (Crawford et al. 2004). Beck et al. (2006) reported September 1 to March 29 survival of juvenile sage-grouse in both Idaho lowland and mountain populations of 86% and 64% respectively. Blomberg et al. (2012) modeled recruitment for a Nevada population based on mark-resight methods, and reported widely varying annual recruitment rates ranging from 1.2 to 0.1 male recruits per adult male. Blomberg et al. (2012) showed sufficient correlation between male recruitment estimates and female age ratios to generalize to the larger population.

Winter

For winter forage and shelter, sage-grouse are almost entirely dependent on sagebrush protruding above the snow (Patterson 1952, Wallestad and Eng 1975, Braun et al. 1977, Crawford et al. 2004). As a result, winter sage-grouse distribution is dependent on sagebrush distribution, weather patterns, and resulting snow depth (Patterson 1952, Beck 1977).

Sage-grouse survival is typically high over winter with severe weather having little impact on survival (Crawford et al. 2004, Connelly et al. 2011). Sage-grouse are sufficiently well adapted to consuming sagebrush and winter conditions that they are able to gain weight in the winter months (Beck and Braun 1978). Beck et al. (2006) found a high survival rate of juveniles over winter with 86% surviving in a moderate elevation site and 64% surviving at a higher elevation site. Hausleitner (2003) reported over winter survival rates between 82% and 100%, and Wik (2002) reported over winter survival at 85 to 100%. However, Moynahan et al. (2006) reported that higher winter mortality was associated with severe winter weather, showing that winter habitat is still critical to

maintaining viable populations. Knerr's (2007) research in Box Elder County also showed higher winter mortality (35.3% and 21.4% in 2005 and 2006) relative to summer mortality rates (16.7% and 18.9% in 2005 and 2006).

CONSERVATION STATUS AND THREATS

The greater sage-grouse are a sagebrush obligate species and requires sagebrush for cover and forage throughout its life cycle (Connelly et al. 2011). USFWS identified loss and fragmentation of habitat as the key causes of sage-population decline (USFWS 2010). Fire, invasive plants including pinyon-juniper (*Pinus edulis*, *Pinus monophylla*, *Juniperus* spp.) encroachment, poor grazing practices, energy development, linear structures such as roads, fences and power lines, and other factors are the drivers of habitat loss and degradation. Climate change will likely exacerbate many of the above factors, most notably increased fire frequency as a result of vegetation change and increased rates of West Nile Virus infection (USFWS 2010).

There are many other factors leading to decrease in sage-grouse populations throughout their range and within the study area including housing/urban development, conversion of habitat to agriculture, predation, and disease. However, the primary cause of sage-grouse decline is the loss and deterioration of sagebrush habitat. Specific threats to the West Box Elder County sage-grouse population were identified in the 2007 local conservation plan and threat evaluations were updated in the 2012 BARM accomplishment report (BARM 2007, 2012). Current top threats are wildfire, predation, invasive weeds, and altered water distribution (BARM 2012). Current conservation efforts focus on reducing pinyon-juniper invasion, reservoir suitability analysis, winter rangeland improvement, and weed management (Cirrus 2013).

Invasive plants can dramatically alter habitat and if left unchecked can cause ecological state changes transforming suitable habitat to unsuitable habitat. Primary concerns in the study area are conversion of sagebrush habitat to pinyon-juniper woodland and annual grasslands. Juniper has historically been part of the western landscape. However, increases in grazing in the late 1800's likely reduced fire size and return interval before the widespread establishment of programmatic fire suppression in the 1900's allowed continued expansion of pinyon-juniper woodlands (Miller et al. 2011). Succession from sagebrush shrubland to juniper woodland is generally categorized into three transitional phases: Phase I – juniper is present but shrubs, forbs, and grasses are the dominant vegetation, Phase II – juniper is co-dominate with shrubs and juniper is influencing ecological processes, and Phase III – trees are dominant and the primary vegetation influencing ecological processes (Miller 2005). Once a stand has transitioned to a juniper woodland, forb, grass, and shrub diversity may be reduced making restoration of sagebrush very difficult and costly (Miller et al. 2000). Even at low levels of juniper invasion, sage-grouse can be precluded from using a site (Baruch-Mordo et al. 2013). Sage-grouse are further precluded from sites containing pinyon-juniper because trees provide elevated raptor perches (Commons et al. 1999). Baruch-Mordo et al. (2013) reported that conifer cover of only 4% would preclude leks within 1km, Doherty et al (2008) found that sage-grouse avoid conifer in habitats on a 650 m² scale, and Doherty et al. (2010) found that sage-grouse avoid conifers when selecting nest locations. Most effective, both in terms of results and cost, treatment of juniper encroachment focuses on early Phase II communities where there is ample shrub, forb

and grass communities remaining to maintain native communities once trees are removed (Baruch-Mordo et al. 2013).

Invasive annual grasses pose a serious threat to sagebrush habitat through changes in fuel loading and resulting changes in fire regime (Miller et al. 2011). Invasive annual grasses, namely cheatgrass (*Bromus tectorum*) easily invade disturbed areas, burned areas, and poorly managed grazing lands. Once established cheatgrass will increase fuel continuity resulting in larger fires, and increase light fine fuel loading leading to higher ignition probability and a more frequent fire return interval. Annual grasses recover quickly post-fire, while sagebrush requires much longer for recovery, leading to habitat conversion (Whisenant 1990).

HISTORIC LAND USE AND MANAGEMENT

Livestock grazing was established in the Intermountain West in the mid to late 1800's (BARM 2007). In the Park Valley area, there was an intense dry farming boom by Euro-Americans from 1910 into the 1920's linked to homestead land grants and the sale of railroad lands (Morris 2010). Total forb cover is generally lower in historic dry farming plots, with increased cover of squirrel tail (*Elymus elymoides*) and mixed shrub habitat shifting toward a Wyoming big sagebrush (*A. tridentata wyomingensis*) dominated habitat (Morris et al. 2011). Many of the historic dry farming plots are associated with the Homestead Act of 1862 and the Enlarged Homestead Act of 1909 which required a percentage of the land to be cultivated. Many of these historic dry farming plots are still visible in aerial and satellite images reflecting lasting effects on vegetation communities (Morris 2010).

Livestock grazing has remained the primary land use and economic driver in west Box Elder County. Grazing land use is dominated by beef cattle (*Bos* spp.), however, there are ranches raising domestic sheep (*Ovis aries*) (BARM 2007). Private landowners, public land management agencies, and academic institutions have manipulated the sagebrush community to enhance the economic contribution of these areas. More recently habitat manipulations have been conducted to benefit sage-grouse (Thacker 2010). Early academic research in the area included experimental burns and seedings in 1974-76 as collaborative efforts between Utah State University and the Hereford Corporation (Ralphs and Busby 1978, 1979). More recently sagebrush treatments have been applied in areas close to the study site to investigate sage-grouse response to mechanical, chemical and prescribed fire treatments (Thacker 2010), and green stripping with forage kochia (*Kochia prostrata*) to protect sage-grouse habitat (Graham 2013).

The Natural Resource Conservation Service (NRCS) has been involved in public-private partnerships to improve habitat quality, generally with the goal of increasing forage values and general wildlife habitat quality. Recently, with the creation of the NRCS Sage-Grouse Initiative (SGI), the goal of improving sage-grouse habitat has become more prominent. The state of Utah's Watershed Restoration Initiative (WRI) has funded projects to improve habitat in the form of juniper removal, sagebrush mechanical treatments, and burn rehabilitation. Lands managed by the Bureau of Land Management (BLM) and U.S. Forest Service (USFS) also make up a portion of the study site, and many of the above mentioned or similar treatments have been carried out on their lands. There are also vegetation treatments done on private lands similar to the above mentioned

treatments; however, they are generally poorly documented or records are unavailable due to privacy concerns (J. Schick, NRCS – personal communication).

IMPACTS OF CAPTURE AND HANDLING

Because the greater sage-grouse is a species of intense conservation interest, the number of studies implemented to learn more about the species' ecology has increased. Google Scholar (<http://scholar.google.com>) results for articles containing "*Centrocercus urophasianus*" or "sage-grouse" in the title showed an average of 23 documents published in 1990s, with publications numbers following an increasing trend to over 69 documents published in 2014. Many of these studies involved sage-grouse capture and handling to collect data using various marking devices. Effects of the markings such as poncho and harness mounted radios on sharp-tailed grouse (*Tympanuchus phasianellus*; Amstrup 1980, Marks and Marks 1987), necklace mounted radios on lesser prairie chickens (*Tympanuchus pallidicinctus*; Hagen et al. 2006), as well as effects of color, mounting system and shape (Boitani and Fuller 2000) have been studied. Frye et al. (2014) found that necklace mounted radio transmitters did not affect sage-grouse flushing behavior, though there was a noise indicative of wings striking the transmitter antenna that could possibly induce study biases. However, there has been very little study of possible acute and chronic effects from capture and handling required to equip sage-grouse with telemetry transmitters or other markings (Caudill 2011).

Although studies on handling effects are rare in the literature, primarily due to the difficulty of establishing a control group (Hagen et al. 2006), there are studies that suggest the possibility of significant deleterious effects due to capture and handling on other gallinaceous species. Death resulting from capture stress is rare during capture and

handling of sage-grouse and when occurs is generally a result of capture myopathy, a stress related condition characterized by muscle rupture and blood acidosis (Giesen et al. 1982, Friend and Thomas 1999). However, sub-lethal effects of capture myopathy, which are difficult to detect in the field, may affect sage-grouse post capture as they have in bobwhite quail (Abbott et al. 2005). Lasting, sub-lethal effects, if present, may cause decreased response to predators (Abbott et al. 2005). Friend and Thomas (1999) also stated that capture myopathy related tissue damage to skeletal and cardiac muscle in a variety of bird species can cause mortality days after release, making it difficult to directly attribute capture myopathy to a mortality. General outward symptoms of capture myopathy include dyspnea (shortness of breath), hyperthermia, weakness, muscle rigidity, and collapse (Hulland 1993). Abbott et al. (2005) suggest that studies investigating the effects of radio transmitters that found no effect of transmitters on survival and reproduction may have a false null effect due to similar handling effects on treatment and control groups.

There are few studies that attempt to answer questions of trapping effects on study animals. Some studies try to mitigate the capture effects in data and avoid negative bias on study outcomes by censoring animals that do not survive a minimum time post capture (Abbott et al. 2005). In a northern bobwhite (*Colinus virginianus*) study, Abbott et al. (2005) found that treating bobwhite for muscular damage via an injection of Vitamin E and selenium increased survival from 29% to 58% at 45 days when compared to a control group injected with saline, implying that there is significant handling stress from capture that has a long-term effect on survival. Sublethal effects on sage-grouse remain poorly understood.

HABITAT MODELING

Many approaches to modeling species distributions relative to their habitat are available. Traditionally, modeling has been accomplished using presence-absence or presence-nondetection data. However, in many biological studies absence data are not available and presence only modeling can only provide estimation of the relative intensity of species occurrence (Fithian and Hastie 2013). Species distribution modeling is key for understanding the environmental factors influencing the habitat use and distribution of a population and for informing conservation efforts and management (Franklin 2009). Logistic regression methods, while wide spread in the ecological literature, are somewhat limited when applied to presence only data (Phillips et al. 2006, Yost et al. 2008); however, presence only methods such as Maxent (Phillips et al. 2006) and Random Forest (Cutler et al. 2007) are available to develop species distribution models from limited data (Hernandez et al. 2008).

Random Forest modeling technique uses environmental variables with presence and pseudo absence locations to develop decision trees that describe variables that are suitable for a species and define areas of species occurrence (Hernandez et al. 2008). Random Forrest is a decision tree based method of classification that avoids over fitting that can occur with single decision tress by developing hundreds to thousands of decision trees with a subset of the data, and generating each split in the tree from a random subset of predictor variables (Franklin 2009). Data not included in each tree are used to estimate error and the importance of input variables as an alternative to holding back data to use for model validation (Freeman and Frescino 2009).

STUDY SITE

The Box Elder study site includes the Raft River and Pilot Mountain subunits of the West Box Elder Resource Area as defined in the 2002 Utah Sage Grouse Plan and is located in the northwest corner of Utah (UDWR 2002). This study focuses on sage-grouse inhabiting the Raft River Subunit. Geographically, the core of the study area is bounded by the Raft River Mountains to the north, the Grouse Creek and Pilot Mountains to the west, by the Great Salt Lake to the east, and areas of salt flats to the south. The study area includes the entire West Box Elder Resource Area which contains a mix of private, state and federally owned land consisting of 50.7% private land (349,439 ha), 39% BLM (268,121 ha), 6% SITLA (41,386 ha), and 4% USFS land (29,110 ha) totaling 688,877 ha (Utah AGRC 2013).

Vegetation structure in the study area varies with elevation from salt desert scrub at low elevations through various sagebrush communities and into juniper and mahogany woodlands at higher elevations. Elevation ranges from 1,400 to 3,000 m above sea level.

From 1990 to 2012 annual precipitation averaged 22.6 cm in Park Valley (5000 ft. elevation), with 14.2 cm falling as snow between November and April. Temperatures range from a monthly average high of 86° F (30° C) in July to a monthly average low of 15° F (-9.4° C) in December and January (Western Regional Climate Center (WRCC) 2012). Snow does not typically persist through spring at lower elevations but can remain at elevations over 8000 ft. (2438 m) into late summer. Greater levels of snowfall and colder temperatures exist at higher elevations. During the 2012 field season, the study area experienced a dry winter and unusually early spring. The 2013 field season was

proceeded by a bitterly cold winter with below average precipitation, although there was an increase in summer moisture.

The dominant land use throughout the study area is livestock grazing with both cattle and sheep. There are also irrigated agricultural lands used primarily used for hay and alfalfa (*Medicago sativa*) production.

RESEARCH OBJECTIVES

There has been little study, other than lek counts, of the local ecology of sage-grouse in the Park Valley area of northwestern Utah despite the West Box Elder population being one of the sage-grouse population strongholds of the state (UDWR 2009). This study will describe seasonal habitats, response to conifer removal, effects of capture and handling on this population to augment previous research by Knerr (2007), Thacker (2010), and Graham (2013) in the adjacent Grouse Creek area of West Box Elder County.

Chapter 2 investigates seasonal sage-grouse habitat use by incorporating vegetation, topographical and vegetation disturbance with sage-grouse location using a Random Forest modeling approach. Chapter 3 analyzes sage-grouse use of recent conifer removal projects using a combination of fecal pellet surveys and telemetry locations. Chapter 4 evaluates the effects of sage-grouse behavior at capture and other capture covariates on survival and reproductive success.

This thesis is written in a multiple paper format following the Journal of Wildlife Management format guidelines for chapters 1,2,4, and 5 and the Wildlife Society Bulletin format guidelines for Chapter 3.

LITERATURE CITED

- Abbott, C. W., C. B. Dabbert, D. R. Lucia, and R. B. Mitchell. 2005. Does muscular damage during capture and handling handicap radiomarked northern bobwhites? *Journal of Wildlife Management* 69:664–670.
- Aldridge, C. L., and M. S. Boyce. 2007. Linking occurrence and fitness to persistence: habitat-based approach for endangered greater sage-grouse. *Ecological Applications* 17:508–526.
- Amstrup, S. C. 1980. A radio-collar for game birds. *Journal of Wildlife Management* 44:214–217.
- Box Elder Adaptive Resource Management Local Working Group [BARM]. 2007. West box elder greater sage-grouse (*Centrocercus urophasianus*) local conservation plan. Utah State University Extension and Jack H. Berryman Institute and Utah Division of Wildlife Resources, Salt Lake City, Utah, USA.
- Box Elder Adaptive Resource Management Local Working Group [BARM]. 2012. 2012 West Box Elder CRM sage-grouse accomplishment report. Utah State University Extension, Logan, Utah, USA.
- Baruch-Mordo, S., J. S. Evans, J. P. Severson, D. E. Naugle, J. D. Maestas, J. M. Kiesecker, M. J. Falkowski, C. A. Hagen, and K. P. Reese. 2013. Saving sage-grouse from the trees: a proactive solution to reducing a key threat to a candidate species. *Biological Conservation* 167:233–241.
- Baumgardt, Jeremy A. 2011. Probability of attendance and sightability of greater sage-Grouse on leks: relating lek-based indices to population abundance. Dissertation, University of Idaho. Moscow, Idaho, USA.

- Beck, J. L., D. L. Mitchell, and B. D. Maxfield. 2003. Changes in the distribution and status of sage-grouse in Utah. *Western North American Naturalist* 63:203–214.
- Beck, J. L., K. P. Reese, J. W. Connelly, and M. B. Lucia. 2006. Movements and survival of juvenile greater sage-grouse in southeastern Idaho. *Wildlife Society Bulletin* 34:1070–1078.
- Beck, T. D. I. 1977. Sage grouse flock characteristics and habitat selection in winter. *Journal of Wildlife Management* 41:18–26.
- Beck, T. D. I., and C. E. Braun. 1978. Weights of Colorado sage grouse. *The Condor* 80:241–243.
- Berry, J. D., and R. L. Eng. 1985. Interseasonal movements and fidelity to seasonal use areas by female sage grouse. *Journal of Wildlife Management* 49:237–240.
- Blomberg, E. J., J. S. Sedinger, M. T. Atamian, and D. V. Nonne. 2012. Characteristics of climate and landscape disturbance influence the dynamics of greater sage-grouse populations. *Ecosphere* 3:55.
- Boitani, L., and T. K. Fuller. 2000. Research techniques in animal ecology: controversies and consequences. Columbia University Press, West Sussex, England.
- Braun, C. E., T. Britt, and R. O. Wallestad. 1977. Guidelines for maintenance of sage grouse habitats. *Wildlife Society Bulletin* 5:99–106.
- Caudill, D. 2011. Factors affecting greater sage-grouse (*Centrocercus urophasianus*) survival and movement in south-central Utah. Thesis, Utah State University, Logan, Utah, USA.

- Chi, R. Y. 2004. Greater sage-grouse reproductive ecology and tebuthiuron manipulation of dense big sagebrush on Parker Mountain. Thesis, Utah State University, Logan, Utah, USA.
- Cirrus Ecological Solutions, and Logan Simpson Design. 2013. West Box Elder County coordinated resource management plan. Cirrus Ecological Solutions, Logan, Utah, USA.
- Commons, M. L., R. K. Baydack, and C. E. Braun. 1999. Sage grouse response to pinyon-juniper management. Pages 238–239 in USDA Forest Service Proceedings RMRS-P-9. Ogden, Utah, USA.
- Connelly, J., M. A. Schroeder, A. R. Sands, and C. E. Braun. 2000. Guidelines to manage sage grouse populations and their habitats. *Wildlife Society Bulletin* 28:967–985.
- Connelly, J. W., H. W. Browers, and R. J. Gates. 1988. Seasonal movements of sage grouse in southeastern Idaho. *Journal of Wildlife Management* 52:116–122.
- Connelly, J. W., C. A. Hagen, and M. A. Schroeder. 2011. Characteristics and dynamics of Greater Sage-Grouse populations. Pages 53–67 in S. T. Knick and J. W. Connelly, editors. *Greater sage-grouse: ecology and conservation of a landscape species and its habitats*. Volume 38. University of California Press, Berkeley, California, USA.
- Connelly, J. W., S. T. Knick, M. A. Schroeder, and S. J. Stiver. 2004. Conservation assessment of greater sage-grouse and sagebrush habitats. Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming, USA.
- Connelly, J. W., W. L. Wakkinen, A. D. Apa, and K. P. Reese. 1991. Sage grouse use of nest sites in southeastern Idaho. *Journal of Wildlife Management* 52:521–524.

- Crawford, J. A., R. A. Olson, N. E. West, J. C. Mosley, M. A. Schroeder, T. D. Whitson, R. F. Miller, M. A. Gregg, and C. S. Boyd. 2004. Ecology and management of sage-grouse and sage-grouse habitat. *Rangeland Ecology & Management* 57:2–19.
- Cutler, D. R., T. C. Edwards Jr, K. H. Beard, A. Cutler, K. T. Hess, J. Gibson, and J. J. Lawler. 2007. Random forests for classification in ecology. *Ecology* 88:2783–2792.
- Dahlgren, D. K. 2006. Greater sage-grouse reproductive ecology and response to experimental management of mountain big sagebrush on Parker Mountain, Utah. Dissertation, Utah State University, Logan, Utah, USA.
- Doherty, K. E., D. E. Naugle, and B. L. Walker. 2010. Greater sage-grouse nesting habitat: The importance of managing at multiple scales. *Journal of Wildlife Management* 74:1544–1553.
- Doherty, K. E., D. E. Naugle, B. L. Walker, and J. M. Graham. 2008. Greater sage-grouse winter habitat selection and energy development. *Journal of Wildlife Management* 72:187–195.
- Eng, R. L. 1963. Observations on the breeding biology of male sage grouse. *Journal of Wildlife Management* 27:841–846.
- Fedy, B. C., C. L. Aldridge, K. E. Doherty, M. O'Donnell, J. L. Beck, B. Bedrosian, M. J. Holloran, G. D. Johnson, N. W. Kaczor, and C. P. Kirol. 2012. Interseasonal movements of greater sage-grouse, migratory behavior, and an assessment of the core regions concept in Wyoming. *Journal of Wildlife Management* 76:1062–1071.

- Fischer, R. A., A. D. Apa, W. L. Wakkinen, K. P. Reese, and J. W. Connelly. 1993. Nesting-area fidelity of sage grouse in southeastern Idaho. *The Condor* 95:1038–1041.
- Fischer, R. A., K. P. Reese, and J. W. Connelly. 1996. An investigation on fire effects within xeric sage grouse brood habitat. *Journal of Range Management* 49:194–198.
- Fischer, R. A., W. L. Wakkinen, K. P. Reese, and J. W. Connelly. 1997. Effects of prescribed fire on movements of female sage grouse from breeding to summer ranges. *The Wilson Bulletin* 109:82–91.
- Fithian, W., and T. Hastie. 2013. Finite-sample equivalence in statistical models for presence-only data. *Annals of Applied Statistics*.
<<http://www.stanford.edu/~hastie/Papers/secondRev1.pdf>>. Accessed 3 Dec 2013.
- Franklin, J. 2009. Mapping species distributions: spatial inference and prediction. Cambridge University Press, Cambridge, United Kingdom.
- Freeman, E., and T. A. Frescino. 2009. ModelMap: An R package for modeling and map production using Random Forest and Stochastic Gradient Boosting. USDA Forest Service, Rocky Mountain Research Station 507. Ogden, Utah, USA.
- Friend, M., and N. J. Thomas. 1999. Miscellaneous Diseases. Field Manual of Wildlife Diseases. US Geological Survey, Washington, D.C., USA.
- Frye, G. G., J. W. Connelly, D. D. Musil, R. Berkley, M. C. Kemner, C. Cardinal, L. Cross, and J. S. Forbey. 2014. Do necklace-style radiotransmitters influence flushing behavior of greater sage-grouse? *Wildlife Society Bulletin* 38:433–438.

- Garton, E. O., J. W. Connelly, J. S. Horne, C. A. Hagen, A. Moser, and M. A. Schroeder. 2011. Greater sage-grouse population dynamics and probability of persistence. Pages 293–381 in S. T. Knick and J. W. Connelly, editors. *Greater sage-grouse: ecology and conservation of a landscape species and its habitats. Volume 38. Studies in Avian Biology*, University of California Press, Berkeley, California, USA.
- Giesen, K. M., T. J. Schoenberg, and C. E. Braun. 1982. Methods for trapping sage grouse in Colorado. *Wildlife Society Bulletin* 10:224–231.
- Graham, S. E. 2013. Greater sage-grouse habitat selection and use patterns in response to vegetation management practices in northwestern Utah. Thesis, Utah State University, Logan, Utah, USA.
- Gregg, M. A., J. K. Barnett, and J. A. Crawford. 2008. Temporal variation in diet and nutrition of preincubating greater sage-grouse. *Rangeland Ecology & Management* 61:535–542.
- Gregg, M. A., J. A. Crawford, M. S. Drut, and A. K. DeLong. 1994. Vegetational cover and predation of sage grouse nests in Oregon. *Journal of Wildlife Management* 58:162–166.
- Hagen, C. A., B. K. Sandercock, J. C. Pitman, R. J. Robel, and R. D. Applegate. 2006. Radiotelemetry survival estimates of lesser prairie-chickens in Kansas: are there transmitter biases? *Wildlife Society Bulletin* 34:1064–1069.
- Hausleitner, D. 2003. Population dynamics, habitat use and movements of greater sage-grouse in Moffat County, Colorado. Thesis, University of Idaho, Moscow, Idaho, USA.

- Hernandez, P. A., I. Franke, S. K. Herzog, V. Pacheco, L. Paniagua, H. L. Quintana, A. Soto, J. J. Swenson, C. Tovar, and T. H. Valqui. 2008. Predicting species distributions in poorly-studied landscapes. *Biodiversity and Conservation* 17:1353–1366.
- Holloran, M. J. 1999. Sage grouse (*Centrocercus urophasianus*) seasonal habitat use near Casper, Wyoming. Thesis, University of Wyoming, Laramie, Wyoming, USA.
- Holloran, M. J., B. J. Heath, A. G. Lyon, S. J. Slater, J. L. Kuipers, and S. H. Anderson. 2005. Greater sage-grouse nesting habitat selection and success in Wyoming. *Journal of Wildlife Management* 69:638–649.
- Hornaday, W. T. 1916. Save the sage grouse from extinction: a demand from civilization to the western states. New York Zoological Park, New York, New York, USA.
- Hulland, T. J. 1993. Muscle and tendon. Pages 183–265 in K. V. F. Jubb, P. C. Kennedy, and N. Palmer, editors. *Pathology of domestic animals*. Fourth edition. Volume 1. Academic Press, New York, New York, USA.
- Jenni, D. A., and J. E. Hartzler. 1978. Attendance at a sage grouse lek: implications for spring censuses. *Journal of Wildlife Management* 42:46–52.
- Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. *Ecology* 61:65–71.
- Johnson, G. D., and M. S. Boyce. 1990. Feeding trials with insects in the diet of sage grouse chicks. *Journal of Wildlife Management* 54:89–91.
- Klebenow, D. A., and G. M. Gray. 1968. Food habits of juvenile sage grouse. *Journal of Range Management* 21:80–83.

- Knerr, J. S. 2007. Greater sage-grouse ecology in western Box Elder County, Utah. Thesis, Utah State University, Logan, Utah, USA.
- Lyon, A. G., and S. H. Anderson. 2003. Potential gas development impacts on sage grouse nest initiation and movement. *Wildlife Society Bulletin* 31:486–491.
- Marks, J. S., and V. S. Marks. 1987. Influence of radio collars on survival of sharp-tailed grouse. *Journal of Wildlife Management* 51:468–471.
- Miller, R. F. 2005. Biology, ecology, and management of western juniper (*Juniperus occidentalis*). Agricultural Experiment Station, Oregon State University, Corvallis, Oregon, USA.
- Miller, R. F., S. T. Knick, D. A. Pyke, C. W. Meinke, S. E. Hanser, M. J. Wisdom, and A. L. Hild. 2011. Characteristics of sagebrush habitats and limitations to long-term conservation. Pages 69–83 in. *Greater sage-grouse: Ecology and conservation of a landscape species and its habitats*. Volume 38. Studies in Avian Biology, University of California Press, Berkeley, California, USA.
- Miller, R. F., T. J. Svejcar, and J. A. Rose. 2000. Impacts of western juniper on plant community composition and structure. *Journal of Range Management* 53:574–585.
- Morris, L. 2010. Land-Use Legacies of Cultivation in Shrubland: Ghosts in the Ecosystem. Pages 11–16 in *Threats to shrubland ecosystem integrity*. Volume XVII. S.J. and Jessie E. Quinney Natural Resources Research Library, Logan, Utah, USA.

- Morris, L. R., T. A. Monaco, and R. L. Sheley. 2011. Land-use legacies and vegetation recovery 90 years after cultivation in Great Basin sagebrush ecosystems. *Rangeland Ecology & Management* 64:488-497.
- Moynahan, B. J., M. S. Lindberg, and J. W. Thomas. 2006. Factors contributing to process variance in annual survival of female greater sage-grouse in Montana. *Ecological Applications* 16:1529–1538.
- Patterson, R. L. 1952. The sage grouse in Wyoming. Sage Books for Wyoming Game and Fish Commission, Denver, Colorado, USA.
- Phillips, S. J., R. P. Anderson, and R. E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. *Ecological Modelling* 190:231–259.
- Ralphs, M. H., and F. E. Busby. 1978. A project that made a second spring for Park Valley. *Rangeman's Journal* 5:86–88.
- Ralphs, M. H., and F. E. Busby. 1979. Prescribed burning: vegetative change, forage production, cost, and returns on six demonstration burns in Utah. *Journal of Range Management* 32:267–270.
- Reinhart, J. S., T. A. Messmer, and T. Black. 2013. Inter-seasonal movements in tri-state greater sage-grouse: implications for state-centric conservation plans. *Human-Wildlife Interactions* 7:172–181.
- Rogers, G. E. 1964. Sage grouse investigations in Colorado. Game Research Division, Colorado Game, Fish and Parks Department, Denver, Colorado, USA.
- Schroeder, M. A. 1997. Unusually high reproductive effort by sage grouse in a fragmented habitat in north-central Washington. *Condor* 90:933–941.

- Schroeder, M. A., C. L. Aldridge, A. D. Apa, J. R. Bohne, C. E. Braun, S. D. Bunnell, J. W. Connelly, P. A. Deibert, S. C. Gardner, and M. A. Hilliard. 2004. Distribution of sage-grouse in North America. *Condor* 106:363–376.
- Schroeder, M. A., and L. A. Robb. 2003. Fidelity of greater sage-grouse (*Centrocercus urophasianus*) to breeding areas in a fragmented landscape. *Wildlife Biology* 9:291–299.
- Smith, R. E. 2013. Conserving Montana's sagebrush highway: long distance migration in sage-grouse. Thesis, The University of Montana, Missoula, Montana, USA.
- Stiver, S. J. 2011. The legal status of Greater Sage-Grouse: organizational structure of planning efforts. Pages 33–49 in. *Greater Sage-Grouse: ecology and conservation of a landscape species and its habitats. Volume 38. Studies in Avian Biology.* Volume 38, University of California Press, Berkeley, California, USA.
- Stiver, S. J., E. T. Rinkes, and D. E. Naugle. 2010. Sage-grouse habitat assessment framework. US Bureau of Land Management. Unpublished report, US Bureau of Land Management, Idaho State Office, Boise, Idaho, USA.
- Sveum, C. M., W. D. Edge, and J. A. Crawford. 1998. Nesting habitat selection by sage grouse in south-central Washington. *Journal of Range Management* 265–269.
- Thacker, E. T. 2010. Greater sage-grouse seasonal ecology and responses to habitat manipulations in northern, Utah. Dissertation, Utah State University, Logan, Utah, USA.
- Utah Automated Geographic Reference Center [AGRC]. 2013. Land Ownership. <<http://gis.utah.gov/data/sgid-cadastre/land-ownership/>>. Accessed 12 Nov 2013.

Utah Division of Wildlife Resources [UDWR]. 2002. Strategic management plan for sage-grouse. Utah Department of Natural Resources, Division of Wildlife Resources, Salt Lake City, Utah, USA.

Utah Division of Wildlife Resources [UDWR]. 2009. Utah greater sage-grouse management plan. Utah Department of Natural Resources, Division of Wildlife Resources, Publication 09-17, Salt Lake City, Utah, USA.

Utah Governor's Office. 2013. Conservation Plan for Greater Sage-grouse in Utah.

Utah's Public Lands Policy Coordination Office, Salt Lake City, Utah, USA.

United States Fish and Wildlife Service [USFWS]. 2001. Endangered and threatened wildlife and plants; 12-month finding for a petition to list the washington population of western sage grouse (*Centrocercus urophasianus* phaios). Federal Register 66:22984-22986.

United States Fish and Wildlife Service [USFWS]. 2005. Endangered and threatened wildlife and plants; 12-month finding for petitions to list the greater sage-grouse as threatened or endangered; proposed rule. Federal Register 70:2244-2282.

United States Fish and Wildlife Service [USFWS]. 2010. Endangered and threatened wildlife and plants; 12-month finding for petitions to list the Greater Sage-Grouse (*Centrocercus urophasianus*). Federal Register 75:13910-13598.

Wallestad, R., and R. L. Eng. 1975. Foods of adult sage-grouse in central Montana.

Journal of Wildlife Management 39:628–630.

Whisenant, S. G. 1990. Changing fire frequencies on Idaho's Snake River Plains: ecological and management implications. Symposium on Cheatgrass Invasion,

Shrub DieOff, and Other Aspects of Shrub Biology and Management. Las Vegas, Nevada, USA.

Wik, P. A. 2002. Ecology of greater sage-grouse in south-central Owyhee County, Idaho. Dissertation, University of Idaho, Moscow, Idaho, USA.

Wing, B. R. 2014. The role of vegetation structure, composition, and nutrition in greater sage-grouse ecology in northwestern Utah. Thesis, Utah State University, Logan, Utah, USA.

Yost, A. C., S. L. Petersen, M. Gregg, and R. Miller. 2008. Predictive modeling and mapping sage-grouse (*Centrocercus urophasianus*) nesting habitat using Maximum Entropy and a long-term dataset from Southern Oregon. Ecological Informatics 3:375–386.

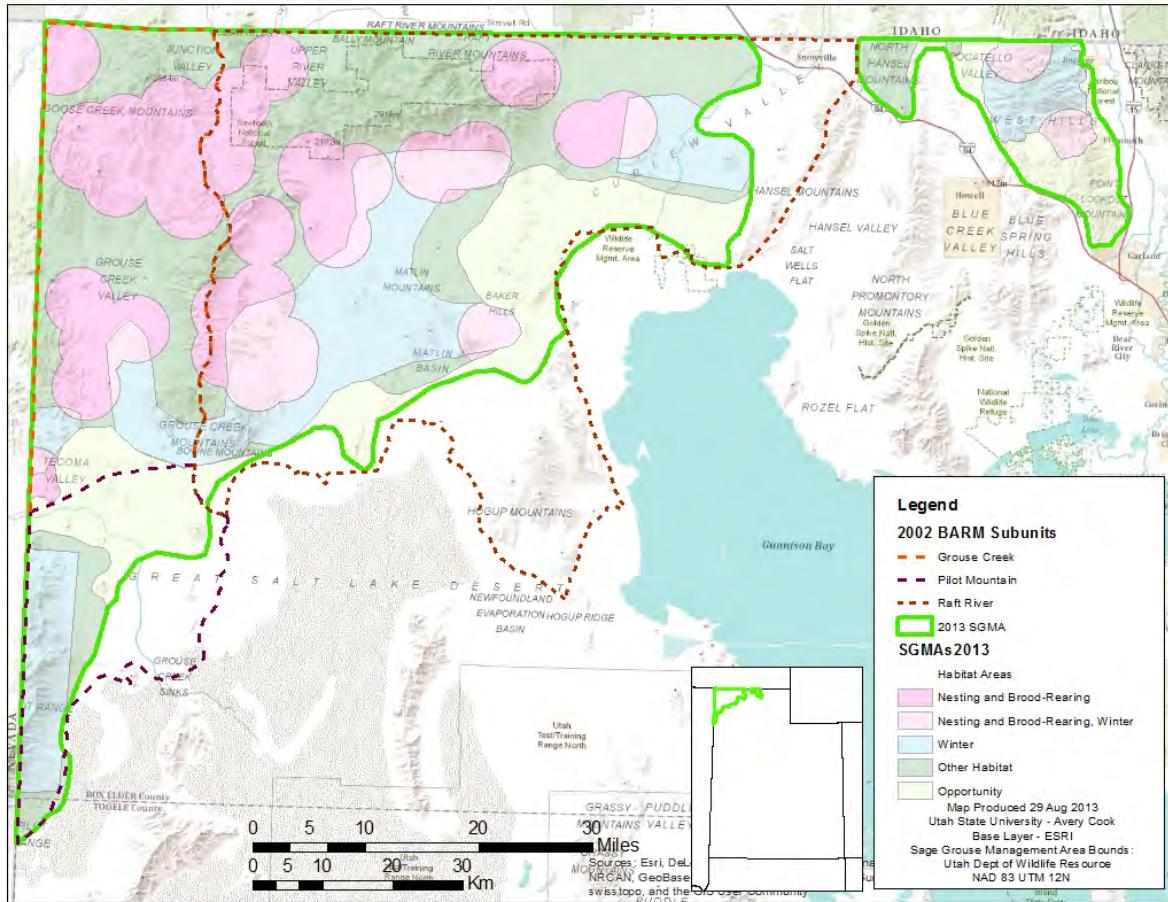


Figure 1-1. West Box Elder County study area as defined by the 2002 BARM Greater Sage-grouse Management Area and the 2013 Utah Box Elder Sage-grouse Management Area. This study focuses on the sage-grouse inhabiting the Raft River Subunit of the Box Elder Sage-grouse Management Area (SGMA). Utah's management areas were updated in 2013 by the Governors Conservation Plan for Greater Sage-grouse in Utah. The new SGMA's encompass areas with the highest sage-grouse breeding densities and together contain more than 90% of Utah's Sage Grouse. Rather than subunits, the new SGMA's are broken down into areas of habitat, non-habitat and opportunity areas. Habitat areas are further split into nesting, brood-rearing, winter, and other habitat.

CHAPTER 2

EVALUATING A GREATER SAGE-GROUSE HABITAT SUITABILITY MODEL FOR BOX ELDER COUNTY, UTAH

ABSTRACT

The rapid increase in habitat protection and restoration projects designed to mitigate range wide declines in greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) coupled with finite funding has highlighted the need for tools to prioritize project implementation and optimize conservation benefits. The US Fish and Wildlife Service emphasized the need to focus management efforts on protecting and enhancing priority habitats as an essential mechanism for species conservation. Thus having better knowledge of sage-grouse seasonal habitat-use relative to environmental conditions is paramount in the prioritization of conservation measures. I generated Random Forest seasonal habitat models to predict sage-grouse use within the Box Elder Sage-grouse Management Area in northwest Utah using a suite of vegetation and topographical parameters and known locations of radio-marked sage-grouse. To examine cumulative effects of vegetation disturbance on sage-grouse seasonal habitat-use I incorporated a vegetation disturbance layer into the models. I built the vegetation disturbance layer using historical project records and satellite imagery that documented fire, sagebrush (*Artemisia* spp) treatments, conifer removal, habitat restoration projects and other vegetation changes detected in the study area from 1985 to 2013. Model fit for predicted and documented brood, early summer, late summer, lekking, and non-breeding and nest and winter habitat was good with models achieving receiver operating characteristic area under the curve (AUC) of > 0.90 . Nest and winter models reported AUCs of 0.87 and

0.85 respectively. The general vegetation disturbance layer or subsets of specific disturbance types were not strong predictors of sage-grouse seasonal habitat-use.

INTRODUCTION

Greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) populations have been declining range-wide (Connelly et al. 2004). Their estimated occupied range has declined from a historical pre-settlement distribution of 1.2 million km² to 668,000 km² by the year 2000 (Schroeder et al. 2004). These declines have been largely attributed to the deterioration, loss, and fragmentation of sagebrush (*Artemesia* spp.) habitats (Connelly et al. 2011a). In Utah, sage-grouse now occupy 41% of historic habitats, with the largest remaining populations in Box Elder, Garfield, Rich, Uintah, and Wayne Counties (Beck et al. 2003, Utah Division of Wildlife Resources [UDWR] 2009).

In March 2010, the U.S. Fish and Wildlife Service (USFWS) found that listing sage-grouse for protection under the Endangered Species Act (ESA) was warranted on a range-wide basis, but that further action was precluded because of higher ESA priorities (USFWS 2010). The USFWS determined the range wide listing was warranted because of habitat loss and fragmentation, and the lack of a regulatory structure designed to protect habitat.

In response to continuing sage-grouse population declines and the species ESA status, wildlife managers, industry, private citizens, and nongovernmental organizations initiated conservation planning efforts to identify and implement conservation actions to benefit sage-grouse by protecting and restoring habitats (Stiver 2011). The Bureau of Land Management (BLM), the U.S. Forest Service (USFS), and the western states and Canadian provinces with sage-grouse populations and habitats, have initiated planning

and other actions designed to mitigate the identified threats, protect important sagebrush habitats, and develop adequate regulatory mechanisms to eliminate the need for federal protection.

The UDWR developed and published a Utah Strategic Management Plan for Sage-grouse in 2002 (UDWR 2002), and a revised plan in 2009 (UDWR 2009). These plans identified specific sage-grouse conservation areas and the need to organize local sage-grouse working groups (LWGs) to develop and implement voluntary sage-grouse conservation plans for these areas. The first LWGs were organized in Utah 1997.

In 2007, the West Box Elder Adaptive Resource Management Local Working Group (BARM) developed a conservation plan to manage sage-grouse in northwestern Utah (BARM 2007). The BARM plan identified local threats to sage-grouse populations, including conifer encroachment, invasive weeds and fire, as well as conservation actions they believed could mitigate those threats.

The Utah Conservation Plan for Greater Sage-grouse (Utah 2013) consolidated the conservation strategies found in the 2009 Utah Strategic Management Plan for Sage-grouse and LWG plans, and identified 11 sage-grouse management areas (SGMAs). The Utah Plan as the official policy document guiding the future management and conservation of sage-grouse was developed to protect high-quality habitat, enhance impaired habitat, and restore converted habitat for the sage-grouse population inhabiting Utah, largely through conifer reduction.

In Utah, sage-grouse habitat restoration projects are conducted under the auspices of the Utah Watershed Restoration Initiative (WRI), the Natural Resources Conservation Service (NRCS) Sage-grouse Initiative (SGI), BLM, USFS, and private landowners.

Contemporary sage-grouse conservation planning emphasizes a strategic landscape management approach (Williams et al. 2004, Idaho 2006, Doherty et al. 2011, Goble et al. 2012, Utah 2013) to optimize use of finite resources. The USFWS has further emphasized the need to focus management efforts on protecting and enhancing the priority habitats as an essential mechanism for species conservation (USFWS 2013). For managers, priority habitats and conservation strategies need to be identified at the appropriate level of resolution to be applicable at the project scale. In addition, past habitat change needs to be evaluated relative to sage-grouse habitat use.

The Box Elder SGMA has experienced development typical of many western landscapes (UDWR 2009). Sage-grouse habitat loss through development and agriculture in the SGMA has been ongoing since the early 1900's (BARM 2007). In the Park Valley area of the Box Elder SGMA dry farming increased from 1910 into the 1920's stimulated by homestead land grants and the sale of railroad lands (Morris 2010). In the intervening years, much of the low-lying mesic areas have been converted to production agriculture and pasture (BARM 2007).

To enhance the economic contribution of rangelands within the SGMA, private landowners, federal and state land management agencies, and academic institutions have manipulated the sagebrush community to increase desired vegetation conditions (Ralphs and Busby 1979, Thacker 2010, Graham 2013, Utah WRI 2013). Many of these habitat improvement projects focused on increasing livestock forage production through the removal of sagebrush and planting forage species, such as crested wheatgrass (*Agropyron cristatum*; Ralphs and Busby 1979). More recently sagebrush treatments have been undertaken to investigate sage-grouse response to mechanical, chemical and prescribed

fire treatments (Thacker 2010), green stripping with forage kochia (*Kochia prostrata*) as a method of constructing fire breaks (Graham 2013), and projects beneficial to sage-grouse through the Utah WRI and NRCS SGI (Utah WRI 2013).

In the Box Elder SGMA, the conversion of sagebrush habitat to cheatgrass (*Bromus tectorum*) following fire and the encroachment of conifers into sagebrush communities have been identified as major sage-grouse conservation threats (BARM 2007). Cheatgrass easily invades disturbed areas, burned areas, and poorly managed grazing lands. Once established, cheatgrass increases fuel continuity resulting in larger fires, and increases fine fuel loading leading to higher ignition probability and a more frequent fire return interval (Miller et al. 2011). Further, annual grasses recover quickly post-fire, while sagebrush recovery takes considerably longer, leading to habitat conversion (Whisenant 1990).

Although conifers have historically been part of the western landscape, conversion of sagebrush habitat to juniper (*Juniperus* spp.) woodlands poses a conservation concern. Increases in grazing in the late 1800's combined with programmatic fire suppression in the 1900's have contributed to conifer encroachment into sagebrush ecosystems (Miller et al. 2011). Prior research has demonstrated sage-grouse avoidance of conifer dominated landscapes, with only occasional use of early successional stands (Commons et al. 1999, Robinson 2007, Doherty et al. 2008, Burnett 2013, Frey et al. 2013). Baruch-Mordo et al. (2013) reported that conifer cover at relatively small percentages (>4%) of the landscape near (<1 km) lek sites resulted in declining numbers of males counted on leks. The UDWR has recommended conifer reduction as a sage-grouse habitat restoration tool in their sage-grouse conservation plan

(Utah 2013), and has implemented over 200,000 ha of restoration projects labeled as benefiting sage grouse since 2006 (Eric Ellis, UDWR personal communication).

Given the current emphasis on sage-grouse conservation coupled with new but finite funding for sage-grouse projects (Utah WRI 2013, www.sagegrouseinitiative.com) it is important to incorporate sage-grouse responses to vegetation disturbance to ensure appropriate project prioritization. Species distribution modeling predicts distribution of a species on a landscape relative to environmental variables and has been used to examine landscape scale habitat use of sage-grouse and other species (Aldridge and Boyce 2007, Atamian et al. 2010, Crabb and Black 2011, Burnett 2013). Species distribution models are useful tools for projecting likely distributions of species outside of areas in which spatially explicit data are available.

When the importance of input variables is unknown, machine learning methods are useful to build classification and regression trees to evaluate the importance of input variables. Random Forest modeling, a type of machine learning, uses environmental variables, presence, and pseudo-absence locations to develop decision trees that describe variables that are suitable for a species and define areas of species occurrence (Hernandez et al. 2008). Models are developed by constructing many decision trees, each made with a subset of the available data. At each node in the decision tree, a subset of predictor variables is used to generate decision criteria. The remaining data are used to evaluate the accuracy of the tree, generating estimates of model fit and classification accuracy (Liaw and Wiener 2002). Data not included in each tree are used to estimate relative influence of each input variable on model predictions (Freeman and Frescino 2009). Random Forrest avoids over fitting that can occur with single decision trees by

developing hundreds to thousands of decision trees with a subset of the data, and generating each split in the tree from a random subset of predictor variables (Franklin 2009).

With considerable project funding likely available into the future for sage-grouse habitat improvements, optimal placement of restoration projects is critical for project effectiveness (see also Chapter 4). Spatially explicit habitat suitability maps will be a valuable tool in prioritizing habitat projects to provide the most benefit per cost. This modeling effort aims to evaluate and map sage-grouse seasonal habitat suitability relative to a variety of habitat features. My objective was to identify spatial environmental factors influencing sage-grouse use of habitat within the Box Elder SGMA and provide information to aid project design to maximize conservation benefits to sage-grouse using Random Forest based species distribution modeling. This modeling effort identifies seasonal sage-grouse habitat within the Box Elder SGMA and evaluates the relative importance of known vegetation disturbances on current sage-grouse distributions.

STUDY AREA

The study area consisted of the western portion of Box Elder County (WBE), Utah, in the southeast extent of the Snake River Plain/Sage-grouse Management Zone II (Connelly et al. 2004, Stiver et al. 2006). Specifically, the research area was located on the Box Elder SGMA as defined in the Utah Conservation Plan for Greater Sage-Grouse (Utah 2013). The modeled area, a subset of the SGMA, encompassed telemetry locations collected in 2012 and 2013, as well as areas of previous sage-grouse studies in the area and most of known habitat (UDWR 2009). Areas excluded from the modeling area are primarily salt desert scrub.

The study area included 381,169 ha of mixed private, state and federal land including 50.4% private land (191,999 ha), 37.1% BLM (141,237 ha), 5.0% various Utah state lands (18,945 ha), and 7.6% US Forest Service land (28,988 ha) (Utah Automated Geographic Reference Center [AGRC] 2013). The core of the study area was bordered by the Raft River Mountains to the north, Grouse Creek Mountains to the west and the hardpan of the Great Salt Lake to the southwest (Fig. 1-1). The study area encompasses 75 (94%) of the active sage-grouse leks in the Box Elder Sage-grouse Management Area. The primary land use is grazing by domestic livestock (*Bos taurus*) and associated activities including irrigated pastures and alfalfa (*Medicago sativa*) production.

The study area is at the edge of sagebrush-steppe communities and Great Basin sagebrush communities with parts of the study area exhibiting characteristics of each ecological type (Miller and Eddleman 2000). Vegetation communities in the study area include salt desert shrub, mixed Wyoming and black sagebrush communities (*A. t. tridentata*, *A. nova*) and juniper belts at lower elevations along a fluvial bench. Mixed mountain shrub and aspen (*Populus tremuloides*) patches are present at mid elevations, and mountain mahogany (*Cercocarpus ledifolius*) and isolated Douglas fir (*Pseudotsuga menziesii*) forests mixed with mountain big sagebrush (*A. t. vaseyana*) at higher elevations. Elevations range from 1,400 to 3,000 m above sea level.

From 1990 to 2012, the weather station (1732 m elevation) at Rosette, UT, near the center of the study area, documented an average annual precipitation of 22.6 cm with 14.2 cm occurring as snow between November and April. Temperatures ranged from a monthly average high of 30°C in July to a monthly average low of -9.4°C in December and January (Western Regional Climate Center [WRCC] 2013). Snow does not typically

persist through spring at lower elevations but can persist into late summer at higher elevations.

METHODS

Known habitat-use locations were obtained from radio-marked sage-grouse. Sage-grouse were captured and radio-marked between 2005 to 2013 using the nocturnal spotlight method (Giesen et al. 1982, Wakkinen et al. 1992, Connelly et al. 2003). Each sage-grouse was equipped with a very high frequency (VHF) radio collar (Advanced Telemetry Systems, Isanti, MN, Model A4050) weighing approximately 22 g with necklace (1-2% of body weight). Sage-grouse locations from 2005 to 2011 were obtained from birds radio-marked during previous research projects (Knerr 2007, Thacker 2010, Graham 2013). Additional sage-grouse location information was obtained from 123 sage-grouse (68 female, 55 male) trapped from January 2012 to March 2013 under research protocols approved by the Utah State University Institutional Animal Care and Use Committee permit #1547, and UDWR Certificate of Registration number 2BAND8743.

Beginning mid-March in 2012 and 2013, radio-marked females were visually located 2-3 times per week to monitor movements, survival and reproductive success. Males were located biweekly throughout the spring, summer and fall. Due to limited winter access, all birds were located one to two times during the winter season via ground and aerial telemetry. Data were subdivided for analysis into nest, brood, early non-breeding summer, late non-breeding summer and winter categories. Nest locations consisted of a single location for each successful or unsuccessful nest. Brood locations documented hens with accompanying broods. Early non-breeding summer locations

were hen and male locations not otherwise categorized as nest or brood from April 16 to June 30. Late non-breeding summer locations were females and males locations not otherwise categorized as nest or brood from July 1 to Sept 30. Winter locations were all locations obtained from October 1 to February 14. Lekking season locations included all locations obtained from February 15 to April 15. Lekking season locations did not include lek locations since leks are simply congregations of sage-grouse in open areas within other habitat. Adding lek locations would have resulted in model inputs that related sage-grouse locations to sage-grouse locations, rather than relating sage-grouse locations to habitat variables.

To delineate and date vegetation disturbances, I collected Landsat 5 Thematic Mapper images from 1987 to 2011, Landsat 5 Multispectral Scanner images from 2012, and Landsat 8 Orbital Land Imager images from 2013 (Path 39 Row 31) from the USGS Global Visualization Viewer (glovis.usgs.gov) with a target anniversary date of August 15. I used August 15 to allow vegetation time to senesce and reduce phenological differences caused by seasonal variations in precipitation, temperature and the length of the growing season. I normalized between years using full TM scenes with a variation of the COST method (Chavez 1996). My study area was encompassed by a single TM scene. Image differencing was used with Normalized Difference Vegetation Index (NDVI) images derived from Landsat data by subtracting the latter year from the former year to produce annual NDVI change detection images (Jensen 2004).

Vegetation disturbances were delineated using Landsat, derived NDVI, and change detection images. In addition, WRI project data were used to identify vegetation disturbances created by habitat restoration and rangeland projects (Utah WRI 2013).

Data on NRCS Grazing Improvement Program and SGI projects were not available due to privacy regulations. Geospatial Multi-Agency Coordination Group Fire perimeters and LANDFIRE Disturbance data sets were obtained and integrated into the vegetation disturbance layer (http://rmgsc.cr.usgs.gov/outgoing/GeoMAC/historic_fire_data/, USGS 2010).

Additional vegetation disturbances were identified through examination of imagery available via Google Earth. All known vegetation disturbances were combined into a single data layer containing the extent of each vegetation disturbance, type of disturbance if known (Fire, Sagebrush Conversion, Conifer Reduction, Unknown), and year. The majority of fire acreage was wildfire; however, cause and management of many fires was unknown. Sagebrush conversion was typically preformed for agricultural purposes to increase livestock forage, but details of mapped conversions was not included in this analysis. Roads and other developments were not recorded in the vegetation change layer unless they were built and the change was detected between 1985 and 2013. However roads and other development are reflected in the LANFIRE Existing Vegetation Type, Major Roads, and Minor Roads data layers.

In addition to mapping known vegetation disturbances throughout the study area, additional data layers representing habitat characteristics, as described below, were prepared as model inputs. Three Normalized Difference Vegetation Index (NDVI) images were produced using a Landsat 5 Multispectral Scanner image from August 2012 and Landsat 8 Orbital Land Imager images from June and September 2013 (Path 39 Row 31) collected from the USGS Global Visualization Viewer (glovis.usgs.gov). The 2010 LANDFIRE Existing Vegetation Type, Existing Vegetation Cover, Existing Vegetation

Height, and Biophysical Settings were used as model inputs (USGS 2010). All developed (Developed-Low Intensity, Developed-Medium Intensity, Developed-Roads, Developed-Upland Deciduous Forest, and Developed-Upland Evergreen) and agriculture (Agricultural-Orchard, Agricultural-Row Crop, Agricultural-Close Grown Crop, Agricultural-Fallow, Idle Cropland, and Agricultural-Pasture) Landfire Existing Vegetation Type classes were combined to a single developed and a single agriculture class. A 10 m digital elevation model (DEM), and road centerline layer was obtained from the Utah Automated Geographic Reference Center (Utah AGRC 2013). The DEM was resampled to 30 m and used to derive elevation, aspect, and slope datasets. Aspect was reclassified into 8 categories (N, NE, E, etc.). Road data were separated into 445 km of major roads defined as having speeds greater than 25 mph, and 2765 km of minor roads, consisting mainly of 2 tracks, with speeds equal to or less than 25 mph. Distance to road layers were derived from each road layer using the Euclidean Distance tool in ArcMap 10.1. The 2014 USDA-NRCS Conifer Mapping Spatial Layer was resampled to 30 m for import into the model (Falkowski et al. 2014).

Pseudo-absence points, randomly generated points that reflect the overall distribution of variables within the modeling area are required when running random forest models as a substitute for true absence points. I randomly generated pseudo-absence points within the modeling area using the Create Random Points tool in ArcMap 10.1. I generated pseudo-absence data sets for each presence data (i.e., sage-grouse locations) category in a 10:1 ratio of pseudo-absence to presence points, up to 1000 pseudo-absence points (Barbet-Massin et al. 2012). Layers with greater than 1000 input points have an equal number of presence and pseudo-absence points.

Presence points, pseudo-absences, and geospatial data layers were input into program R to construct random forest models predicting probability of sage-grouse occurrence across the landscape using the ModelMap and Random Forest packages (Liaw and Wiener 2002, Freeman and Frescino 2009). Separate models were developed for each presence category. Vegetation disturbance evaluation models incorporating all predictor variables (Table 2-3) and recent sage-grouse location data (2012-2013) were run to evaluate the influence of vegetation disturbance on current sage-grouse distribution. Sage-grouse location data from 2005-2011 were not included in vegetation disturbance evaluation modes because many of the disturbances occurred during and after data collection.

Subsequently, models were run that included all available sage-grouse telemetry location data (2005-2013) with subset vegetation disturbance layers withheld (Table 2-3). Otherwise, the same suite of input variables as vegetation disturbance evaluation modes was used for final random forest model development. Random forest models were used to evaluate relative variable importance on sage-grouse distribution, and to generate seasonal distribution maps.

Overall model predictive ability was evaluated using out-of-bag (OOB) samples to estimate Area Under the Curve (AUC) and classification accuracy (Freeman 2009). During model runs, each bootstrap iteration uses approximately two-thirds of the data; the remaining third was run through the classification tree. Accuracy measures were the percentage of known (presence) locations predicted to have a probability of occurrence of 50% or greater. The AUC metric was derived from a Receiver Operator Characteristic (ROC) plot of sensitivity (true positives) and specificity (false positives); an AUC of 0.50

indicated random classification, with values above 0.50 indicating predictive ability of the model (Freeman and Frescino 2009).

RESULTS

Vegetation Disturbance

I mapped 185 vegetation disturbances in the study area from 1985 to 2013 (Fig. 2-8) encompassing 77,370 ha. Wildfire was the predominant vegetation disturbance, including 82 fires encompassing 49,336 ha and 11 post-fire rehabilitation projects covering 10,252 ha. There were 49 private and publically funded conifer reduction projects encompassing 11,885 ha. In addition, there were 21 sagebrush conversions (3,587 ha), eight range seeding projects (799 ha), one sagebrush reduction project (Thacker 2010) (690 ha), one aspen (*Populus tremuloides*) regeneration project (41 ha), and 12 unknown vegetation disturbances (722 ha). Areas of vegetation disturbance ranged in size from 0.13 ha to 9,739 ha, with the largest vegetation disturbances attributed to wildfire (Table 2-2). The most vegetation disturbances occurred in 2007 (n = 20), of which 8 were fires. The fewest vegetation disturbances were in 1989 (n = 1), 1991 (n = 1), 1993 (n = 1), and 1998 (n = 1). The number of mapped vegetation disturbances generally increased over time (Fig. 2-2).

Predictive Models

I incorporated vegetation disturbance layers into random forest models predicting sage-grouse distribution in the study and evaluating variable importance. Models using only 2012-2013 telemetry data were constructed to evaluate cumulative effects of vegetation disturbance on current sage-grouse distribution. Many vegetation disturbances

occurred after and during 2005-2011 sage-grouse location data collection. Models were built for Nest, Brood, Early Summer, Late Summer, Winter, Lekking, and Year Round distribution of sage-grouse using 990 non-breeding, 40 nest and 261 brood points (Table 2-2). Models were built using a full suite of predictor variables (Table 2-3) with the vegetation disturbance layer being further divided into fire, conifer removal projects, and habitat improvement projects (other than conifer removal) in addition to the full vegetation disturbance layer. The vegetation disturbance layers had equal or less influence on modeled distribution as random points; vegetation disturbance layer inputs did not influence modeled sage-grouse distribution.

To generate sage-grouse seasonal distribution maps, habitat was modeled in each seasonal habitat-use period using the full set of telemetry data from 2005 to 2013. Data were collected in the field in 2012 and 2013 and obtained from three previous sage-grouse research projects within the SGMA from 2005-2011 (Knerr 2007, Thacker 2010, Graham 2013). Previous research projects focused on the Grouse Creek area of Box Elder County, while data collected in 2012 and 2013 were collected primarily from the Park Valley area of Box Elder County. I used 1,851 non-breeding, 123 nest, and 1,129 brood locations to construct habitat models (Table 2-2).

Model accuracy and AUC values varied by model with lek, early summer, late summer, and brood models providing AUC values above 0.90 (Table 2-2). Top variables contributing to the nest model include: June 2013 NDVI, 2014 USDA-NRCS Conifer Mapping Spatial Layer, and elevation. Top variables contributing to the brood model in descending order of importance include Distance to Major Road, June 2013 NDVI, 2014 USDA-NRCS Conifer Mapping Spatial Layer, elevation, slope, distance to minor road,

September 2013 NDVI and aspect. Top variables contributing to the early summer non-breeding model in decreasing order of importance include elevation, distance to major road, 2014 USDA-NRCS Conifer Mapping Spatial Layer, aspect, and June 2013 NDVI. Top variables contributing to the late summer non-breeding model in order of decreasing importance include June 2013 NDVI, and elevation. Top variables contributing to the winter habitat model in order of decreasing importance included: June 2013 NDVI, elevation, 2014 USDA-NRCS Conifer Mapping Spatial Layer, and slope. Top variables contributing to the lekking period habitat model in order of decreasing importance include elevation, 2014 USDA-NRCS Conifer Mapping Spatial Layer, slope, and distance to major road. Top variables contributing to the general non-breeding habitat model in order of decreasing importance include: elevation, distance to major road, 2014 USDA-NRCS Conifer Mapping Spatial Layer, aspect, slope, and June 2013 NDVI. (Fig. 2-6, 2-7).

DISCUSSION

Although vegetation disturbance has been shown to influence the distribution of sage-grouse (Commons et al. 1999, Connelly et al. 2000a, Baruch-Mordo et al. 2013, Burnett 2013, Frey et al. 2013, Knick et al. 2013, see also Chapter 4), I was not able to detect an effect of cumulative vegetation disturbance on sage-grouse seasonal habitat-use in the Box Elder SGMA study area. I examined the cumulative effects of habitat vegetation disturbance on current sage-grouse seasonal habitat-use using 381,169 ha of vegetation disturbance recorded over 26 years and 1,291 known seasonal sage-grouse locations collected in 2012 and 2013. Vegetation disturbance was examined both in aggregate and by vegetation disturbance type. Further, I examined the cumulative effects

of aggregate habitat vegetation disturbance using 3,103 known seasonal sage-grouse locations complied from 2006-2013. Although many of the historical vegetation disturbances were still evident in the imagery used to map them, some sites had transitioned from post-disturbance conditions through natural recovery and restoration efforts to afford sage-grouse habitats that were still seasonally important. Thus immediate sage-grouse responses to vegetation disturbance or management actions may be better detected by examining alternate spatial, temporal scales, and methods such as pellet counts that can detect sage-grouse use in areas without radio marked sage-grouse (see also Chapter 4).

The study area is naturally fragmented relative to many areas of extensive sagebrush steppe habitat in Wyoming and other western states (Utah 2013), with steep mountains, conifer forests and areas of low-lying hardpan and salt desert scrub dividing areas of sagebrush habitat. The natural fragmentation of the area may have decreased detectability of anthropogenic fragmentation and vegetation changes on sage-grouse distribution. Additionally, the total area within the modeling bounds was incorporated into the models, including areas that are not suitable sage-grouse habitat such as PJ stands. Effects on sage-grouse distribution may be more detectable if only areas of suitable habitat are modeled.

A variety of environmental variables were included in the model building process to represent vegetation, topographical, and anthropogenic factors that could influence sage-grouse distribution. The nest model indicated two of the top three model inputs were vegetation metrics: NDVI and 2014 USDA-NRCS Conifer Mapping Spatial Layer (Fig. 2-6). Sage-grouse preference for specific sagebrush vegetation communities has

been previously reported (Connelly et al. 2000b, 2011b), as is their avoidance of conifer, specifically juniper (Baruch-Mordo et al. 2013). Specific habitat characteristics reported to influence sage-grouse nest success and selection include grass height (Moynahan et al. 2007, Doherty et al. 2014), shrub height (Holloran et al. 2005), and vegetation class (Yost et al. 2008).

Vegetation class performed poorly as a predictor of sage-grouse nest site selection in this model. This may be a matter of scale, with 51% of the study area largely consisting of two sagebrush classes resulting in the majority of randomly generated pseudo-absence points falling within sagebrush classes preferred by sage-grouse (Fig. 2-4). The similarity in presence and pseudo-absence data sets rendered the LANDFIRE vegetation cover and biophysical setting data ineffective as model inputs. Conifer density and NDVI data varied between presence and pseudo-absence datasets sufficiently to be used as meaningful predictors; however they produced a nest model with low accuracy. Visual inspection of the modeling output (Fig. 2-9) indicated a realistic distribution of nesting areas in the SGMA, but under represented low elevation nesting sites. This may be a result of 83 of the nest sites being from higher elevation Grouse Creeks study sites (Knerr 2007, Thacker 2010, and Graham 2013, relative to 40 nest locations from the lower elevation Park Valley study site. The 123 nest locations used in modeling were generated by 87 unique hens, with a number of location being re-nests following nest failure or nests in subsequent years. Sage-grouse nest site fidelity may have led to subsequent nests from an individual being located close to previous nests violating assumptions of independence and degrading model accuracy.

Brood model performance reliably predicted brood locations throughout the study area with most modeled variables influencing model output of sage-grouse occurrence (Fig 2-5). Distance to major roads was the top predictor of the model, with a positive relationship between increasing distance from major roads and sage-grouse brood occurrence with presence points on average 2.4 km from a major road and pseudo-absence points on average 3.3 km from a major road. This relationship may have been an artifact of road placement relative to brood habitat rather than a biologically important factor attracting of sage-grouse broods to roads. Important seasonal habitats in the SGMA have major roads running perpendicular, with brood habitat concentrated in the lower elevation foothills. Prior research has shown negative relationships between sage-grouse broods and roads and other infrastructure, however low traffic volumes relative to other studies may confound comparisons of study areas (Lyon and Anderson 2003, Holloran 2005, Aldridge and Boyce 2007).

June NDVI, the second most influential predictor of brood occurrence, is indicative of primary productivity, and mesic areas within the study site. Mesic areas are important areas for brood production providing succulent grasses and forbs as well as insects that are critical for successful brood development (Peterson 1970, Sveum et al. 1998, Guttery et al. 2013). Conifer density was the third most influential predictor as brood occurrence with 88% of all broods occurring in areas classified as 0-4% PJ cover, as compared to 62% of pseudo-absence points. Avoidance of areas with conifer density greater than 4% reinforces previous research showing sage-grouse avoidance of even low densities of conifer and the importance of conifer removal restoration projects to maintain suitable habitat (Baruch-Mordo et al. 2013, Frey et al. 2013).

Topographic measures of habitat also influenced brood model output with sage-grouse broods using steeper slopes, higher elevations and more E, SE and W aspects than random points in the study area, generally consistent with other studies finding brood use of Southern and Western aspects (Knerr 2007, Dzialak et al. 2011). Knerr (2007) found broods were mostly on W aspects, Robinson (2007) found broods on N, NE and E aspects. Visual inspection of modeled probability of brood occurrence (Fig. 2-10) showed the model captured known brood habitat well, as well as highlighted areas of potential habitat without previous documented sage grouse brood use.

Early summer non-breeding locations were modeled with good accuracy with elevation having the most influence on the model. Presence locations were on average 105 m higher than pseudo-absence locations – a reasonable relationship considering our telemetry data show sage-grouse moving to higher elevation areas with succulent grass and forb growth during the early summer. However, within the study area, individuals exhibit diverse seasonally movement patterns with some birds moving to higher elevations and others frequenting lower elevation agricultural fields (Wing 2014).

Distance to roads again influenced the early summer non-breeding model with use points on average 0.8 km closer to a major road than random points. This may be a result of major roads following foothill and valley bottoms, areas of mesic habitat, rather than a true biological link with sage-grouse presence and unpaved roads. Fedy et al. (2014) reported a positive relationship between summer sage-grouse habitat use and roads and hypothesized that the relationship could be due to road placement on the landscape often following or going to mesic areas, and as a result of increased detection probability of sage-grouse close to roads due to telemetry work being conducted from vehicles.

Aldridge and Boyce (2007) reported a similar pattern and suggested it may have been a result of higher abundance of succulent forbs along primitive roads.

Conifer cover strongly influenced modeled early summer sage-grouse distribution, in agreement with previous research on sage-grouse habitat preferences. June NDVI also had a strong influence on model output, indicating sage-grouse preference for mesic areas. Visual inspection of the modeled probability of early summer non-breeding use (Fig. 2-11) showed more use of mesic and higher altitude areas with some individuals continuing to use of more xeric low elevation sagebrush areas. Divergent strategies point to the highly fragmented landscape in the SGMA with different types of suitable habitat and the importance of local data for management of sage-grouse populations.

Late summer non-breeding locations were modeled with only marginal accuracy with June NDVI and elevation serving as top model predictors. Poor model accuracy likely resulted from sage-grouse using habitat throughout the model area covering the full gradient of topographical predictors, NDVI values, and vegetation cover. Also confounding modeling efforts, elevation and NDVI values are also often correlated with higher elevation areas typically retaining higher NDVI values late into the summer, and higher NDVI values being related to sage-grouse population growth (Blomberg et al. 2012, Guttery et al. 2013). In addition, 32% of sage-grouse locations were in areas classified as 4-10% and greater than 10% conifer cover, further confounding differences between modeled presence locations and pseudo-absences. Sage-grouse use of conifer areas as nesting cover, transitional habitat and thermal cover has been documented in other regional sage-grouse studies. (Robinson 2007, Gruber 2012, Burnett 2013).

However, despite the relatively low classification accuracy of the late summer map output, visual inspection of the mapped probability of late summer sage-grouse occurrence accurately represents sage-grouse absence in low elevation habitat with intensive use of both high elevation areas and mesic areas at all elevations, including agricultural fields (Fig. 2-12).

The winter habitat model was poorest performing model. June 2013 NDVI was the most influential variable, with sage-grouse predicted to be found in areas with lower NDVI values due to lower elevation sagebrush flats composing much of the winter habitat having less moisture and green vegetation late in the summer. The second most influential input data was elevation leading to under representation of higher elevation winter habitat in the model output. Visual inspection of the model output shows good model fit at lower elevation wintering habitat, but poor fit at higher elevations, with high elevation winter locations not captured in the model output (Fig. 2-13). Slope was an influential model variable with sage-grouse preferring flatter slopes averaging 3.4 degrees relative to an average slope of 8.4 degrees at random pseudo-absence points. Conifer cover as reported in the 2014 USDA-NRCS Conifer Mapping Spatial Layer was also influential for the model, with wintering grouse showing avoidance for areas classified as greater than 4% conifer cover. The model is informative in showing areas where the UDWR sage-grouse winter habitat layer is missing occupied winter habitat and covering areas not used by sage-grouse during the winter months. An ensemble model separately building decision trees for the high and low elevation winter sites would likely produce more accurate predictions of sage-grouse winter habitat within the study area.

The model predicting sage-grouse occurrence during lekking season was similar to the winter habitat model in accuracy and relative influence of input variables. Upon visual inspection, the lekking period model accurately predicted lower elevation sage-grouse distribution, showing high probability of occurrence in areas predicting both individual sage-grouse locations and also predicting areas where leks are known to be present. However, similar to the winter habitat model, higher elevations were not accurately represented in the model. This was likely a result of low sample size with only 30 of the 291 location input into the model being in higher elevation areas. The same elevation, PJ cover, and slope variables were the top influences on the model, similar to results presented in Knick et al. (2013) in which sage-grouse lek areas were found on shallow slopes with little forest.

The general non-breeding habitat model accurately predicted the area occupied by sage-grouse though the season. The general model classifies the vast majority of the sagebrush habitat types as potential sage-grouse habitat, and in doing so accurately reflects the know distribution of sage-grouse use within the study area. When compared to the UDWR Box Elder SGMA boundary, this model validated the boundaries.

MANAGEMENT IMPLICATIONS

Seasonal habitat needs are an important consideration in conservation planning efforts and habitat restoration projects. Seasonal habitat maps should be used when planning habitat improvement efforts to take often non-overlapping seasonal habitat into consideration and focus resources on limiting habitat with the most potential to increase population vital rates. Sage-grouse avoidance of areas of conifer density greater than 4% further reinforces previous research showing sage-grouse avoidance of conifer and the

importance of conifer reduction projects. Low variable importance of vegetation change in this modeling effort should not be interpreted to mean vegetation change does not affect sage-grouse habitat use, just that it is difficult to document and detect using the above modeling methods on a large spatial and temporal scale. Seasonal habitat models also provide valuable data that can be used to refine seasonal habit delineations used by state wildlife agencies, federal agencies and private partners to establish restoration and planning priorities.

Overall the modeled distribution accurately represented patterns of sage-grouse use within the SGMA and can help inform future restoration and management decisions. Lack of vegetation disturbance variable importance is likely a result of the broad spatial and temporal scale examined and should not be interpreted to mean that fire, conifer reduction, or other vegetation disturbances do not alter the quality and quantity of suitable sage-grouse habitat.

LITERATURE CITED

- Aldridge, C. L., and M. S. Boyce. 2007. Linking occurrence and fitness to persistence: habitat-based approach for endangered greater sage-grouse. *Ecological Applications* 17:508–526.
- Atamian, M. T., J. S. Sedinger, J. S. Heaton, and E. J. Blomberg. 2010. Landscape-level assessment of brood rearing habitat for greater sage-grouse in Nevada. *Journal of Wildlife Management* 74:1533–1543.
- Barbet-Massin, M., F. Jiguet, C. H. Albert, and W. Thuiller. 2012. Selecting pseudo-absences for species distribution models: how, where and how many? *Methods in Ecology and Evolution* 3:327–338.

- Box Elder Adaptive Resource Management Local Working Group [BARM]. 2007. West Box Elder greater sage-grouse (*Centrocercus urophasianus*) local conservation plan. Utah State University Extension, Jack H. Berryman Institute and Utah Division of Wildlife Resources, Salt Lake City, Utah, USA.
- Baruch-Mordo, S., J. S. Evans, J. P. Severson, D. E. Naugle, J. D. Maestas, J. M. Kiesecker, M. J. Falkowski, C. A. Hagen, and K. P. Reese. 2013. Saving sage-grouse from the trees: a proactive solution to reducing a key threat to a candidate species. *Biological Conservation* 167:233–241.
- Beck, J. L., D. L. Mitchell, and B. D. Maxfield. 2003. Changes in the distribution and status of sage-grouse in Utah. *Western North American Naturalist* 63:203–214.
- Blomberg E. J., J. S. Sedinger, M. T. Atamian, D. V. Nonne. 2012. Characteristics of climate and landscape disturbance influence the dynamics of greater sage-grouse populations. *Ecosphere* 3:55.
- Burnett, A. C. 2013. Modeling habitat use of a fringe greater sage-grouse population at multiple spatial scales. Thesis, Utah State University, Logan, Utah, USA.
- Chavez, P. S. 1996. Image-based atmospheric corrections-revisited and improved. *Photogrammetric engineering and remote sensing* 62:1025–1035.
- Commons, M. L., R. K. Baydack, and C. E. Braun. 1999. Sage grouse response to pinyon-juniper management. Pages 238–239 in USDA Forest Service Proceedings RMRS-P-9, Ogden, Utah, USA.
- Connelly, J. W., K. P. Reese, R. A. Fischer, and W. L. Wakkinen. 2000a. Response of a sage grouse breeding population to fire in southeastern Idaho. *Wildlife Society Bulletin* 28:90–96.

- Connelly, J. W., M. A. Schroeder, A. R. Sands, and C. E. Braun. 2000b. Guidelines to manage sage-grouse populations and their habitats. *Wildlife Society Bulletin* 28:967–985.
- Connelly, J. W., C. A. Hagen, and M. A. Schroeder. 2011a. Characteristics and dynamics of Greater Sage-Grouse populations. Pages 53–67 in S. T. Knick and J. W. Connelly, editors. *Greater sage-grouse: ecology and conservation of a landscape species and its habitats*. Volume 38. University of California Press, Berkeley, California, USA.
- Connelly, J. W., S. T. Knick, M. A. Schroeder, and S. J. Stiver. 2004. Conservation assessment of greater sage-grouse and sagebrush habitats. Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming, USA.
- Connelly, J. W., K. P. Reese, and M. A. Schroeder. 2003. Monitoring of greater sage-grouse habitats and populations. College of Natural Resources Experiment Station, University of Idaho, Moscow, Idaho, USA.
- Connelly, J. W., E. T. Rinkes, and C. E. Braun. 2011b. Characteristics of greater sage-grouse habitats: A landscape species at micro- and macroscales. Pages 69–83 in S. T. Knick and J. W. Connelly, editors. *Greater sage-grouse: Ecology and conservation of a landscape species and its habitats*. Volume 38. Studies in Avian Biology, University of California Press, Berkeley, California, USA.
- Crabb, B., and T. Black. 2011. Development of statewide 30 meter winter sage-grouse habitat models for Utah. Utah State University Extension, Logan, Utah, USA.

- Doherty, K. E., D. E. Naugle, B. L. Walker, and J. M. Graham. 2008. Greater sage-grouse winter habitat selection and energy development. *Journal of Wildlife Management* 72:187–195.
- Doherty, K. E., J. L. Beck, and D. E. Naugle. 2011. Comparing ecological site descriptions to habitat characteristics influencing greater sage-grouse nest site occurrence and success. *Rangeland Ecology & Management* 64:344–351.
- Doherty, K. E., D. E. Naugle, J. D. Tack, B. L. Walker, J. M. Graham, and J. L. Beck. 2014. Linking conservation actions to demography: grass height explains variation in greater sage-grouse nest survival. *Wildlife Biology* 20:320–325.
- Dzialak, M. R., C. V. Olson, S. M. Harju, S. L. Webb, J. P. Mudd, et al. 2011. Identifying and prioritizing greater sage-grouse nesting and brood-rearing habitat for conservation in human-modified landscapes. *PLoS ONE* 6(10): e26273.
- Falkowski, M. J., N. Kayastha, and A. J. Poznanovic. 2014. USDA-NRCS Utah conifer mapping spatial layer. <160.94.138.23>.
- Fedy, B. C., K. E. Doherty, C. L. Aldridge, M. O'Donnell, J. L. Beck, B. Bedrosian, D. Gummer, M. J. Holloran, G. D. Johnson, N. W. Kaczor, and others. 2014. Habitat prioritization across large landscapes, multiple seasons, and novel areas: an example using greater sage-grouse in Wyoming. *Wildlife Monographs* 190:1–39.
- Franklin, J. 2009. Mapping species distributions: spatial inference and prediction. Cambridge University Press, Cambridge, United Kingdom.
- Freeman, E., and T. A. Frescino. 2009. ModelMap: An R package for modeling and map production using random forest and stochastic gradient boosting. USDA Forest Service, Rocky Mountain Research Station 507.

- Frey, S. N., R. Curtis, and K. Heaton. 2013. Response of a small population of greater sage-grouse to tree removal: Implications of limiting factors. *Human-Wildlife Interactions* 7:260–272.
- Goble, D. D., J. A. Wiens, J. M. Scott, T. D. Male, and J. A. Hall. 2012. Conservation-reliant species. *BioScience* 62:869–873.
- Graham, S. E. 2013. Greater sage-grouse habitat selection and use patterns in response to vegetation management practices in northwestern Utah. Thesis, Utah State University, Logan, Utah, USA.
- Giesen, K. M., T. J. Schoenberg, and C. E. Braun. 1982. Methods for trapping sage grouse in Colorado. *Wildlife Society Bulletin* 10:224–231.
- Gruber, N. W. 2012. Population dynamics and movements of translocated and resident greater sage-grouse on Anthro Mountain, Utah. Thesis, Utah State University, Logan, Utah, USA.
- Gutierrez, M. R., D. K. Dahlgren, T. A. Messmer, J. W. Connelly, K. P. Reese, P. A. Terletzky, N. Burkepile, and D. N. Koons. 2013. Effects of landscape-scale environmental variation on greater sage-grouse chick survival. *PloS One* 8:e65582.
- Hernandez, P. A., I. Franke, S. K. Herzog, V. Pacheco, L. Paniagua, H. L. Quintana, A. Soto, J. J. Swenson, C. Tovar, and T. H. Valqui. 2008. Predicting species distributions in poorly-studied landscapes. *Biodiversity and Conservation* 17:1353–1366.

- Holloran, M. J. 2005. Greater sage-grouse (*Centrocercus urophasianus*) population response to natural gas field development in western Wyoming. The University of Wyoming, Laramie, Wyoming, USA.
- Holloran, M. J., B. J. Heath, A. G. Lyon, S. J. Slater, J. L. Kuipers, and S. H. Anderson. 2005. Greater sage-grouse nesting habitat selection and success in Wyoming. *Journal of Wildlife Management* 69:638–649.
- Idaho Sage-grouse Advisory Committee. 2006. Conservation Plan for the Greater Sage-grouse in Idaho
- Jensen, J. R. 2004. Introductory digital image processing. Third edition. Prentice Hall, Upper Saddle River, New Jersey, USA.
- Knerr, J. S. 2007. Greater sage-grouse ecology in western Box Elder County, Utah. Thesis, Utah State University, Logan, Utah, USA.
- Knick, S. T., S. E. Hanser, and K. L. Preston. 2013. Modeling ecological minimum requirements for distribution of greater sage-grouse leks: implications for population connectivity across their western range, USA. *Ecology and evolution* 3:1539–1551.
- Liaw, A., and M. Wiener. 2002. Classification and Regression by Random Forest. *R News* 2:18–22.
- Lyon, A. G., and S. H. Anderson. 2003. Potential gas development impacts on sage grouse nest initiation and movement. *Wildlife Society Bulletin* 31:486–491.
- Miller, R. F., and L. Eddleman. 2000. Spatial and temporal changes of sage grouse habitat in the sagebrush biome. Oregon State University, Agricultural Experiment Station, Corvallis, Oregon, USA.

- Miller, R. F., S. T. Knick, D. A. Pyke, C. W. Meinke, S. E. Hanser, M. J. Wisdom, and A. L. Hild. 2011. Characteristics of sagebrush habitats and limitations to long-term conservation. Pages 69–83 in *Greater sage-grouse: ecology and conservation of a landscape species and its habitats*. Volume 38. *Studies in Avian Biology*, University of California Press, Berkeley, California, USA.
- Morris, L. 2010. Land-use legacies of cultivation in shrubland: ghosts in the ecosystem. Pages 11–16 in *Threats to shrubland ecosystem integrity*. Volume XVII. S.J. and Jessie E. Quinney Natural Resources Research Library, Logan, Utah, USA.
- Moynahan, B. J., M. S. Lindberg, J. J. Rotella, and J. W. Thomas. 2007. Factors affecting nest survival of greater sage-grouse in northcentral Montana. *Journal of Wildlife Management* 71:1773–1783.
- Peterson, J. G. 1970. The food habits and summer distribution of juvenile sage-grouse in central Montana. *Journal of Wildlife Management* 34:147–155.
- Ralphs and Busby 1979, Prescribed burning: vegetative change, forage production, cost, and returns on six demonstration burns in Utah. *Journal of Range Management* 32: 267–270
- Robinson, J. D. 2007. Ecology of two geographically distinct greater sage-grouse populations inhabiting Utah's West Desert. Utah State University, Logan, Utah, USA.
- Schroeder, M. A., C. L. Aldridge, A. D. Apa, J. R. Bohne, C. E. Braun, S. D. Bunnell, J. W. Connelly, P. A. Deibert, S. C. Gardner, and M. A. Hilliard. 2004. Distribution of sage-grouse in North America. *Condor* 106:363–376.

- Stiver, S. J., A. D. Apa, J. R. Bohne, S. D. Bunnell, P. A. Deibert, S. C. Gardner, M. A. Hilliard, C. W. McCarthy, and M. A. Schroeder. 2006. Greater sage-grouse comprehensive conservation strategy. Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming, USA.
- Stiver, S. J. 2011. The legal status of Greater Sage-Grouse: organizational structure of planning efforts. Pages 33–49 in Greater sage-grouse: ecology and conservation of a landscape species and its habitats. Volume 38. Studies in Avian Biology, University of California Press, Berkeley, California, USA.
- Sveum, C. M., J. A. Crawford, and W. D. Edge. 1998. Use and selection of brood-rearing habitat by sage grouse in south central Washington. *Western North American Naturalist* 58:344–351.
- Thacker, E. T. 2010. Greater sage-grouse seasonal ecology and responses to habitat manipulations in northern, Utah. Dissertation, Utah State University, Logan, Utah, USA.
- U.S. Fish and Wildlife Service [USFWS]. 2010. Endangered and threatened wildlife and plants; 12-month finding for petitions to list the greater sage-grouse (*Centrocercus urophasianus*). *Federal Register* 75:13910-13598.
- U.S. Fish and Wildlife Service [USFWS]. 2013. Greater sage-grouse (*Centrocercus urophasianus*) conservation objectives: final report. U.S. Fish and Wildlife Service, Denver, Colorado, USA.
- Utah Automated Geographic Reference Center [AGRC]. 2013.
<<http://gis.utah.gov/data/sgid-cadastre/>>. Accessed 12 Nov 2013.

- Utah Governor's Office. 2013. Conservation Plan for Greater Sage-grouse in Utah. Utah's Public Lands Policy Coordination Office, Salt Lake City, Utah, USA.
- Utah Division of Wildlife Resources [UDWR]. 2002. Strategic management plan for sage-grouse. Utah Department of Natural Resources, Division of Wildlife Resources, Salt Lake City, Utah, USA.
- Utah Division of Wildlife Resources [UDWR]. 2009. Utah greater sage-grouse management plan. Utah Department of Natural Resources, Division of Wildlife Resources, Publication 09-17, Salt Lake City, Utah, USA.
- Utah Watershed Restoration Initiative [Utah WRI]. 2013. Utah WRI project boundaries. <<http://wri.utah.gov/WRI/Map.aspx>>. Accessed 7 Dec 2011.
- U.S. Geological Survey [USGS]. 2010. LANDFIRE. <<http://landfire.cr.usgs.gov/viewer>>. Accessed 12 Dec 2014.
- Wakkinen, W. L., K. P. Reese, J. W. Connelly, and R. A. Fischer. 1992. An improved spotlighting technique for capturing sage grouse. *Wildlife Society Bulletin* 20:425–426.
- Western Regional Climate Center [WRCC]. 2013. Climate summary. <<http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ut7408>>. Accessed 6 Dec 2013.
- Whisenant, S. G. 1990. Changing fire frequencies on Idaho's Snake River Plains: ecological and management implications. *Symposium on Cheatgrass Invasion, Shrub Die Off, and Other Aspects of Shrub Biology and Management*. Las Vegas, Nevada, USA.

- Williams, C. K., F. S. Guthery, R. D. Applegate, and M. J. Peterson. 2004. The northern bobwhite decline: scaling our management for the twenty-first century. *Wildlife Society Bulletin* 32:861–869.
- Wing, B. R. 2014. The role of vegetation structure, composition, and nutrition in greater sage-grouse ecology in northwestern Utah. Thesis, Utah State University, Logan, Utah, USA.
- Yost, A. C., S. L. Petersen, M. Gregg, and R. Miller. 2008. Predictive modeling and mapping sage grouse (*Centrocercus urophasianus*) nesting habitat using Maximum Entropy and a long-term dataset from Southern Oregon. *Ecological Informatics* 3:375–386.

Table 2-1. Hectares and number of vegetation changes (parenthetical) mapped by year and type of vegetation change from 1985 to 2013 within Box Elder Sage-grouse Management Area Box Elder County, Utah.

	Aspen Regen	Fire	Fire Rehab	PJ Reduction	Range Seedling	Sagebrush Conversion	Sagebrush Reduction	Unknown
1985	0 (0)	0 (0)	0 (0)	56.2 (2)	0 (0)	0 (0)	0 (0)	0 (0)
1986	0 (0)	217.5 (2)	0 (0)	0 (0)	0 (0)	403.6 (2)	0 (0)	0 (0)
1987	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	43 (1)	0 (0)	14.1 (1)
1988	0 (0)	547.8 (2)	0 (0)	0 (0)	0 (0)	831.8 (2)	0 (0)	0 (0)
1989	0 (0)	29.6 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
1990	0 (0)	204.5 (2)	0 (0)	0 (0)	0 (0)	58.6 (1)	0 (0)	0 (0)
1991	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	73.5 (1)	0 (0)	0 (0)
1993	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	45.9 (1)	0 (0)	0 (0)
1995	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	58.4 (1)	0 (0)	25.8 (2)
1996	0 (0)	1214.6 (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	45.8 (1)
1998	0 (0)	78.7 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
1999	0 (0)	8405.7 (9)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
2000	0 (0)	4611.1 (14)	0 (0)	0 (0)	0 (0)	16.6 (1)	0 (0)	0 (0)
2001	0 (0)	121.8 (5)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
2002	0 (0)	981.6 (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
2003	0 (0)	56.1 (2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
2004	0 (0)	325.1 (2)	0 (0)	76 (1)	0 (0)	24.4 (1)	0 (0)	0 (0)
2005	0 (0)	6332 (1)	0 (0)	303.6 (2)	0 (0)	0 (0)	0 (0)	491.8 (2)
2006	40.9 (1)	9903.3 (8)	1275.5 (1)	173.1 (1)	223.8 (1)	0 (0)	0 (0)	0 (0)
2007	0 (0)	12354.3 (8)	1306.9 (3)	537.5 (3)	281.5 (2)	44.4 (1)	0 (0)	143 (3)
2008	0 (0)	1017 (3)	6706 (3)	2727.3 (4)	47.9 (1)	950 (4)	690.3 (1)	0 (0)
2009	0 (0)	576.1 (5)	0 (0)	822.1 (6)	50.5 (1)	241.5 (3)	0 (0)	52.4 (3)
2010	0 (0)	72.1 (1)	0 (0)	615.9 (5)	67 (1)	0 (0)	0 (0)	0 (0)

2011	0 (0)	0 (0)	0 (0)	1269.5 (9)	0 (0)	795.9 (2)	0 (0)	0 (0)
2012	0 (0)	1082.4 (7)	479.9 (1)	2932.4 (5) 2371.6	129 (2)	0 (0)	0 (0)	0 (0)
2013	0 (0)	1204.9 (3)	483.8 (3)	(11)	0 (0)	0 (0)	0 (0)	0 (0)

Table 2-2. Sample size of greater sage-grouse (*Centrocercus urophasianus*) telemetry locations within the Box Elder Sage-grouse Management Area, Box Elder County, Utah collected between 2005 and 2013 by Knerr (2007), Thacker (2010), Graham (2013), and in 2012 and 2013 for this research project in association with Wing (2014). Only 2012 and 2013 telemetry data was used to evaluate impacts of vegetation change on current sage-grouse distribution. The AUC metric was derived from a Receiver Operator Characteristic (ROC) plot of sensitivity (true positives) and specificity (false positives); an AUC of 0.50 indicated random classification, with values above 0.50 indicating predictive ability of the model. A contingency table of commission and omission error was analyzed for each model run to derive classification accuracy (Freeman and Frescino 2009).

	2012-2013		2005-2013		
	Sample Size		Sample Size	AUC	Accuracy
Non-Breeding	990		1338	0.90	85.40%
Lek	206		284	0.92	75.70%
Early Summer	490		1001	0.91	85.00%
Late Summer	255		388	0.92	74.70%
Winter	39		158	0.85	67.70%
Nest	40		123	0.87	62.60%
Brood	261		1129	0.95	86.30%
Total	1291		3090		

Table 2-3. Variables used in Random Forest models predicting sage-grouse distribution, and influence of vegetation change on sage-grouse distribution in the Box Elder Sage-grouse Management Area Box Elder County, Utah.

Model Input	Description	Data Type	2005-2013 Distribution Models	2012-2013 Vegetation Change Variable Evaluation
aspect	Aspect: Aspect of sage-grouse point location (Utah AGRC 2013).	Categorical	X	X
dist_to_2trk	Distance to Minor Road: Euclidian distance to nearest minor road (speed \leq 25 mph) (Utah AGRC 2013).	Continuous	X	X
dist_to_mj_rd	Distance to Major Road: Euclidian distance to nearest major road (speed > 25 mph) (Utah AGRC 2013).	Continuous	X	X
distAll	All Mapped Vegetation Change: This layer represents all vegetation change detected between 1985 and 2013.	Categorical	X	X
elevation	Elevation: Meters above sea level (Utah AGRC 2013).	Continuous	X	X
fire_all	All Mapped Vegetation Change due to Fire: This layer is a subset of distAll, and represents all vegetation change detected between 1985 and 2013 resulting from fire.	Categorical		X
lf_bps	LANDFIRE Biophysical Setting (USGS 2010).	Categorical	X	X
lf_veg_cover	LANDFIRE Existing Vegetation Cover (USGS 2010).	Categorical	X	X
lf_veg_ht	LANDFIRE Existing Vegetation Height (USGS 2010).	Categorical	X	X
lf_veg_type	LANDFIRE Existing Vegetation Type (USGS 2010).	Categorical	X	X
NDVI_Jun_12	NDVI: Normalized Difference Vegetation Index derived from a June 2012 Landsat image (glovis.usgs.gov).	Continuous	X	X
NDVI_Jun_13	NDVI: Normalized Difference Vegetation Index derived from a June 2013 Landsat image (glovis.usgs.gov).	Continuous	X	X
NDVI_Sep_13	NDVI: Normalized Difference	Continuous	X	X

	Vegetation Index derived from a September 2013 Landsat image (glovis.usgs.gov).		
NRCS_PJ	Conifer Cover: 2014 USDA-NRCS Conifer Mapping Spatial Layer resampled to 30 m (Falkowski et al. 2014). All Mapped Vegetation Change due to Conifer Removal: This layer is a subset of distAll, and represents all vegetation change detected between 1985 and 2013 resulting from conifer removal.	Categorical	X
pj_all		Categorical	X
slope	Slope: The slope at each sage grouse location in degrees (Utah AGRC 2013). All Mapped Vegetation Change due to Habitat Improvement Projects: This layer is a subset of distAll, and represents all vegetation change detected between 1985 and 2013 resulting from habitat improvement projects other than conifer removal.	Continuous	X
trt_all		Categorical	X

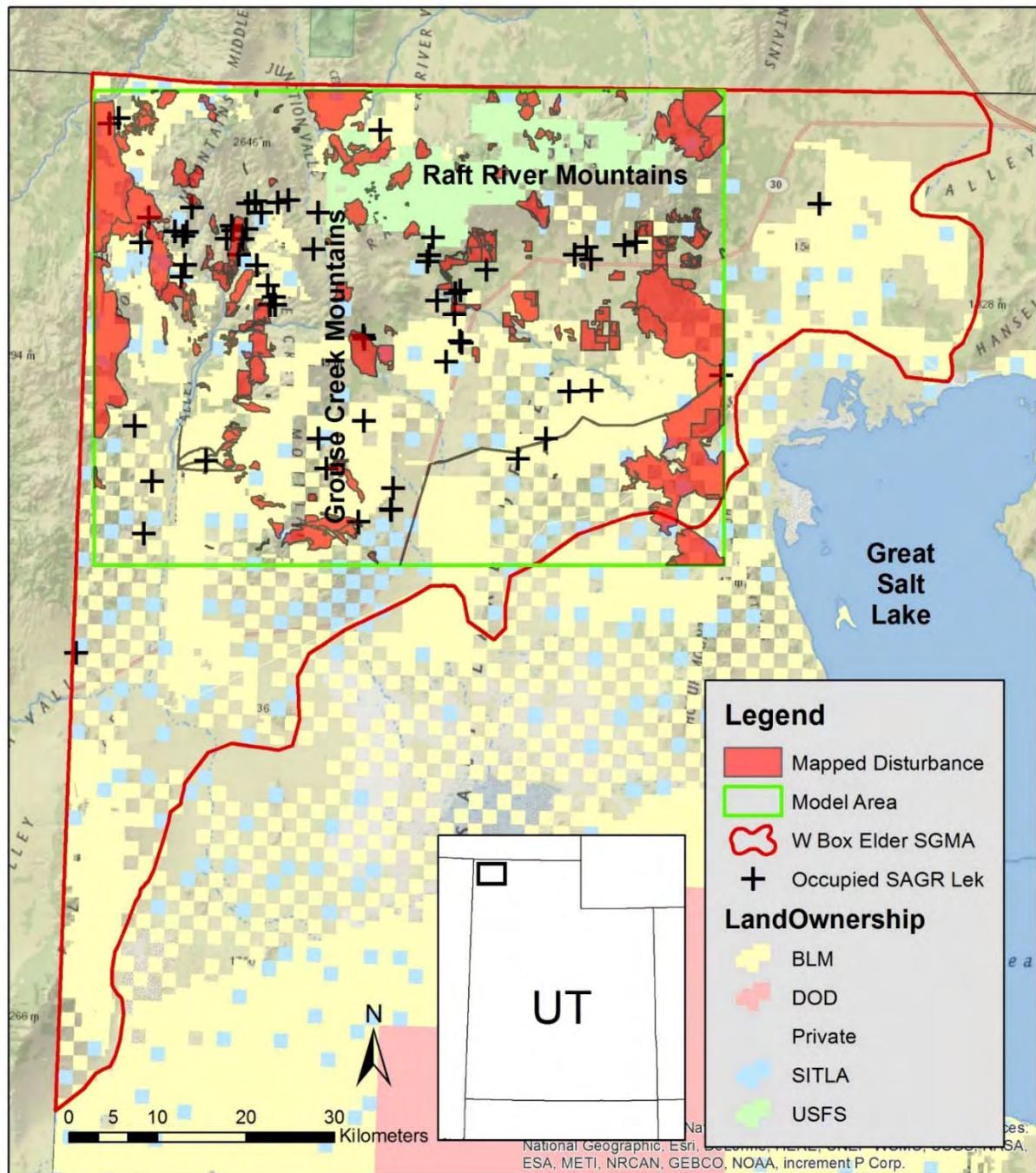


Figure 2-1. Overview of the greater sage-grouse (*Centrocercus urophasianus*) seasonal habitat modeling area within the Box Elder Sage-Grouse Management Area (SGMA) in Box Elder County, Utah, containing 94% of the SGMA's active leks,

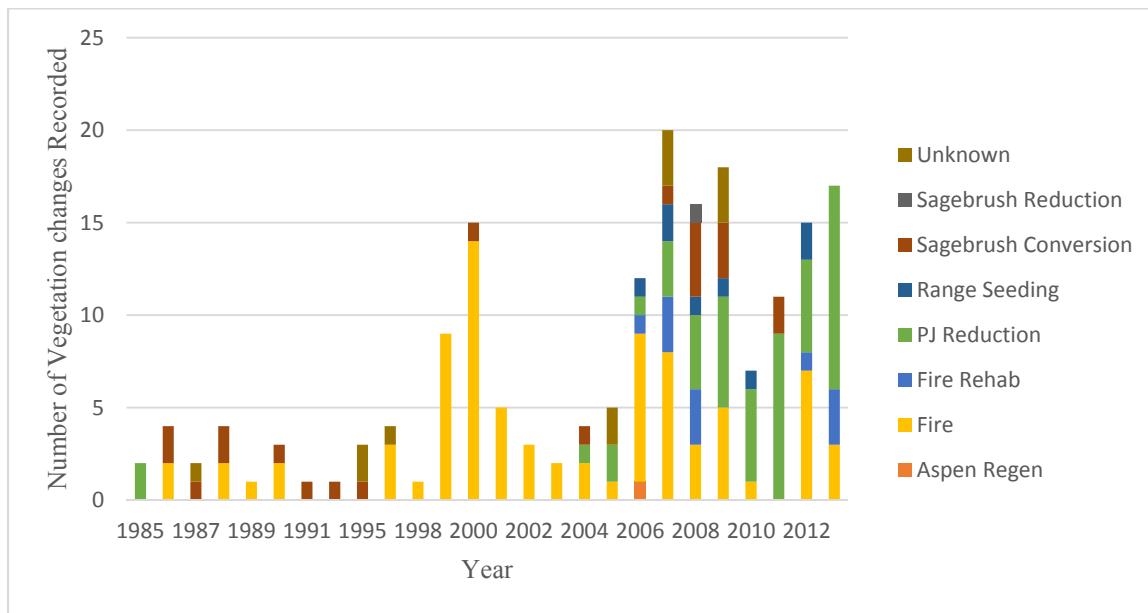


Figure 2-2. Vegetation changes mapped by year and type of vegetation change from 1985 to 2013 within the Box Elder Sage-grouse Management Area, Box Elder County, Utah.

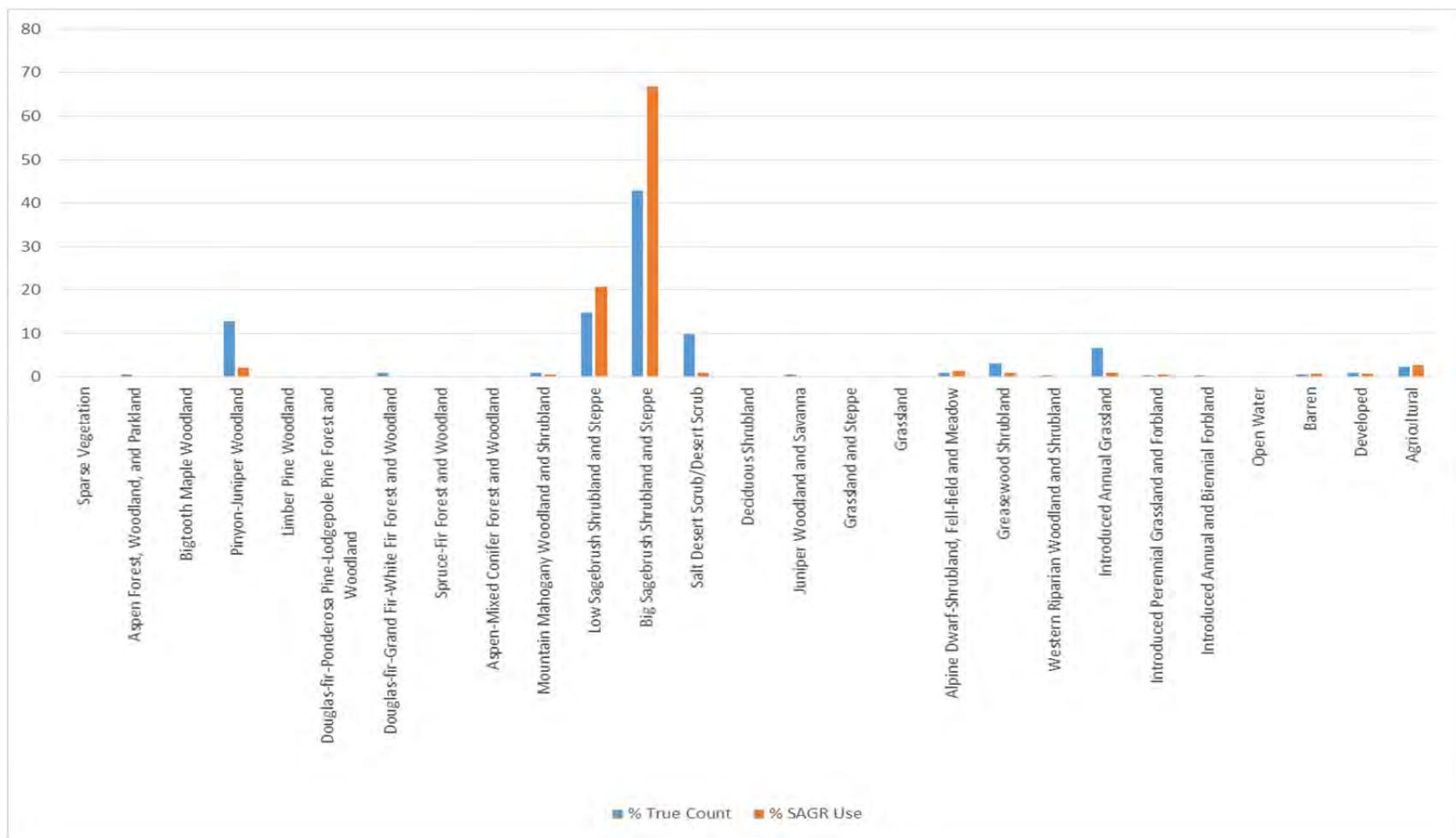


Figure 2-3. Percent LANDFIRE Existing Vegetation Type within the modeling area (% True Count) relative to percent LANDFIRE Existing Vegetation Type for greater sage-grouse (*Centrocercus urophasianus*) use points (% SAGR Use) collected from 2005 to 2013 within the Box Elder modeling area, Box Elder County, Utah.

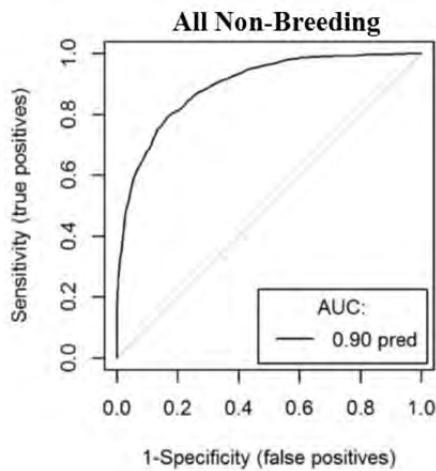


Figure 2-4. Receiver Operator Characteristic (ROC) plot of sensitivity (true positives) and specificity (false positives) for greater sage-grouse (*Centrocercus urophasianus*) non-breeding models of the Box Elder Sage-grouse Management Area, Box Elder County, Utah, based on telemetry locations collected from 2005-2013. An area under the curve (AUC) of 0.50 indicates random classification, with values above 0.50 indicating predictive ability of the model.

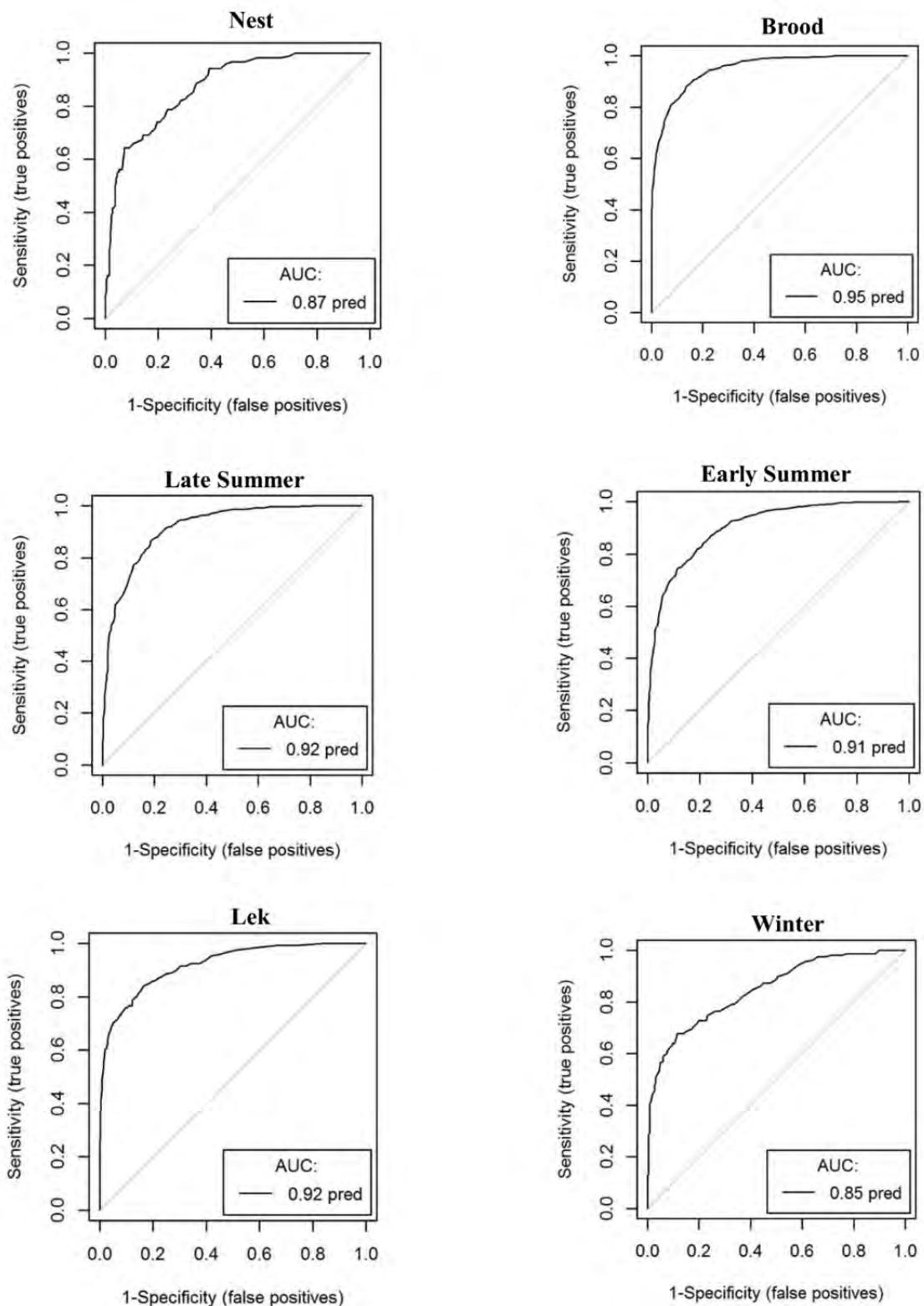


Figure 2-5. Receiver Operator Characteristic (ROC) plots of sensitivity (true positives) and specificity (false positives) for greater sage-grouse (*Centrocercus urophasianus*) seasonal habitat models of Box Elder Sage-grouse Management Area, Box Elder County, Utah, based on telemetry locations collected from 2005-2013. An area under the curve (AUC) of 0.50 indicates random classification, with values above 0.50 indicating predictive ability of the model

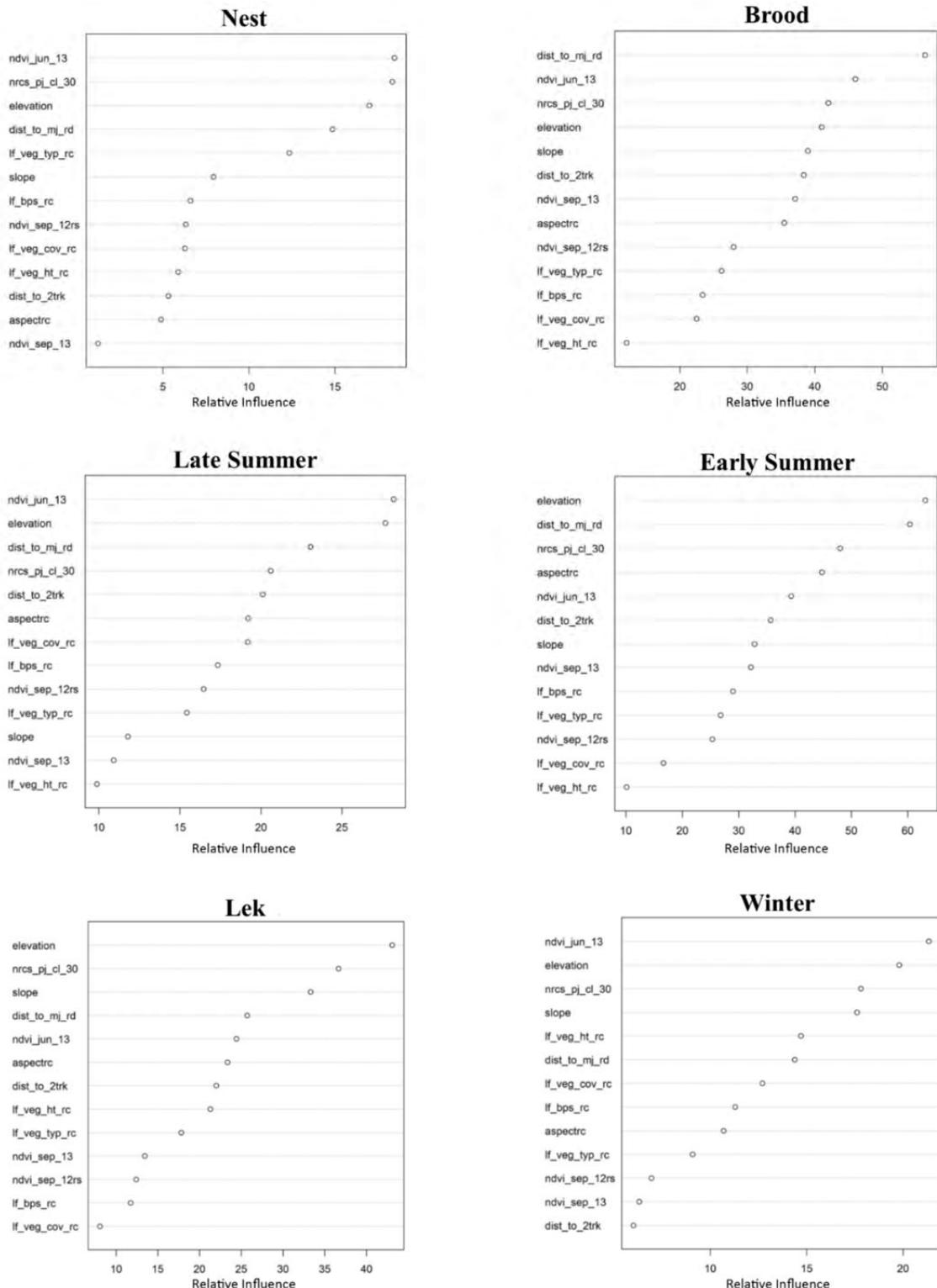


Figure 2-6. Variable importance plots for greater sage-grouse (*Centrocercus urophasianus*) Random Forest seasonal habitat models of the Box Elder Sage-grouse Management Area, Box Elder County, Utah, based on telemetry locations collected from 2005-2013.

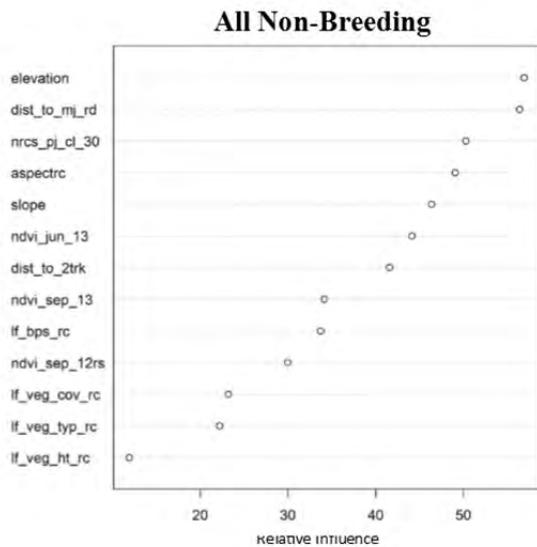


Figure 2-7. Variable importance plot for the greater sage-grouse (*Centrocercus urophasianus*) random forest general non-breeding habitat model for the Box Elder Sage-grouse Management Area, Box Elder County, Utah based on non-breeding telemetry locations collected from 2005-2013.

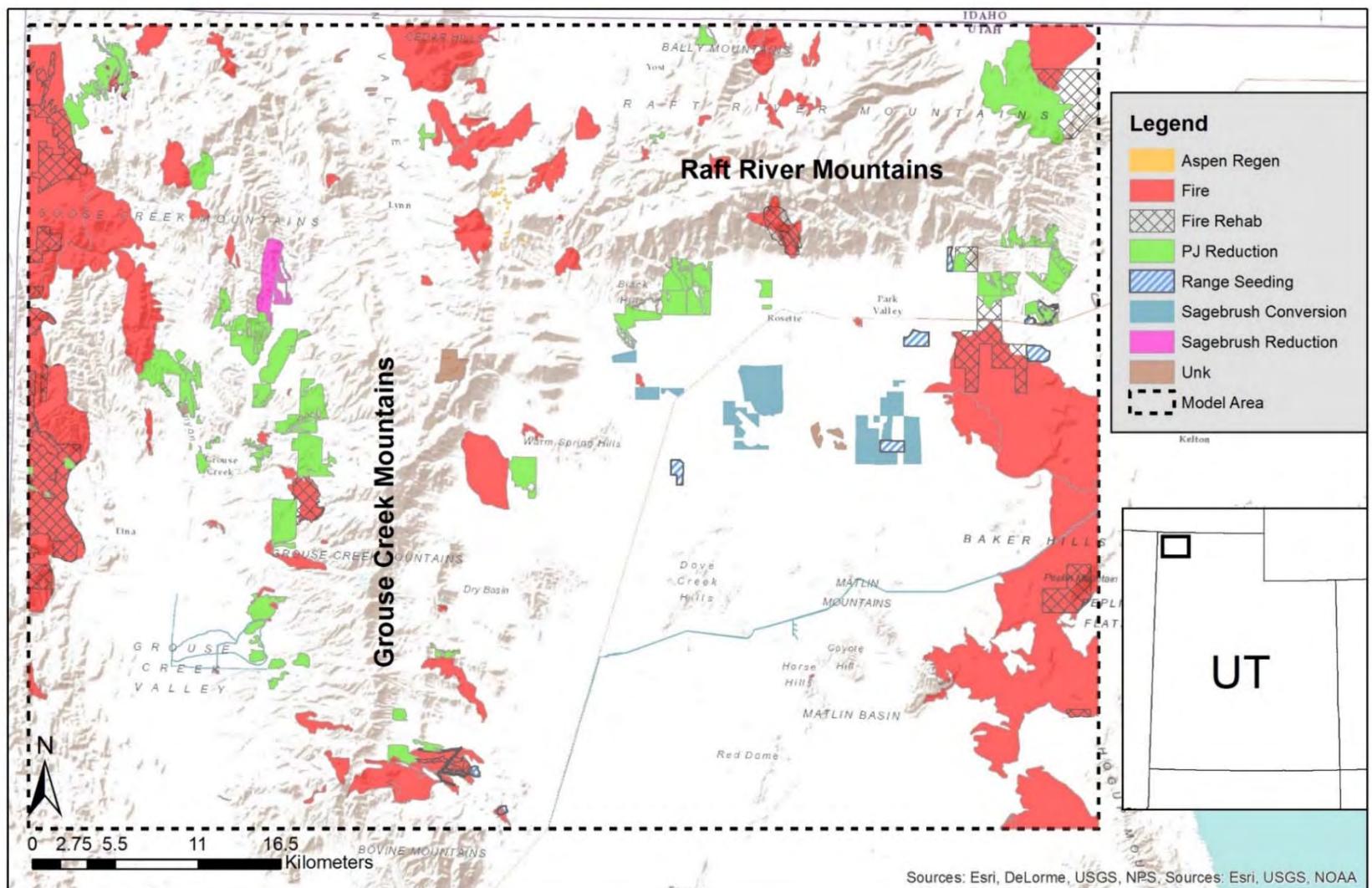


Figure 2-8. Mapped vegetation changes within the Box Elder Sage-grouse Management Area model, Box Elder County, Utah from 1985 to 2013.

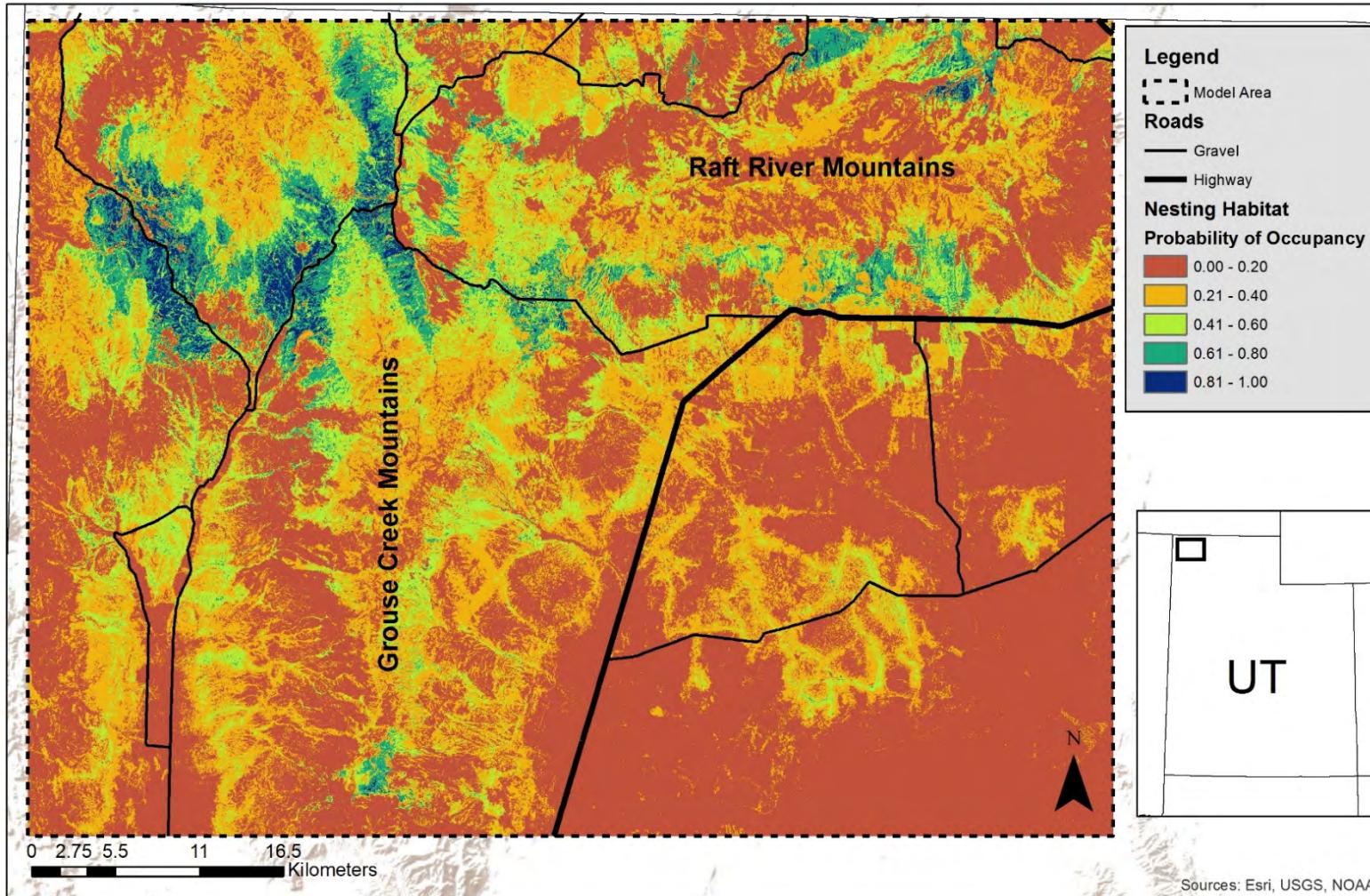


Figure 2-9. Predicted probability of greater sage-grouse (*Centrocercus urophasianus*) nest occupancy within the Box Elder Sage-grouse Management Area Box Elder County, Utah, based on vegetation and topographical model inputs and greater sage-grouse telemetry locations collected between 2005 and 2013.

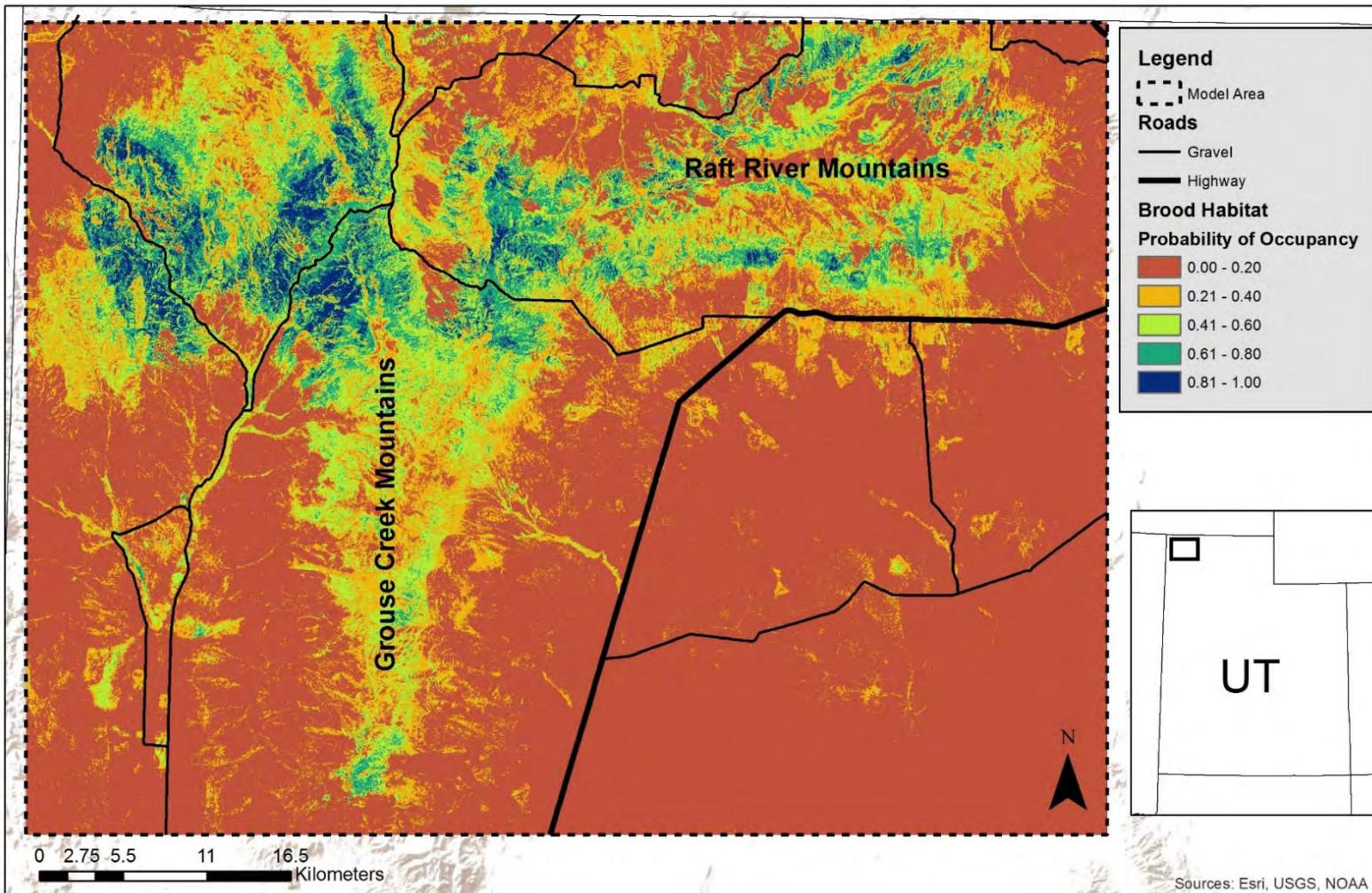


Figure 2-10. Predicted probability of greater sage-grouse (*Centrocercus urophasianus*) brood occupancy within the Box Elder Sage-grouse Management Area, Box Elder County, Utah based on vegetation and topographical model inputs and greater sage-grouse telemetry locations collected between 2005 and 2013.

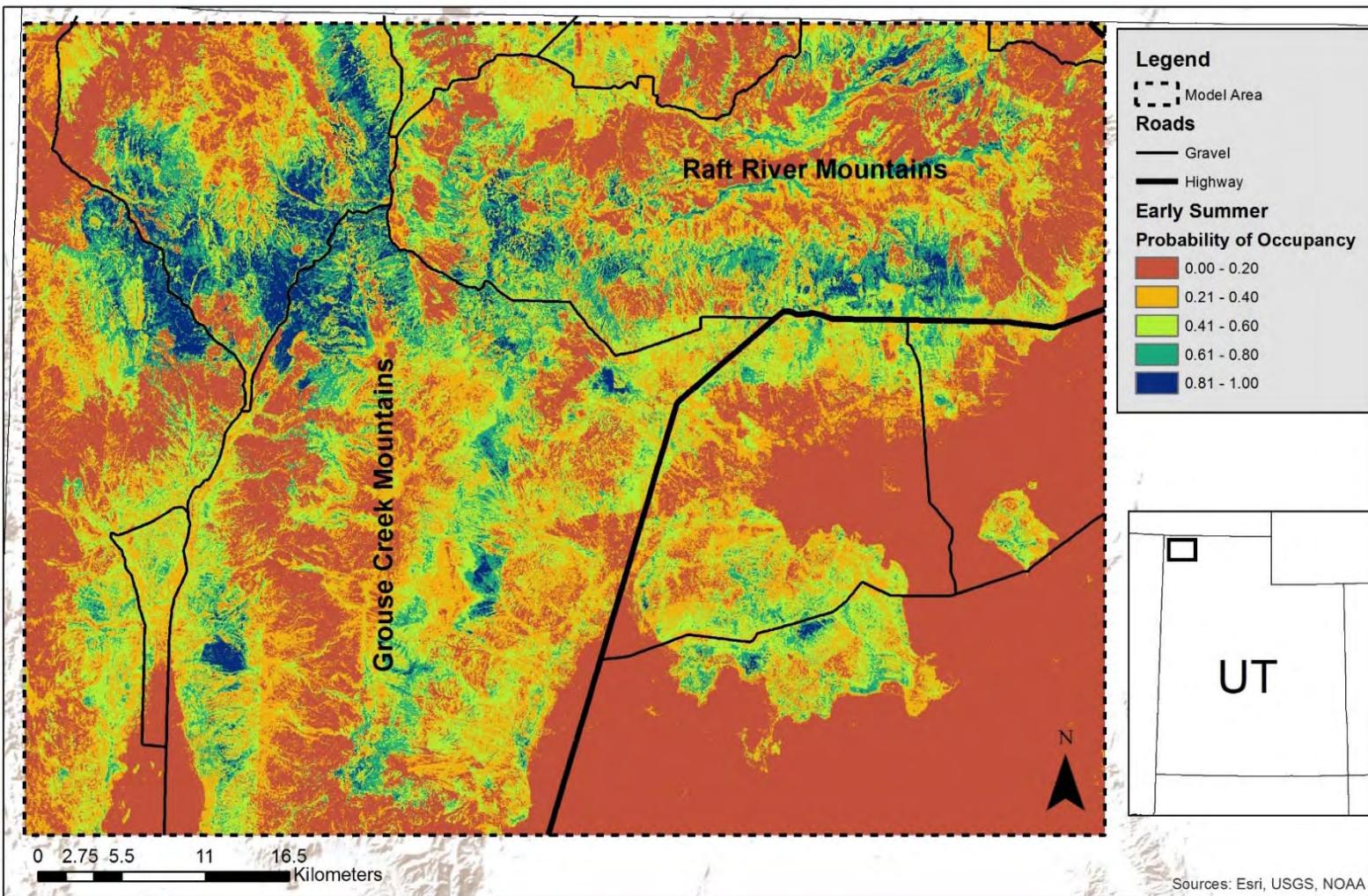


Figure 2-11. Predicted probability of greater sage-grouse (*Centrocercus urophasianus*) early summer non-breeding occupancy within the Box Elder Sage-grouse Management Area, Box Elder County, Utah based on vegetative and topographical model inputs and greater sage-grouse telemetry locations collected between 2005 and 2013.

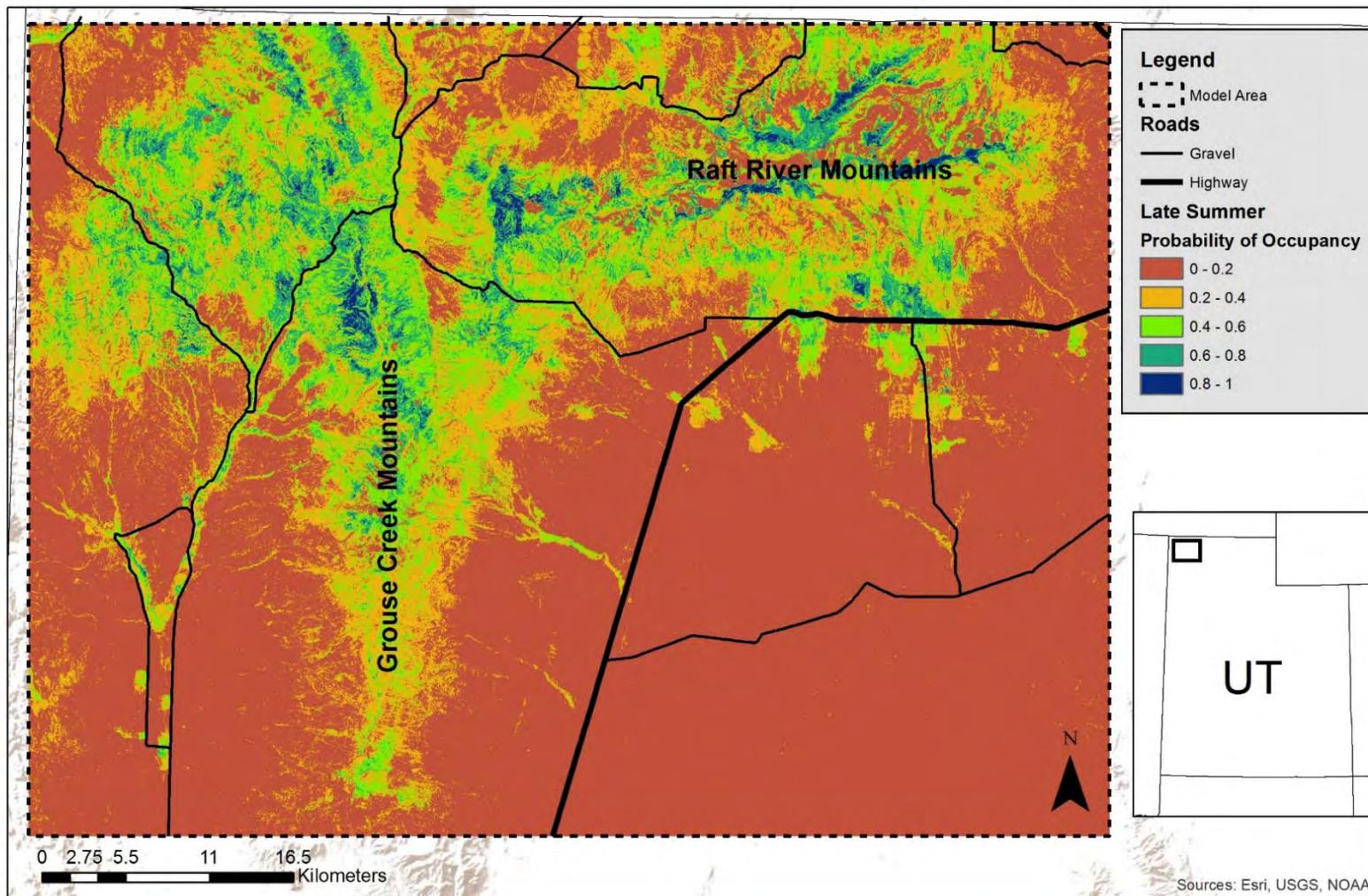


Figure 2-12. Predicted probability of greater sage-grouse (*Centrocercus urophasianus*) late summer non-breeding occupancy within the Box Elder Sage-grouse Management Area, Box Elder County, Utah modeled based on vegetation and topographical model inputs and greater sage-grouse telemetry locations collected between 2005 and 2013.

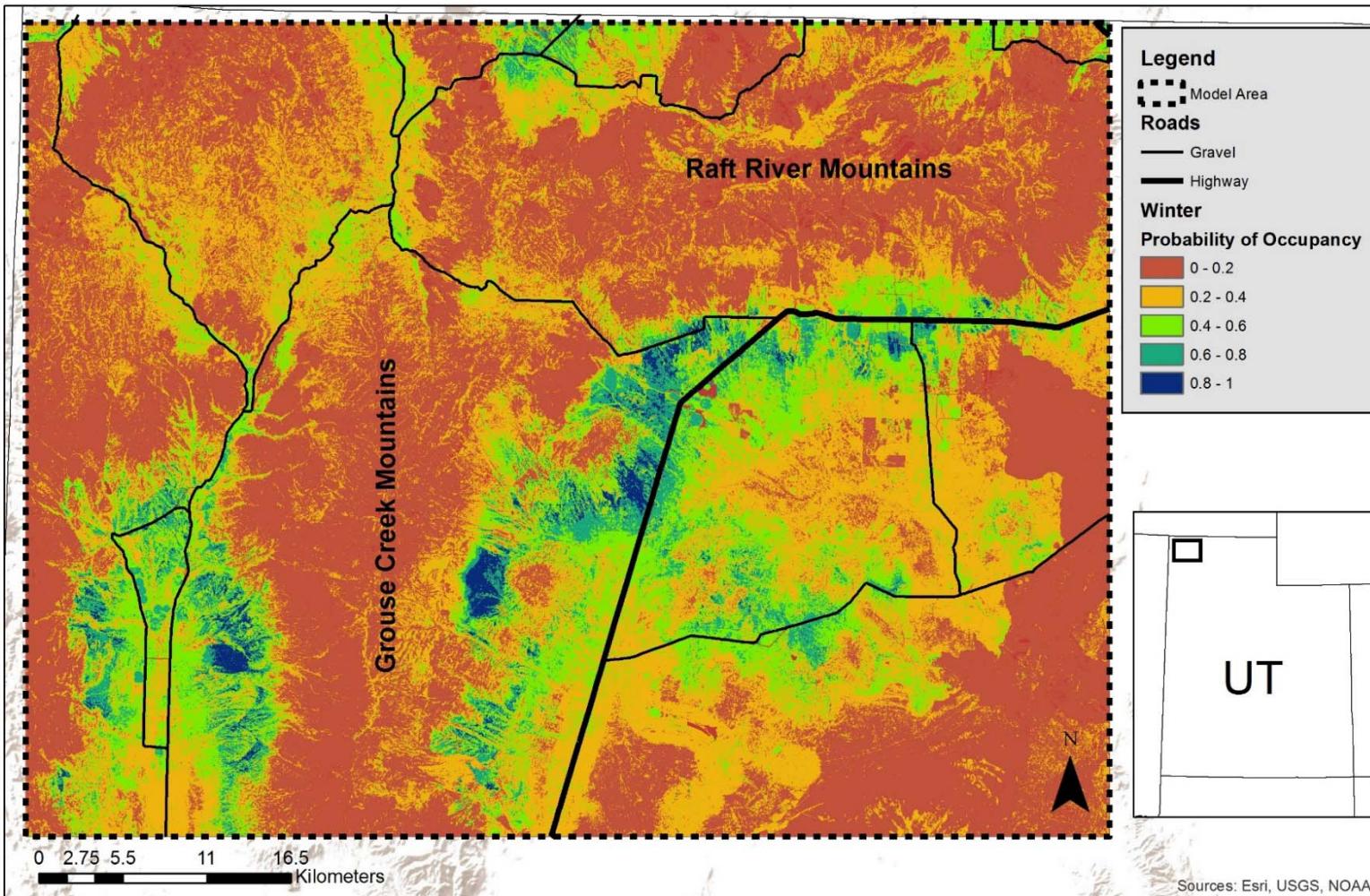


Figure 2-13. Predicted probability of greater sage-grouse (*Centrocercus urophasianus*) winter occupancy within the Box Elder Sage-grouse Management Area, Box Elder County, Utah modeled based on vegetation and topographical model inputs and greater sage-grouse telemetry locations collected between 2005 and 2013.

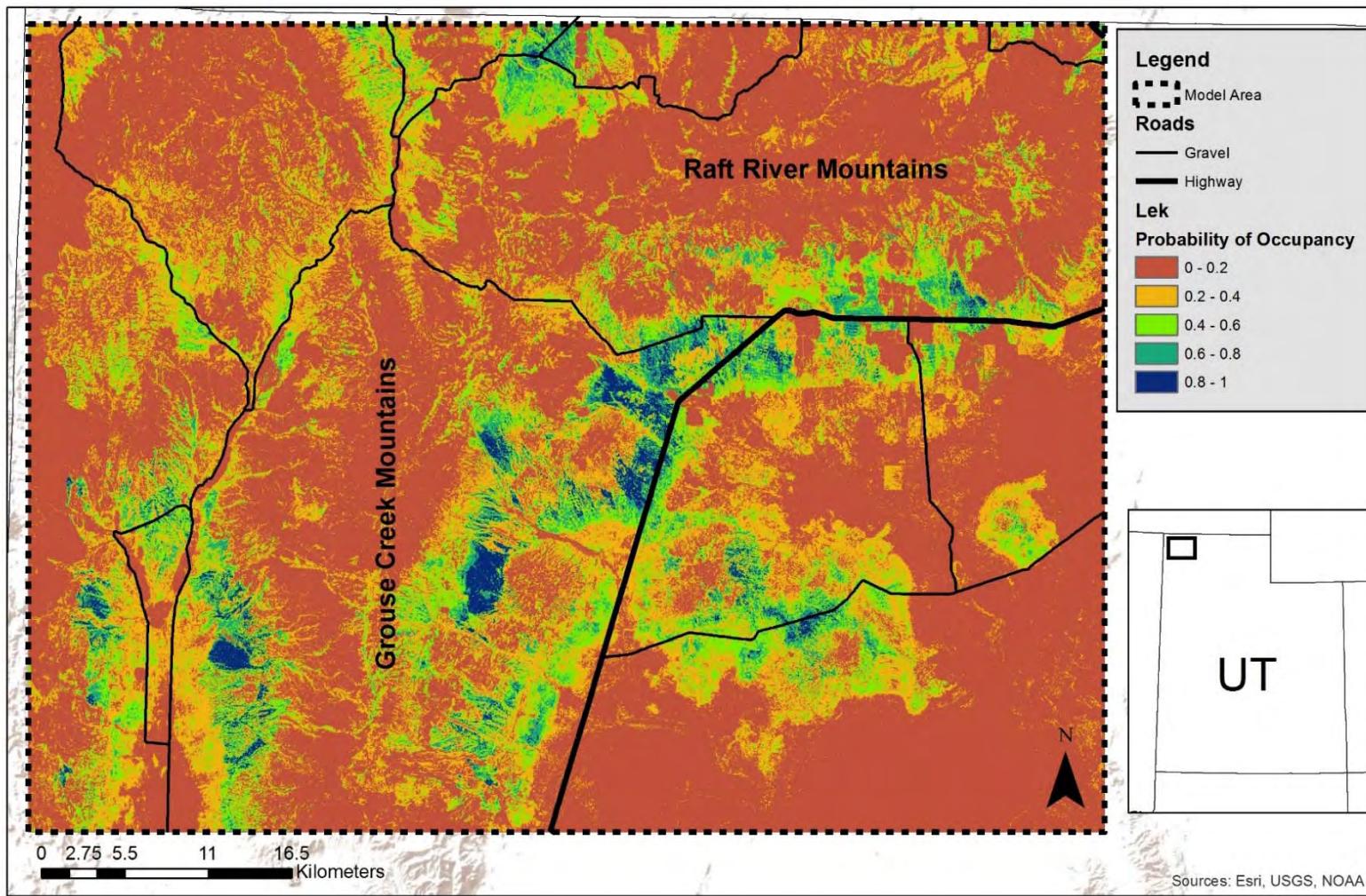


Figure 2-14. Predicted probability of greater sage-grouse (*Centrocercus urophasianus*) lekking season occupancy within the Box Elder Sage-grouse Management Area, Box Elder County, Utah modeled based on vegetation and topographical model inputs and greater sage-grouse telemetry locations collected between 2005 and 2013.

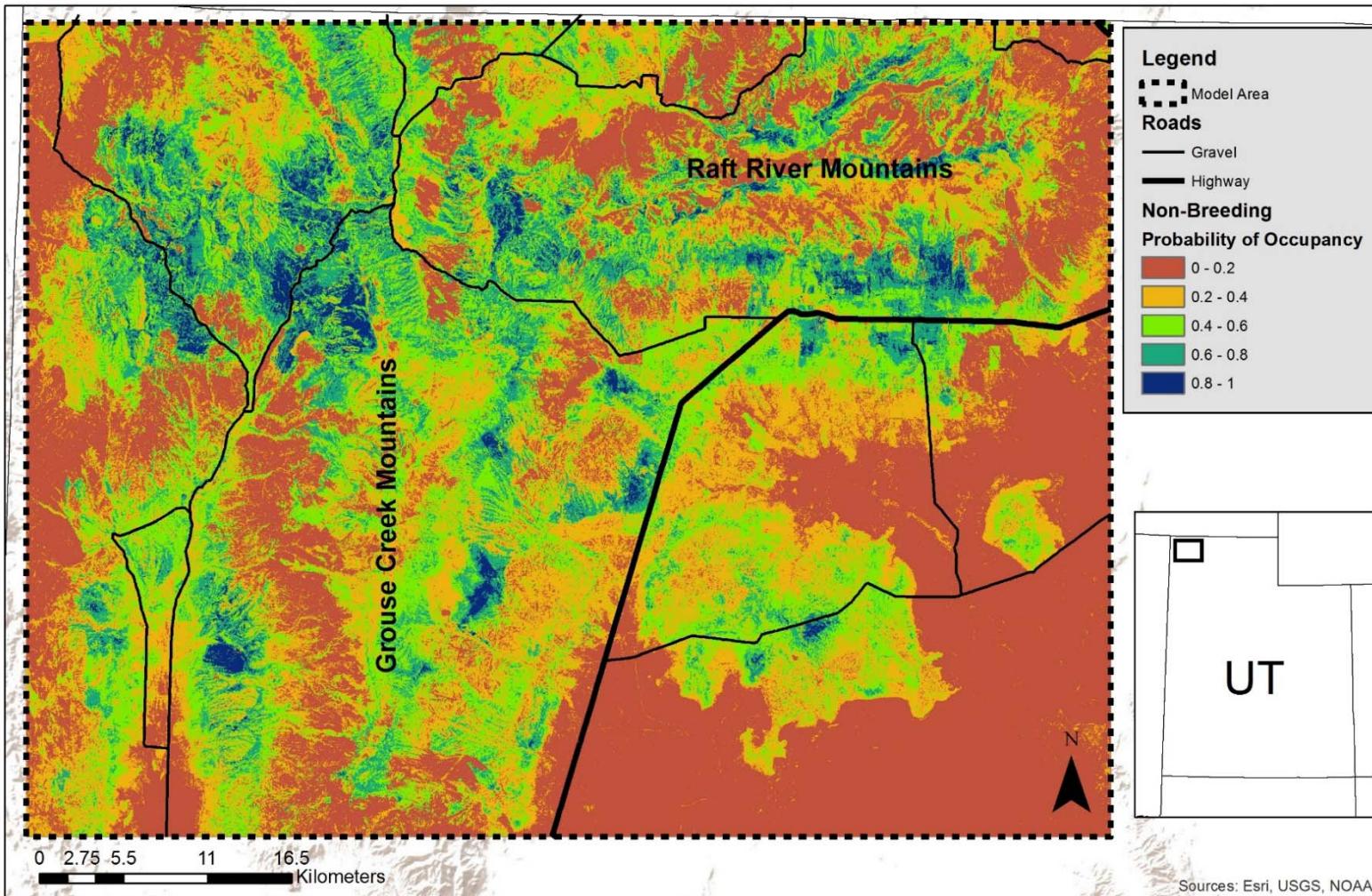


Figure 2-15. Predicted probability of greater sage-grouse (*Centrocercus urophasianus*) general non-breeding occupancy within the Box Elder Sage-grouse Management Area, Box Elder County, Utah based on vegetation and topographical model inputs and greater sage-grouse telemetry locations collected between 2005 and 2013.

CHAPTER 3

FACTORS INFLUENCING GREATER SAGE-GROUSE USE OF CONIFER REDUCTION TREATMENTS: IMPLICATIONS FOR RANGE-WIDE CONSERVATION

ABSTRACT One of the potential consequences of climate change, changed fire regimes, and other biotic factors in western North America is increased displacement of desirable sagebrush (*Artemisia* spp.) communities by invasive plant species. Annually, up to 90,000 ha of sage-grouse (*Centrocercus* spp.) habitat is estimated to be degraded by pinyon (*Pinus* spp.) and juniper (*Juniperus* spp; PJ) encroachment, leading to sage-grouse avoidance of suitable habitats and population declines. Wildlife managers have identified restoration of PJ encroached areas with intact sagebrush understories as a conservation priority. However, better information regarding sage-grouse responses to the removal or reduction of PJ canopy cover is needed to guide management actions. We used fecal pellet and vegetation surveys in concert with radio-telemetry data to determine what factors may influence sage-grouse use of PJ treatments. Increased sage-grouse use of PJ treatments was positively associated with sage-grouse presence in adjacent habitats ($P = 0.018$), percent shrub cover ($P = 0.039$), and mesic environments within 1000 m of treatments ($P = 0.048$). Sage-grouse use of PJ treatments was negatively associated with PJ canopy cover ($P = 0.048$) within 1000 m of treatments. Although we documented increased sage-grouse spatial use of PJ treatments, more research will be required to determine if PJ treatments will result in increased populations through enhanced vital rates.

INTRODUCTION

Prior to European settlement of the western United States, pinyon pine (*Pinus* spp.) and juniper (*Juniperus* spp.; PJ) woodlands were primarily located on rocky ridges and other areas of sparse vegetation (Miller et al. 2000). Encroachment of PJ woodlands into sagebrush (*Artemesia* spp.) landscapes has accelerated over the last century (Miller et al. 2000), and PJ woodlands are estimated to be expanding at a greater rate than during previous climatic cycles (Weisberg et al. 2007, Sankey and Germino 2008, Miller et al. 2011). Miller et al. (2011) estimated an additional 12% of extant sagebrush distribution will be displaced by other woody vegetation for each degree Celsius increase in average temperature in a warming climate. Proximate causes of conversion of shrub-steppe to PJ woodland include programmatic fire suppression resulting in reduced fire frequency, and heavy livestock grazing during the late 1800's and early 1900's (Miller et al. 2000).

As PJ canopy cover increases in sagebrush systems, shrub canopy is reduced and displaced (Miller et al. 2000). Stiver et al. (2006) estimated 60,000-90,000 ha of greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) sagebrush habitat range-wide is lost to PJ encroachment each year. Herbaceous cover also decreases dramatically with PJ encroachment. Miller et al. (2000) showed that herbaceous cover declined by 69% as PJ communities progressed from open to closed canopy cover. Coultrap et al. (2008) found that the process can be reversed with juniper removal resulting in increased total grass cover, increased herbaceous productivity and reduced bare ground. Roundy et al. (2014) found that shrub and perennial grass cover can be maintained when PJ is removed before becoming dominant and displacing understory species, but treatments implemented at high PJ densities can result in herbaceous dominated plant communities. Miller (2005)

further classified successional progress of PJ encroachment into three transitional phases; 1) Phase I – PJ is present but shrubs, forbs, and grasses are the dominant vegetation, tree canopy <20% of maximum potential, 2) Phase II – PJ is co-dominate with shrubs and juniper is influencing ecological processes, tree canopy 20-50% of maximum potential, and 3) Phase III – PJ is dominant and the primary vegetation influencing ecological processes, tree canopy >50% of maximum potential.

Due to range-wide declines and habitat loss, in 2010 the U.S. Fish and Wildlife Service (USFWS) identified sage-grouse as a candidate species for protection under the Endangered Species Act of 1973 (USFWS 2010). The USFWS encouraged states in the Conservation Objectives Team (COT) report to focus their management actions in core conservation areas with the greatest potential for habitat conservation (USFWS 2013). Mitigating PJ encroachment into sage-grouse habitat was identified as a key method for species conservation in the COT report (USFWS 2013).

Sage-grouse populations have declined range-wide because of habitat loss and degradation to include PJ encroachment (Beck et al. 2003, Schroeder et al. 2004). Prior research has demonstrated sage-grouse avoidance of PJ dominated landscapes, with only occasional use of early successional (Commons et al. 1999, Robinson 2007, Doherty et al. 2008, Burnett 2013, Frey et al. 2013). Baruch-Mordo et al. (2013) reported that conifer cover at relatively small percentages ($\geq 4\%$) of the landscape near (<1 km) lek sites resulted in declining counts of male sage-grouse in Oregon.

Few studies have evaluated sage-grouse use of PJ reduction projects. Although, Frey et al. (2013) reported sage-grouse using PJ removal treatments one year post-treatment, they did not quantify the habitat factors contributing to the observed use.

Commons et al. (1999) reported the number of Gunnison sage-grouse (*C. minimus*) males counted on leks doubled three years post-treatment. Although sage-grouse may avoid PJ when selecting nest sites (Doherty et al. 2010), Gruber (2012) and Duvuvuei (2013) reported translocated sage-grouse nesting and raising broods in small (shrub-like) standing junipers and slash piles created by PJ treatments on the Ashley National Forest in northeastern Utah. The breeding habitat occupied by this population consisted of ~ 2,500 ha and the translocated birds were using PJ habitats due to the limited availability of sagebrush cover (Gruber 2012, Duvuvuei 2013).

Through its Sage-Grouse Initiative (www.sagegrouseinitiative.com) the National Resource Conservation Service (NRCS) has funded thousands of hectares of PJ removal in the western U.S. (J. Maestra, NRCS, personal communication). Federal land management agencies have also implemented PJ removal projects on Bureau of Land Management (BLM) and U.S. Forest Service (USFS) administered lands (Utah Division of Wildlife Resources [UDWR] 2009). The UDWR has recommended PJ reduction as a sage-grouse habitat restoration tool in their sage-grouse conservation plan (Utah Governor's Office 2013). Pinyon-juniper reduction projects are relatively low cost on a per hectare basis, and have immediate potential to increase sage-grouse habitat availability (Guthery 1997, UDWR 2009, Cirrus Ecological Solutions and Logan Simpson Design 2013, Utah Governor's Office 2013). Between 2006 and 2013, the state of Utah funded over 154,000 ha of PJ treatments to specifically benefit sage-grouse (Utah Governor's Office 2013).

Given potential for large-scale PJ removal projects, it is important to evaluate sage-grouse responses to ensure project prioritization. Our objective was to identify

factors influencing sage-grouse use of PJ treatments and provide recommendations for designing projects that may maximize conservation benefits to sage-grouse.

STUDY AREA

The study area consisted of the western portion of Box Elder County (WBE), Utah, in the southeast extent of the Snake River Plain/ Sage-grouse Management Zone II (Connelly et al. 2004, Stiver et al. 2006). Specifically, the research area was located on the West Box Elder Sage-grouse Management Zone as defined in the 2013 Utah Conservation Plan for Greater Sage-grouse (Utah Governor's Office. 2013). The study area included 566,117 ha of mixed private, state and federal land consisting of 49.0% private land (277,149 ha), 40.0% BLM (226,407 ha), 5.9% various Utah state lands (33,447 ha), and 5.1% US Forest Service land (29,114 ha) (Utah Automated Geographic Reference Center [AGRC] 2013). The core of the study area was bounded by the Raft River Mountains to the north, Grouse Creek Mountains to the west and the hardpan of the Great Salt Lake to the southwest (Fig. 3-1). The primary land use is grazing by domestic livestock (*Bos taurus*) and associated activities including irrigated pastures and alfalfa (*Medicago sativa*) production.

The study area is at the edge of sagebrush-steppe communities and Great Basin sagebrush communities with parts of the study area exhibiting characteristics of each ecological type (Miller and Eddleman 2000). Vegetation communities in the study area included salt desert shrub to mixed Wyoming and black sagebrush communities (*A. t. tridentata*, *A. nova*) and juniper belts at lower elevations along a fluvial bench. Mixed mountain shrub and aspen (*Populus tremuloides*) patches were present at mid elevations, and mountain mahogany (*Cercocarpus ledifolius*) and isolated Douglas Fir (*Pseudotsuga*

menziesii) forests mixed with mountain big sagebrush (*A. t. vaseyana*) at higher elevations. Elevations range from 1,400 to 3,000 m above sea level.

From 1990 to 2012 the weather station (1732 m elevation) at Rosette, Utah, near the center of the study area, documented an average annual precipitation of 22.6 cm with 14.2 cm occurring as snow between November and April. Temperatures ranged from a monthly average high of 30°C in July to a monthly average low of -9.4°C in December and January (Western Regional Climate Center 2013). Snow does not typically persist through spring at lower elevations but can persist into late summer at higher elevations.

We evaluated 19 PJ reduction projects completed in the study area between 2007 and 2013. Five projects removed PJ cover using complete mastication (i.e., Fecon Bull Hog, Lebanon, OH), and 14 reduced cover by chaining (Cain 1971). We did not evaluate successional stages of PJ communities prior to treatments, however analysis of National Agriculture Imagery Program [NAIP] imagery showed treated areas were primarily Phase II and III of PJ encroachment (Miller 2005). Projects ranged in size from 57 to 547 ha and were located on a mix of public and private land. Most projects were located in the foothills of the Raft River and Grouse Creek Mountains between 1654-1930 m above sea level, and near or adjacent to intact sagebrush communities (Fig. 3-1).

METHODS

We mapped 19 PJ treatment areas using data obtained from a combination of sources, including ground observations, aerial imagery and maps provided by Utah's Watershed Restoration Initiative (WRI) (Utah WRI 2014). Eleven treatments were on private land. Of the remaining, 4 were on BLM land and one was on Utah School and Institutional Trust Lands Administration property. We established plots within each of

the 19 PJ treatment areas. Fourteen reference plots were established in the closest adjacent sagebrush-dominated area. Because of the lack of suitable habitat and limited access to private lands, we were not able to establish a unique paired reference plot for each treatment, thus, some plots served as reference for more than one treatment.

Distance from the edge of treatments to the closest edge of reference plots ranged from 20 m to 1800 m ($\bar{x} = 355$ m, median = 95.5 m).

Sage-grouse fecal pellet surveys have been used to estimate and compare sage-grouse use of small treatment plots in sagebrush (Dahlgren et al. 2006, Guttery 2011, Hanser et al. 2011, Graham 2013). Previous research in Utah used relatively short transect lengths to estimate fecal pellet densities: 500 m (Graham 2013); 1908 m (3 stratified transects of 636 m by sample unit; Dahlgren et al. 2006); and four 1 m circular plots per random site (Guttery 2011). Because numbers of pellets detected during pilot transects were low transect lengths were increased to 2400 m. Transects were laid out with a square design. Each transect was walked by a single observer with the guidance of a handheld Global Positioning System (GPS) receiver. Observers visually scanned for fecal pellets and cecal droppings within 2 m of either side of the transect line (Dahlgren et al. 2006). However, pellets detected outside the 4 m belts were also recorded as a sage-grouse presence. In addition to sage-grouse feces, observers also recorded number and density of domestic cattle pats along transects as a proxy for grazing intensity (Jankowski et al. 2014).

Percent grass, forb, and shrub canopy cover were measured along each transect using a step-point method (Evans and Love 1957, Herrick et al. 2005). A point intercept observation was taken every 40 m along each 2400m transect, for a total of 60 points per

transect. At each point, distance to, and height of the closest grass or forb, and tree or shrub was recorded. Presence of litter was recorded separately at each point. Percent cover for grass, forb, tree and shrub was calculated as the proportion of points with the vegetation class present at the point. Percent litter was calculated as the proportion of points with litter cover at the point. All sagebrush species were combined to calculate total sagebrush cover. Percent cover of “small” sagebrush was calculated by combining black and low sagebrush. Percent big sagebrush cover was calculated by combining all big sagebrush subspecies.

In addition to pellet surveys, we used radio telemetry locations within a treatment area to document sage-grouse use. To obtain telemetry locations we trapped 123 sage-grouse (68 female, 55 male) from January 2012 to March 2013 using the nocturnal spotlight method (Giesen et al. 1982, Wakkinen et al. 1992, Connelly et al. 2003). Each sage-grouse was equipped with a very high frequency (VHF) radio collar (Advanced Telemetry Systems, Isanti, MN, Model A4050) weighing approximately 22 g with necklace (1-2% of body weight. Research protocols were approved by the Utah State University Institutional Animal Care and Use Committee permit #1547, and UDWR Certificate of Registration number 2BAND8743.

Beginning mid-March in 2012 and 2013, radio marked hens were visually located 2-3 times per week to monitor movements. Males were located biweekly throughout the spring, summer and fall field seasons. Due to limited winter access, all birds were located one to two times during the winter season via ground and aerial telemetry.

The 2010 LANDFIRE Existing Vegetation Type data were used to evaluate vegetation type adjacent to and surrounding treatment areas (United State Geological

Survey [USGS] 2010). We buffered each treatment area by 1 m, 500 m, 1000 m, and 2000 m. The LANDFIRE vegetation type layer was clipped to buffers, and vegetation types within buffers were categorized into PJ, sagebrush, mesic, agriculture, urban, and other (Table 3-1). Dominant land cover type, percent dominant land cover type, and percent land cover for PJ, sagebrush, mesic, agriculture, and urban were calculated for each treatment buffer. Springs, lakes, streams, and active sage-grouse lek data layers were acquired, and distance to nearest feature of each category was calculated from the closest edge of each treatment area (UDWR 2013, Utah AGRC 2014).

To determine the year of treatment implementation when not documented, we reviewed annual Landsat 5 Thematic Mapper images from 1987 to 2011, Landsat 5 Multispectral Scanner images from 2012, and Landsat 8 Orbital Land Imager images from 2013 (Path 39 Row 31) collected from the USGS Global Visualization Viewer (glovis.usgs.gov) with a target post-senescence anniversary date of August 15.

Vegetation data collected in both reference and treatment areas generally did not fit a normal distribution due to skewness of data as well as coarse distributions resulting from small sample sizes. Lack of normality violated assumptions required for standard t-tests. To compensate for lack of normality, we used nonparametric bootstrapped t-tests using program R (R version 3.0.2, www.r-project.org, accessed 1 Jan 2014) using the *yuenbt* function in the Wilcox Robust Statistics [WRS] package (WRS version 0.25, [r-forge.r-project.org/projects/wrs](http://forge.r-project.org/projects/wrs), accessed 1 Jan 2014). Each t-test comparing means of site characteristics was bootstrapped 3000 iterations. Bootstrapped p-values are generally higher than standard t-tests, thereby reducing probability of type I errors when analyzing numerous statistical tests between two groups (Rice 1989). We used t-tests to compare

vegetative characteristics of treatment plots relative to reference plots and all occupied plots relative to all unoccupied plots.

Mean percent of LANDFIRE existing vegetation types within treatment buffers and distance to water features were compared between treatment areas where sage-grouse were and were not detected. Treatment areas with shared borders were treated as one area for analysis of surrounding vegetation type, and treatment size, resulting in the 19 treatments being reduced to 16 for this analysis. Bootstrapped t-tests to examine differences in group means of surrounding vegetation type, treatment size, distance to nearest lek, treatment age, and cow pat density were performed using the same method used for vegetation data.

We used a two by two contingency table with a Fisher's exact test (Fisher 1922) in program R to compare plot sage-grouse detection rates to test the null hypothesis that sage-grouse use was uniform regardless of sage-grouse use at the nearest reference plot. A Fisher's exact test was used to determine if any relationships existed between treatment method (chaining or mastication) and sage-grouse detected use.

RESULTS

We detected sage-grouse use in 12 of 19 treatments surveyed; 4 by pellet survey only, 4 using radio telemetry only, and 4 with both radio telemetry and pellet surveys. Sage-grouse use also was detected in 7 of the 14 reference plots. We detected a positive relationship ($P = 0.018$) between recorded sage-grouse presence in treatment and nearest reference plots. We did not detect any relationship between sage-grouse use and size of treatment ($P = 0.877$) or treatment method ($P = 0.604$).

We detected a relationship between LANDFIRE existing vegetation type PJ cover (Table 3-1) within 500 m ($P = 0.056$) and 1000 m ($P = 0.048$) of treatment areas and sage-grouse use. Sage-grouse were more likely to be detected in treatment areas that exhibited 22.5% and 21.7 % average PJ land cover within 500 m and 1000 m treatment buffers, respectively. Sage-grouse were not detected in treatment areas that exhibited 43.6% and 40.7% average PJ land cover within 500 m and 1000 m treatment buffers, respectively. Mean percent PJ land cover did not differ for treatments with and without sage-grouse detections within 1 m and 2000 m buffers of treatments ($P = 0.320$, $P = 0.097$ respectively). Mean percent land cover type at all buffer distances was similar for sagebrush, agriculture and urban cover; no differences in sage-grouse presence were found based on the proportion of these land cover groups.

The presence of mesic habitats (Table 3-1) within 1000 m treatment buffers was related to sage-grouse presence ($P = 0.048$). Mesic land cover within 1000 m of treatment areas averaged 1.9% for treatments where sage-grouse use was detected compared to 0.4% for treatments where sage-grouse use was not detected. However, distance to the closest spring ($P = 0.487$), lake ($P = 0.561$), stream ($P = 0.408$), or lek ($P = 0.297$) did not differ between detection and non-detection plots. Increased sage-grouse use was detected in older PJ treatments ($P = 0.067$). Treatments plots where sage-grouse use was detected were on average twice ($\bar{x} = 3.56$ years) the age of treatments where use was not detected ($\bar{x} = 1.57$ years).

The average number of cattle pats was higher in reference plots adjacent to treatments where sage-grouse use was detected ($P = 0.002$, $\bar{x} = 81.7$ pats/km) relative to reference plots adjacent to treatments where sage-grouse use was not detected ($\bar{x} = 27.9$

pats/km). There was a weak relationship ($P = 0.078$) between the average number of pats counted in treatment areas where sage-grouse were detected ($\bar{x} = 40.9$ pats/km) and treatment areas where sage-grouse were not detected ($\bar{x} = 20.4$ pats/km).

When vegetation characteristics were compared across all survey plots relative to sage-grouse presence, percent shrub cover was greater ($P = 0.039$, $\bar{x} = 13.4\%$) on treatment and reference plots where sage-grouse were detected compared to plots where they were not ($\bar{x} = 7.03\%$). When only the sagebrush component of shrub cover was analyzed, we detected a difference ($P = 0.044$) between plots where sage-grouse were detected ($\bar{x} = 9.3\%$) and not detected ($\bar{x} = 4.6\%$). Percent cover of forb ($P = 0.109$), grass ($P = 0.121$), tree ($P = 0.802$), and litter ($P = 0.214$) cover did not differ between plots where sage-grouse were detected and not detected. Height of forbs ($P = 0.983$), grasses ($P = 0.829$), shrubs ($P = 0.265$), trees ($P = 0.749$), and sagebrush ($P = 0.568$) also did not differ between plots where sage-grouse were detected and not detected.

Average tree (i.e., juniper) height was taller in reference ($\bar{x} = 218.6$ cm, $SE \pm 33.4$ cm) than treatments ($\bar{x} = 90.7$ cm, $SE \pm 13.6$ cm) plots ($P = 0.043$). Big sagebrush average height was greater in reference ($\bar{x} = 61.2$ cm, $SE \pm 7.1$ cm) than treatment ($\bar{x} = 38.3$ cm, $SE \pm 5.1$ cm) plots ($P = 0.015$). Average percent litter cover was higher in reference ($\bar{x} = 85.6\%$, $SE \pm 1.2\%$) than treatment plots ($\bar{x} = 68.1\%$, $SE \pm 1.4\%$) plots ($P < 0.001$). We did not detect any difference between percent canopy cover in reference and treatment plots for forbs ($P = 0.812$), grasses ($P = 0.781$), or shrubs ($P = 0.197$). Also average height of forbs ($P = 0.965$), grasses ($P = 0.725$), and shrubs ($P = 0.502$) did not differ between reference and treatment plots.

DISCUSSION

Our study demonstrated that sage-grouse used areas where PJ was reduced or removed within a short period of time following treatment. Sage-grouse use of the PJ treatment areas was positively related to sage-grouse use of adjacent reference plots, surrounding mesic environments, and sites with relatively high sagebrush canopy cover. Pinyon-juniper treatments in our study area exhibiting these characteristics likely increased the useable space available to sage-grouse (Guthery 1997).

Guthery (1997) advanced the concept of useable space, using the example of bobwhite quail (*Colinus virginianus*), as an important factor in increasing wildlife populations. He argued that increasing habitat quality does not necessarily lead to an increase in total population or densities. However, increasing overall space that is usable (including seasonally explicit space) for the species may lead to an increase in populations. Our results demonstrate a relatively quick response of sage-grouse to increased usable space, and therefore the need to prioritize PJ treatments near current sage-grouse habitats that exhibit suitable sagebrush cover (Baruch-Mordo 2013, Roundy et al. 2014).

Differences were observed in tree height between the plots, with reference plots exhibiting taller tree cover (i.e., PJ), suggesting treatments were effective in reducing overall tree height below levels found in used habitats. Low and black sagebrush average heights were greater in reference plots than treatment plots, suggesting some sagebrush reduction resulting from either PJ encroachment, and/or conifer removal methods. However, the lack of difference in forb, grass, and overall shrub cover between plots suggests the chaining and mastication methods used to reduce PJ cover retained key

understory habitat components. Frey et al. (2013) also reported a negligible change in shrub cover and height between control and treatment plots in response to PJ removal projects.

Sagebrush canopy cover in our reference (10.6%) and treatment (6.1%) plots was below the levels recommended (15-25%) for breeding cover in occupied sage-grouse habitat (Connelly et al. 2000, Connelly et al. 2011). The reduced understory cover was expected because of Phase II and III PJ cover impacts in areas prior to treatment (Miller et al. 2000, Miller 2005, Roundy et al. 2014). Overall shrub cover was related to sage-grouse presence. Use plots exhibited almost twice the shrub cover as areas without sage-grouse use. The relationship between shrub cover and sage-grouse presence reinforces the importance of shrub canopy (sagebrush dominated) cover to the species and highlights the importance of removing PJ canopy while shrub communities are intact.

Overall grass and forb cover met Connelly et al. (2000) habitat guidelines of >15% for arid sites, with combined 31.5% grass and forb cover on reference and 27.8% cover on treatment sites. Average grass-forb cover for plots where sage-grouse use was detected and plots without detected sage-grouse use also met habitat guidelines of >15% cover. The PJ treatments we studied occurred on a fluvial bench exhibiting relatively deep soils. These characteristics may have mitigated some of the effect of PJ encroachment on understory components (Roundy et al. 2014).

Sage-grouse detection in treatment plots was positively associated with sage-grouse presence in reference plots. The relationship between sage-grouse use of treatment and reference plots demonstrated that PJ treatments implemented adjacent to currently occupied habitat were more likely to be used by sage-grouse post-treatment.

The inverse was also apparent. Frey et al. (2013) found similar results when PJ was removed in areas close to occupied sage-grouse habitat.

The relationships we detected between land cover at 500 m and 1000 m spatial scales and sage-grouse use provides guidance to prioritize PJ removal projects intended to benefit sage-grouse. In these buffer areas surrounding treatments used by sage-grouse, mesic patches, which are often associated with sage-grouse brood use (Klebenow 1969, Wallestad 1971, Atamian et al. 2010, Connelly et al. 2011, Dzialak et al. 2011), were found at nearly four times the density of treatments where sage-grouse use was not detected.

The negative relationship found between surrounding percent land cover classified as PJ and sage-grouse use indicated lower potential for sage-grouse use of a treatment area as PJ cover surrounding the site increased. Baruch-Mordo et al. (2013) supported this conclusion reporting that male lek counts decreased in areas containing > 4% conifer cover within 1 km. Our results also corroborate numerous other studies reporting negative relationships between conifer cover and sage-grouse habitat use at varying spatial scales (Doherty et al. 2008, Atamian et al. 2010, Casazza et al. 2011, Frey et al. 2013).

The positive relationship between sage-grouse occupancy and number of cattle pats counted suggests that sage-grouse and cattle were attracted to similar areas where herbaceous vegetation was enhanced because of the treatments (Roundy et al. 2014). Age of pats was not accounted for during data collection complicating interpretation of results, because we do not know if cattle pats were from previous years or other times not concurrent with sage-grouse use. We did not have information on stocking rates in the

surveyed areas and were not able to survey more broadly for cattle densities in the study area, and therefore cannot draw definitive conclusions on relationships between stocking rates and sage-grouse use.

We detected increased sage-grouse use of older PJ treatments. Although not statistically significant, this observation may be biologically important. Areas that have had time to recover post-treatment generally exhibit better shrub, forb, and grass cover depending on pre-treatment conditions (Roundy et al. 2014). As vegetation responds over time to management treatments, sage-grouse may have increased opportunities to move into new habitat areas (Dahlgren et al. 2006, Fedy et al. 2012).

MANAGEMENT IMPLICATIONS

Our results demonstrate that PJ treatments intended to increase usable space for sage-grouse habitat should be placed adjacent to areas currently occupied by sage-grouse. Additionally, PJ reduction projects should be sited in areas that minimize surrounding PJ canopy cover and maximize mesic areas within 1 km. The selection of PJ removal project areas should consider present vegetation communities and prioritize areas with higher shrub, perennial grass, and forb cover for treatment.

Continuing to remove PJ from sagebrush ecological sites will likely increase the amount of useable space available for sage-grouse in areas where habitat may be a limiting factor. Although we demonstrated the factors that enhanced sage-grouse use of our study sites, we were not able to document an effect on population vital rates. Therefore, we recommend the implementation and continued monitoring of large-scale PJ removal experiments to determine the effect of these projects on sage-grouse population dynamics.

LITERATURE CITED

- Atamian, M. T., J. S. Sedinger, J. S. Heaton, and E. J. Blomberg. 2010. Landscape-level assessment of brood rearing habitat for greater sage-grouse in Nevada. *Journal of Wildlife Management* 74:1533–1543.
- Baruch-Mordo, S., J. S. Evans, J. P. Severson, D. E. Naugle, J. D. Maestas, J. M. Kiesecker, M. J. Falkowski, C. A. Hagen, and K. P. Reese. 2013. Saving sage-grouse from the trees: a proactive solution to reducing a key threat to a candidate species. *Biological Conservation* 167:233–241.
- Beck, J. L., D. L. Mitchell, and B. D. Maxfield. 2003. Changes in the distribution and status of sage-grouse in Utah. *Western North American Naturalist* 63:203–214.
- Burnett, A. C. 2013. Modeling habitat use of a fringe Greater Sage-grouse population at multiple spatial scales. Thesis, Utah State University, Logan, Utah, USA.
- Cain, D. 1971. The Ely chain. Bureau of Land Management. Ely, Nevada, USA.
- Casazza, M. L., P. S. Coates, and C. T. Overton. 2011. Linking habitat selection and brood success in greater sage-grouse. *Ecology, conservation, and management of grouse. Studies in Avian Biology* 39:151–167.
- Cirrus Ecological Solutions and Logan Simpson Design. 2013. West Box Elder county coordinated resource management plan. Logan, Utah, USA.
- Coultrap, D. E., K. O. Fulgham, D. L. Lancaster, J. Gustafson, D. F. Lile, and M. R. George. 2008. Relationships between western juniper (*Juniperus occidentalis*) and understory vegetation. *Invasive Plant Science and Management* 1:3–11.

- Commons, M. L., R. K. Baydack, and C. E. Braun. 1999. Sage grouse response to pinyon-juniper management. Pages 238–239 in USDA Forest Service Proceedings RMRS-P-9, Ogden, Utah, USA.
- Connelly, J. W., S. T. Knick, M. A. Schroeder, and S. J. Stiver. 2004. Conservation assessment of greater sage-grouse and sagebrush habitats. Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming, USA.
- Connelly, J. W., K. P. Reese, and M. A. Schroeder. 2003. Monitoring of greater sage-grouse habitats and populations. College of Natural Resources Experiment Station, University of Idaho, Moscow, Idaho, USA.
- Connelly, J. W., E. T. Rinkes, and C. E. Braun. 2011. Characteristics of greater sage-grouse habitats: a landscape species at micro- and macroscales. Pages 69–83 in S. T. Knick and J. W. Connelly, editors. Greater sage-grouse: ecology and conservation of a landscape species and its habitats. Volume 38. Studies in Avian Biology, University of California Press, Berkeley, California, USA.
- Connelly, J. W., M. A. Schroeder, A. R. Sands, and C. E. Braun. 2000. Guidelines to manage sage grouse populations and their habitats. Wildlife Society Bulletin 28:967–985.
- Dahlgren, D. K., R. Chi, and T. A. Messmer. 2006. Greater sage-grouse response to sagebrush management in Utah. Wildlife Society Bulletin 34:975–985.
- Doherty, K. E., D. E. Naugle, B. L. Walker, and J. M. Graham. 2008. Greater sage-grouse winter habitat selection and energy development. Journal of Wildlife Management 72:187–195.

- Doherty, K. E., D. E. Naugle, and B. L. Walker. 2010. Greater sage-grouse nesting habitat: The importance of managing at multiple scales. *Journal of Wildlife Management* 74:1544–1553.
- Duvuvuei, O. V. 2013. Vital rates, population trends, and habitat-use patterns of a translocated greater sage-grouse population: implications for future translocations. Thesis, Utah State University, Logan, Utah, USA.
- Dzialak, M. R., C. V. Olson, S. M. Harju, S. L. Webb, J. P. Mudd, J. B. Winstead, and L. Hayden-Wing. 2011. Identifying and prioritizing greater sage-grouse nesting and brood-rearing habitat for conservation in human-modified landscapes. *PLoS ONE* 6:e26273.
- Evans, R. A., and R. M. Love. 1957. The step-point method of sampling-a practical tool in range research. *Journal of Range Management* 10:208-212
- Fedy, B. C., C. L. Aldridge, K. E. Doherty, M. O'Donnell, J. L. Beck, B. Bedrosian, M. J. Holloran, G. D. Johnson, N. W. Kaczor, and C. P. Kirol. 2012. Interseasonal movements of greater sage-grouse, migratory behavior, and an assessment of the core regions concept in Wyoming. *Journal of Wildlife Management* 76:1062–1071.
- Fisher, R. A. 1922. On the interpretation of χ^2 from contingency tables, and the calculation of P. *Journal of the Royal Statistical Society* 85:87–94.
- Frey, S. N., R. Curtis, and K. Heaton. 2013. Response of a small population of greater sage-grouse to tree removal: implications of limiting factors. *Human-Wildlife Interactions* 7:260–272.

- Giesen, K. M., T. J. Schoenberg, and C. E. Braun. 1982. Methods for trapping sage grouse in Colorado. *Wildlife Society Bulletin* 10:224–231.
- Graham, S. E. 2013. Greater sage-grouse habitat selection and use patterns in response to vegetation management practices in northwestern Utah. Thesis, Utah State University, Logan, Utah, USA.
- Gruber, N. W. 2012. Population dynamics and movements of translocated and resident greater sage-grouse on Anthro Mountain, Utah. Thesis, Utah State University, Logan, Utah, USA.
- Guthery, F. S. 1997. A philosophy of habitat management for northern bobwhites. *Journal of Wildlife Management* 61:291–301.
- Gutierrez, M. R. 2011. Ecology and management of a high elevation southern range greater sage-grouse population: vegetation manipulation, early chick survival, and hunter motivations. Dissertation, Utah State University, Logan, Utah, USA.
- Hanser, S. E., C. L. Aldridge, M. Leu, M. M. Rowland, S. E. Nielsen, and S. T. Knick. 2011. Greater sage-grouse: general use and roost site occurrence with pellet counts as a measure of relative abundance. Pages 112–140 in Sagebrush ecosystem conservation and management: ecoregional assessment tools and models for the Wyoming Basins. Allen Press, Lawrence, Kansas, USA.
- Herrick, J. E., J. W. Van Zee, K. M. Havstad, L. M. Burkett, and W. G. Whitford. 2005. Monitoring manual for grassland, shrubland and savanna ecosystems. USDA-ARS Jornada Experimental Range, Las Cruces, New Mexico, USA.
- Jankowski M. D., R. E. Russell, J. C. Franson, R. J. Dusek, M. K. Hines, M. Gregg, and E. K. Hofmeister. 2014. Corticosterone metabolite concentrations in greater sage-

- grouse are positively associated with the presence of cattle grazing. *Rangeland Ecology & Management*: 67:237–246.
- Klebenow, D. A. 1969. Sage grouse nesting and brood habitat in Idaho. *Journal of Wildlife Management* 33:649–662.
- Miller, R. F., and L. Eddleman. 2000. Spatial and temporal changes of sage grouse habitat in the sagebrush biome. Oregon State University, Agricultural Experiment Station, Corvallis, Oregon, USA.
- Miller, R. F., S. T. Knick, D. A. Pyke, C. W. Meinke, S. E. Hanser, M. J. Wisdom, and A. L. Hild. 2011. Characteristics of sagebrush habitats and limitations to long-term conservation. Pages 69–83 in S. T. Knick and J. W. Connelly, editors *Greater sage-grouse: ecology and conservation of a landscape species and its habitats*. Volume 38. *Studies in Avian Biology*, University of California Press, Berkeley, California, USA.
- Miller, R. F., T. J. Svejcar, and J. A. Rose. 2000. Impacts of western juniper on plant community composition and structure. *Journal of Range Management* 53:574–585.
- Miller, R. F. 2005. Biology, ecology, and management of western juniper (*Juniperus occidentalis*). Agricultural Experiment Station, Oregon State University, Corvallis, Oregon, USA.
- Rice, W. R. 1989. Analyzing tables of statistical tests. *Evolution* 43:223–225.
- Robinson, J. D. 2007. Ecology of two geographically distinct greater sage-grouse populations inhabiting Utah's West Desert. Utah State University, Logan, Utah, USA.

- Roundy, B. A., R. F. Miller, R. J. Tausch, K. Young, A. Hulet, B. Rau, B. Jessop, J. C. Chambers, and D. Egget. 2014. Understory cover responses to piñon-juniper treatments across tree dominance gradients in the Great Basin. *Rangeland Ecology & Management* 67:482–494.
- Sankey, T. T., and M. J. Germino. 2008. Assessment of juniper encroachment with the use of satellite imagery and geospatial data. *Rangeland Ecology & Management* 61:412–418.
- Schroeder, M. A., C. L. Aldridge, A. D. Apa, J. R. Bohne, C. E. Braun, S. D. Bunnell, J. W. Connelly, P. A. Deibert, S. C. Gardner, and M. A. Hilliard. 2004. Distribution of sage-grouse in North America. *Condor* 106:363–376.
- Stiver, S. J., A. D. Apa, J. R. Bohne, S. D. Bunnell, P. A. Deibert, S. C. Gardner, M. A. Hilliard, C. W. McCarthy, and M. A. Schroeder. 2006. Greater sage-grouse comprehensive conservation strategy. Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming, USA.
- UDWR [Utah Division of Wildlife Resources]. 2009. Utah greater sage-grouse management plan. Utah Department of Natural Resources, Division of Wildlife Resources, Publication 09-17, Salt Lake City, Utah, USA.
- UDWR [Utah Division of Wildlife Resources] 2013 Greater sage-grouse occupied leks. <<http://dwrcdc.nr.utah.gov/ucdc/downloadgis/disclaim.htm>>. Accessed 10 December 2013.
- USFWS [U.S. Fish and Wildlife Service]. 2010. Endangered and threatened wildlife and plants; 12-month finding for petitions to list the Greater Sage-Grouse (*Centrocercus urophasianus*). *Federal Register* 75:13910-13598.

- USFWS [U.S. Fish and Wildlife Service]. 2013. Greater sage-grouse (*Centrocercus urophasianus*) conservation objectives: final report. U.S. Fish and Wildlife Service, Denver, Colorado, USA.
- USGS [United State Geological Survey] LANDFIRE Existing Vegetation Type Layer. 2010. <<http://landfire.cr.usgs.gov/viewer>>. Accessed 12 Dec 2014.
- Utah AGRC. 2013. Land Ownership. <<http://gis.utah.gov/data/sgid-cadastre/land-ownership/>>. Accessed 12 Nov 2013.
- Utah AGRC. 2014. Water Data. <<http://gis.utah.gov/data/water-data-services/>>. Accessed 5 Feb 2014.
- Utah Governor's Office. 2013. Conservation Plan for Greater Sage-grouse in Utah. Utah's Public Lands Policy Coordination Office, Salt Lake City, Utah, USA.
- Utah Watershed Restoration Initiative [WRI]. 2014. WRI homepage.
<<http://wildlife.utah.gov/watersheds>>
- Wakkinen, W. L., K. P. Reese, J. W. Connelly, and R. A. Fischer. 1992. An improved spotlighting technique for capturing sage grouse. *Wildlife Society Bulletin* 20:425–426.
- Wallestad, R. O. 1971. Summer movements and habitat use by sage grouse broods in central Montana. *Journal of Wildlife Management* 38:129–136.
- Weisberg, P. J., E. Lingua, and R. B. Pillai. 2007. Spatial patterns of pinyon-juniper woodland expansion in central Nevada. *Rangeland Ecology & Management*. 60:115–124.
- Western Regional Climate Center. 2013. Climate Summary.
<<http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ut7408>>. Accessed 6 Dec 2013.

Table 3-1. Grouped LANDFIRE land cover classifications (USGS 2010) present in buffers surrounding conifer reduction projects in West Box Elder County, Utah evaluated in 2013 for greater sage-grouse (*Centrocercus urophasianus*) use.

Landcover Groups
Pinyon-Juniper
Great Basin Pinyon Juniper Woodland
Inter Mountain Basins Juniper Savanna
Sagebrush
Artemisia Tridentata Ssp Vaseyana Shrubland Alliance
Columbia Plateau Low Sagebrush Steppe
Great Basin Xeric Mixed Sagebrush Shrubland
Inter Mountain Basins Big Sagebrush Shrubland
Inter Mountain Basins Big Sagebrush Steppe
Inter Mountain Basins Montane Sagebrush Steppe
Inter Mountain Basins Semi Desert Shrub Steppe
Agriculture
Close Grown Crop
Fallow Idle Cropland
Pasture And Hayland
Row Crop
Wheat
Mesic
Inter Mountain Basins Montane Riparian Systems
Rocky Mountain Bigtooth Maple Ravine Woodland
Rocky Mountain Montane Riparian Systems
Rocky Mountain Subalpine Montane Mesic Meadow
Urban

Developed Low Intensity
Urban Deciduous Forest
Urban Evergreen Forest
Urban Herbaceous
Urban Shrubland

Other
Barren
Developed Roads
Developed Ruderal Deciduous Forest
Developed Ruderal Grassland
Developed Ruderal Shrubland

Inter Mountain Basins Curl Leaf Mountain Mahogany Woodland

Inter Mountain Basins Greasewood Flat
Inter Mountain Basins Mixed Salt Desert Scrub
Inter Mountain Basins Semi Desert Grassland
Inter Mountain Basins Sparsely Vegetated Systems

Introduced Upland Vegetation Annual And Biennial Forbland

Introduced Upland Vegetation Annual Grassland
Introduced Upland Vegetation Perennial Grassland And Forbland

Rocky Mountain Alpine Montane Sparsely Vegetated Systems
Rocky Mountain Aspen Forest And Woodland
Rocky Mountain Gambel Oak Mixed Montane Shrubland
Rocky Mountain Lower Montane Foothill Shrubland
Southern Rocky Mountain Montane Subalpine Grassland

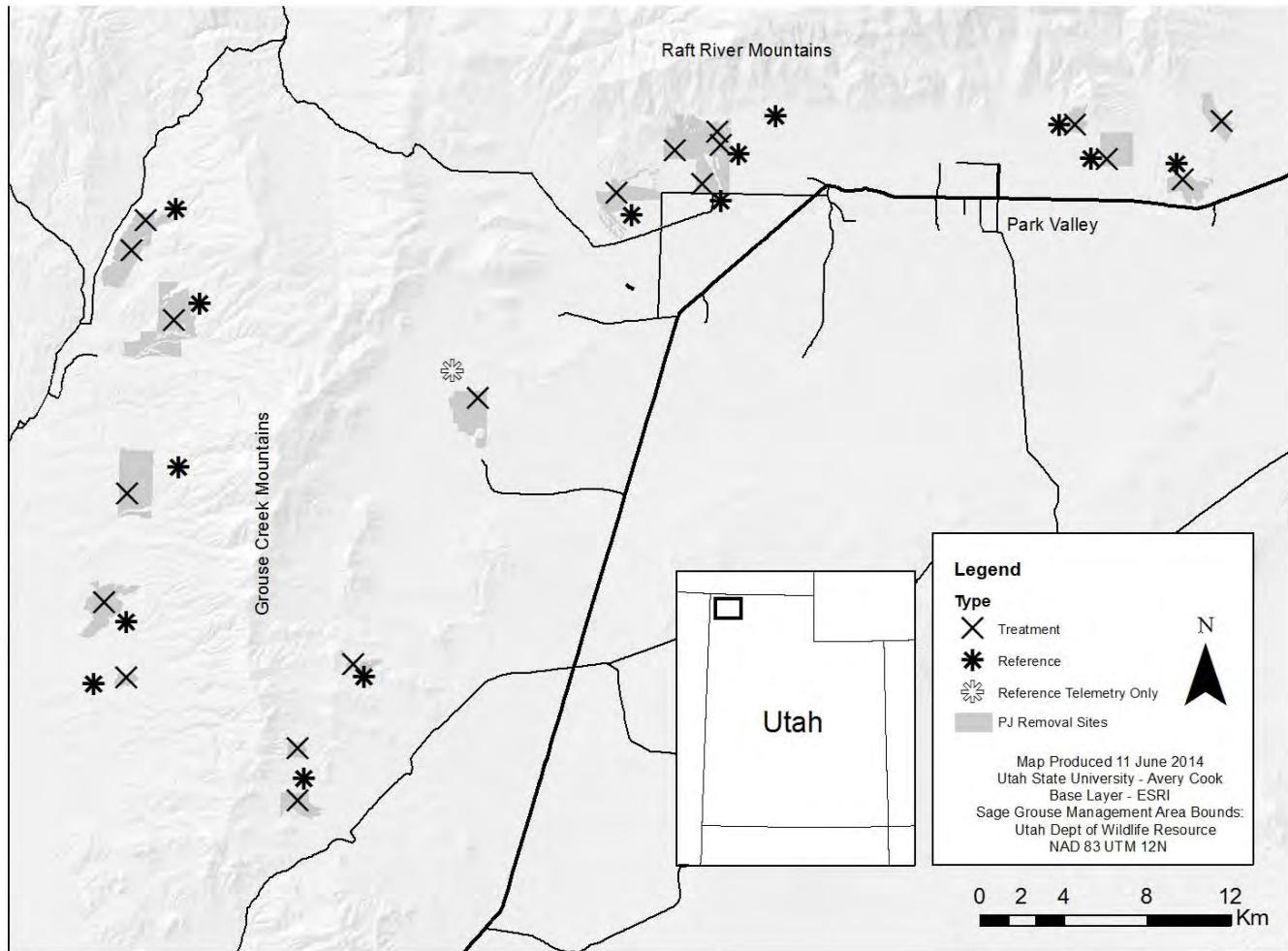


Figure 3-1. Conifer removal projects with treatment and reference plots surveyed in 2013 evaluating greater sage-grouse (*Centrocercus urophasianus*) use and habitat characteristics in Utah's West Box Elder Sage-grouse Management Area.

CHAPTER 4

GREATER SAGE-GROUSE SURVIVAL AND REPRODUCTIVE SUCCESS RELATIVE TO ENVIRONMENTAL CONDITIONS AND BEHAVIOR

ABSTRACT

In 2010, the U.S. Fish and Wildlife Service identified the greater sage-grouse (*Centrocercus urophasianus*; sage-grouse), as a candidate for protection under the Endangered Species Act of 1973. Prior to and since this decision, mounting conservation concern has led to increasing numbers research projects to provide information to guide conservation efforts, with an average of 22 studies per year during the 1990s increasing to 69 in 2014. Most of these projects typically involve capturing, handling, radio-marking, and the subsequent monitoring of sage-grouse to determine habitat use and vital rates. Biologists have expressed concerns that differences in individual bird behavior could not only affect capture potentials but also bias reported vital rates. Although capture-related mortality has been previously documented in other gallinaceous species, no information has been published regarding the potential effects on sage-grouse. We monitored 204 radio-marked sage-grouse in northern Utah between January 2012 and March 2013 to determine if nest success, brood and annual survival differed relative to capture circumstances. Sage-grouse that flushed one or more times prior to capture had higher brood ($P = 0.014$) and annual survival ($P = 0.027$) than those that did not. Sage-grouse that experienced more capture trauma had decreased survival probabilities ($P = 0.035$). Our results suggest researchers need to consider the effects of capture and handling when reporting sage-grouse vital rates obtained through radio-marking.

INTRODUCTION

Greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) populations have been declining range-wide for the last century (Connelly et al. 2004). The observed declines parallel reported reductions in the species historic range (Schroeder et al. 2004). The observed populations declines have been largely attributed to the deterioration, loss, and fragmentation of sagebrush (*Artemisia spp.*) habitats (Connelly et al. 2011). In Utah, sage-grouse are believed to occupy 41% of historic habitats (Beck et al. 2003). The largest Utah populations are found in Box Elder, Garfield, Rich, Uintah, and Wayne Counties (Beck et al. 2003).

Because of continued habitat loss and fragmentation, the US Fish and Wildlife Service (USFWS) identified sage-grouse as a candidate species for listing for protection under the Endangered Species Act of 1973 (USFWS 2010). This discussion reversed a 2005 USFWS decision which stated listing the species was unwarranted (USFWS 2005). Prior to and subsequent to these actions, stakeholders expressed concern that the information available to managers to guide conservation and management was limited. In response to these growing concerns, the number of regional and state-based ecological studies initiated has steadily increased. Google Scholar (<http://scholar.google.com>) results for articles containing “*Centrocercus urophasianus*” or “sage-grouse” in the title showed an average of 23 documents published in 1990s, with publications numbers following an increasing trend to over 69 published in 2014.

Most sage-grouse field studies involve sage-grouse capture and handling, radio-marking or banding, followed by monitoring to document habitat use and vital rates. Effects of the markings such as poncho and harness mounted radios on sharp-tailed

grouse (*Tympanuchus phasianellus*; Amstrup 1980, Marks and Marks 1987), necklace mounted radios on lesser prairie chickens (*Tympanuchus pallidicinctus*; Hagen et al. 2006), as well as effects of color, mounting system, and shape (Small and Rusch 1985, Boitani and Fuller 2000, Caudill et al. 2013, Frye et al. 2014) have been studied. However, there has been very little study of possible acute and chronic effects from capture and handling required to equip sage-grouse with telemetry transmitters, other markings, or behavioral impacts on capture probability and survival (Caudill et al. 2013).

Mortalities attributed to the capture and handling of sage-grouse are relatively rare (Giesen et al. 1982, Utah State University, unpublished data). However, sub-lethal effects of capture, which are difficult to detect in the field, could also affect vital rates post-capture (Abbott et al. 2005). These lasting, sub-lethal effects of capture, if present, may cause decreased response to predators (Abbott et al. 2005), other behavioral alterations such as difficulty with coordination, or even inability to walk or fly (Ponjoan et al. 2008). Undetected tissue damage to skeletal and cardiac muscle can cause mortality days after the release of the bird making it difficult to directly attribute capture effects to a mortality (Friend and Thomas 1999).

Abbott et al. (2005) suggested that studies finding no effect of transmitters on survival and reproduction may have a false null effect due to similar handling effects of treatment and control groups. General factors that can increase risk during capture include high ambient temperatures, dietary deficiencies in selenium and/or vitamin E, stressful capture methods (Spraker et al. 1987, Höfle et al. 2004), and handling time (Beringer et al. 1996, Ponjoan et al. 2008).

Although studies on handling effects are rare due to the difficulty of establishing a control group (Hagen et al. 2006), studies on other galliformes suggest the possibility of deleterious effects due to capture and handling. Abbott et al. (2005) reported treating northern bobwhite (*Colinus virginianus*) for muscular damage via an injection of Vitamin E and selenium increased survival from 29% to 58% at 45 days when compared to a control group injected with a saline solution. Their results suggested that stress related to handling during capture affected survival. Höfle et al. (2004) reported 30% of red-legged partridge captured using spotlight and hoop net techniques (*Alectoris rufa*) died within hours as a result of capture myopathy and self-injury from attempting to remove necklace radiotags. Ponjoan et al. (2008) found 15% of radio tagged little bustard (*Tetrax tetrax*) captured using leg snares, cannon nets or funnel traps suffered from impaired mobility and coordination upon release as a result of capture myopathy. Höfle et al. (2004) also reported that higher death rates were associated with lower mean temperatures and capture methods, with spotlight and net trapping methods leading to higher mortality relative to baited wire cage traps.

Because logistical constraints make it impossible to follow unmarked sage-grouse for even short periods of time, we used biological and behavioral data recorded during the handling and monitoring of radio-marked individuals to test the hypotheses bird behavior prior to during capture and handling, physical condition ,and activities associated with handling and release are not related to reported vital rates.

STUDY AREA

We used data collected from two sage-grouse studies conducted in 2012-2013 in Box Elder County and Rich County, Utah (Fig. 4-1). The West Box Elder (WBE) study site is at the southeast extent of the Snake River Plane sage-grouse management zone (Management Zone II) (Connelly et al. 2004, Stiver et al. 2006, Knick 2011). The WBE study site was part of the Raft River and Pilot Mountain subunits of the WBE Resource Area defined in the 2002 Utah Sage Grouse Plan (UDWR 2002), in the northwest corner of Utah. The WBE Resource Area encompassed 688,877 ha of mixed private, state and federal land (Utah 2011).

Vegetation in the study area varied with elevation, from salt desert scrub at low elevations through various sagebrush communities and into juniper (*Juniperus* spp.) and mahogany (*Cercocarpus ledifolius*) woodlands at higher elevations. Elevations ranged from 1,400 m to 3,000 m above sea level.

From 1990 to 2012 weather data from Rosette, a small town at the center of the WBE study site (1732 m elevation) indicated annual precipitation averaged 22.6 cm with 14.2 cm, occurring as snow between November and April. Temperatures ranged from a monthly average high of 30°C in July to a monthly average low of -9.4°C in December and January (WRCC 2013). Snow does not typically persist through spring at lower elevations but can remain at high elevations into late summer. Greater levels of snowfall and colder temperatures exist at higher elevations compared to the relatively low elevation of the weather station. During the 2012 field season, the study area experienced a dry winter and unusually early spring. The 2013 field season was preceded by a colder

winter with below average precipitation, but increased persistence of snow on the ground into the spring and increased summer moisture.

The Rich County (RC) study site was in the northeast corner of Utah, in the southwestern portion of the Wyoming Basin Sage-grouse Management Zone II (Connelly et al. 2004, Knick 2011). The study encompassed two adjacent sites: the Deseret Land and Livestock ranch composed of 80,600 ha of private land and 6,300 ha of BLM land, and Three Creeks, composed of 56,000 ha of mixed private, BLM, and USFS land (Dettenmaier and Messmer 2013).

Both RC Sites consist of sagebrush steppe dominated by Wyoming big sagebrush (*A. tridentata wyomingensis*) and a bunchgrass understory with aspen (*Populus tremuloides*), and conifer forest at higher elevations. Elevation ranges from 1900 to 2600 m above sea level. Mean annual precipitation ranges from 25.0 cm in the lower elevations to 45.7 mm at higher elevations. Roughly half of precipitation occurs as snow from December to March with mean temperatures ranging from 28.7° C in July to -6° C in January (Dettenmaier and Messmer 2013).

METHODS

Capture and Handling

We trapped female and male sage-grouse near leks in the WBE study area in the spring of 2013 and 2014 and the fall of 2012 and the winter and spring of 2013 using a spotlight, hoop net, and all-terrain vehicle (Giesen et al. 1982, Wakkinen et al. 1992, Connelly et al. 2003). Sage-grouse were concurrently but independently captured on the RC study site using the same methods (Dettenmaier and Messmer 2013). Each sage-grouse was equipped with a very high frequency (VHF) radio collar (Advanced

Telemetry Systems, Isanti, MN, model A4050) weighing approximately 22 g with necklace (1-2% of body weight), and an individually numbered aluminum leg band (National Band Company size 16 for males and size 14 for females). We determined age of each bird based on the appearance of primaries 9 and 10, sex was determined by general plumage characteristics, and size (Eng 1955, Connelly et al. 2003). This research was conducted under protocols approved by the Utah State University Institutional Animal Care and Use Committee permit #1547 (Box Elder), and #2322 (Rich County), and Utah Division of Wildlife Resources (UDWR) Certificate of Registration number 2BAND8743 (Box Elder), and 2BAND8744 (Rich County).

Captured sage-grouse were classified as minimally processed (MP) or a fully processed (FP). Treatments were assigned via a systematic random sample based on sex; the first bird captured of each sex assigned to one group. Each subsequent capture alternated treatments, with each sex tracked separately. We did not stratify treatments by age because we were primarily interested in trapping effects on the study population as a whole, and stratifying samples by both sex and age would have reduced our effective sample size and complicated logistics.

The MP birds were fitted with a radio collar and leg band then aged. The MP birds were released by being placed on the ground facing away from field personnel and equipment. The FP birds were further handled to measure tarsus, wing chord, and head length. A contour feather was collected to provide a genetic sample. Finally, the bird was placed in a bag and weighed before being released in the same manner as the MP group.

We recorded additional metrics classifying individual bird behavior and handling characteristics displayed during the capture using a scale of 1 to 5 (Table 4-1). Additional covariates recorded for each captured and radio-marked bird included: handling time (time from capture to release), previously flushed (if the trapping crew had flushed the bird one or more times prior to capture, and were able to follow the individual and capture it), roost pile (if there was a roost pile under the bird upon capture), and low (daily low temperature from the nearest weather station), morphometric measurements (mass, tarsus, cord; MP group only), sex, age, and location (GPS coordinates).

Telemetry

Beginning mid-March, we located radio collared females 2-3 times per week to monitor movements and nesting status. Because of sage-grouse's propensity to abandon nests when flushed (Connelly et al. 2003) observers avoided flushing females during the nesting season by walking an approximately 30 m diameter loop around the hen while recording the path walked on a handheld global positioning system (GPS) unit. The track was then used to plot the bird location at the center of the loop. This method was quicker and more accurate than recording bearings and later calculating a location. Further, this method provided a simple, easy method to judge hen movement on subsequent visits. If a hen was located in the same area during two subsequent locations, it was assumed to be nesting and we approached to visually confirm nesting status and nest location from as great a distance as possible. If the hen was not visually located within 10 minutes, the attempt to visually locate the bird was stopped and reattempted on the next visit. If the hen was found to be nesting, we recorded the observation location, bearing to nest,

distance to nest, and marked an observation location with a small, discreet line of rocks to aid observers in to re-sighting the nest.

Confirmed nests were monitored 2-3 times per week from a distance of >7 m to record nesting status. Nest success was recorded by inspecting the nest remains on the visit immediately after a hen had left the nest. Nests were deemed successful if eggs were split equatorially, the fragments left relatively intact, and the inner membrane had separated from the shell (Rearden 1951), or if the hen was found accompanied by a brood. Predated nests were identified by eggs being crushed, fragmented, punctured or completely absent from the nest (Patterson 1952). We searched the area surrounding each predicated or successful nest for egg fragments removed by the hen or scavengers and matched top/bottom pairs to determine minimum clutch size. When a hen was not present but eggs were intact, we returned the following visit to determine if the nest was abandoned or if the hen was on an incubation break. Nests were considered abandoned if a hen was absent on two subsequent visits and eggs were cold. Nests were considered successful if one or more eggs hatched. Date of nest failure was calculated as the midpoint between observations following Schroeder (1997); however, last known alive and last checked dates were used for modeling purposes.

After a clutch hatched, hen and brood locations were observed 2-3 times per week. Broods were counted at 50 days of age to determine size of the surviving brood (Schroeder 1997, Knerr 2007, Graham 2013). Counts were conducted via visual day time searches starting at the hen's location and systematically searching in an outward spiral pattern to 50 m from the hen location. A brood was considered successful if one or more chicks survived to 50 days. Dahlgren et al. (2010b) reported more accurate counts using

spotlighting searches relative to day time searches. However, his testing of spotlight vs walk up counts was done on Parker Mountain, an area dominated by high visibility landscapes of black sagebrush. In the Park Valley study area, daytime searches were more effective. Brood hens in this study were generally encountered in areas of tall big sagebrush and mixed mountain shrub communities, reducing visibility and detectability of spotlight eye shine. Visual daytime searches may have only detected roughly $\frac{3}{4}$ of chicks in a brood, possibly inducing a low bias relative to the true count (Dahlgren et al. 2010*b*).

After broods reached 50 days of age, hens were monitored biweekly to monitor survival. Males were also located biweekly throughout the spring, summer and fall field seasons. Due to limited winter access, all birds were only located 1 to 3 times during the winter season via ground and aerial telemetry. Most WBE birds were tracked through November 2013, which allowed us to use two years of data to estimate survival probabilities. Radio collars deployed in winter and spring of 2012 did not have sufficient battery life to track into late fall and winter of 2013 and were censored from the last quarterly survival period.

Data Analysis

We used program MARK (White and Burnham 1999) to build and evaluate nest success models for nesting and brood success and known-fate models to evaluate annual survival. We built nest success models incorporating single or combinations of capture covariates to estimate daily survival rates (DSR) and describe influence capture covariates on nest and brood survival. Nesting attempts were pooled among years and sites to increase power, a season start date for modeling purposes was chosen as the first

date a nest was detected across years and study sites. Our modeled nesting season was 76 days (13 April to 29 June). Brood locations were also pooled across years and study sites to define a brood season of 91 days (3 May to 2 August). Known-fate models were built in program MARK to estimate annual survival probability within and across sites. Known-fate locations for the BE study site were binned into quarterly detection periods, from January 2012 to December, 2013, for 8 detection periods used to estimate annual survival rates. Known-fate locations to compare capture effects and study site differences (both WBE and RC) were binned into 7 quarters, from January 2012 to September 2013, the final October to December 2013 quarter was censored due to insufficient data. Individual covariates recorded on ordinal and interval scales were binned to increase power and allow for pairwise comparison of survival estimates (Table 4-1).

Models were constructed with biologically relevant a priori combinations of covariates, and ranked using Akaike Information Criterion adjusted for small samples sizes (AICc) (Burnham and Anderson 2002). Models ranking within two AIC units of the top model were considered to have approximately equal weight and were averaged to estimate overall survival rates. Models between 2 and 7 AIC units from the top model were considered to have considerable support for showing true differences in data and survival rates (White and Burnham 1999). Models less than 7 AIC units from the top model and some poorer ranking a priori models were run with covariates fixed to estimate survival rates for each covariate group. Nesting, brood and overall survival rates associated with binned covariates were tested for significant differences using a Wald z test (Agresti 1996). Maximum likelihood estimates of survival rates (real parameter

estimates) were calculated using a logit link function in program MARK (White and Burnham 1999).

Daily Survival Rates (DSR) calculated for both a 27 day nesting period (Schroeder 1997, Connelly et al. 2011) and a 35 day laying and incubation periods to aid in comparability with other studies. The 35 day laying and nest period was determined by adding 8 days to the incubation period (Connelly et al. 2011; range 7-10 days). Nest DSRs were raised to the 27th and 35th power to calculate nest survival rates. Brood DSRs were raised to the 50th power to calculate the probability of a brood having at least one chick live to independence (50 days). Annual survival rates were calculated as the product of four quarterly maximum likelihood survival estimates output from known-fate models. Associated variance and 95% confidence intervals for nest, brood, and annual survival were calculated using the delta method (Seber 1982).

RESULTS

During the study period, we captured and recorded data from 204 sage grouse: 144 hens and 60 males. We captured 114 sage-grouse in WBE, and 101 in RC. Eleven RC birds were not available for analysis due to non-detection post release leaving 90 birds available for analysis.

Observed capture effects varied by individual bird. Seventy-four percent (150 of 204) did not display signs of stress upon release with 26% (54 of 204) displaying some sign of stress, generally some degree of wheezing upon release. No mortalities were recorded (category 1) and the release condition scale was truncated for survival analysis. Eighty-four percent (171 of 204), were not flushed before capture; 33 of 204 flushed and were subsequently captured after they had landed (Table 4-2).

Nest Survival

We located 83 nests over the course of the 2012 and 2013 field seasons; 37 were from BE, 9 in 2012 and 28 in 2013. There were 46 nests located in RC, 26 in 2012 and 20 in 2013. Nesting season dates in WBE ranged from 13 April to 7 June, 2012 and 20 April to 15 June, 2013. Nesting season dates in RC ranged from 18 April to 5 June, 2012 and from 28 April to 29 June, 2013. Nine of 15 hens in 2012 and 28 of 37 hens in 2013 were recorded nesting in WBE, for apparent nest initiation rates of 60% and 76%, respectively. Thirty-two of 49 hens in 2012 and 28 of 59 hens in 2013 were recorded nesting in RC, for apparent nest initiation rates of 65% and 48%, respectively.

The top ranked nest survival model, S (age), did not include capture covariates. However, two models within 2 AICc points of the top model had capture covariates incorporated into survival estimates: S (ReleaseCondition) and S (Flushed). Eight nest survival models within 7 AIC units of the top model contained capture covariates (Table 4-3). Based on the S (site) nest survival model, 27 day nest success in WBE was 47.3% (95% CI: 30.8, 63.8, n = 37), 27.8% (95% CI: 12.1, 43.5; n = 31) in Three Creeks, and 37.5% (95% CI: 26.5, 48.6; n = 15) on Deseret Land and Livestock. Nest survival rates differed between the WBE and Three Creeks study sites ($P = 0.047$). Overall model averaged nest success at 27 days from the top seven models within 2 AIC units of the top model (Table 4-3) was 38.0% (95% CI: 26.9, 49.1), and was calculated across study sites and years. Nest success was estimated at 28.5% (95% CI: 17.7, 39.3) over a 35 days period accounting for incubation and laying.

Model results differed for nest success between yearling breeding hens and adult hens ($P = 0.089$) across sites and years. Adult and yearling hens 27 day nest success rate

was 45.6% (95% CI: 29.5, 61.8; n = 39) and 30.8% (95% CI: 16.2, 45.3; n = 44), respectively. Release condition of the birds may have influenced nesting success ($P = 0.076$), with modeled nest success rates for birds in poorer release condition (category 1 to 4) at 33.3% (95% CI: 20.9, 45.6; n = 62) and better condition birds at 51.8% (95% CI: 29.6, 74.1; n = 21). Models parameterizing interactions between age and release condition preformed more poorly than the null model, and did not indicate interaction between age, release condition, and nest success. Estimated nest success rates differed ($P = 0.102$) for flushed birds, and birds not flushed prior to capture was 28.4% (95% CI: 10.9, 46.0; n = 27) and 42.9% (95% CI: 29.1, 56.6; n = 56), respectively. No interactions were found between age and flushing status on nest survival. However, a larger sample size is needed to differentiate between statistical anomaly and biological effect. Other covariates were not biologically significant (Tables 4-4 and 4-5).

Brood Survival

We monitored 43 broods over the 2012 and 2013 field seasons, 26 in WBE and 17 in RC study areas. Brood season dates in WBE ran from 14 May to 16 July, 2012 and 3 May to 2 August, 2013, and from 12 May to 24 July, 2012 and 5 June to 28 July, 2013 in RC. The top models with data combined across study sites and years did include a capture covariate as well as county in a time invariant model (S[Flushed+County]). A single other model was within 2 AIC points, and included only the county covariate (S[County]). Broods pooled across years and study sites had differing 50 day survival rates ($P = 0.014$) with flushed hens successfully raising 74.4% (95% CI: 52.8, 96.0) of broods and hens captured before flushing successfully raising 42.2% (95% CI: 23.1, 61.3) of broods. In WBE, brood survival estimates showed a 19.8% difference ($P = 0.102$)

between flushed and non-flushed groups with survival probabilities of 81.2% (95% CI: 63.1, 99.3) and 61.4% (95% CI: 36.8, 86.1), respectively. The RC brood survival estimates showed a 27.0% difference ($P = 0.084$) in survival between flushed and non-flushed groups with survival probabilities of 23.5% (95% CI: 2.3, 44.7) and 53.7% (95% CI: 16.4, 91.0), respectively.

All other evaluated capture covariates produced models within 7 AIC points of the top model, except an over-parameterized time varying model (Table 4-6). Overall brood success from across study sites and years calculated using model averages of the 2 top models is 59.6% (95% CI: 43.0 76.1) at 50 days of age. Brood survival rates differed between study sites ($P = 0.002$) as estimated by the model incorporating study county as a covariate (S[County]); RC study site had an average brood survival rate of 30.5% (95% CI: 8.9, 52.0, n = 14), and WBE study site had a brood survival rate of 71.0% (95% CI: 53.1 89.0, n = 26).

Predicted brood survival rates differed based on capture covariates Flushed ($P = 0.014$), Roost ($P = 0.021$), and Daily Low ($P = 0.028$). Flushed and Roost are closely related due to the fact that when a bird has recently flushed it will not have built up a pile of fecal pellets and the data shows a significant association between covariates (Fisher's Exact Test: $P = 0.007$). Predicted survival rates for the two models are similar with widely overlapping confidence intervals. We reported the rates for the Flushed covariate due to its higher model ranking. Hens flushed once or more prior to capture exhibited a higher brood survival rate of 74.4% (95% CI: 52.8 96.0, n = 16) relative to 42.2% (95% CI: 23.1 61.3, n = 24) from hens that had not been flushed prior to capture.

Daily low temperature during capture also appeared to influence survival ($P = 0.028$). Birds captured on nights when the temperature stayed above freezing had brood survival rates estimated at 71.0% (95% CI: 49.6 92.3, $n = 17$), and hens captured on days with a low below freezing 42.5% (22.7 62.3, $n = 23$). However, this result is confounded by differences in average temperature between study sites and is likely an artefact of differing survival rates in each study site rather than a biological effect of temperature.

Adult Survival

Overall survival rates were calculated from 204 sage-grouse (144 hens and 60 males) over all study sites and years. Year and site covariates were included to account for differing survival between years and sites. Four birds died within 2 weeks of capture and but were not removed from the sample because this study was investigating survival relative to capture and handling.

Annual survival for the full 2 year duration of the study was only available for WBE. The top model for WBE was a fully time varying model incorporating sex and release time as covariates. Modes were not averaged for estimating annual survival; there were no models within two AIC points of the top model. The top model estimated a 42.0% probability (95%CI 31.4, 53.4) of a bird surviving the duration of the 2 year study. Survival rates differed between years for both males ($P = 0.022$) and females ($P = 0.021$), with higher survival in 2012 for both sexes. Males had a 64.0% (95% CI: 49.5, 78.5) annual survival probability in 2012 and a 39.8% (95%CI: 21.3, 58.4) annual survival probability in 2013. Hens have a higher survival probability each year relative to males ($P = 0.031$ in 2012 and $P = 0.144$ in 2013) with an 81.8% (95% CI: 70.0, 93.6) annual survival rate in 2012 and a 64.4% (95% CI: 52.5, 76.3) annual survival rate in 2013.

Quarterly survival remained relatively constant, with higher survival through the late winter in January-March, 2013, and lower survival April-June and October-December, 2013. October-December, 2013 was relatively poorly estimated due to censoring a large proportion of the study population as we lost signals from radios at the end of their design lives, and because of less intense monitoring during the fall relative to spring and summer (Fig. 4-2).

Capture covariates were analyzed using models incorporating data across both WBE and RC study sites and years. Survival rates reflect the probability of a bird surviving seven 3 month sampling periods from January 2012 to September 2013. These estimates are one sampling period short of a full 2 years due to unavailable data for RC in the final quarter of 2013. All top models were time varying by detection period.

Survival varied throughout the year with lower survival shown in the late fall period (October-December 2012) (Fig. 4-3). Covariates included in models within 2 AIC units of the top model were sex, capture hour, handling time, and flushing status (Table 4-8). The top model was $S(t+CapHr+Sex+RelTime)$, covariate effects below are compared using simplified a priori models.

Survival rates differed ($P = 0.027$) between birds that flushed once or more prior to capture 70.5% (95% CI: 49.6, 85.3) and birds captured before flushing (50.4% (95% CI: 41.6, 59.2) using the $S(t+Flushed)$ model. Sage-grouse survival rates differed ($P = 0.035$) by level of capture trauma and survival through the study period using the $S(t+CapTra)$ model; birds who were caught cleanly (category 5) had an estimated survival rate of 58.7% (95% CI: 48.7, 68.1) compared to birds who endured a rough capture (category ≤ 4) with a survival rate of 43.1% (95% CI: 30.1, 57.1). Release time

($P = 0.06$), Capture Hour ($P = 0.08$), and energy expended ($P = 0.07$) also differed between groups, but differences were not significant (Table 4-9).

Probability of surviving the study duration was slightly higher in RC relative to WBE, however the differences were relatively small, and there was not a robust relationship when hen ($P = 0.187$) and male ($P = 0.218$) survival was examined individually (Table 4-9). Four birds died within 2 weeks of capture, there was not any apparent relationship between any recorded capture covariate and death. Three of 4 birds were rated in best condition upon release, with clean captures. All showed mild to moderate struggle (categories 1-3) while being handled and were also evenly split between sexes, age, study sites, and processing group.

DISCUSSION

Nest Success

Top models suggest that some variation in nest success is accounted for by factors describing release condition and behavior characteristics. Propensity to flush was correlated with lower nest, but higher brood and annual survival rates. Release condition was correlated with nest survival, with birds being released in better condition having a higher chance of successfully hatching a brood. These factors have the potential to bias vital rates of a sample population relative to the study population.

A model incorporating release condition of the bird, describing if there were signs of stress exhibited at the time of release, may account for differences in nest success probabilities ($P = 0.083$). Sage-grouse in released in apparent better condition showed a survival rate of 42.7% at 35 days, which is within one standard deviation of the average nest success of 52.1% (SD: 18.2) for the western portion of sage-grouse range (Connelly

et al. 2011). However, the nest success probability for birds released in poorer condition dropped down to 24.0%, outside of one standard deviation of the western range average, and lower than all but one study reported by Connelly et al. (2011) that had a 15% apparent survival nest success rate (Gregg et al. 1994). If a similar study were repeated, it would be advisable to include more objective body condition measurements.

Previous sage-grouse studies in WBE reported varying nest success rates generally lower than the rangewide average reported by Connelly et al. (2011), and lower than estimated nest survival of hens in our study released in good condition (category 5 on a scale of 1 to 5, Table 4-1). Previously reported nest success rates in WBE are 38% (Knerr 2007), 50% (Thacker 2010; Apparent survival), and 24-28% (Graham 2013). Large differences in nest survival, 51.8% vs. 33.3%, based on release condition could have large impacts on the interpretation of study results and evaluations of a population's viability. Variation in release condition is not generally taken into account and survival estimates have the potential to vary greatly depending of the number of birds released in poor condition.

When nest success was modeled with flushing behavior nest survival rates at 35 days differed ($P = 0.099$) between birds that were flushed (19.6%, $n = 27$) and birds that were not (33.3%, $n = 56$), a 13.7% difference in probability of successfully laying and incubating a nest. Although this result is marginally significant it has the potential to be biologically important (Guthery 2008). Results were similar when daily survival rates were extrapolated to a 27 day nesting period with flushed birds having a 19.6%, and non-flushed birds having a 33.3% chance of surviving the incubation period. The difference in survival probability suggests that there may be behavioral traits related to willingness

to flush that influence the probability of a nest surviving to hatch. We were not able to detect an effect of interactions between age and flushing behavior on nest survival.

Sage-grouse exhibiting a greater willingness to flush in response to trapping crews may be more likely to flush in response to predators that have not detected the nesting hen, or in response to livestock, rancher, researcher, or other non-predator activity in the vicinity of the nest. Because sage-grouse readily abandon nests after flushing (Patterson 1952, Connelly et al. 2011), an increased individual likelihood of flushing could lead directly to lowered nest success in the studied population.

Differences in survival strongly correlated to a behavior that impacts capture probabilities has a high probability of imparting bias into sage-grouse telemetry studies. Trapping crews capture the birds they are able to, and in the case of typical two person teams trapping groups of sage-grouse it is often the slowest bird in a group that is ultimately captured, collared, and studied. If birds are slow to react to a pseudo-predation event (being trapped), it would logically follow that they may also be relatively slow, and vulnerable to an actual predation event. Having a sample population comprised disproportionately vulnerable birds could decrease survivorship of the sample population relative to the study population, and lead to an overall low bias to estimated survival.

Nest success rates of adult and yearling nesting hens at 27 days differed ($P = 0.089$), with a 45.6% nest survival probability for adult hens and 30.8% for yearling nesting hens. However, there are also many studies that have reported differences in yearling and adult nest success rates with a larger difference in adult and yearling nest success rates than the 15% difference in this study (Connelly et al. 2011). Of studies summarized by Connelly et al. (2011), 6 of 14 report a larger magnitude difference in

nest success by age class. One, Wallestad and Pyrah (1974), reported 33% higher nest success from adult hens, albeit with a small sample of 13 adults and 9 yearlings. However, even if not always statistically significant, there is a persistent trend of adult hens exhibiting a higher nesting survival rate than yearlings, with 13 of 15 studies summarized by Connelly et al. (2011) reporting higher survival rates for adult hens relative to juveniles. This consistent trend suggests that the results seen in this study represent a consistent biological difference seen amongst many populations of sage-grouse.

Nest success rates at 27 days differed between the Box Elder and Three Creek study sites ($P = 0.047$). However, they did not differ between Deseret Land and Livestock and Three Creeks ($P = 0.160$) or Deseret Land and Livestock and Box Elder ($P = 0.168$). When nest success was modeled by study site, the nest success for Box Elder is 47.3%. Connelly et al. (2011) reported overall nest success was 46% on average for 29 telemetry studies, and that studies in unaltered habitats showed average nest success rates greater than 50%. Nest success rates in WBE were similar to rates typically found in unaltered habitat, suggesting that the WBE habitat and population is relatively healthy condition. Nest survival probabilities on the Three Creeks study site were lower at 27.8%. Large differences between areas relatively close together highlights the importance of local management, and understanding of small-scale demographic drivers for conservation and effective management of the larger population.

Other modeled covariates relating to capture and handling, including capture treatment group, degree of struggle during capture, handling time, and temperature did not result in differing nest success probabilities indicating that handling duration and

manipulations may not negatively affect vital rates, and that poor response to handling is more related to individual behavioral heterogeneity and trauma during the capture process.

Brood Survival

The top brood survival model incorporated one behavioral capture covariate (whether or not the bird flushed prior to capture) and one study site covariate (county). Only one additional model, which only incorporated study site, was within two AIC units of the top model. However, models incorporating all tested covariates fell within 7 AIC units of the top model. Significance tests among individual model outputs evaluating covariates showed brood survival varied by Year ($P = 0.008$), County ($P = 0.002$),Flushed ($P = 0.014$), Roost ($P = 0.021$), Daily Low ($P = 0.028$), and Age Class ($P = 0.079$).

There was a substantial difference between the brood survival of hens that were flushed prior to capture and hens that were not flushed prior to capture in each study area (RC: flushed: 53.7% not-flushed: 23.5%, $P = 0.084$, WBE: flushed: 81.2% not-flushed: 61.4, $P = 0.102$) (Table 4-7). In both study areas hens that flushed before being captured had higher rates of survival compared to the hens that were captured without first flushing. Due to the positive magnitude of effects of flushing behavior on nest survival rates, differences in survival rates would be best explained by behavioral traits of individuals rather than physiological damage sustained during capture and handling. Increased likelihood of flushing could have a positive effect on brood survival with chicks learning predator avoidance behavior from hens, or as a result of hens leading predators away from broods.

We did not monitor individual chick survival; we only accounted for brood survival as a whole and considered broods successful when at least one chick survived to 50 days. Brood survival estimates of 71% (95% CI: 53.1, 89.0) for WBE was considerably higher ($P = 0.002$) than RC (30.5% 95% CI: 8.9, 52.0). Differing methodologies between the 2 study areas had the potential to give inconsistent results. The WBE broods were generally checked 1 to 2 times per week, RC broods were generally only checked twice per brood season, once at hatching and once at the end of the brooding period. Increased frequency of disturbance could lead increases in brood mixing resulting gain or loss of chicks from a brood (Dahlgren et al. 2010a), or increased exposure to predation. We do not believe this caused major bias, as we would have expected a reduction in brood survival if increased frequency of disturbance negatively influenced broods, and the broods who were disturbed more often had higher brood success. Data collection methods also did not appear to impact modeled survival rates, modeled survival rates closely matched apparent survival rates in each study site with RC having apparent brood survival of 29.4% and 73.1% Box Elder. Brood survival rates in WBE were close to survival rates of 77% (Knerr 2007), 44% (Thacker 2010, recalculated to from 42 to 50 days for comparability), and 67% (Graham 2013) from studies of other segments of the Box Elder County population.

Brood survival differed by age of the brooding hen across both sites and study years ($P = 0.079$). Brood survival of yearling hens was 22% lower than the brood survival of adult hens (40% yearling and 62% adult). Propensity to flush was not related to age ($P = 1.00$). These results are consistent with Gregg (2006), who also reported higher brood survival with adult hens as compared to yearlings. However, there are

many studies that do not report differences between hen age classes in relation to brood survival including the three studies previously documenting sage-grouse vital rates in WBE (Knerr 2007, Thacker 2010, Graham 2013).

Annual Survival

Overall annual survival for WBE differed from the first to second year of the study (Males: $P = 0.022$, Hens: $P = 0.021$) with an annual survival rate of 64.0% in 2012 and 39.8% in 2013 for males and 81.7% in 2012 and 64.4% in 2013 for hens. These survival rates are difficult to directly compare to other studies done in Box Elder County because of inconsistent reporting methods; Knerr (2007) reported total mortalities, Thacker (2010) did not report annual survival, and Graham (2013) reported annual survival by sex. Graham's (2013) annual survival rates of 22-39% for males and 73-84% for females were similar our modeled annual survival rates for WBE females, however our survival estimate for males was considerably higher.

Although there was considerable difference in nest and brood survival rates between study areas there was not a difference detected in annual survival rates between study areas for either males ($P = 0.218$) or hens ($P = 0.187$), suggesting that poor conditions in an area may have considerable impact on recruitment, but little impact on adult survival.

Daily low on the night of trapping also appeared to influence brood survival ($P = 0.027$), however daily low did not influence nest or annual survival. We believe this is an artifact of low brood survival caused by other factors in RC, which also had lower average temperatures while trapping. The RC site was on average 6.4°C colder on successful trapping nights than WBE (1.3°C average in WBE vs. -5.1°C average in RC).

Flushing behavior at the time of trapping may have impacted overall survival rates ($P = 0.027$) when the study population was combined across study sites and years, with flushed birds having a survival estimate 20.2% higher over the duration of the study (70.5% flushed, 50.4% not flushed). Capture trauma affected annual survival ($P = 0.035$). Clean captures showed a 15.6% higher survival relative to birds with poorly executed captures. These differences between groups is quite large and would have the potential to impact evaluations of a population's limiting vital rates.

Processing time was weakly associated with survival ($P = 0.068$); sage-grouse held over 6 minutes had a 12.2% higher survival rate over the course of the study. This result is unexpected but may be an artifact of behavioral traits (i.g. more active individuals) associated with longer handling times also influencing annual survival rates.

The consistency of survival differences related to flushing behavior during capture suggests an influence of individual behavioral characteristics on population fitness. The negative association of increased likelihood to flush with nest survival and positive association with brood and annual survival suggests that differences reflect a behavioral trait that is consistently expressed throughout life stages, and is not the result of injury induced by repeated attempts to capture an individual sage-grouse. It would be logical that hens more likely to flush would be more likely to flush unnecessarily during nesting leading to nest abandonment, while increased wariness could lead to decreased predation risk during brooding and other life stages.

MANAGEMENT IMPLICATIONS

Effects of marking study populations is not generally considered when presenting vital rate results of sage-grouse telemetry studies. Our research suggests that the same

behavioral characteristics that can influence capture rates have the potential to impact vital rates and bias the study population. Capture and marking individuals has the potential to influence survival rates, and methods used for capturing sample populations can leave researchers with a sample population that is not representative of the study population. This study shows that there may be a negative impact on brood survival as a result of stress or injury sustained during capture. Researchers should carefully consider the impact of capture and marking on individuals, especially in areas of low population numbers, and strive to collaborate and answer as many questions as possible from a set of marked animals. Possible effects of capture and handling on survival and reproduction also highlights the importance of having experienced trapping crews to avoid injuring birds during the capture process.

The differences in survival recorded between study sites emphasizes the importance of understanding local factors driving populations. Despite the two study areas being relatively close together and both having histories of stable sage-grouse populations, brood and nest success and resulting production was low at the RC site relative to the WBE site and range wide averages (Connelly et al. 2011). Regional conditions including winter precipitation, late summer precipitation, and drought can influence chick, and brood survival (Robinson and Messmer 2013, Guttery et al. 2013). It is also of note that there have been a series of large sagebrush removal projects on the DLL ranch. Variability in recruitment with relatively stable, high survival of adults supports conclusions by Blomberg et al. (2012) that sage-grouse populations are dependent on occasional high recruitment to the breeding population when conditions are optimal, and area able to withstand occasional periods of poor recruitment.

Understanding the ecological factors driving nest, brood, and annual survival is key to understanding changes in population numbers, and are often not be captured in a short-term study.

Sage-grouse studies relying on marked individuals for investigation of vital rates or behavioral characteristics may bias vital rate estimates through selection of easily captured individuals and effects of capture and handling on study animals. We have shown lower nest success, higher brood success and higher annual survival in birds more likely to flush before capture, a group of birds that may be under-represented in samples. Potential biases should be taken into account when modeling population viability as the differences in vital rates between groups has potential to shift estimated populations trajectories. If widespread, similar capture biases have potential to influence reported vital rates and focus conservation efforts on life stages that are not the limiting factors.

LITERATURE CITED

- Abbott, C. W., C. B. Dabbert, D. R. Lucia, and R. B. Mitchell. 2005. Does muscular damage during capture and handling handicap radiomarked northern bobwhites? *Journal of Wildlife Management* 69:664–670.
- Agresti, A. 1996. An introduction to categorical data analysis. Wiley, New York, New York, USA.
- Amstrup, S. C. 1980. A radio-collar for game birds. *Journal of Wildlife Management* 44:214–217.
- Beck, J. L., D. L. Mitchell, and B. D. Maxfield. 2003. Changes in the distribution and status of sage-grouse in Utah. *Western North American Naturalist* 63:203–214.

- Beringer, J., L. P. Hansen, W. Wilding, J. Fischer, and S. L. Sheriff. 1996. Factors affecting capture myopathy in white-tailed deer. *Journal of Wildlife Management* 60:373–380.
- Blomberg, E. J., J. S. Sedinger, M. T. Atamian, and D. V. Nonne. 2012. Characteristics of climate and landscape disturbance influence the dynamics of greater sage-grouse populations. *Ecosphere* 3:55.
- Boitani, L., and T. K. Fuller. 2000. Research techniques in animal ecology: controversies and consequences. Columbia University Press, West Sussex, England.
- Burnham, K. P., and D. R. Anderson. 2002. Model selection and multi-model inference: a practical information-theoretic approach. Springer-Verlag, New York, New York, USA.
- Caudill, D., T. Messmer, B. Bibles, and M. Guttery. 2013. Winter habitat use by juvenile greater sage-grouse on Parker Mountain, Utah: implications for sagebrush management. *Human-Wildlife Interactions* 7:231–250.
- Connelly, J. W., C. A. Hagen, and M. A. Schroeder. 2011. Characteristics and dynamics of greater sage-grouse populations. Pages 53–67 in S. T. Knick and J. W. Connelly, editors. *Greater Sage-Grouse: Ecology and conservation of a landscape species and its habitats*. Volume 38. University of California Press, Berkeley, California, USA.
- Connelly, J. W., S. T. Knick, M. A. Schroeder, and S. J. Stiver. 2004. Conservation assessment of greater sage-grouse and sagebrush habitats. Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming, USA.

- Connelly, J. W., K. P. Reese, and M. A. Schroeder. 2003. Monitoring of greater sage-grouse habitats and populations. College of Natural Resources Experiment Station, University of Idaho, Moscow, Idaho, USA.
- Dahlgren, D. K., T. A. Messmer, and D. N. Koons. 2010a. Achieving better estimates of greater sage-grouse chick survival in Utah. *Journal of Wildlife Management* 74:1286–1294.
- Dahlgren, D. K., T. A. Messmer, E. T. Thacker, and M. R. Guttery. 2010b. Evaluation of brood detection techniques: recommendations for estimating greater sage-grouse productivity. *Western North American Naturalist* 70:233–237.
- Dettenmaier, S., and T. Messmer. 2013. 2013 Annual Report: Greater sage-grouse response to season long and prescribed grazing (NRCS conservation practice 528) on paired ecological sites (Phase 1). Rich County CRM and Jack H Berryman Institute, Logan, Utah, USA.
- Eng, R. L. 1955. A method for obtaining sage grouse age and sex ratios from wings. *Journal of Wildlife Management* 19:267–272.
- Friend, M., and N. J. Thomas. 1999. Miscellaneous diseases. *Field Manual of Wildlife Diseases*. US Geological Survey, Washington, D.C., USA.
- Frye, G. G., J. W. Connelly, D. D. Musil, R. Berkley, M. C. Kemner, C. Cardinal, L. Cross, and J. S. Forbey. 2014. Do necklace-style radiotransmitters influence flushing behavior of greater sage-grouse? *Wildlife Society Bulletin* 38:433–438.
- Giesen, K. M., T. J. Schoenberg, and C. E. Braun. 1982. Methods for trapping sage grouse in Colorado. *Wildlife Society Bulletin* 10:224–231.

- Graham, S. E. 2013. Greater sage-grouse habitat selection and use patterns in response to vegetation management practices in northwestern Utah. Thesis, Utah State University, Logan, Utah, USA.
- Gregg, M. A. 2006. Greater sage-grouse reproductive ecology: linkages among habitat resources, maternal nutrition, and chick survival. Dissertation, Oregon State University, Corvallis, Oregon, USA.
- Gregg, M. A., J. A. Crawford, M. S. Drut, and A. K. DeLong. 1994. Vegetational cover and predation of sage grouse nests in Oregon. *Journal of Wildlife Management* 58:162–166.
- Guthery, F. S. 2008. Statistical ritual versus knowledge accrual in wildlife science. *Journal of Wildlife Management* 72:1872–1875.
- Gutierrez, M. R., D. K. Dahlgren, T. A. Messmer, J. W. Connelly, K. P. Reese, P. A. Terletzky, N. Burkepile, and D. N. Koons. 2013. Effects of Landscape-Scale Environmental Variation on Greater Sage-Grouse Chick Survival. *PloS One* 8:e65582.
- Hagen, C. A., B. K. Sandercock, J. C. Pitman, R. J. Robel, and R. D. Applegate. 2006. Radiotelemetry survival estimates of lesser prairie-chickens in Kansas: Are there transmitter biases? *Wildlife Society Bulletin* 34:1064–1069.
- Höfle, U., J. Millán, C. Gortázar, F. J. Buenestado, I. Marco, and R. Villafuerte. 2004. Self-injury and capture myopathy in net-captured juvenile red-legged partridge with necklace radiotags. *Wildlife Society Bulletin* 32:344–350.
- Knerr, J. S. 2007. Greater sage-grouse ecology in western Box Elder County, Utah. Thesis, Utah State University, Logan, Utah, USA.

- Knick, S. T. 2011. Historical development, principal federal legislation, and current management of sagebrush habitats. Pages 13–31 in S. T. Knick and J. W. Connelly, editors. *Greater sage-grouse: ecology and conservation of a landscape species and its habitats*. Volume 38. *Studies in Avian Biology*, University of California Press, Berkeley, California, USA.
- Marks, J. S., and V. S. Marks. 1987. Influence of radio collars on survival of sharp-tailed grouse. *Journal of Wildlife Management* 51:468–471.
- Patterson, R. L. 1952. *The sage grouse in Wyoming*. Sage Books for Wyoming Game and Fish Commission, Wyoming, USA.
- Ponjoan, A., G. Bota, E. L. G. Morena, M. B. Morales, A. Wolff, I. Marco, and S. Mañosa. 2008. Adverse effects of capture and handling little bustard. *Journal of Wildlife Management* 72:315–319.
- Rearden, J. D. 1951. Identification of waterfowl nest predators. *Journal of Wildlife Management* 15:386–395.
- Robinson, J. D., and T. A. Messmer. 2013. Vitals rates and seasonal movements of two isolated greater sage-grouse populations in Utah's West Desert. *Human–Wildlife Interactions* 7(2):182–194.
- Schroeder, M. A. 1997. Unusually high reproductive effort by sage grouse in a fragmented habitat in north-central Washington. *Condor* 90:933–941.
- Schroeder, M. A., C. L. Aldridge, A. D. Apa, J. R. Bohne, C. E. Braun, S. D. Bunnell, J. W. Connelly, P. A. Deibert, S. C. Gardner, and M. A. Hilliard. 2004. Distribution of sage-grouse in North America. *Condor* 106:363–376.

- Seber, G. A. F. 1982. The estimation of animal abundance and related parameters. Second edition. Blackburn Press, Caldwell, New Jersey, USA.
- Small, R. J., and D. H. Rusch. 1985. Backpacks vs. ponchos: survival and movements of radio-marked ruffed grouse. *Wildlife Society Bulletin* 13:163–165.
- Spraker, T. R., W. J. Adrian, and W. R. Lance. 1987. Capture myopathy in wild turkeys (*Meleagris gallopavo*) following trapping, handling and transportation in Colorado. *Journal of Wildlife Diseases* 23:447.
- Stiver, S. J., A. D. Apa, J. R. Bohne, S. D. Bunnell, P. A. Deibert, S. C. Gardner, M. A. Hilliard, C. W. McCarthy, and M. A. Schroeder. 2006. Greater sage-grouse comprehensive conservation strategy. Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming, USA.
- Thacker, E. T. 2010. Greater sage-grouse seasonal ecology and responses to habitat manipulations in northern, Utah. Dissertation, Utah State University, Logan, Utah, USA.
- Utah Division of Wildlife Resources [UDWR]. 2002. Strategic management plan for sage-grouse. Utah Department of Natural Resources, Division of Wildlife Resources, Salt Lake City, Utah, USA.
- United States Fish and Wildlife Service [USFWS]. 2005. Endangered and threatened wildlife and plants; 12-month finding for petitions to list the Greater Sage-Grouse as threatened or endangered; proposed rule. *Federal Register* 70:2244-2282.
- United States Fish and Wildlife Service [USFWS]. 2010. Endangered and threatened wildlife and plants; 12-month finding for petitions to list the Greater Sage-Grouse (*Centrocercus urophasianus*). *Federal Register* 75:13910-13598.

- Utah GIS Portal. 2011. Vector GIS Data Layers, By Category - Utah GIS Portal. Utah GIS Portal. <<http://gis.utah.gov/sgid-vector-download/utah-sgid-vector-gis-data-layers-by-category#ENVIRONMENT>>. Accessed 14 Oct 2011.
- Wakkinen, W. L., K. P. Reese, J. W. Connelly, and R. A. Fischer. 1992. An improved spotlighting technique for capturing sage grouse. *Wildlife Society Bulletin* 20:425–426.
- Wallestad, R., and D. Pyrah. 1974. Movement and nesting of sage grouse hens in central Montana. *Journal of Wildlife Management* 38:630–633.
- White, G. C., and K. P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. *Bird Study* 46th Supplement 120–138.
- Western Regional Climate Center [WRCC]. 2013. Climate summary.
<<http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ut7408>>. Accessed 6 Dec 2013.

Table 4-1. Covariates used to evaluate the effects of capture, handling, and behavior on survival and reproduction of greater Sage-grouse (*Centrocercus urophasianus*) captured between January 2012 and March 2013 in northern Utah. Data was recorded on ordinal scales at time of capture and binned for pairwise analysis.

Covariate	Data Form at Collection	Data Form for Analysis
Release Time	Time From Netting to Release	> 6 min = 1 ≤ 6 min = 0
Low	Daily Low for Rosette Utah (BEC), and Evanston, WY (RC) provided by the Utah Climate Center.	≥0°C = 1 < 0°C = 0
AgeA-SA	Age at Capture: Juvenile (first fall, winter, and spring, before first breeding season); Yearling (first breeding season through second fall molt)	Juvenile or Yearling = 1 Adult = 2
Morpho	Morphometric Measurements: Minimally Processed Group (Marked with leg band and VHF collar, aged and sexed) or Extensively Processed (same treatment as Minimally processed in addition to tarsus and chord measurement, bagged and weighed, feather sample taken)	Extensively Processed = 1 Minimally Processed = 0
ReleaseCond	Disposition Upon Release: 1 = Dead; 2 = Serious Injury, no flight; 3 = Primary or Tail Feather Loss, Respiratory Distress (continuous audible wheezing); 4 = Contour Feather Loss, Minor Respiratory Distress (intermittent audible wheezing); 5 = No Visible Stress	Category 5 = 0 Category 1 to 4 = 1
CaptureTrauma	1 = Dead; 2 = Serious Injury; 3 = Caught in Air, Hit With Net Hoop, Significant Struggle in Net (>5 second unrestrained flapping); 4 = Hard Capture (bird was about to take flight or standing tall and pushed to ground), Minimal Struggle (< 5 second unrestrained flapping); 5 = Clean Capture	Category 5 = 1 Category 1 to 4 = 0
EneExp	1 = Placid (unusually cooperative, very calm); 2 = Calm (minimal struggle after removal from net); 3 = Moderate Struggle (consistent but not constant struggle); 4 = Significant Struggle (constantly trying to get out of the handlers grip); 5 = Significant Struggle, Bad Handling (able to get one wing free)	Category 3 to 5 = 1 Category 1 to 2 = 0
RoostPile	Roost Pile Present or Absent (was there a roost pile under the bird indicating it had not been previously flushed?)	Present = 1 Absent = 0

Flushed	Bird was observed flushing then subsequently captured or was not flushed prior to capture	Flushed = 1 Not Flushed = 0
StudyCounty	Box Elder County, UT or Rich County, UT	Box Elder Co, UT = 1 Rich Co, UT = 2
StudySite	Box Elder County; Deseret Land and Livestock in Rich County, UT; Three Creeks area in Rich County, UT	Box Elder = 1 Deseret Land and Livestock = 2 Three Creeks = 3
Sex	Male or Female	Male = 0 Female = 1

Table 4-2. Sample sizes of individual covariates examined while investigating capture and handling effects on nest, brood, and annual survival of greater sage-grouse (*Centrocercus urophasianus*) during calendar years 20012 and 2013 in northern Utah.

Covariate	Nest Models			Brood Models			Annual Survival		
	0	1	2	0	1	2	0	1	2
ReleaseTime	47	36		20	20		99	105	
Low	52	31		23	17		133	71	
Age		44	39		13	27		90	114
Morpho	32	51		18	22		93	111	
RelCond	62	21		25	15		150	54	
CapTra	28	55		14	26		60	144	
EneExp	29	54		11	29		77	127	
RoostPile	39	44		24	16		95	109	
Flushed	56	27		24	16		171	33	
StudyCounty	37	46		26	14		114	90	
StudySite	37	15	31	26	5	9	114	43	47
Sex	NA	83		NA	40		60	144	

*See Table 1 for explanations of covariate values.

Table 4-3. Model ranking of greater sage-grouse (*Centrocercus urophasianus*) nest daily survival rate of in northern Utah during the 2012 and 2013 breeding seasons. Models were developed in program MARK using a nest model approach and are ranked by delta AICc.

Model	Delta AICc	AICc Weight	Number Parameters
S(Age)	0.00	0.14	2
S(Age+Site)	0.33	0.12	3
S(Site)	0.76	0.10	2
S(RelCond)	1.06	0.08	2
S(.)	1.13	0.08	1
S(Ad_SubAd)	1.36	0.07	2
S(Flushed)	1.64	0.06	2
S(Age+Site+Flushed)	1.87	0.05	4
S(County)	2.18	0.05	2
S(Roost)	2.62	0.04	2
S(Ad_SubAd+County)	2.67	0.04	3
S(Morpho)	2.89	0.03	2
S(CapTra)	3.10	0.03	2
S(Low)	3.11	0.03	2
S(RelTime)	3.13	0.03	2
S(Year)	3.14	0.03	2
S(EneExp)	3.14	0.03	2
S(t)	121.16	0.00	79

Table 4-4. Top models showing 27 day nest survival estimates and associated 95% confidence intervals derived from modeled greater sage-grouse (*Centrocercus urophasianus*) daily survival rates. P values represent tests of estimated population differences between groups with fixed covariates using a wald z test, bolded values are significant or otherwise of note.

Nest Model	Nest Survival Estimate (95% CI)	Nest Model (Fixed Covariate)	Nest Survival Estimate Fixed Covariate (95% CI)	Nest Model (Fixed Covariate)	Nest Survival Estimate Fixed Covariate (95% CI)	p
S(RelCond)	0.380 (0.270 0.490)	S(RelCond=0)	0.333 (0.209 0.456)	S(RelCond=1)	0.518 (0.296 0.741)	0.076
S(Flushed)	0.381 (0.271 0.492)	S(Flushed(No))	0.429 (0.291 0.566)	S(Flushed(Yes))	0.284 (0.109 0.460)	0.102
S(Roost)	0.383 (0.272 0.494)	S(Roost(No))	0.426 (0.258 0.594)	S(Roost(Yes))	0.345 (0.201 0.489)	0.236
S(Morpho)	0.381 (0.271 0.491)	S(Morpho=0)	0.346 (0.171 0.520)	S(Morpho=1)	0.403 (0.262 0.544)	0.309
S(CapTra)	0.382 (0.272 0.492)	S(CapTra=0)	0.396 (0.204 0.588)	S(CapTra=1)	0.374 (0.240 0.508)	0.426
S(Low)	0.381 (0.271 0.491)	S(Low(\leq 0°C))	0.374 (0.235 0.513)	S(Low(>0°C))	0.393 (0.213 0.573)	0.434
S(RelTime)	0.384 (0.273 0.495)	S(RelTime=0)	0.338 (0.199 0.476)	S(RelTime=1)	0.444 (0.267 0.621)	0.178
S(EneExp)	0.381 (0.271 0.491)	S(EneExp=0)	0.382 (0.202 0.563)	S(EneExp=1)	0.381 (0.242 0.519)	0.495
S(Age)	0.378 (0.267 0.488)	S(Age=Adult)	0.456 (0.295 0.618)	S(Age=SubAd)	0.308 (0.162 0.453)	0.089
S(County)	0.383 (0.272 0.493)	S(County=BE)	0.444 (0.272 0.616)	S(County=RC)	0.333 (0.192 0.474)	0.164
S(Site)	0.383 (0.272 0.494)	S(Site=BE)	0.473 (0.308 0.638)	S(Site=3Cr)	0.278 (0.121 0.435)	0.047
		S(Site=3Cr)	0.278 (0.121 0.435)	S(Site=DLL)	0.375 (0.265 0.486)	0.160
		S(Site=DLL)	0.375 (0.265 0.486)	S(Site=BE)	0.473 (0.308 0.638)	0.168
S(.)	0.368 (0.258 0.478)	N/A		N/A		

Table 4-5. Top models showing greater sage-grouse (*Centrocercus urophasianus*) 35 day nest survival estimates and associated 95% confidence intervals derived from modeled daily survival rates. P values represent tests of estimated population differences between groups with fixed covariates using a wald z test, bolded values are significant or otherwise of note.

Nest Model	Nest Survival Estimate (95% CI)	Nest Model (Fixed Covariate)	Nest Survival Estimate Fixed Covariate (95% CI)	Nest Model (Fixed Covariate)	Nest Survival Estimate Fixed Covariate (95% CI)	p
S(RelCond)	0.286 (0.178 0.393)	S(RelCond=0)	0.24 (0.125 0.355)	S(RelCond=1)	0.427 (0.189 0.664)	0.083
S(Flushed)	0.287 (0.179 0.394)	S(Flushed(No))	0.333 (0.195 0.472)	S(Flushed(Yes))	0.196 (0.039 0.353)	0.099
S(Roost)	0.288 (0.18 0.396)	S(Roost(No))	0.331 (0.162 0.5)	S(Roost(Yes))	0.252 (0.115 0.388)	0.237
S(Morpho)	0.286 (0.179 0.393)	S(Morpho=0)	0.252 (0.087 0.418)	S(Morpho=1)	0.308 (0.168 0.447)	0.308
S(CapTra)	0.287 (0.18 0.394)	S(CapTra=0)	0.301 (0.112 0.491)	S(CapTra=1)	0.279 (0.149 0.409)	0.426
S(Low)	0.286 (0.179 0.394)	S(Low(< 0°C))	0.279 (0.145 0.414)	S(Low(warm))	0.298 (0.121 0.475)	0.434
S(RelTime)	0.289 (0.181 0.397)	S(RelTime=0)	0.245 (0.115 0.375)	S(RelTime=1)	0.349 (0.169 0.529)	0.180
S(EneExp)	0.286 (0.179 0.394)	S(EneExp=0)	0.287 (0.111 0.463)	S(EneExp=1)	0.286 (0.151 0.421)	0.495
S(Age)	0.283 (0.176 0.39)	S(Age=Adult)	0.362 (0.196 0.527)	S(Age=SubAd)	0.217 (0.084 0.35)	0.091
S(County)	0.288 (0.18 0.396)	S(County=BE)	0.349 (0.174 0.524)	S(County=RC)	0.24 (0.109 0.372)	0.836
S(Site)	0.288 (0.18 0.396)	S(Site=BE)	0.379 (0.208 0.55)	S(Site=3Cr)	0.19 (0.051 0.33)	0.047
		S(Site=3Cr)	0.19 (0.051 0.33)	S(Site=DLL)	0.281 (0.174 0.388)	0.156
		S(Site=DLL)	0.281 (0.174 0.388)	S(Site=BE)	0.379 (0.208 0.55)	0.171
S(.)	0.286 (0.179 0.394)	N/A		N/A		

Table 4-6. Model ranking of greater sage-grouse (*Centrocercus urophasianus*) daily brood survival rates in northern Utah during the 2012 and 2013 breeding seasons. Models were developed in program MARK using a nest model approach and are ranked by delta AICc.

Model	Delta AICc	AICc Weights	Num. Par
S(Flushed+County)	0	0.26845	3
S(County)	0.4461	0.21478	2
S(Flushed+County+Year)	2.0103	0.09825	4
S(Year+County)	2.4543	0.07869	3
S(Flushed)	3.0579	0.05819	2
S(Site)	3.2829	0.052	2
S(Roost)	3.4698	0.04736	2
S(Low)	3.8958	0.03827	2
S(Year)	4.506	0.02821	2
S(Reftime)	5.0656	0.02132	2
S(.)	5.2464	0.01948	1
S(Ad_SubAd)	5.3459	0.01854	2
S(EneExp)	5.8208	0.01462	2
S(ReLCond)	6.3275	0.01135	2
S(Morpho)	6.3564	0.01118	2
S(Age)	6.3988	0.01095	2
S(CapTra)	6.9413	0.00835	2
S(t)	204.5611	0	104

Table 4-7. Top models showing 50 day greater sage-grouse (*Centrocercus urophasianus*) brood survival estimates and associated 95% confidence intervals. P values represent tests of estimated population differences between groups with fixed covariates using a wald z test, bolded values are significant or otherwise of note.

Brood Model	Brood Survival Estimate (95% CI)	Brood Model (Fixed Covariate)	Brood Survival Estimate Fixed Covariate (95% CI)	Brood Model (Fixed Covariate)	Brood Survival Estimate Fixed Covariate (95% CI)	p
S(Flushed+County)	0.601 (0.434 0.769)	S(Flushed=Y+County=R) S(Flushed=Y+County=BE)	0.537 (0.164 0.91) 0.812 (0.631 0.993)	S(Flushed=N+County=R) S(Flushed=N+County=BE)	0.235 (0.023 0.447) 0.614 (0.368 0.861)	0.084 0.102
S(RelCond)	0.553 (0.399 0.708)	S(RelCond=0)	0.491 (0.301 0.681)	S(RelCond=1)	0.647 (0.4 0.894)	0.164
S(Flushed)	0.57 (0.409 0.731)	S(Flushed(No))	0.422 (0.231 0.613)	S(Flushed(Yes))	0.744 (0.528 0.96)	0.014
S(Roost)	0.559 (0.401 0.716)	S(Roost(No))	0.669 (0.483 0.856)	S(Roost(Yes))	0.363 (0.135 0.592)	0.021
S(Morpho)	0.545 (0.392 0.699)	S(Morpho(Yes))	0.609 (0.412 0.807)	S(Morpho(No))	0.46 (0.227 0.694)	0.170
S(CapTra)	0.547 (0.394 0.7)	S(CapTra=0)	0.487 (0.227 0.746)	S(CapTra=1)	0.578 (0.391 0.765)	0.288
S(Low)	0.56 (0.401 0.718)	S(Low(freeze))	0.425 (0.227 0.623)	S(Low(warm))	0.71 (0.496 0.923)	0.028
S(EneExp)	0.556 (0.401 0.711)	S(EneExp=0)	0.405 (0.133 0.676)	S(EneExp=1)	0.607 (0.428 0.786)	0.111
S(RelTime)	0.554 (0.399 0.709)	S(RelTime=0)	0.459 (0.247 0.671)	S(RelTime=1)	0.639 (0.428 0.851)	0.119
S(Year)	0.569 (0.420 0.717)	S(Year=2012)	0.412 (0.243 0.580)	S(Year=2013)	0.668 (0.543 0.793)	0.008
S(County)	0.589 (0.426 0.752)	S(County(BoxElder))	0.710 (0.530 0.890)	S(County(Rich))	0.305 (0.089 0.520)	0.002
S(Ad_SubAd)	0.555 (0.400 0.711)	S(Ad_SubAd(Sub))	0.397 (0.143 0.651)	S(Ad_SubAd(Ad))	0.623 (0.440 0.806)	0.079
S(.)	0.546 (0.394 0.699)	N/A		N/A		

Table 4-8. Model ranking of greater sage-grouse (*Centrocercus urophasianus*) quarterly survival rates of in northern Utah from Jan 2012 to Sept 2013. Models were developed in program MARK using a known fate model approach and are ranked by delta AICc.

Model	Delta AICc	AICc Weights	Num. Par
S(t+sex)	0.00	0.33	8
S(Flushed+sex)	0.25	0.29	9
S(t+county+sex)	1.05	0.20	9
S(t+Site)	4.11	0.04	8
S(t+Flushed+County)	5.16	0.03	9
S(t+County)	5.48	0.02	8
S(t+Flushed)	5.77	0.02	8
S(t+CapTra)	5.86	0.02	8
S(t+EneExp)	6.83	0.01	8
S(t+RelTime)	6.86	0.01	8
S(t+CapHr)	7.05	0.01	8
S(t) Design Matrix	7.06	0.01	7
S(t+Morpho)	8.72	0.00	8
S(t+RelCond)	8.87	0.00	8
S(t+RoostPile)	8.95	0.00	8
S(t+Low)	8.97	0.00	8
S(t+Ad_SubAd)	9.10	0.00	8
S(.)	37.22	0.00	1

Table 4-9. Top annual survival known fate models for greater sage-grouse (*Centrocercus urophasianus*) data aggregated over the WBE and RC study sites from Jan 2012 to Sept 2013. Values indicate probability of surviving the 7 quarter study duration with associated 95% confidence intervals. P values represent values from Wald z tests of estimated population differences between covariate groups.

Annual Model	7 Quarter Survival Estimate (95% CI)	Annual Model (Fixed Covariate)	7 Quarter Survival Estimate Fixed Covariate (95% CI)	Annual Model (Fixed Covariate)	7 Quarter Survival Estimate Fixed Covariate (95% CI)	p
S(t Sex)	0.560 (0.476, 0.641)	S(t+Sex(f))	0.631 (0.529, 0.723)	S(t+Sex(m))	0.371 (0.253, 0.506)	0.001
S(t+Flushed)	0.539 (0.456, 0.620)	S(t+Flushed(Yes))	0.705 (0.496, 0.853)	S(t+Flushed(No))	0.504 (0.416, 0.592)	0.027
S(t+Flushed+Sex)	0.562 (0.477, 0.643)	S(Flushed(n)+Sex(m))	0.359 (0.241, 0.496)	S(Flushed(n)+Sex(f))	0.603 (0.491, 0.705)	0.002
		S(Flushed(y)+Sex(m))	0.535 (0.276, 0.776)	S(Flushed(y)+Sex(f))	0.740 (0.540, 0.873)	0.107
		S(Flushed(y)+Sex(f))	0.740 (0.540, 0.873)	S(Flushed(n)+Sex(f))	0.603 (0.491, 0.705)	0.092
		S(Flushed(y)+Sex(m))	0.535 (0.276, 0.776)	S(Flushed(n)+Sex(m))	0.359 (0.241, 0.496)	0.013
S(t+EneExp)	0.541 (0.458, 0.622)	S(t+EneExpReclass=1)	0.492 (0.394, 0.590)	S(t+EneExpReclass=0)	0.620 (0.481, 0.743)	0.065
S(t+CapHr)	0.544 (0.461, 0.625)	S(t+CapHrReclass=1)	0.587 (0.478, 0.689)	S(t+CapHrReclass=0)	0.470 (0.352, 0.591)	0.078
S(t+RelTime)	0.537 (0.455, 0.618)	S(t+RelTimeReclass=1)	0.596 (0.481, 0.701)	S(t+RelTimeReclass=0)	0.474 (0.362, 0.588)	0.068
S(t+CapTra)	0.543 (0.460, 0.624)	S(t+CapTra=0)	0.431 (0.301, 0.571)	S(t+CapTra=1)	0.587 (0.487, 0.681)	0.035
S(t+County)	0.546 (0.463, 0.628)	S(t+County=Rich)	0.632 (0.502, 0.746)	S(t+County=BoxElder)	0.473 (0.371, 0.577)	0.027
S(t+County+Sex)	0.564 (0.479, 0.646)	S(t+County(BE)+Sex(m))	0.354 (0.235, 0.494)	S(t+County(BE)+Sex(f))	0.590 (0.456, 0.712)	0.006
		S(t+County(RC)+Sex(m))	0.451 (0.264, 0.652)	S(t+County(RC)+Sex(f))	0.671 (0.541, 0.779)	0.035
		S(t+County(RC)+Sex(f))	0.671 (0.541, 0.779)	S(t+County(BE)+Sex(f))	0.590 (0.456, 0.712)	0.187
		S(t+County(RC)+Sex(m))	0.451 (0.264, 0.652)	S(t+County(BE)+Sex(m))	0.354 (0.235, 0.494)	0.218
S(t+Relcond)	0.536 (0.454, 0.617)	S(t+Relcond=0)	0.548 (0.452, 0.641)	S(t+Relcond=1)	0.503 (0.354, 0.651)	0.314

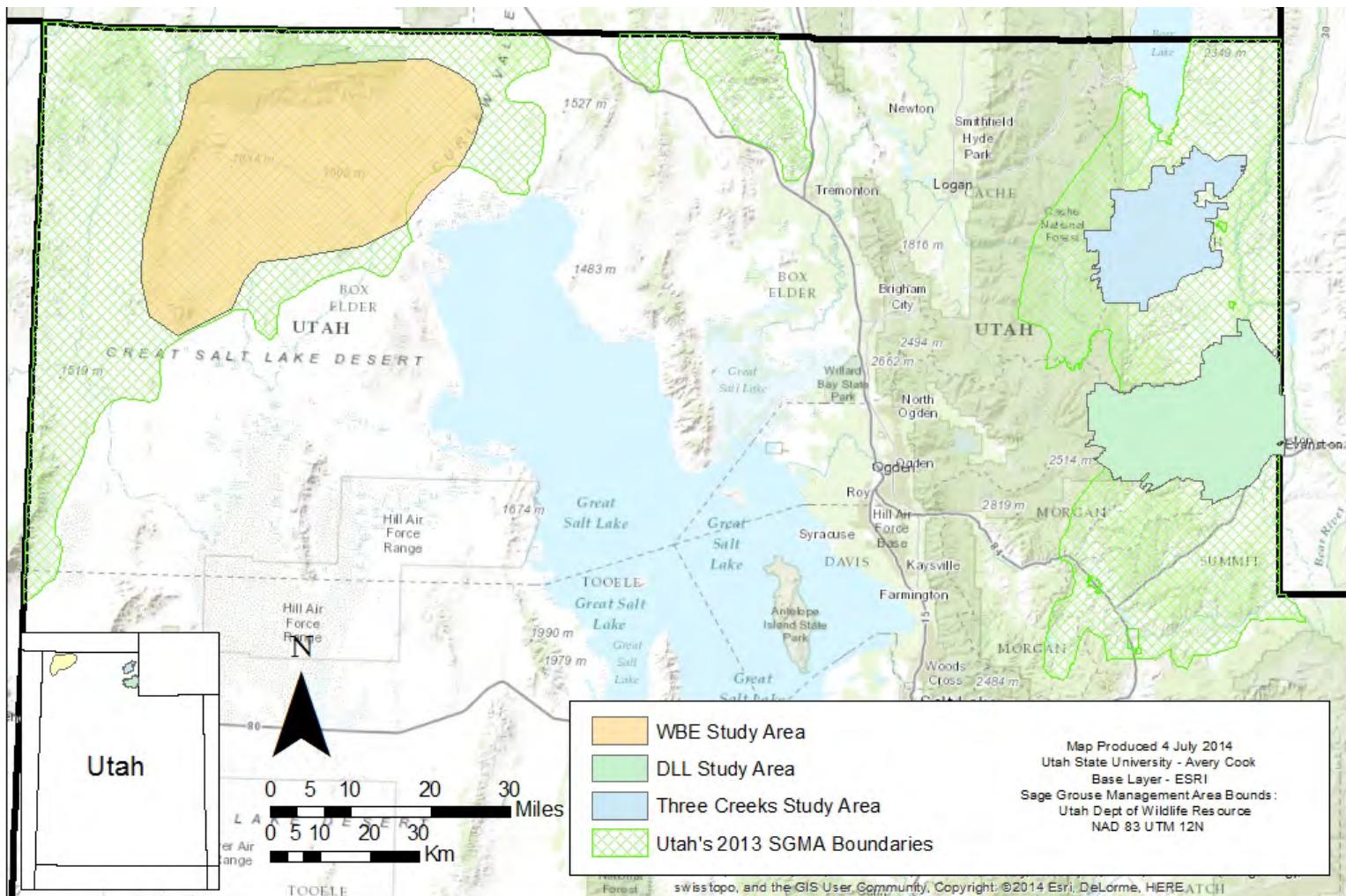


Figure 4-1. West Box Elder and Rich County study areas used for evaluating effects of behavior, capture and handling on greater sage-grouse in 2012 and 2013 with the encompassing Sage Grouse Management Areas.

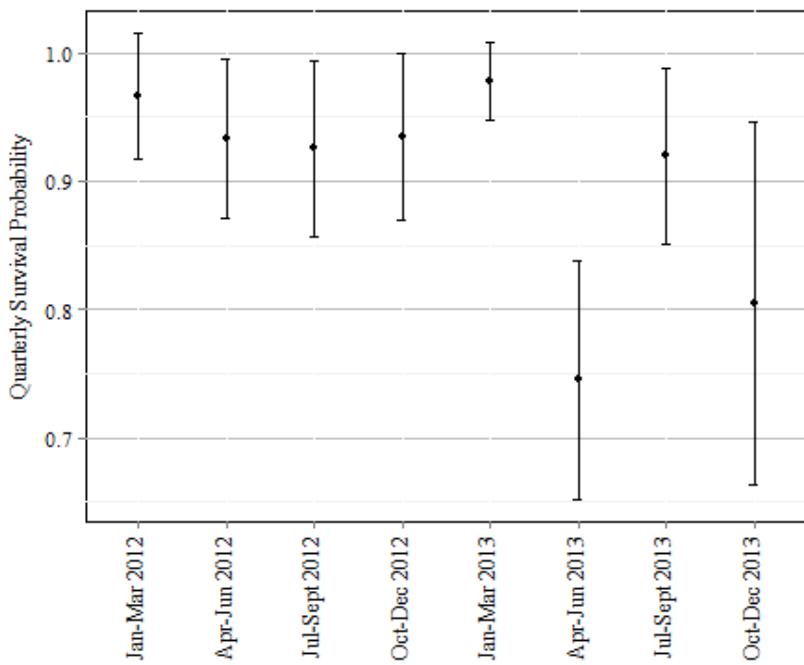


Figure 4-2. Estimated survival probabilities of all groups of monitored greater sage-grouse (*Centrocercus urophasianus*) in West Boxed Elder County by quarter from January 2012 to December 2013. Survival probabilities estimated using a known fate model in program MARK.

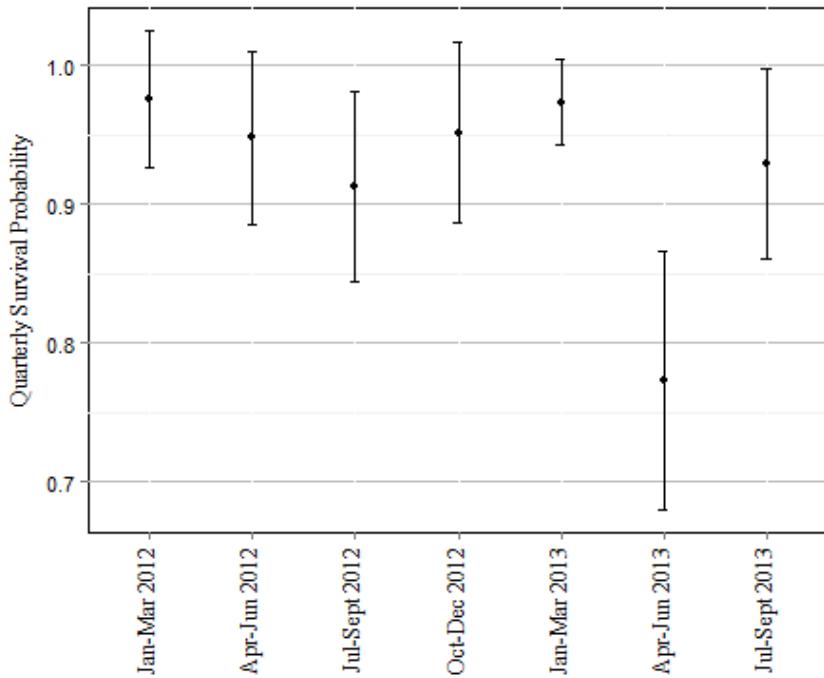


Figure 4-3. Estimated survival probabilities of all groups of monitored greater sage-grouse (*Centrocercus urophasianus*) in Rich County by quarter from January 2012 to September 2013. Survival probabilities estimated using a known fate model in program MARK, error bars

CHAPTER 5

CONCLUSIONS

Greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) are a species of conservation concern due to declining population trends and loss of sagebrush habitat on which they depend. In response to declining populations and the possible listing under the Endangered Species Act, Utah and other western states have increased the rate of habitat improvement projects and bolstered research programs to protect populations and better understand sage-grouse ecology. To effectively plan sage-grouse habit restoration and improvement projects it is necessary to understand sage-grouse habitat use across all seasonal habitat as well as sage-grouse response to habitat treatments. With the continued extensive study of sage-grouse it is also important to understand the effects of research in particular, capturing and radio-marking individuals may have on a study population and study results.

To answer questions on sage-grouse seasonal habitat use in the West Box Elder SGMA, I captured, radio marked, and tracked 123 (68 female, 55 male) sage grouse between January 2012 and December 2013 and also incorporated telemetry locations from previous studies in the area (Knerr 2007, Thacker 2010, Graham 2013) to model habitat use and response to landscape disturbance (Chapter 2). I additionally used the 2012-2013 telemetry in conjunction with sage-grouse pellet survey data to analyze sage-grouse response to conifer removal projects (Chapter 3). Data on capture characteristics and vital rates was used to examine potential behavioral and survival bias in sage-grouse study samples (Chapter 4). Additional information on seasonal survival and microhabitat is available in Wing (2014).

I mapped landscape disturbance within the study area from 1985 to 2013 with a combination of satellite imagery, available records of habitat projects, records of disturbance and on the ground observations. I documented extensive disturbance covering over 77,000 ha within the study area, with 49,000 ha of the total categorized as fire, and 12,000 ha as conifer reduction. Models did not reveal a relationship between disturbance and sage-grouse distribution at a landscape scale, despite known use of conifer reduction treatments (also see chapter 3, Frey et al. 2013) and generally negative effects of fire on sage-grouse habitat (Fischer et al. 1996, Connelly et al. 2000, Nelle et al. 2000). However, we documented sage-grouse use of conifer reduction treatments throughout the study area by telemetry locations and sage-grouse pellets surveys (Chapter 3) suggesting that effect sizes were simply too small to be detected for the type of disturbances present over the spatial and temporal scales modeled.

Habitat models were developed using radio telemetry locations recorded between 2005 and 2014 using a suite of landcover and topographic data using Random Forest decision trees in program R. Seasonal habitat models for the lekking, brood, nesting, early summer non-breeding, late summer non-breeding, and winter periods are available to aid in planning and prioritization of future conservation efforts and population monitoring efforts.

To closely examine sage-grouse use of conifer removal treatments, and factors affecting use I surveyed 19 conifer reduction treatments and 14 adjacent reference plots for evidence of sage-grouse use via pellet surveys and radio telemetry. Survey results showed sage-grouse use of 12 conifer reduction treatments. Use was positively associated with sage-grouse presence in adjacent habitats, shrub cover and adjacent mesic

habitat, and negatively associated with surrounding conifer cover. Sage-grouse use of habitat treatments shows that treatments led to increases in useable space available to sage-grouse that likely would have a positive influence on vital rates (Guthery 1997). Continued use of conifer reduction treatments as a sage-grouse habitat restoration tool is effective and should continue, however continued monitoring is necessary to establish a positive link between sage-grouse vital rate improvement and restoration projects.

With increased conservation concern for sage-grouse there has been an accompanying increase in the number of research projects studying their ecology and management. These projects typically involve capture and radio attachment; however, there is little information available on capture effects specifically related to sage-grouse. I used telemetry and capture data collected in West Box Elder County, and Rich County Utah during 2012 and 2013 to evaluate effects of behavior and condition at time of capture to vital rates. Sage-grouse flushed one or more times before capture, a segment of the population that is likely underrepresented in study samples, had higher brood and annual survival rates than birds that did not flush before capture. Differences in survival rates suggests that this and other research projects may have biased study samples. Future research should consider possible effects of capture, handling and behavior on vital rates.

LITERATURE CITED

- Connelly, J. W., K. P. Reese, R. A. Fischer, and W. L. Wakkinen. 2000. Response of a sage grouse breeding population to fire in southeastern Idaho. *Wildlife Society Bulletin* 90–96.
- Fischer, R. A., K. P. Reese, and J. W. Connelly. 1996. An investigation on fire effects within xeric sage grouse brood habitat. *Journal of Range Management* 194–198.
- Frey, S. N., R. Curtis, and K. Heaton. 2013. Response of a small population of greater sage-grouse to tree removal: implications of limiting factors. *Human-Wildlife Interactions* 7:260–272.
- Graham, S. E. 2013. Greater sage-grouse habitat selection and use patterns in response to vegetation management practices in northwestern Utah. Thesis, Utah State University, Logan, Utah, USA.
- Guthery, F. S. 1997. A philosophy of habitat management for northern bobwhites. *Journal of Wildlife Management* 61:291–301.
- Knerr, J. S. 2007. Greater sage-grouse ecology in western Box Elder County, Utah. Thesis, Utah State University, Logan, Utah, USA.
- Nelle, P. J., K. P. Reese, and J. W. Connelly. 2000. Long-term effects of fire on sage grouse habitat. *Journal of Range Management* 586–591.
- Thacker, E. T. 2010. Greater sage-grouse seasonal ecology and responses to habitat manipulations in northern, Utah. Dissertation, Utah State University, Logan, Utah, USA.

Wing, B. R. 2014. The role of vegetation structure, composition, and nutrition in greater sage-grouse ecology in northwestern Utah. Thesis, Utah State University, Logan, Utah, USA.