Greater Sage-Grouse Response to Tree Canopy Removal: Habitat Vegetation Composition and Sage-Grouse Use 10–15 Years Post Treatment in the Southern Periphery of the Species Range

Benjamen Donnelly
Utah State University

Follow this and additional works at: https://digitalcommons.usu.edu/etd

Part of the Life Sciences Commons

Recommended Citation

This Thesis is brought to you for free and open access by the Graduate Studies at DigitalCommons@USU. It has been accepted for inclusion in All Graduate Theses and Dissertations, Spring 1920 to Summer 2023 by an authorized administrator of DigitalCommons@USU. For more information, please contact digitalcommons@usu.edu.
GREATER SAGE-GROUSE RESPONSE TO TREE CANOPY REMOVAL: HABITAT
VEGETATION COMPOSITION AND SAGE-GROUSE USE 10-15 YEARS POST
TREATMENT IN THE SOUTHERN PERIPHERY OF THE SPECIES RANGE

by

Benjamen Donnelly

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

MASTERS OF SCIENCE

in

Wildlife Biology

Approved:

S. Nicki Frey, Ph.D. Michael Conover, Ph.D.
Major professor Committee member

Steven Petersen, Ph.D. D. Richard Cutler, Ph.D.
Committee member Vice Provost of Graduate
Studies

UTAH STATE UNIVERSITY
Logan, Utah

2023
ABSTRACT

Greater Sage-grouse Response to Tree Canopy Removal: Habitat Vegetation Composition and Sage-Grouse Use 10-15 Years Post Treatment in the Southern Periphery of the Species Range

by

Benjamen C. Donnelly, Master of Science

Utah State University, 2023

Major professor: Dr. S. Nicki Frey
Department: Wildland Resources

Pinyon juniper woodland expansion into Greater sage-grouse (Centrocercus urophasianus, hereafter ‘sage-grouse’) habitat in southern Utah continues to threaten sage-grouse survival. Habitat restoration after pinyon-juniper removal treatment is key to the continued persistence and survival of sage-grouse along the southern edge of their range. Few long-term studies are available that examine sage-grouse use of areas treated to remove pinyon-juniper forests (i.e., ‘restored habitat’). The purpose of this research was to determine if sage-grouse used ‘restored’ areas in the long-term, as a measure of the actual effectiveness of pinyon-juniper woodland control treatments. I compared vegetation composition, shrub height and shrub cover at known sage-grouse locations to randomly selected sites within a pinyon-juniper removal treatment that was conducted in 2005 Sage-grouse use of pinyon juniper treatments was determined using locations recorded from GPS transmitters between September 2020 - December 2021. Additionally, to determine the change within the treatment area over the course of 15
years, I compared vegetation composition, shrub height, and shrub cover from data collected 2006-2009 to similar data collected in 2020-2021. I used this information to determine if habitat restoration was comparable to Utah sage-grouse state guidelines implemented in 2020. Using ANOVA to analyze these comparisons I found that the largest difference in variance between sage-grouse locations and the treated area was the percentage of forb cover, with sage-grouse locations containing more forb cover. I modeled seasonal home ranges during the breeding, summer, and fall/winter periods for all females. I calculated the percent of these home ranges found within the seasonal habitats of the Panguitch Sage-grouse Management Area. When analyzing sage-grouse home ranges within pinyon juniper removal treatments I found the highest percentage within pinyon juniper treatments 5 years old or less. Monitoring the southern edge of the sage-grouse range is particularly important as climate change is a major concern impacting sage-grouse habitat selection. Managers should conduct pinyon juniper removal treatment while maintaining and increasing forb cover to support sage-grouse. Information from this study will inform land managers in restoring sage-grouse habitat and help determine how to augment current management guidelines to better support sage-grouse habitat in southern Utah.

(116 pages)
PUBLIC ABSTRACT

Greater Sage-grouse Response to Tree Canopy Removal: Habitat Vegetation Composition and Sage-Grouse Use 10-15 Years Post Treatment in the Southern Periphery of the Species Range

Benjamen C. Donnelly

Pinyon juniper woodland expansion into Greater sage-grouse (*Centrocercus urophasianus*, hereafter ‘sage-grouse’) habitat in southern Utah continues to threaten sage-grouse survival. Habitat restoration after pinyon-juniper removal treatment is key to the continued persistence and survival of sage-grouse along the southern edge of their range. Few long-term studies are available that examine sage-grouse use of areas treated to remove pinyon-juniper forests (i.e., ‘restored habitat’). The purpose of this research was to determine if sage-grouse used ‘restored’ areas in the long-term, as a measure of the actual effectiveness of pinyon-juniper woodland control treatments. I compared vegetation composition, shrub height and shrub cover at known sage-grouse locations to randomly selected sites within a pinyon-juniper removal treatment that was conducted in 2005. Sage-grouse use of pinyon juniper treatments was determined using locations recorded from GPS transmitters between September 2020 - December 2021. Additionally, to determine the change within the treatment area over the course of 15 years, I compared vegetation composition, shrub height, and shrub cover from data collected 2006-2009 to similar data collected in 2020-2021. I used this information to determine if habitat restoration was comparable to Utah sage-grouse state guidelines implemented in 2020. Using ANOVA to analyze these comparisons I found that the
largest difference in variance between sage-grouse locations and the treated area was the percentage of forb cover, with sage-grouse locations containing more forb cover. I modeled seasonal home ranges during the breeding, summer, and fall/winter periods for all females. I calculated the percent of these home ranges found within the seasonal habitats of the Panguitch Sage-grouse Management Area. When analyzing sage-grouse home ranges within pinyon juniper removal treatments I found the highest percentage within pinyon juniper treatments 5 years old or less. Monitoring the southern edge of the sage-grouse range is particularly important as climate change is a major concern impacting sage-grouse habitat selection. Managers should conduct pinyon juniper removal treatment while maintaining and increasing forb cover to support sage-grouse. Information from this study will inform land managers in restoring sage-grouse habitat and help determine how to augment current management guidelines to better support sage-grouse habitat in southern Utah.
ACKNOWLEDGMENTS

I give special thanks to my advisor Dr. Nicki Frey, who’s patience and encouragement lead to the completion of this document. My committee members Dr. Steven Petersen, and Dr. Mike Conover for assistance in the editing process. I want to thank my family and friends for support. This project was funded by the Bureau of Land Management. Additionally, they provided housing support and trapping assistance.

Benjamen Donnelly
CONTENTS

Page
Abstract .............................................................................................................................. iii
Public Abstract .................................................................................................................... v
Acknowledgments............................................................................................................. vii
List of Tables ...................................................................................................................... x
List of Figures .................................................................................................................... xi
Chapter I Literature Review ............................................................................................ 1
  Greater Sage-grouse Ecology .................................................................................... 1
  Methods to Monitor Sage-grouse Habitat Use .......................................................... 4
  Sage-grouse Habitat Decline And Restoration ......................................................... 6
  Pinyon Juniper Encroachment .................................................................................... 8
  Pinyon Juniper Removal And Grouse Use ................................................................. 9
  References ................................................................................................................... 13

Chapter II Is Sagebrush ‘Restored’ 15 Years After Pinyon Juniper Removal On The
Southern Colorado Plateau ............................................................................................... 22
  Abstract ....................................................................................................................... 22
  Introduction .................................................................................................................. 23
  Study Area .................................................................................................................... 26
  Methods ....................................................................................................................... 30
  Vegetation Surveys ....................................................................................................... 30
  Vegetation Of Occupied Sage-grouse Habitat ............................................................. 32
  Results .......................................................................................................................... 34
  Vegetation Cover And Composition Of Treatments Over Time............................... 34
  Vegetation Composition Of Occupied Grouse Locations ......................................... 36
  Discussion .................................................................................................................... 37
  Management Implications/Conclusions ..................................................................... 40
  References ................................................................................................................... 42
  Tables .......................................................................................................................... 47
  Figures .......................................................................................................................... 48

Chapter III Sage-grouse Habitat Use 15 Years After Pinyon Juniper Removal On The
Southern Colorado Plateau ............................................................................................... 54
Abstract .......................................................................................................................... 54
Introduction .................................................................................................................. 55
Study Area .................................................................................................................... 58
  Vegetation Treatments And Disturbances ................................................................. 60
Methods.......................................................................................................................... 62
  Sage-grouse Capture and Monitoring ................................................................. 62
  Seasonal Sage-grouse Home Ranges Within Pinyon Juniper Removal Treatments .......................................................................................................................... 63
  Survey of Sage-grouse Presence In Vegetation Treatments ............................... 64
Results.............................................................................................................................. 66
  Home Range Models ............................................................................................... 66
  Pellet Count Surveys .............................................................................................. 68
Discussion ..................................................................................................................... 70
Management Implications/Conclusions ................................................................. 74
References .................................................................................................................... 76
Tables .............................................................................................................................. 83
Figures ........................................................................................................................... 85
Chapter IV Conclusions ............................................................................................... 94
References .................................................................................................................... 98
Appendices ................................................................................................................... 100
  Appendix A .............................................................................................................. 101
  Appendix B .............................................................................................................. 102

Table 2.2. Summary Statistics Comparing average shrub height, average shrub intercept cover, percent shrub composition, percent forb cover, and percent grass cover within GR2021 and T2020 locations within the 2016 retreatment and outside of it. 2020-2021…………………………………………………………………………………………………47

Table 3.1. Percent of home ranges of sage-grouse females within pinyon juniper treatment removal project areas fall winter, (Oct-Feb) breeding (Mar-May), summer (June-Sept) Panguitch SGMA Utah 2020-2021…………………………………………………………83

Table 3.2. Percentage of land type found within seasonal sage-grouse home ranges within the Panguitch SGMA based on locations from October 2020- December 2021……………………………………………………………………………………………………84
LIST OF FIGURES

Figure 2.1. Panguitch and Surrounding Sage Grouse Management areas in Southern Utah, 2020-2021………………………………………………………………………………… 48

Figure 2.2. Map of Treatment areas for mastication conifer removal treatment conducted in 2005 and hand thinning and removal of large diameter trees not removed in the initial treatment conducted in 2016 within study area, Alton, Utah……49

Figure 2.3. Images of the landscape taken at the same location in 2005 before treatment, 2006 after treatment and 2020 during the study Sink Valley, Alton, Utah, USA………………………………………………………………………………50

Figure 2.4. Treatment transect survey locations of T2007 and T2020 and sagebrush (I2020). ……………………………………………………………………………………………51

Figure 2.5. Diagram of vegetation survey transects and pellet count survey transects conducted within Sink Valley conifer removal treatment area, intact sagebrush, restored grassland, and mechanically thinned sagebrush from June 2020 – November of 2021. …………………………………………………………………………………………………52

Figure 2.6. Random surveyed locations, locations were randomly generated in ArcPro a minimum distance from on another of 50 meters and the border (GR2021), June 1, 2021 – July 31, 2021, Alton, Utah …………………………………………………………………53

Figure 3.1. Locations of the study area, indicating conifer treatment areas, surveys, lek, and coalmine, Sink Valley, Utah 2020-2021…………………………………………………………85

Figure 3.2. Location and age of conifer removal treatments completed within the Panguitch SGMA treatments are shaded from black 2006 to white 2021. Southern Utah 2021……………………………………………………………………………………………………86

Figure 3.3. Seasonal habitat of Panguitch SGMA by the Utah sage-grouse management plan including nesting brood rearing, nest brood rearing and winter, non-specified habitat, winter, opportunity and non-habitat southern Utah 2020-2021……87

Figure 3.4. Core home ranges of sage-grouse females during the breeding season, five individual females, conifer removal treatments shade from black 2006 to white 2021 Panguitch SGMA southern Utah 2020-2021………………………………………………………….88

Figure 3.5. Core home ranges of sage-grouse females during the summer season, five individual females, conifer removal treatments shade from black 2006 to white 2021 Panguitch SGMA southern Utah 2020-2021…………………………………………………………89
Figure 3.6. Core home ranges of sage-grouse females during the fall winter season, seven individual females, conifer removal treatments shade from black 2006 to white 2021 Panguitch SGMA southern Utah 2020-2021.................................90

Figure 3.7. Extended home ranges of sage-grouse females during the breeding season, five individual females, conifer removal treatments shade from black 2006 to white 2021 Panguitch SGMA southern Utah 2020-2021.................................91

Figure 3.8. Extended home ranges of sage-grouse females during the summer season, five individual females, conifer removal treatments shade from black 2006 to white 2021 Panguitch SGMA southern Utah 2020-2021.................................92

Figure 3.9. Extended home ranges of sage-grouse females during the fall winter season, seven individual females, conifer removal treatments shade from black 2006 to white 2021 Panguitch SGMA southern Utah 2020-2021.................................93
CHAPTER I
LITERATURE REVIEW

Greater sage-grouse ecology

The greater sage-grouse (*Centrocercus urophasianus*; henceforth ‘sage-grouse’) is a sagebrush obligate species found in sagebrush (*Artemisia spp.*) dominated plant communities in the western United States and parts of southern Canada (Schroeder et al. 2004).

The United States Fish and Wildlife Service and was petitioned to be listed under the Endangered Species Act in 2002, with additional petitions received in 2003 (USFWS 2005). The United States Fish and Wildlife Service reviewed a collection of petitions and found sage-grouse were not warranted of listing in 2005 (USFWS 2005). The petition for the listing of species was reviewed again in 2010 and deemed warranted but precluded by other species that were at greater risk (USFWS 2010). In 2015, the United States Fish and Wildlife service decreed that the sage-grouse was not warranted to be listed under the Endangered Species Act (USFWS 2015). While management efforts by state and federal servicers throughout their range have kept sage-grouse from needing federal protection to date, they remain a Utah species of concern (USFWS 2015, Utah Department of Wildlife Recourses 2019).

Sage-grouse are the largest grouse species in North America (Phasianidae: Galliformes) with individuals measuring up to 76 cm in length and up to 60 cm tall. Males weigh between 2-3 kilograms while females weigh between 1-1.5 kilograms. Each
year, male sage-grouse conduct their daily courtship display on leks in the early morning hours throughout the breeding season. Leks are comprised of relatively flat, open areas with patches of sagebrush. The open area allows for the males to display, while the cover provides protection to the observing females. The leks are often located in shortgrass openings, low sagebrush, or disturbed areas such as those caused by fire. Males predominantly stay on or near leks throughout the breeding season March - May (Dahlgren et al. 2016, UDWR 2019).

Successful leks are located within close proximity to desirable nesting habitat. Dahlgren et al. (2016) found that from 1998 - 2013 in Utah, the average distance between a nesting location and the closest lek was 2.20 km (range 40m – 11.91km). Sage-grouse females attend leks from pre-dawn to a few hours after dawn each day of the breeding season to observe males displaying. After mating, sage-grouse females will seek out a nesting location in the surrounding habitat. Nest initiation dates vary between March - May throughout Utah and are dependent on elevation and latitude (Stoner et al. 2020). Sage-grouse nests have shown to have a higher success rate when located under a sagebrush rather than another species of shrub or other vegetation (Connelly et al. 1991). A more recent study has shown sagebrush cover is not as important as total shrub cover in a sagebrush stand, in which females choose nesting sites with a more diverse group of shrub species (Gibson et al. 2016). Herbaceous vegetation cover is also an important factor in sage-grouse nest success. Visual obstruction caused by herbaceous and shrub vegetation cover allows for greater nest success by increasing hiding cover (Doherty et al. 2014, Anthony et al. 2021). In addition to protection from predators, cover shrub cover is important for temperature insulation for nest bowls (Anthony et al. 2021). Nest site
selection has been shown to be based on nest shrub characteristics (Schroff et al. 2018). In addition to shrub cover, it has been shown that sage-grouse select for higher vertical cover from grasses near nesting sites (Gibson et al. 2016). The sagebrush must be high enough to allow a sage-grouse to nest underneath but at the same time must provide enough cover to hide the nest from predators. Shrub cover in in sagebrush habitat in Utah should be at a minimum of 17%, while shrub height should be > 15 centimeters. Depending on the sagebrush habitat, a higher percentage of sagebrush cover and height may be required for suitable nesting habitat (Dahlgren et al. 2019).

During the breeding and brood-rearing seasons, sage-grouse still depend on sagebrush for cover, but also require habitat that provides a diet of forbs and insects. Sage-grouse consume sagebrush leaves as their main diet but supplement it with forbs which are important for females during egg production (Gregg et al. 2008). During the brood rearing period, chicks’ diets consist predominantly of insects in the first week with forbs added shortly later to help the development and growth of chicks (Smith et al. 2019). Females feed on insects as well as forbs to restore weight loss from egg production. Optimal early brood rearing habitat consists of vegetation cover providing shelter from predators, a mosaic of grasses and forbs providing habitat for a robust insect community and access to a water source. Early brood rearing habitat is usually similar to nesting habitat. Additionally, Sanford et al. (2016) determined that sage-grouse females had a higher likelihood of brood survival if they were found in habitat with minimal conifer cover. Depending on geographic location and altitude there are slight differences in optimal brood rearing habitat across their distribution (Dahlgren et al. 2019).
During the late brood period (June -August) and into Autumn sage-grouse diets consists of sagebrush supplemented with forbs, insects, and grass seed. Late brood-rearing habitat consists of a mosaic of sagebrush habitat that includes grasses, forbs, and wet meadows. These wet areas are important food and water sources for the growing chicks (Smith et al. 2019). Optimal conditions for late brood-rearing habitat range from region to region (UDWR 2019, Dahlgren et al. 2019). While the optimal conditions for late brood-rearing habitat are similar to those of the breeding/early brood-rearing period there are some differences such as less shrub cover needed and overall lower shrub heights.

**Methods to monitor sage-grouse habitat use**

Sage-grouse habitat use is monitored through multiple methods including global positioning systems (GPS) and radio telemetry, pellet count surveys, and observational counts (Christiansen 2012). To conduct radio telemetry and GPS satellite telemetry, sage-grouse must first be captured. Spotlighting with hand held nets at night, drive trapping, and cannon nets are three different methods used in capturing sage-grouse (Wakkinen et al. 1992). Transmitters are commonly placed on sage-grouse using a necklace or rump-mounted conformation that lasts anywhere from 1-5 years. Radio transmitters can be applied to grouse chicks using a suture method to determine chick survival and location use (Dahlgren et al. 2010). There are advantages to using each type of method, with satellite GPS transmitters removing the need of countless man hours tracking and following the birds. GPS transmitters send locations based on set time intervals often without the ability to track in the field without the addition of a radio transmitter.
Affixing radio or GPS transmitters allows for multiple types of information collection and data analysis including home range, utilization distribution, mortality rate, seasonal habitat use, response to habitat disturbances, dispersal and other movement patterns (Christiansen 2012).

In addition to tracking a subset of a sage-grouse population to determine space and habitat use, populations can be monitored through other methods, such as pellet surveys or observational monitoring. Pellet surveys help determine sage-grouse presence within different areas; single pellet occurrences are associated with general use locations while pellet group locations indicate sage-grouse roost locations (Hanser et al. 2011, Cook et al. 2017). Pellet surveys can be conducted at regular intervals to determine sage-grouse presence from season to season, and are not constrained by captured sample size (Christiansen 2012).

Sage-grouse habitat use can also be monitored through direction observation of sage-grouse using systematic searches in the study area. Surveying the same area and repeatedly noting the locations in which sage-grouse are observed is one of the most straightforward methods of monitoring habitat use. Usually, an observer will monitor a set route and record the number and location of sage-grouse seen while conducting the survey. To assist observers with finding sage-grouse, trained bird dogs can be utilized to help locate sage-grouse. Trained bird dogs will point to locations when they detect sage-grouse often causing them to flush when the observer approaches (Dahlgren et al. 2010).
Sage-grouse habitat decline and restoration

Sagebrush vegetation communities have been in decline since the late 19th century due to climate change, human expansion, and human development, resulting in the decline of sage-grouse populations across their distribution (Schroeder et al. 2004, Pyke et al. 2015). Estimates from previous studies suggest that current sage-grouse habitat occupies only 50-60 percent of the historical distribution before the 19th century (Schroeder et al. 2004, Pyke et al. 2015). Current sage-grouse habitat covers roughly 647,500 km² across eleven states and 2 Canadian provinces, meaning that over 515,000 km² of habitat has been lost since colonization of the Western United States (Johnson et al. 2008, Miller et al. 2011, Pyke et al. 2015). Studies estimate historical sage-grouse population levels as high as 16 million prior to colonization, while today’s population is estimated between 200,000 - 400,000 (Johnson et al. 2008, Miller et al. 2011, Pyke et al. 2015).

Utah contains 6% of the sage-grouse population (Nielson et al. 2015, Western Association of Fish and Wildlife Agencies WAFWA 2015). Furthermore, it is estimated that sage-grouse occupy 41.3 % (~29,800 km²) of their historic habitat (~73,000 km²) within Utah (Beck et al. 2003). Historical pioneer records and the historical distribution of sagebrush suggest that sage-grouse were once found within all Utah counties but are currently found in 27 of the 29 counties with no sage-grouse being found in Salt Lake or Davis counties (UDWR 2019). Conservation guidelines for sage-grouse were proposed in 1977, but were largely ignored by land managers due to lack of concern for sagebrush communities (Braun et al. 1977). These original guidelines focused on reducing damage to habitat, but did not discuss restoring sagebrush communities. Growing concern for sage-grouse in the 1980’s and 1990’s resulted in updated sagebrush habitat guidelines
being suggested in 2000 (Connelly et al. 2000). These guidelines suggest height and canopy cover values of sagebrush, grasses, and forbs for breeding, brooding, and winter habitat within arid and mesic habitats across the entire sage-grouse habitat. While an improvement, these guidelines noted that actual habitat requirements of sage-grouse may change across their distribution.

In 2019 to increase the success of local management, and recognize differing habitat components across Utah, the Conservation Plan for Greater Sage-Grouse plan identified 11 areas (SGMAs, sage-grouse management areas) within Utah which contain the habitat required for 94% of the sage-grouse population (UDWR 2019). Utah management guidelines presented in UDWR (2019) outline vegetation characteristics for sage-grouse during breeding and late brood rearing seasons based on data collected throughout Utah. Dahlgren et al. (2019) found that elevation was determined to be the most important factor driving habitat characteristics, and thus sage-grouse habitat in Utah was separated into three categories with similar elevation and habitat: low elevation, high elevation, and Parker Mountain. Minimum values for key habitat elements were calculated based on percentiles for each habitat area during breeding and brood-rearing seasons. Shrub cover, shrub height, sagebrush composition, sagebrush cover, perennial grass cover, perennial grass height, forb cover, and forb height are each given a minimal value to be considered a suitable sage-grouse habitat (Dahlgren et al. 2019). While selection for sage-brush cover is the driving factoring in sage-grouse habitat selection, Picardi et al. found sage-grouse selected for higher elevations and greater slopes in Southern Utah (2020). This deviation from the range wide trends showcases the unique environmental conditions found within sage-grouse habitat along their southern edge.
**Pinyon juniper encroachment**

In the last twenty years, conifer encroachment, particularly of pinyon pine (*Pinus spp.*) and juniper (*Juniperus spp.*; henceforth ‘conifers’) in Utah, has been a concern for land and wildlife managers seeking to conserve sage-grouse habitat (Coates et al. 2017). In the last century, land managers suppressed wildfire, resulting in an increased establishment of conifer woodlands in the western United States, reducing potential food and adequate cover for sage-grouse. Conifers currently occupy 190,000 km² of the Intermountain West; up to 90 percent of that area was historically sagebrush before American European settlement (Johnson et al. 2008, Miller et al. 2011, Pyke et al. 2015). Falkowski et al. (2017) estimated that nearly 500,000 km² of sagebrush had been encroached by conifers since pre-European settlement.

In multiple studies sage-grouse have shown a strong avoidance of pinyon-juniper woodlands (Atamian et al. 2010, Casazza et al. 2011, Baruch-Mordo et al. 2013, Knick et al. 2013, Coates et al. 2017). In addition to contributing to a loss of sagebrush for food and cover, pinyons and junipers provide perches for avian predators of sage-grouse, resulting in declines in sage-grouse survival rates (Severson et al. 2017a, Coates et al. 2017). Additionally, research has suggested that sage-grouse will abandon lek sites as tree cover increases (Baruch-Mordo et al. 2013). Sage-grouse undergo higher risk movements when sagebrush cover is sporadic and when traveling within pinyon juniper (PJ) encroached sagebrush stands. There are three phases in which pinyon juniper woodlands encroach into sagebrush. In phase one pinyons and junipers are the minority of the vegetation composition, characterized by sparse seedlings and juvenile trees (Miller et al. 2005). In phase two, the landscape is co-dominated between the pinyon and...
juniper trees and all other vegetation. In this stage, sage-grouse may use the landscape, but incur higher risk due to a possible increased presence of avian predators. While in phase three, pinyons and junipers dominate the landscape, having a high density and taking up the majority of cover within the area (Tausch et al. 2009, Boyd et al. 2017). Once PJ encroachment has transitioned to phase 3, shrubs begin to disappear and the vegetation community has transformed into juniper or juniper pinyon-woodland and is no longer suitable for sage-grouse (Miller et al. 2005).

**Pinyon juniper removal and grouse use**

In Utah, ‘PJ removal’ refers to the removal of juniper (*Juniperus* spp.) and pinyon (*Pinus* spp.) trees to return landscapes to a desert-shrub community. There have been multiple studies determining the efficiency of different methods of PJ removal treatments (Bybee et al. 2016, McIver et al. 2014, Provencher and Thompson 2014, Redmond et al. 2014, Stephens et al. 2016, Williams et al. 2017, 2019). There are several commonly used removal methods, selected based on the ‘phase’ or density of tree canopy cover (Bureau of Land Management BLM 2008). PJ removal methods can be divided into three different categories, mechanical, fire, and chemical; a combination of methods may be used during conifer removal projects. Chemical treatments have resulted in mixed results in the past and are currently rarely used (Tausch et al. 2009). When compared to fire, mechanical removal allows for flexibility of timing and allows for more precise targeting. Mechanical treatment methods consist of chaining, mastication (‘bullhog’), and hand chainsaw cutting (‘lop and scatter’, ‘thinning’). Location, topography, time, and management budget are all considered when selecting a PJ removal method (Boyd et al.
Each type of method has a monetary and conservation cost that must be considered before being implemented. The anchor chain method, ‘chaining’, consists of two heavy equipment vehicles with a modified heavy anchor chain being dragged between them to uproot and destroy conifer trees (Bureau of Land Management, 2008). Historically chaining was the main method of PJ removal in the west with over 1.2 million hectares of juniper removed between 1950 -1964 (Box et al. 1966). Chaining is useful in clearing large areas of large older trees and senescent stands of sagebrush, and disturbing the soil, allowing for shrub and grass species to establish. Chaining can also lead to unwanted effects resulting in increased juniper dominance, surface fuel loads, bare ground cover and non-native species (Redmond et al. 2013). Mastication can be implemented to remove pinyon and junipers by shredding trees to provide habitat for sage-grouse, allowing for herbaceous plants to thrive without competition with minimal disturbance to established sagebrush (Wozniak et al. 2020). Controlled burns, meant to replicate historic fire cycles and patterns, are utilized to remove some pinyon juniper woodlands but cannot be utilized when topography prevents safe containment of the fire or when sagebrush within the encroached area needs to survive (Miller et al. 2014). Burns are often used in tandem with machinery or hand removal allowing for some sage-grouse habitat to remain while removing a large area (Boyd et al. 2017). Mechanical removal of pinyons and junipers can lead to unsafe buildup of woody fuel while burning causes a reduction in intact habitat suggesting a combination of methods should be used when conditions allow (Bernau et al. 2018). Mastication areas within sage-grouse management areas should be monitored every 10 - 15 years after treatment to maintain sage-grouse habitat (Wozniak et al. 2020). Hand removal is also a method of removal in phase one
encroachment, when there are limited numbers of trees, or when topography prevents machinery from access (Boyd et al. 2017). For effective long-term pinyon-juniper removal treatments all tree age classes should be removed to prevent further pinyon juniper woodland encroachment (Bates et al. 2017). In addition to PJ removal, reseeding of sagebrush and other native plants is essential in reestablishing sagebrush habitat. The federal land management agencies have developed seed mixes for each region of Utah to ensure the most successful species are used and the proper proportion of sagebrush, forbs, and grasses is used. After seeding at least two growing seasons should be allowed before livestock grazing should commence allowing for new plant growth (Bureau of Land Management, 2008).

Multiple management practices have been carried out to remove pinyon pine and juniper from historic and current sagebrush ecosystems (Severson et al. 2017a, Sandford et al. 2017), but the long-term effects of these management practices have not been studied in depth. From 2006 - 2021, the Watershed Restoration Initiative of Utah conducted 422 pinyon juniper removal projects associated with sage-grouse. These 422 projects have amounted to over 2326 km² of treated area, including 157 projects in southern Utah (WRI 2021).

Kane County, Utah is the southernmost distribution of sage-grouse in Utah and possibly within its entire distribution. Sage-grouse within this region are managed as part of the Panguitch Sage-Grouse Management Area. Within this SGMA is Sink Valley, which contains the southernmost lek within the region. Habitat restoration, including tree removal, has been conducted to improve and increase the sagebrush communities in Sink Valley since 2005 (Utah Watershed Restoration Initiative WRI 2021).
While there have been several short-term projects to measure the impacts of habitat restoration to sage-grouse (Frey et al. 2013, Knick et al. 2014, Cook et al. 2017, Sandford et al. 2017, Severson et al. 2017b, Olsen et al. 2021a, 2021b), to date, there have been few studies researching the long-term impact pinyon juniper removal has on a habitat.

This study will revisit the prior restoration efforts in Sink Valley to determine the impact pinyon juniper removal treatments had on restoring sage-grouse habitat. I will determine if the treatments resulted in suitable sage-grouse habitat, based on the Utah guidelines produced in 2020. Further I will determine if sage-grouse are actively using pinyon juniper treatment removal areas. This study will identify the future needs of management to continue to restore sagebrush habitat along the southern distribution margin.
REFERENCES

nest bowls buffer microclimate in a post-megafire landscape although effects on
nest survival are marginal. The Condor 123(1)duaa068.

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. The

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 Reese, K. P. 2013. Saving sage-
grouse from the trees: a proactive solution to reducing a key threat to a candidate

availability and plant composition in sagebrush steppe. Forest Ecology and
Management 400:631-644.


Box, T. W., G. M. VanDyne, and N. E. West. 1966. Syllabus on range resources of North
America, Part IV: Pinyon-juniper ranges. Utah State University, Logan, UT,
USA.

2017. The sage-grouse habitat mortgage: effective conifer management in space


Knick, S. T., S. E. Hanser, and M. Leu. 2014. Ecological scale of bird community


Picardi, S, T. Messmer, B. Crabb, M. Kohl, D. Dahlgren, N. Frey, R. Larsen, and R.


Tausch, R. J., R. F. Miller, B. A. Roundy, and J. C. Chambers. 2009. Piñon and juniper
field guide: asking the right questions to select appropriate management actions.


Utah Division of Wildlife Resources (UDWR). 2019. Strategic management plan for sage-grouse. Utah Department of Natural Resources, Publication 02-20. Salt Lake City, Utah, USA.

Utah’s Watershed Restoration Initiative (WRI). 2021 Utah Department of Natural Resources Project Database. https://wri.utah.gov/wri/project/search.html


Williams, C. J., F. B. Pierson, P. R. Kormos, O. Z. Al-Hamdan, S. K. Nouwakpo, and M.


CHAPTER II
IS SAGEBRUSH ‘RESTORED’ 15 YEARS AFTER PINYON JUNIPER REMOVAL
ON THE SOUTHERN COLORADO PLATEAU

ABSTRACT

Pinyon (Pinus spp.) juniper (Juniperus spp.) encroachment has been identified as a major contributor to the loss of sagebrush (Artemisia spp.) communities. Within Utah, the restoration of sagebrush habitat for Greater Sage-grouse has been conducted throughout the state by removing pinyon-juniper woodlands which have been encroaching into sagebrush habitat since European settlement. In Sink Valley, located in Southern Utah near the town of Alton, a previous short-term study of vegetation growth and sage-grouse use of an area immediately following a treatment of pinyon juniper removal by mastication was conducted from 2005-2009. However, an assessment of long-term plant community change is lacking. The purpose of this study is to determine the long-term effectiveness of pinyon juniper removal treatments. In 2020 and 2021 I repeated the vegetation surveys measuring shrub height, shrub line intercept, and percent vegetation composition of grasses, forbs, and shrubs and compared them with those collected in 2007 and 2009 that were collected after the initial pinyon juniper removal treatment. Additionally, I measured vegetation structure at known greater sage-grouse locations to compare with the measurement within the treatment area. I conducted an ANOVA analysis comparing these vegetation measurements to detect differences. I only found a difference in forb cover and percent shrub composition when comparing the treatments 2-
4 years and 15-16 years after the conifer removal ($F_{1,18} = 18.47, p = <0.000; F_{1,18} = 5.78, p = 0.027$). I found that 15 years after conifer removal the habitat had been restored to Utah State guidelines for sage-grouse management; however, percent grass and percent forb cover were both significantly lower at these sites than at sage-grouse locations ($F_{1,78} = 17.58, p = <0.001; F_{1,78} = 7.88, p = 0.0063$). State guidelines provide broad management standards across all of Utah. However, care should be taken to evaluate needs at a local scale, particularly in the margins of the species’ distribution. For example, within the Panguitch SGMA, the minimum percent forb cover recommended for the state overall may not be adequate for regional sage-grouse habitat management. I found that sage-grouse locations had higher forb and grass cover than proposed by the Utah State guidelines. Within the Panguitch SGMA I suggest increasing the minimum percent forb and grass cover guideline for sage-grouse habitat management to reach levels seen at sage-grouse locations. Additionally, conifer removal treatments should be bolstered with secondary treatments to prevent further conifer encroachments by regrowth.

INTRODUCTION

In Utah and across the range of Greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse), conifer encroachment continues to threaten sage-grouse habitat, creating a growing concern for land and wildlife managers (Coates et al. 2017). Recent studies estimate conifer woodlands once occupied 190,000 km$^2$ of the Intermountain West; Prior to American European settlement up to 90% of this area was considered sagebrush habitat (Johnson et al. 2008, Miller et al. 2011, Pyke et al. 2015). Currently, conifers now occur on approximately 500,000 km$^2$ of typically sagebrush dominated
communities, habitat for sage-grouse (Falkowski et al. 2017). Conifer removal, more
specificity pinyon-juniper removal has been implemented throughout Utah to return Utah
juniper (*Juniperus osteosperma*) – Colorado pinyon (*Pinus edulis*) woodlands (hereafter
‘pinyon-juniper’) to desert-shrub ecosystems. The efficiency of PJ removal and
sagebrush restoration methods have been studied extensively (McIver et al. 2014,

Mastication, the removal of conifers by shredding trees, improves habitat for sage-grouse
by enhancing herbaceous plant growth with minimal disturbance to sagebrush while
significantly reducing pinyon-juniper tree canopy cover and density (Redmond et al.
2014, Bybee et al 2016, Wozniak et al. 2020). Multiple management practices have been
carried out to remove pinyon-juniper from historic and current sagebrush ecosystems
(Severson et al. 2017a, Sandford et al. 2017a,), but the long-term effects of these
management practices have not been studied in depth. From 2006 - 2021, the Watershed
Restoration Initiative of Utah (WRI) conducted 422 pinyon juniper removal projects
associated with sage-grouse. These 422 projects have amounted to over 2326 km² of
treated area, including 157 projects in southern Utah (WRI 2021).

The initial Utah Conservation Plan for Greater Sage-Grouse by the Utah
Department of Wildlife Resources (UDWR) designated 11 locations to become Sage-
grouse management areas (SGMA) in 2019; supporting 94% percent of Utah’s sage-
grouse population (UDWR 2019). Utah management guidelines for sage-grouse breeding
and brood rearing habitat were updated in 2019 with an elevation-based factor splitting
the habitat into three zones; low elevation, high elevation, and Parker Mountain
(Dahlgren et al. 2019, UDWR 2019). The guidelines outlined minimum levels of shrub
cover, shrub height, sagebrush composition, sagebrush cover, perennial grass cover, perennial grass height, forb cover, and forb height at each elevation during breeding and brood rearing seasons.

Kane County, Utah is the southernmost distribution of sage-grouse in Utah and possibly within the species’ entire distribution. In this county, sage-grouse are managed as part of the Panguitch SGMA. Within the Panguith SGMA is Sink Valley, a region located near the town of Alton, Utah that contains the southernmost lek and breeding population within the region. Since 2005 habitat restoration, including tree removal, has been conducted to improve and increase sagebrush dominated habitat within the Sink Valley region.

While there have been several short-term projects to measure the impacts of habitat restoration to sage-grouse (Frey et al. 2013, Knick et al. 2014, Cook et al. 2017, Sandford et al. 2017, Severson et al. 2017b, Olsen et al. 2021a, 2021b), to date, there have been few long-term studies (e.g., studies lasting more than 2 years) characterizing the condition of sagebrush habitat restoration efforts and their suitability in sustaining healthy sage-grouse populations. The purpose of this study is to evaluate current sage-grouse habitat conditions and pinyon-juniper establishment by revisiting areas that were treated by reducing pinyon-juniper stands within Sink Valley. We then compared these results with the Utah guidelines that were created in 2020 to assess the degree of habitat recovery. Finally, we will identify the future needs of management to continue to restore sagebrush habitat along the southern distribution margin.
STUDY AREA

The Panguitch SGMA was established in 2019 to manage sage-grouse within the southwestern region in the state of Utah (Figure 2.1). Its range spans 118 km north to south in Beaver, Garfield, Iron, Kane, and Piute counties. This area encompasses a total of 2457 km², with central coordinates of UTM 12S 367516 4176552. Within the UDWR conservation guidelines, the Panguitch SGMA was split into three different categorical land types: ‘habitat’, which includes all habitats used by sage-grouse at some point during the yearly life-cycle of the grouse; ‘non-habitat’, which are areas that don’t contribute to the life cycle of sage-grouse; and ‘opportunity areas’ that include lands sage-grouse don’t currently utilize, but through restoration or natural recovery may contribute to sage-grouse life cycle in the future. A large portion of ‘opportunity areas’ were altered by invasive plant species, damaged by wildfires, or altered by the encroachment of pinyon juniper forests (UDWR 2019). Over 55% of the Panguitch SGMA was described as sage-grouse habitat, and approximately 36% described as opportunity habitat. Land ownership of the sage-grouse habitat and opportunity habitat areas within the Panguitch SGMA consists of the Bureau of Land Management (‘BLM’; 60 km² sage-grouse habitat, 404 km² opportunity habitat), US Forest Service (237 km² habitat, 259 km² opportunity), State Institute Trust Lands Administration (122 km² habitat, 25.3 km² opportunity), and Utah Department of Natural Resources (4 km² habitat, 4 km² opportunity). Private lands account for 565.5 km² (366.7 km² habitat, 198.8 km² opportunity). As of 2021, 115 projects have been conducted by the Utah Watershed Restoration Initiative (WRI) for the support of sage-grouse habitat within the Panguitch SGMA, encompassing 814.8 km² of
habitat area. Of those projects, 71 included pinyon juniper removal (624.6 km²) in the support of sage-grouse habitat restoration.

Within the Panguitch SMGA, the primary study location was Sink Valley, an area located south of the town of Alton (Figure 2.2, UTM 12 S 370600 4139200). Pinyon-juniper woodlands, desert-shrub, grassland pastures, and irrigated croplands were all land types within the Sink Valley study area. Colorado pinyon and Utah Juniper were the dominant tree species in pinyon-juniper ecosystems. The desert-shrub ecosystems included big sagebrush (*Artemisia tridentata var. tridentata and var. vaseyana*), black sagebrush (*Artemisia nova*), and antelope bitterbrush (*Purshia tridentata*); the predominate grass species were bluebunch wheatgrass (*Pseudoroegneria spicata*), Idaho fescue (*Festuca idahoensis*), and needlegrass (*Stipa spp.*). squirreltail (*Sitanion hystrix*), Kentucky bluegrass (*Poa pratensis*), timothy (*Phleum pratense*), and intermediate wheatgrass (*Thinopryum intermedium*). Alfalfa was the dominant crop within the farmland with some cereal grain crops that are also produced. The average annual precipitation of Alton is 40.6 cm. However, during the initial vegetation study in 2007-2009, and our current study 2020-2021, the annual precipitation ranged 18.4 – 34.9 cm. The 100-year average daily high summer temperature was 25.9°C (Utah Climate Center, 2020, Alton station ID USC00420086). However, the average daily high summer temperatures during the years of the vegetation surveys ranged from 27.4°C – 29.5°C. The 100-year average daily low temperature was -8.5°C; the range of daily low temperature during our study was -9.2°C - -7.3°C. The majority of southern Utah’s moisture comes in the form of snowfall from October – March. The 100-year average annual snowfall in Alton was 200 cm. Annual snowfall in 2007 and 2009 were 145.4 cm.
and 231.4 cm, respectively. The annual snow fall in Alton was not entered for 2020 or 2021, but the average annual snow fall at the next nearest recorded station was 146.7 cm in 2020 and 48.2 cm in 2021 (Utah Climate Center, 2020, Panguitch Station USC00426601).

The primary study location was in the footprint of a pinyon-juniper forest removal project conducted on 3.3 km² of BLM administered land in 2005 (Figure 2.2). The treatment area had a mean elevation of 2100 m with a range of 2069 m – 2201 m. The dominate soil type within the pinyon juniper removal treatment area consisted of silty clay and fell within the hydrologic soil group c, having slow water infiltration and transmission rates (United States Department of Agriculture 2022). Within designated areas, 90% of the pinyon and junipers trees were masticated in 2005, with the mulch dispersed across the ground. The treated area was aerially seeded containing a seed mix to restore native forbs and grasses. The seed mix for the desert-shrub rehabilitation consisted of native forbs and grasses, including crested wheatgrass (*Agropyron cristatum*), intermediate wheatgrass, Russian wildrye (*Psathyrostachys juncea*), Indian ricegrass (*Achnatherum hymenoides*), western yarrow, Rocky Mountain beeplant (*Cleome serrulata*), blue flax (*Linum perenne lewisii*), yellow sweetclover (*Melilotus officinalis*), alfalfa, sainfoin (*Onobrychis viciifolia*), and small burnet (*Sanguisorba minor*). The area was rested from livestock grazing for two growing seasons after seeding. In 2016, pinyon-juniper removal was conducted on 2.7 km² of land of which 2.5 km² was of the previous treated area, with 0.2 km² added to the treatment footprint (Figure 2.2). This second treatment increased the total acreage of the originally treated area, including the removal of newly grown saplings of pinyons and junipers, and
removed older large trees previously not removed during the initial pinyon juniper removal treatment. Aerial seeding was conducted following the bullhog treatment, and the area was rested from cattle grazing for two years. Grass and forb species in the aerial seeding included crested wheatgrass (*Agropyron cristatum*), Indian ricegrass (*Oryzopsis hymenoides*) pubescent wheatgrass (*Agropyron trichophorum*), Snake River wheatgrass (*Elymus wawawaiensis*), Sandberg bluegrass (*Poa secunda*), Russian wildrye (*Elymus junceus*), small murnet (*Sanguisorba minor*), yellow sweetclover (*Melilotus officinalis*), blue flax (*Linum perenne*), western yarrow (*Achillea millefolium*), sainfoin (*Onobrychis viciifolia*), Rocky Mountain penstemon (*Penstemon strictus*), alfalfa (*Medicago sativa*), and forage kochia (*Kochia prostrata*). Cattle grazing occurred within the treatment study area during 2020-2021. A visual comparison of images taken at a study transect in 2005, 2006, and 2020 clearly shows vegetation changes that occurred from one and 15 years following the original treatment (Figure 2.3).

In 2009, a surface coal mining operation was initiated within the study area, on private lands adjacent to the BLM administered lands. This operation caused alterations to the landscape (Figure 2.4) which included road courses, and more recent mining excavation. Additionally, constant light and noise pollution from the mine were observed from within the study area during the study periods of 2020-2021. No negative effects on sage-grouse population cycles were found with respect to the surface coal mining activities, and sage-grouse continued to use the general area based on a study conducted within surrounding private lands (Petersen et al. 2016). Mining operations since 2016 have not been analyzed for impacts they may have had on sage-grouse using the area.
METHODS

My study compared the vegetation composition in treated areas 2–4 years post-treatment (T2007) to the same area 15-16 years post treatment (T2020) and sagebrush that never received treatment (‘intact’) in 2020-2021 (I2020). I used this comparison to determine if areas treated to reduce tree canopy cover can be restored to Utah state habitat guidelines for sage-grouse. Additionally, my study compared vegetation composition of known sage-grouse locations in 2021 (G2021) to paired-random locations in 2021 (GR2021), and the 2 sets of data were compared to intact sites (2020-2021). This made it possible to determine if the areas selected by sage-grouse differed in vegetation composition from the ‘restored’ treatment areas.

Vegetation surveys

I conducted vegetation surveys in the treated study areas to a) compare vegetation growth in 2020-2021 to 2007-2009 and b) compare vegetation growth in the treated areas to adjacent sagebrush habitat that hadn’t been disturbed in the past 10-15 years (i.e., ‘intact’). To begin the investigation, I conducted vegetation surveys in June and July of 2020 and 2021 (T2020) on 5 survey transects that were created prior to the removal of the pinyon juniper in 2005 (T2007). Of the 5 survey transects 4 were found within the 2016 retreatment footprint. The survey transects were created at randomly selected coordinates within the treatment area polygons (Figure 2.4). The survey transects consisted of a 100m survey line with 5 perpendicular ‘arms’, 60m in length, that bisected the 100m line. Two arms were located at each end of the 100m survey line and the other three were randomly placed along the survey with a minimum of 20 meters between any two arms. Each of
These 60m arms were further divided into two 30m arms with one each side of the 100m survey line to have a total of 10 arms going forward (Frey et al. 2013, Figure 2.5). Additionally, I conducted vegetation surveys on five additional transects in sagebrush that had not been disturbed in the last 15 years (‘intact sagebrush’, ‘I2020’) following the same pattern with five perpendicular “arms” bisecting the central line in the surrounding area to compare as ‘controls’ to the treatment transects (Figure 2.5).

In each transect, I measured vegetation cover, shrub height and % shrub cover. To determine vegetation composition, a modified Daubenmire technique was used to replicate the methods used in the study conducted by Frey et al. (2013). I measured vegetation cover with a modified Daubenmire frame (1m x 1m). On each arm of the transect, I placed the frame at distances of 10, 20 and 30 meters from the intercept with the 100m survey line, resulting in three measurements per arm and 30 measurements per transect. I recorded the dominate species and percent cover for tree, shrub, forb, grass, litter, and bare ground in each frame.

To calculate percent shrub cover and average shrub height, a line-intercept method of data collection was implemented (Connelly et al. 2003). I placed a measuring tape along each 30m arm of the transect, for a total of 10 measurements per transect. Along each arm the line-intercept was determined by measuring the proportion of tape that covered trees and/or shrubs along with the species of tree or shrub. The coverage along the measuring tape was totaled and divided by the transect length to create a measurement of shrub cover per meter. Additionally, for each shrub or tree intercepted by the measuring tape, I measured the height to the top of the growing leaf tissue and recorded the species. I then averaged shrub height at each location.
To compare vegetation growth over time, I calculated summary statistics with vegetation survey data collected in 2007 and 2009 (T2007), and 2020 - 2021 (T2020). At each of the five transects, I calculated the average height of shrubs (cm) across all arms of the transect, to acquire 1 measurement per transect. I calculated percent shrub cover at each transect by totaling shrub intercept and calculating the proportion over the total distance measured (300 meters). The percent cover within each Daubenmire frame was calculated and then averaged to determine the average percent cover of each vegetation type at each location. I compared the T2020 surveys within the 2016 retreatment to those outside of the retreatment to determine impact 2016 retreatment and seeding may have on restoration. I conducted ANOVAs of each vegetation measurement between T2007 and T2020 to determine the change in vegetation cover over time. Additionally, I conducted ANOVAs of each vegetation measurement comparing both sets of data collected in the treated area to 5 control transects of intact sagebrush stands measured in 2020 and 2021 (I2020) to determine if the treated areas were similar to sagebrush that had not been treated in the two time periods (T2007, T2020): 2-4 years after treatment, and 15-16 years after treatment.

Vegetation of occupied sage-grouse habitat

In addition to comparing vegetation growth over time, I compared current vegetation cover in the treated areas to sage-grouse locations acquired via GPS telemetry conducted concurrent to the vegetation study (Donnelly 2023 Chapter 3). I selected 40 grouse locations during June - July of 2021. These locations were taken at midday hours to be consistent across the study. I selected five locations from each week, for a total of 40
locations in eight weeks. For each survey, the grouse location was considered the center of the survey. I then created a 30m transect line in each cardinal direction from the known location, for a total of 120m of measurements per location (hereafter referred to as ‘G2021’). I paired each grouse location with a random location within the 2005 treatment area boundary, created in ARCGIS (ESRI 2022); each random location (hereafter referred to as ‘GR2021’) was at least 50 m from any other random location and at least 50m from the boundary of the treatment area (Figure 2.6). Of the 40 random locations, 11 were located only within the original treatment footprint while 27 were within the pinyon juniper removal 2016 retreatment area. At each GR2021 location, I conducted a vegetation survey using the 30m x30m design of the G2021 surveys. Each of the GR2021 locations were surveyed within 3 days of a corresponding G2021 survey so that vegetation fluctuations over the survey span of June and July would be comparable to the locations taken at G2021 locations. Along each 30-meter section, of each of the 80 locations, I calculated vegetation composition, percent shrub cover and shrub height using the methods described above for the 100m transects.

To determine if the vegetation composition of grouse locations (G2021) and current vegetation of the treatment area (paired random locations, GR2021) were similar, I conducted ANOVAs comparing average shrub height, shrub intercept, percent forb cover, percent shrub cover, and percent grass cover between these two categories. To determine how similar bird locations (GR2021) were across individuals I conducted ANOVAs of vegetation characteristics between individual grouse from which the locations were chosen from. To determine if the 2016 retreatment impacted vegetation characteristics, I conducted ANOVAs comparing GR2021 locations within the
retreatment footprint and those only within the 2005 pinyon juniper removal treatment footprint. Finally, I conducted ANOVAs comparing the vegetation characteristics among G2021, GR2021, T2020, and I2020 to compare vegetation similarities across all locations surveyed in 2020-2021. All ANOVA calculations were conducted using the R project (R Core Team, 2020).

RESULTS

Vegetation cover and composition of treatments over time

The most commonly detected forb within the pinyon juniper removal treatment area, the intact sagebrush, and sage-grouse locations was *Lupinus spp*. The most common grasses detected within the pinyon juniper removal treatment and at grouse locations were crested wheatgrass (*Agropyron cristatum*) and Western wheatgrass (*Pascopyrum smithii*). Western wheatgrass was the most common grass species found within the intact sagebrush. Of the grass species seeded within the pinyon juniper treatment crested wheatgrass and Indian ricegrass (*Oryzopsis hymenoides*) were detected. Of the forb species western yarrow (*Achillea millefolium*) was detected.

In these analyses, I compared treatment data 2-4 years after treatment (T2007), 15-16 years after treatment (T2020) and intact sagebrush (I2020). I calculated the average shrub height, percent shrub intercept, percent shrub composition, percent forb composition, and percent grass composition for T2007, T2020, and I2020 (Table 2.1). Within the standard deviation T2020, reach or exceed the minimum of the 2020 Utah state guidelines for breeding and brood rearing habitats, for all vegetation components
within this study (UDWR 2019). The T2020 outside of the 2016 retreatment had a higher average shrub height (51.1 cm), an increased shrub intercept cover (31.4%), higher forb coverage (3.1%), greater percent shrub cover (29.1%), but a lower grass cover than the average of the locations within the retreatment (Table 2.2). The average shrub height was similar across the study location types, ranging from 28.7 cm - 34 cm with no significant difference (Table 2.1). Intact sagebrush (I2020) had higher intercept shrub cover and percent shrub composition than either T2007 (F1,18 = 54.67 p = <0.001, F1,18 = 72.84 p = <0.001, respectively) or T2020 (F1,18 = 8.72 p = 0.0085, F1,18 = 9.18 p = 0.0072, respectively). A comparison of T2007 to T2020 showed no significant difference (F1,18 = 3.17 p = 0.092). Continuing the direct comparison between T2007 and T2020, there was a significant variance in shrub composition (F1,18 = 5.78 p = 0.027) with T2020 having a higher composition (Table 2.1). Within the treatment area, grass cover was lower in T2020 than it had been previously in T2007 but this difference was not significant (Table 2.1; F1,18 = 3.19 p = 0.091). In comparison, the percentage of grass cover within I2020 was significantly lower than T2007, but not T2020 (Table 2.1; F1,18 = 6.85 p = 0.017, F1,18 = 1.60 p = 0.22, respectively). Percent forb cover also decreased over time within the treatment area (Table 2.1; F1,18 = 18.47, p = <0.001) and was lower in I2020 (Table 2.1; F1,18 = 24.068, p = <0.001) than T2007. The average percent forb cover values were higher in T2020 than in I2020 but the differences were not significant (Table 2.1; F1,18 = 2.0283, p = 0.1715). After the initial treatment in 2005, minimal trees were present within the treatment area. When comparing tree cover across all location types there was less than one percent found across all location types and was not furthered analyzed.
Vegetation composition of occupied grouse locations

I calculated average shrub height, percent shrub intercept, percent shrub cover, percent forb cover and percent grass cover for G2021 and GR2021 (Table 2.1.) I compared the GR2021 locations within the retreatment (2016) to those only in the initial treatment (2005) and found no significant difference to be found in any of the vegetation characteristics, therefore I pooled all data for the vegetation comparisons. G2021 locations exceeded the minimum 2020 Utah state guidelines for sage-grouse management for breeding and brood rearing for all vegetation components in the study. Within GR2021 locations Utah Stage sage-grouse guidelines were meet for all vegetation measurements except for forb percent cover. No significant difference was found when comparing sagebrush height between G2021 and GR2021 ($F_{1,78} = 0.17 \ p = 0.68$). GR2021 had significantly greater percent shrub intercept and percent shrub composition than G2021 ($F_{1,78} = 6.63 \ p = 0.012$, $F_{1,78} = 5.35 \ p = 0.023$). G2021 had significantly greater percent forb composition and percent grass composition than GR2021, with percent grass composition having the greatest significant difference ($F_{1,78} = 7.88 \ p = 0.0063$, $F_{1,78} = 17.58 \ p = <0.001$).

Additionally, I compared G2021 with T2020 and I2020 to have further comparison of grouse habitat to the pinyon-juniper removal area and intact sagebrush. When comparing G2021 to T2020 shrub height was not significantly different ($F_{1,48} = 0.051 \ p = 0.82$). Also, there was no significant differences found in shrub intercept cover ($F_{1,48} = 2.39 \ p = 0.13$), percent grass cover ($F_{1,48} = 2.44 \ p = 0.12$), or percent forb cover ($F_{1,48} = 0.080 \ p = 0.78$). Percent shrub intercept showed some significant difference between G2021 and T2020, with T2020 having more ($F_{1,48} = 4.10 \ p = 0.048$). Overall, the
G2021 locations were similar to the T2020 locations. When comparing G2021 to I2020 shrub height and percent grass composition were the only comparisons that were not significantly different ($F_{1,48} = 0.31 \ p = 0.58$, $F_{1,48} = 3.46 \ p = 0.069$). Percent shrub intercept and percent shrub composition were both significantly lower within G2021 than I2020 ($F_{1,48} = 33.33 \ p < 0.001$, $F_{1,48} = 34.80 \ p < 0.001$).

I compared GR2021 to T2020 to show if similar results were found by both surveys conducted within the pinyon juniper removal treatment area. Shrub height was similar when comparing T2020 to GR2021 ($F_{1,48} = <0.001 \ p = 0.99$). Percent shrub intercept and percent shrub composition showed no significant difference ($F_{1,48} = <0.001 \ p = 0.99$, $F_{1,48} = 0.44 \ p = 0.51$). Percent forb composition and percent grass composition were significantly different with higher percentages within T2020 than GR2021 ($F_{1,48} = 27.03 \ p < 0.001$ $F_{1,48} = 15.25 \ p < 0.001$). All ANOVAs will be shown in the appendix.

**DISCUSSION**

Long-term monitoring of pinyon juniper mastication treatments is essential in providing insight to land managers. Past research suggests that pinyon juniper encroachment retreatment would only be needed every 30-to-50 years (Bates et al. 2017) following the initial pinyon juniper removal; however, in our study of pinyon juniper mastication, follow-up treatment was needed 10 years after the initial treatment. The retreatment was needed to remove young trees from establishing themselves and causing pinyon juniper to encroach back into the treatment area. The maintenance treatment conducted in 2016 was within the 10-to-15-year length of time suggested for sage-grouse management (Wozniak et al. 2020). The area treated in 2016 had reached stage I of pinyon juniper
encroachment though this largely due to large trees not removed in the 2005 treatment rather than regrowth. My observations five years after the maintenance treatment showed minimal tree regrowth.

Multiple studies have shown that sagebrush can recover with the assistance of sagebrush seeding (Bate et al 2017, Davies and Bates 2019, Williams et al. 2020); though my study showed sagebrush cover in treated areas similar to intact sagebrush stands no sagebrush seed was included in the post treatment seeding. Additionally, the sagebrush vegetation within the treatment areas reached the guidelines set forth by the Utah greater sage-grouse conservation strategy (UDWR 2019). It has been well documented that there are initial forb cover increases after disturbances such as pinyon juniper removal (Abella et al. 2012, Herron et al. 2013). In addition to forbs, studies have shown that perennial grasses establish quicker that sagebrush (Abella et al. 2012, Herron et al. 2013). While a majority of grass and forb species found within the seed mixture were not recorded within the study surveys, they were observed sporadically throughout the treatment area. Additionally grass species within the same genus may have been missed identified leading to a less accurate representation of seeded species observed. I believe that the seeding conducted after the 2005 and 2016 contributed to the grass and forb cover observed within my study.

Unfortunately, multiple studies demonstrate that without disturbance sagebrush will grow to an extent; and without the opportunity caused by a disturbance, forb and grass cover will correspondingly decline. (Abella et al. 2012, Herron et al. 2013, Bates et al. 2017, Davies and Bates 2019, Williams et al. 2020). My results support these findings, with a high percentage of forb and grass coverage observed from the previous study in
2007 and 2009, but a significant decline of these elements in 2020 and 2021, to levels similar to nearby undisturbed sagebrush vegetation. While the 2016 retreatment presumably caused additional disturbance and supplemented forb and grass growth by seeding, there was still a decline in forb and grass presence by 2021.

The female grouse I tracked within the SGMA selected areas with higher forb cover than was found within the treatment area. The female grouse even selected for locations with forb coverage higher than is suggested by the Utah state guidelines. Additionally, these grouse chose areas with higher average grass cover than what was found at the random locations within the treatment and above Utah state guidelines as well. Due to the geographical uniqueness of sage-grouse habitat in southern Utah in comparison to the rest of Utah and other states management guidelines should be geared to support this location rather than manage it based on state or federal guidelines (Picardi et al 2020). However, when comparing vegetation surveys conducted at the transect locations within the treatment (T2020) to female grouse locations (G2021) there were no significant differences found in either forb or grass cover. The similarities found indicated that a portion of the treatment area had habitat that was similar to the locations selected by the female grouse in this study.

This study had a limited sample size of sage-grouse from which to choose vegetation survey locations. Yet while locations were only selected from three individual female grouse that were all captured at the same location, those three individuals moved to different locations throughout the Panguitch Sage-Grouse Management Area, spanning 51.1 km, providing a diverse study set of locations to select from. While distance from trees wasn’t actively measured within this study it has been shown to be important to
sage-grouse habitat selection (Baxter et al. 2017, Beers et al. 2022). The removal of perches used by avian predators likely contributed to maintaining the population in this area. My study determined that the vegetation components within portions of the treated areas were similar to the habitat they were selecting throughout the Panguitch SGMA. The average vegetation components across the entire pinyon juniper removal treatment area were not similar to areas selected by sage-grouse. Even though this study found only portions of the treatment were similar to sage-grouse selected habitat, those portions continue to support sage-grouse.

**MANAGEMENT IMPLICATIONS/CONCLUSIONS**

My study supports the mastication of pinyon and junipers as a strategy to improve and restore sagebrush vegetation communities. Regularly monitoring pinyon juniper removal treatment areas will inform managers when pinyon juniper removal retreatments may be needed, perhaps sooner than previously suggested in other regions of where this treatment occurs. When comparing the treated area in Sink Valley to grouse locations within different areas of the Panguitch SGMA, the grouse were found to be at locations with higher perennial grass and forb cover. Female sage-grouse were found at locations that contained higher grass cover and higher forb cover than the Utah greater sage-grouse conservation strategy guidelines; suggesting that forb cover and perineal grass cover may need to be higher in this region than elsewhere in the state. While forbs and grasses recover and establish themselves quickly after soil disturbances, continued retention of forbs and perineal grass within managed areas may be difficult without repeated treatments. The continuing change in southern Utah’s climate may be contributing to the
decrease in forb cover as less and less consistent annual rainfall causes the lack of moisture needed for forbs to germinate year after year. To address this change within the Panguitch SGMA land managers may need to increase the minimal guideline set for forb cover when managing land for sage-grouse, and plan for periodic retreatments.
REFERENCES


Dahlgren, D. K., T. A. Messmer, B. A. Crabb, M. T. Kohl, S. N. Frey, E. T. Thacker, R.


Utah Division of Wildlife Resources (UDWR). 2019. Strategic management plan for sage-grouse. Utah Department of Natural Resources, Publication 02-20. Salt Lake City, Utah, USA.


Williams, C. J., F. B. Pierson, P. R. Kormos, O. Z. Al-Hamdan, S. K. Nouwakpo, and M.


**TABLES**


<table>
<thead>
<tr>
<th>Vegetation Characteristic</th>
<th>Shrub Height</th>
<th>Shrub Intercept</th>
<th>Shrub Percent</th>
<th>Forb Percent</th>
<th>Grass Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T2007</td>
<td>10</td>
<td>28.7 ± 7.24</td>
<td>7.49 ± 6.24</td>
<td>7.25 ± 4.75</td>
<td>12.7 ± 6.98</td>
</tr>
<tr>
<td>T2020</td>
<td>10</td>
<td>34.0 ± 9.29</td>
<td>12.4 ± 6.54</td>
<td>13.6 ± 6.47</td>
<td>2.45 ± 2.06</td>
</tr>
<tr>
<td>I2020</td>
<td>10</td>
<td>29.1 ± 2.69</td>
<td>24.6 ± 4.11</td>
<td>25.0 ± 4.83</td>
<td>1.85 ± 1.97</td>
</tr>
<tr>
<td>G2021</td>
<td>40</td>
<td>32.6 ± 19.4</td>
<td>9.7 ± 7.17</td>
<td>9.18 ± 7.59</td>
<td>3.30 ± 5.87</td>
</tr>
<tr>
<td>GR2021</td>
<td>40</td>
<td>34.0 ± 10.2</td>
<td>13.9 ± 7.52</td>
<td>13.0 ± 7.19</td>
<td>0.678 ±0.735</td>
</tr>
</tbody>
</table>

Table 2.2. Summary Statistics Comparing average shrub height, average shrub intercept cover, percent shrub cover, percent forb cover, and percent grass cover within GR2021 and T2020 locations within the 2016 retreatment and outside of it. 2020-2021

<table>
<thead>
<tr>
<th>Locations</th>
<th>Shrub height</th>
<th>Shrub Cover</th>
<th>Forb Cover</th>
<th>Grass Cover</th>
<th>Shrub Cover Intercept</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2020 out</td>
<td>51.152 ± 2.5</td>
<td>31.428 ± 0.511</td>
<td>3.085 ± 2.708</td>
<td>6.665 ± 4.476</td>
<td>29.085 ± 6.243</td>
</tr>
<tr>
<td>GR2021 in</td>
<td>34.876 ± 11.522</td>
<td>12.720 ± 6.209</td>
<td>0.734 ± 0.728</td>
<td>3.692 ± 2.530</td>
<td>12.256 ± 5.823</td>
</tr>
<tr>
<td>GR2021 out</td>
<td>31.673 ± 5.055</td>
<td>17.131 ± 9.844</td>
<td>0.531 ± 0.770</td>
<td>2.955 ± 2.433</td>
<td>14.961 ± 10.029</td>
</tr>
</tbody>
</table>
Figure 2.1. Panguitch and Surrounding Sage Grouse Management areas in Southern Utah, 2020-2021
Figure 2.2. Map of Treatment areas for mastication pinyon juniper removal treatment conducted in 2005 and hand thinning and removal of large diameter trees not removed in the initial treatment conducted in 2016 within study area, Alton, Utah.
Figure 2.3. Images of the landscape taken at the same location in 2005 A. before treatment, 2006 B. after treatment and 2020 C. during the study in Sink Valley, Alton, Utah, USA.
Figure 2.4. Treatment transect survey locations of T2007 and T2020 and sagebrush (I2020). Transect survey at mechanically thinned sage-brush location not included within study. Each group of locations is a single survey location depicting the grid used to conduct the surveys. Coal Mine footprint and original location of nearby lek, Alton, Utah 2020-2021.
Figure 2.5. Diagram of vegetation survey transects and pellet count survey transects conducted within Sink Valley pinyon juniper removal treatment area, intact sagebrush, restored grassland, and mechanically thinned sagebrush from June 2020 – November of 2021. Not Drawn to scale.
Figure 2.6. Random surveyed locations within the study area. All random point locations were generated in ArcPro using a minimum distance of 50m from each other point location and the border (GR2021), June 1, 2021 – July 31, 2021, Alton, Utah.
CHAPTER III
SAGE-GROUSE HABITAT USE 15 YEARS AFTER PINYON JUNIPER REMOVAL ON THE SOUTHERN COLORADO PLATEAU

ABSTRACT

Pinyon (Pinus spp.) juniper (Juniperous spp.) removal treatments have been conducted by the Utah Watershed Initiative and other government agencies throughout Utah to improve Greater sage-grouse (Centrocercus urophasianus, hereafter: sage-grouse) habitat. While the effectiveness of pinyon juniper removal treatments is often measured by sagebrush community recovery the true effectiveness of these treatments - creating suitable sage-grouse habitat - can be directly evaluated by the presence of sage-grouse within the treatment areas. Determining sage-grouse use of treated areas informs managers if current management procedures should be continued or if alternative methods should be considered. Within the Panguitch Sage-Grouse Management Area (SGMA), 71 pinyon juniper removal projects were conducted from 2005 to 2021 to improve or expand sagebrush communities, habitat that is essential to sage-grouse. To determine sage-grouse use of these treated areas I deployed satellite GPS transmitters on 8 female sage-grouse and monitored their locations from October 2020 - December 2021. I conducted utilization distributions to determine the seasonal home ranges of the 8 female grouse, and found that 19.2 – 90.6 % of the home ranges of sage-grouse were within pinyon juniper removal treatments. I separated the treatments within the seasonal home ranges by age of treatment as of 2021. The majority of pinyon juniper treatment area found within home ranges was five years old or less. I analyzed the seasonal home
ranges in comparison to SGMA designated seasonal habitats and found major discrepancies within the data. In addition to monitoring the GPS transmitters, I conducted walking surveys (flush counts) and pellet-count surveys monthly from June 2020 - November 2021 (excluding December 2020 and January February 2021) to determine if sage-grouse were present within a pinyon juniper removal treatment area. Within the pinyon juniper removal treatment area, I determine sage-grouse were present year-round based on sage-grouse being detected each of the monthly pellet surveys. Sage-grouse were present in the original 15-years old treatment; however, my data suggests that sage-grouse are more likely to be present within treatments completed within the last 5 years. It is important to determine why sage-grouse are avoiding older treatments and determine why they are using younger treatments so that management practices can be updated so sage-grouse will continue to used pinyon juniper removal treatments for mor than five years.

**INTRODUCTION**

The conifer encroachment of pinyon pine (*Pinus spp.*) and juniper (*Juniperus spp.*) into sage-grouse habitat has been a concern of wildlife managers seeking to conserve sage-grouse habitat (Coates et al. 2017). The suppression of wildfires over the last century, has resulted in an increase in conifer woodlands in the western United States. This reduced potential food and adequate cover for sage-grouse. Conifer woodlands spanned 190,000 km² of the Intermountain West; up to which 90 percent was historically sagebrush before American European settlement (Johnson et al. 2008, Miller et al. 2011, Pyke et al. 2015).
Nearly 500,000 km² of sagebrush is estimated to had been encroached by conifers since pre-European settlement (Falkowski et al. 2017).

Pinyon juniper encroachment is described as a three phased process. In the initial phase pinyon and junipers are the minority consisting of scattered seedlings and juvenile trees (Miller et al. 2005). In the second phase these conifers have reached a co-dominance with the original vegetation. During phase two of pinyon juniper encroachment in sagebrush communities, sagebrush obligate species, such as Greater sage-grouse (*Centrocercus urophasianus*, hereafter ‘sage-grouse’), may continue to use this habitat. However, because increased trees provide perches for avian predators and decrease the sagebrush needed for food and cover, sage-grouse experience a decline in their survival rates in these habitats (Severson et al. 2017a, Coates et al. 2017). Phase three of encroachment consists of a conifer-dominated landscape with little of the original vegetation present (Tausch et al. 2009, Boyd et al. 2017). With the advancement of the vegetation community into phase three pinyon juniper encroachment, the landscape no longer supports sage-grouse due to the disappearance of sagebrush, and the land has been transformed into juniper-pinyon woodland (Miller et al. 2005).

To date, more than 500,000 km² of sagebrush habitat, critical to the conservation of sage-grouse, has been converted to conifer woodlands in the United States (Falkowski et al. 2017). A strong avoidance of pinyon-juniper woodlands by sage-grouse has been documented in numerous studies (Atamian et al. 2010, Casazza et al. 2011, Baruch-Mordo et al. 2013, Knick et al. 2013, Coates et al. 2017). The lack of sagebrush cover and increased abundance of potential predators causes sage-grouse to be at higher risk while moving through pinyon-juniper woodland habitat. Additionally, studies show that
lek attendance decreases and leks are more frequently abandoned as tree canopy cover increases (Baruch-Mordo et al. 2013). The encroachment of pinyon pine (\textit{Pinus spp.}) and juniper (\textit{Juniperus spp.}) into sagebrush communities has caused concern for Utah natural resource and wildlife managers charged with conserving and restoring sage-grouse habitat (Coates et al. 2017). While Utah currently only contains 6% of the sage-grouse population (Nielson et al. 2015, WAFWA 2015), sage-grouse also only occupy 41.3% of their historic Utah sagebrush habitat, suggesting there is opportunity to support a higher sage-grouse population within Utah if these sagebrush communities are restored (Beck et al. 2003).

The conversion of pinyon-juniper woodlands back to sagebrush is critical to sage-grouse conservation in Utah (Cook et al. 2017, Frey et al. 2013). Multiple studies have documented the efficiency of different conifer removal methods in restoring sagebrush habitat (Provencher and Thompson 2014, Redmond et al. 2014, Stephens et al. 2016, Williams et al. 2017, 2019). While the immediate response of management practices to restore sagebrush communities from pinyon juniper encroachment has been studied extensively (McIver et al. 2014, Bybee et al. 2016, Severson et al. 2017a, Sandford et al. 2017), the long-term effects is not yet well understood. However, one study has suggested that conifers may recolonize a site with 10-15 years post-treatment (Wozniak et al. 2020). Determining the frequency of conifer removal treatments required to maintain sage-grouse habitat is important. The longer sage-grouse utilize the area after conifer removal suggests that the treatment remains effective. Analyzing sage-grouse use of treated areas will help determine how long after removal these habitats continue to
support sage-grouse. From this knowledge, changes can be implemented to better support sage-grouse habitat.

To date few studies have assessed the long-term influence of pinyon juniper removal in Utah. The goal of my study was to estimate sage-grouse use of pinyon juniper removal projects within the Panguitch Sage-grouse Management Area (SGMA) in southern Utah to determine if there is a relationship between treatment age and sage-grouse use. Additionally, I determined if sage-grouse seasonal use of the management area reflects the designated seasonal habitat within the SGMA.

**STUDY AREA**

The study area is located within the Panguitch SGMA, created by Utah Division of Wildlife Resources to manage sage-grouse within the southern extant of its range. (Figure 3.1; UDWR 2019). The SGMA encompasses portions of Beaver, Garfield, Iron, Kane, and Piute counties, spanning 118 km north to south, and encompassing 2457 km². The Utah sage-grouse conservation strategy outlines three different habitat categories within the Panguitch SGMA, in reference to sage-grouse management: ‘habitat’, ‘non-habitat’ and ‘opportunity habitat’ (UDWR 2019). ‘Habitat’ indicates any areas used by sage-grouse throughout the year, ‘non-habitat’ indicates that sage-grouse don’t use the area (i.e., rock outcrops, cliffs, etc.), and ‘opportunity habitat’ has the potential to be used by sage-grouse, with proper management. Much of the ‘opportunity habitat’ once was sage-grouse habitat but has become unsuitable due to invasive grasses, wildfires, or encroachment of pinyon-juniper woodlands (UDWR 2019). Within the Panguitch SGMA, 55% of the land was designated sage-grouse habitat and 36% was designated
‘opportunity’ habitat. The SGMA contained 566 km² (367 habitat, 199 opportunity) of private lands and 1,115 km² of federal lands the Bureau of Land Management (BLM) own 60 km² of habitat and 404 km² of opportunity habitat, while the US Forest Service (USFS) own 237 km² of habitat and 259 km² of opportunity habitat. Additionally, the State Institute and Trust Lands Administration managed 147 km² (122 km² habitat, 25 km² opportunity) and the Utah Department of Natural Resources managed 8 km² (4 km² habitat, 4 km² opportunity). To create or improve sage-grouse habitat, 115 vegetation treatment projects, affecting 814.8 km² were completed by the Utah Watershed Initiative as of 2021 within the Panguitch SGMA. Pinyon-juniper removal were a part of 71 projects, removing 624.6 km² of woodland habitat.

The sage-grouse capture area (i.e., where we trapped individuals and deployed transmitters) spanned a 2005 mastication treatment and the surrounding area in Sink Valley, near the town of Alton (Figure 3.1). The Sink Valley area of the Panguitch SGMA was comprised of pinyon-juniper woodland, desert-shrub, grassland pastures, and irrigated croplands. The pinyon-juniper woodland was dominated by Colorado pinyon (Pinus edulis) and Utah juniper (Juniperus osteosperma) but also contained big sagebrush (Artemisia tridentata var. tridentata and var. vaseyana), black sagebrush (Artemisia nova), and antelope bitterbrush (Purshia tridentata). The predominate grass species within the woodlands included bluebunch wheatgrass (Pseudoroegneria spicata), Idaho fescue (Festuca idahoensis), and needlegrass (Stipa spp.). The desert-shrub was dominated by black sagebrush followed by big sagebrush, and antelope bitterbrush. The grasses within the desert-shrub included bluebunch wheatgrass, Idaho fescue, and squirreltail (Sitanion hystrix). The grassland pastures were comprised of addition grass
including Kentucky bluegrass (*Poa pratensis*), timothy (*Phleum pratense*), intermediate wheatgrass (*Thinopyrum intermedium*). The irrigated cropland predominately consisted of alfalfa with some cereal grain crops. During 2020-2021, summer average daily high temperature was 25.88°C, while winter average daily low winter temperature was -8.5°C (Utah Climate Center Alton station ID USC00420086). The average annual precipitation of Alton was 40.59 cm. The average annual snowfall total for the area was 2000 mm. The recorded average annual snowfall for 2020 and 2021 was 1467mm and 482mm, respectively (Utah Climate Center, 2020, Panguitch Station USC00426601). The elevation of Sink Valley study area ranged from 2,072 - 2,194 m.

**Vegetation treatments and disturbances**

In 2005, pinyon-juniper was removed by mastication on BLM lands (Figure 3.1) within Sink Valley, near the town of Alton. The treatment was contracted by the BLM to remove pinyon and juniper trees to reclaim sage-grouse habitat and improve sage-grouse habitat. The pinyon juniper encroachment within the treatment area was considered a mixture of phase two, and phase three, before the pinyon-juniper removal was conducted. The initial treatment footprint encompassed 3.3 km². Within the pinyon juniper removal treatment, the dominate soil type consisted of silty clay and fell within the hydrologic soil group e, having slow water infiltration and transmission rates (United States Department of Agriculture 2022). The removal project eliminated standing pinyon and junipers trees through mastication (bullhog) leaving woody mulch across the area. Mastication is conducted by using a shredding device attached to a mechanical arm attached to a piece of heavy machinery. The mechanical arm moves the shredding mechanism from the
crown of the tree continuing down shredding the tree into mulch. As part of the treatment, the area was aerially seeded with a mix containing wheatgrass (*Agropyron cristatum*), intermediate wheatgrass, Russian wildrye (*Psathyrostachys juncea*), Indian ricegrass (*Achnatherum hymenoides*), western yarrow, Rocky Mountain beeplant (*Cleome serrulata*), blue flax (*Linum perenne lewisii*), yellow sweetclover (*Melilotus officinalis*), alfalfa, sainfoin (*Onobrychis viciifolia*), and small burnet (*Sanguisorba minor*) to reestablish the desert-shrub habitat after the disturbance. No livestock grazing was allowed for two years after the pinyon juniper removal and seeding, allowing for a regrowth of grasses, forbs and shrubs. In 2016, the BLM conducted a follow-up treatment in the area to remove large trees not removed in the initial treatment and any new tree growth. Initially, small patches of trees were retained to provide habitat for ungulate species; these patches were removed in 2016, to create a continuous sagebrush community across the landscape. The follow-up treatment included 76.5 percent of the initial study area, adding 0.2 km² increasing the total removal area to 3.5 km² (Figure 3.1). As part of the 2016 treatment, aerial dispersal seeding was conducted to help reestablish and bolster grasses and forbs. As with the previous treatment, no grazing was permitted within the treatment area for two years. The treatment study area had been seasonally grazed by cattle previous to the initial removal and was similarly grazed by cattle during my study.

On adjacent private and BLM lands, a surface coal mine began in 2009 (Figure 3.1). This caused gradual terrain changes to the surrounding area as the mine developed. The historic lek had been located within the initial mining footprint but had since been reclaimed leading to a grassland dominated community following restoration efforts.
Sage-grouse shifted lekking activity to within the pinyon juniper removal treatment in 2012 though lekking activity resumed within the historical lek in 2015 after reclamation had been completed (Petersen 2016). The mine changed the path of a road through the treated area, and altered the surrounding habitat. Light and noise pollution were observed from 2020-2021 that could have impacted sage-grouse habitat use. With additional reclamation habitat management provide by the coal mine, sage-grouse continued to be active in the area and no detrimental effects on the sage-grouse population were found based on work conducted on adjacent private lands (Petersen 2016).

METHODS

Sage-grouse capture and monitoring

During the spring and fall of 2020-2021, I captured 8 female sage-grouse, fitted them with solar-powered GPS transmitters (PTT-100, Geotrack, North Carolina, USA), and released them back onto the capture site. While I targeted male and female sage-grouse for capture, I only successfully captured females. I conducted sage-grouse trapping by accessing the sites with an all-terrain vehicle while spotlighting the area to detect sage-grouse. Once an individual was spotted, I used a walking method to spotlight and capture the individual using a handheld net, similar to methods described in Connelly et al (2003). My objective was to maintain a monitoring population of 6 birds from 2020 - 2021. Sage-grouse populations can be estimated based on male lek attendance by using a constant male detection probability and sex ratio (Connelly 2003). There is only 1 lek in Sink Valley which had an average male lek attendance of 12-14 birds. Previous
studies have estimated sage-grouse sex ratios favoring female sage grouse 2:1, but more recent studies show variation in sex ratios can cause over estimation of sage-grouse populations (Connelly 2003, Guttery 2013). Without validation of the sex ratio in Sink Valley a conservative sex ratio of 1:1 and a male detection constant of 0.75 would result in a population of 32 grouse 16 males, and 16 females. Thus, 6 birds would represent 37.5% of the female population. Captured grouse were sexed, weighed, aged (adult/juvenile), fitted with a GPS transmitter using a rump-mounted harness, and evaluated for injuries. Finding no injuries, I released the captured animal at the capture site. If the individual did not immediately fly away, I observed the animal until it did fly off, usually within a minute or two of release. I followed capture and handling methods approved by Utah State University (IACUC #10175, 11161). I recorded the location time and date of each grouse capture using a hand-held GPS unit (Garmin eTrex 20x). I programmed the GPS transmitters to acquire a location every 4 hours during the breeding and brood-rearing season (March – October), and every 6 hours during fall/winter (November – February).

**Seasonal sage-grouse home ranges within pinyon juniper removal treatments**

I separated sage-grouse GPS telemetry locations into three time periods, winter and fall (October-February), breeding (March-May), and summer (June-September) (UDWR 2019). Of the locations recorded I excluded locations taken within 48 hours of capture to allow for the grouse to recover from capture and adapt to the GPS transmitter harness. Additionally, I excluded outliers due to GPS transmitter errors. I estimated the extent of habitat use using a kernel density function in R to calculate a utilization distribution
probability. I estimated seasonal utilization distributions for the core (65% distribution) and extended (95% distribution) habitat for each of the eight sage-grouse females monitored during my study to determine seasonal home ranges (R Core Team, 2020). Using ArcGIS Pro (ESRI, 2022) the kernel density shapefiles were overlaid on top of a shapefile detailing pinyon juniper removal treatments conducted by the Utah Watershed initiative as of 2021, within the Panguitch SGMA (WRI 2021; UDWR 2019). Using these datasets, I determined the percentage of each sage-grouse’s estimated home range that contained pinyon juniper removal projects within the Panguitch SGMA (Figure 3.2), for each season. To determine if age of treatment was associated with the extend home ranges. I further analyzed the percentage of pinyon juniper removal treatments within home ranges. I grouped treatments into 3 age groups 0-5 years, 6-10 years and 11-15 years. The age of the treatment was based on their project completion date and ranged from 2006-2021. From this I determined the percentage of each treatment age group within the sage-grouse extend and core home ranges.

I overlaid seasonal designated habitat of the SGMA (Figures 3.3), to determine the proportion of seasonal extend and core home ranges falling within their associated designated habitat and determine potential use of opportunity habitat. I analyzed the extend and core home ranges in reference to habitat type based on LANDFIRE Data, to determine the proportion of shrublands, conifer woodlands, and other land types within the extend and core home ranges (LANDFIRE, 2020).

**Survey of sage-grouse presence in vegetation treatments**
To determine grouse use of the treated areas, in addition to satellite GPS telemetry locations, I conducted pellet counts surveys and walking surveys with bird dogs during all non-winter months (March - November) of 2020 and 2021. The pellet survey transects were within 60 x 100 m rectangles forming the perimeter of a center survey line. The 100m survey line consisted of 5 60-m transects centered perpendicular to the line, essentially creating 10 30-m arms. Two of these transects bounded each end of the survey line, the other 3 were evenly spaced along the survey line between the two ends (Figure 2.5). The pellet count surveys were located on thirteen vegetation survey transects within Sink Valley that were established during a concurrent study presented in Chapter 2. Five were within the pinyon juniper removal treatment area, five within sagebrush stands where no removal treatment had occurred, two within mined areas reclaimed to grasslands, and one within a sagebrush thinned management area in which sage-brush had been mechanically thinned (Figure 3.1).

To conduct pellet count surveys, I walked down each arm of the transects and counted the total number of pellet piles within a meter of the arm, calculating a total for each transect. As I encountered pellets, I removed them from the transect line to eliminate the possibility of double counting. Due to the lack of surveys having been conducted prior to June of 2020 and the pause in surveys from December 2020 through February 2021 the first survey of each year (June 2020 and March of 2021) were anticipated to contain higher pellet counts.

I conducted walking visual and bird dog surveys monthly, in conjunction with pellet count surveys. I used bird dogs to reinforce my visual surveys, when available. Bird dog surveys consisted of a trained hunting dog walking through the transect and
surrounding area to detect sage-grouse (Christiansen 2012, Dahlgren et al. 2010). I used
bird dogs in June, August, and November 2020, and March and June 2021 to increase
grouse detections during my walking surveys. Surveys were conducted in the morning of
the same day that I conducted pellet counts. I used the same dog and handler during each
of the three surveys conducted in 2020. I used a different dog and handler for each of the
surveys conducted in 2021.

RESULTS

I collected 7,241 locations from 8 female grouse from October of 2020 - December of
2021. The lek size during the time of capture was between 12-14 males; assuming a
conservative 1:1 ratio of sex and 75% male detection, my study used 42.8-50% of the
female population (Connelly 2003, Guttery 2013). Of those locations, 4227 were during
the fall/winter season, 1593 during the breeding season, and 1421 during the summer
season (Table 3.1). I found that 0.6% of the locations were found outside of the Panguitch
SGMA, 0.6% of locations were found within opportunity habitat, and 98.8% were found
within sage-grouse designated habitat.

Home range models

Within core home (65%) range models the percentage consisting of pinyon juniper
removal treatments ranged from 19.2% - 61.9% in the breeding season (Figure 3.2),
22.2% - 90.6% in the Summer (Figure 3-3), and 26.9% - 74.3% in the fall/winter season
(Figure 3.4; Table 3.1). Within the extended (95%) home range models the percentage of
pinyon juniper removal treatments within ranged from 17.8% - 43.5% in the breeding season (Figure 3.5), 25.8%-82.9% in the summer season (Figure 3.6), and 23.8% -51.5% in the fall/winter season (Figure 3.7, Table 3.1). The highest average % use of treated areas occurred during the summer (Table 3.1). The extend breeding season home ranges contained 15.3% of treatments from 2006-2010, 27.4% from 2011-2015 and 57.3% from 2016-2021. The summer extended seasonal home ranges were comprised of 13.7% of treatments from 2006-2010, 10.2% from 2011-2015 and 76.1% from 2016-2021. The fall winter extended seasonal home ranges contained 14.9% of treatments from 2006-2010, 22.2% from 2011-2015 and 62.9% from 2016-2021. The percent area of the core breeding home ranges comprised of pinyon juniper removal treatments from 2006-2010, from 2011-2015 and from 2016-2021 were 22.6 % 19.5 % and 57.9 % respectively. The percent area of core summer home ranges comprised of pinyon juniper removal treatments from 2006-2010, from 2011-2015 and from 2016-2021 were 32.6 % 0.7 % and 66.7 % respectively. The percent area of core fall winter home ranges comprised of pinyon juniper removal treatments from 2006-2010, from 2011-2015 and from 2016-2021 were 21.5 % 11.6 % and 66.9 % respectively.

Using the seasonal habitat type designations put forth by the Utah Conservation Plan for Greater Sage-Grouse (UDWR 2019) I calculated that 25.8% of the estimated extended fall/winter home range (n = 7) was within winter designated habitat, while 60.6% was within non-winter habitat and 13.6% was outside of the Panguitch SGMA boundaries. When comparing the extended home ranges during breeding season (n = 5) I calculated that 26.9% was within nesting and brood rearing habitat, 44.1% was within non-nesting and brooding rearing habitat, and 29.0% was outside of the SGMA. In the
summer home ranges (n = 5) I calculated 35.5% within breeding and brood raising habitat, 44.5% in non-nesting and brood rearing habitat, and 20.0% was outside of the SGMA. I found that extended home ranges consisted of 15.4%-17.8% of opportunity habitat. I calculated that 42.3% of the estimated core fall winter home range (n = 7) was within winter designated habitat, 52.7% was within non-winter habitat, 3.3% was found within opportunity habitat and 1.7% was found outside of the Panguitch SGMA. When comparing the core breeding season home ranges (n = 5) I calculated that 32.0% was within nest and brood rearing habitat while 34.6% was found in none nesting or brooding rearing habitat, 12.6% was found in opportunity habitat, and 21.8% was found outside of the Panguitch SGMA. The percentage of summer home ranges (n=5) within nesting or brood rearing habitat, non-brood rearing non nesting habitat, opportunity habitat and outside of the Panguitch SGMA were 76.3%, 2.2%, 14.1%, and 7.4% respectively.

Based on LANDFIRE vegetation data, sage-grouse extended home range contained mostly shrublands (28.2% – 32.8%) and coniferous woodlands (54.6% - 59.5%; Table 3.2). Sage-grouse incorporated developed lands at a similar percentage (3.2% -3.5%) as invasive shrubs and trees (2.9% - 3.3%, Table 3.2). Sage-grouse incorporated agricultural lands more during the breeding season than in fall/winter or summer (Table 3-2). Sage-grouse core home ranges were predominantly composed of coniferous woodlands (44.9 % -53.8%) and shrublands (35.6 % - 40.5%; Table 3.2).

**Pellet count surveys**

I found sage-grouse pellets within the pinyon juniper treatment area in Sink Valley during each month surveyed with the exception of November of 2021. During the survey
in June of 2020, the first pellet count of the study, I had 22 detections within sagebrush stands and 8 detections within the pinyon juniper removed treatment area. I excluded the first survey so I could get an accurate measure on sage-grouse monthly occurrence. By removing the pellets after each survey, I could get an accurate rate of sage-grouse occurrence each month without determining the age of pellets. Similarly, I detected a high pellet count in March of 2021, which represented grouse use of this area from December 2020-March 2021. Grouping the monthly detections into average seasonal detections, I found the average monthly detections within the pinyon juniper removal treatment areas and intact sagebrush areas for spring (April-May 2021 only) Summer (June-August) Fall (September - November) and Winter (Dec 2020 – March 2021) were 4.5 and 5, 6 and 5.6, 1 and 5.3 and 6 and 9.3 respectively. Winter monthly average was estimated from a single count of pellets observed in March and then divided by the number of months since the previous survey conducted in November of the previous year. No detections were ever observed within the sagebrush mechanically thinned treatment area. Within the two grassland treated area detections were fewer with no detections within the spring surveys or accumulated over the winter, a monthly average of 0.7 during the summer and a monthly average of 1.7 during the fall. Due to the small monthly sample size, I did not conduct statistical analyses to determine significant differences between season, monthly, or yearly averages. I had the assistance of bird-dog surveys in June, August, and November of 2020 and March and June of 2021 to assess sage-grouse use in general within treated and untreated areas. During walking bird-dog surveys conducted preceding the pellet count surveys, I observed two groups of 12 and 11 grouse within the study transects at two separate intact sagebrush vegetation locations
during the March 2021 survey, and outside of the transect surveys twice (5 individuals in June 2020 and 7 individuals in November 2020). I did not detect grouse when conducting walking surveys without a bird dog present.

**DISCUSSION**

Monitoring sage-grouse use of pinyon juniper removal treatments is fundamental to determining the overall success of the management action taken, as it is with any other management conducted for wildlife. The continued monitoring of habitat selection is also important, as suggested by my study, in which shrublands such as sagebrush consisted of only 28.2 - 32.8% of sage-grouse extend home ranges while 54.6% - 59.5% of their extended home ranges were dominated by coniferous woodlands. Their core home ranges consisted of 35.5-40.5% shrubland and 44.9-53.8 coniferous woodlands. Additional pinyon juniper removal treatments could be implemented in the neighboring areas to better support sage-grouse. It is important to recognize that sage-grouse are utilizing areas outside of pinyon juniper removal treatment areas. While some of these areas are already shrublands that may not require pinyon juniper removal, a large portion of estimated home ranges was made up of coniferous woodlands. While these utilization models give an estimate of grouse habitat use, they can over estimate grouse home ranges including locations not typical habitat for sage-grouse (Noonan et al. 2019). While their estimated home ranges extend to show potential range, they don’t define the percentage of time spent within the different habitats within the home range. Meaning sage-grouse could be disproportionately utilizing different areas within their core and extended home ranges.
Overlapping the estimated home ranges with the pinyon juniper removal treatments gave further understanding of sage-grouse use of pinyon juniper removal treatment areas. It showed that each grouse used pinyon juniper removal treatments within their home ranges. The use of pinyon juniper removal treatments is further supported by the fact that a portion of all home ranges were within pinyon juniper removal treated areas. At the center of each core and extended home range a pinyon juniper removal treatment was found.

It is likely that coniferous woodlands within the home ranges are used infrequently such as when individuals are moving from one patch of sagebrush habitat to the next (Coates et al. 2017). However, it is possible that based on the large portion of coniferous woodlands within estimated home ranges, grouse are selecting this habitat due to climate conditions in southern Utah. Conifers provide shade during the summer heat, a thermal refuge to sage-grouse (Beers et al. 2022). Additionally, Frey et al. (2013) found sage-grouse using conifer woodland prior to pinyon juniper treatment removal and suggested sage-grouse continue to use woodlands for shelter in winter snow storms when snow depths exceed shrub height.

Monitoring seasonal habitat use is critical to providing suitable sage-grouse habitat throughout the year. In the Panguitch SGMA, female grouse home range estimates exhibited seasonal space use outside of those boundaries suggested by the Utah conservation strategy (UDWR 2019). All extended seasonal home range estimates were found to have a majority of use outside of their designated habitat category. Most notably, 60.6% of the fall-winter home range area was outside of winter designated habitat. The discrepancies that occurred within my study suggest remapping of the season
habitat classifications might be necessary periodically. This may indicate that the habitat has changed and is not as favorable during their categorized season. This may be due to changes to the vegetation such as conifer encroachment, invasive grasses or it could be in response to changes in the climate of southern Utah (Kleinhesselink and Adler 2018, Renwick et al. 2018). Pinyon juniper removal treatments conducted within the SGMA may have caused previously assigned habitat to be suitable for different seasons. Additionally, this may indicate that some areas can support sage-grouse during multiple seasons. The number of pinyon juniper removal projects conducted within the Panguitch SGMA was not the same each year. With more projects having been conducted more recently this may have caused bias towards the age of treatment preference; however, there was at least one treatment conducted each year between 2006 and 2021 (WRI 2021). While 41 projects were completed from 2006-2016 and 30 from 2016-2021 seasonal home range estimates were comprised of a significantly higher portion of the more recent pinyon juniper removal projects. Of the pinyon juniper removal treatments within the estimated sage-grouse home ranges, treatments 5 years old or less accounted for 57.3% of the breeding season, 62.9% of the Fall Winter season and 76.1% during the Summer. Forb and grass abundance is particularly important for juvenile development. Past studies have shown that forbs and grasses reestablish before sagebrush and other shrubs after disturbances (Abella et al. 2012, Herron et al. 2013). This may account for the higher percentage of grouse selecting locations within younger treatments as they will are expected to have higher forb and grass coverage.

Sage-grouse have a strong site fidelity, which may impact their use of a treatment (Gerber et al. 2019). For example, we might expect treatments enacted adjacent to
currently occupied habitat to be used sooner than those treated farther from any occupied habitat; other studies have shown immediate use of treatment areas (Severson et al. 2017b, Frey et al. 2013). The mosaic fashion of the treatments throughout the SGMA allowed for more projects to occur within or adjacent to sage-grouse occupied habitat. Additionally, pinyon juniper removal treatments often occurred within pre-existing sage-grouse habitat. Overall, the placement of the treatments throughout the landscape, in relation to sage-grouse spatial distribution, increased the ability of sage-grouse to exploit these new habitats.

While only 8 females were monitored during the study, this represents an estimated 50% of the female sage-grouse population in sink valley. This lower individual sample size was bolstered by GPS satellite technology allowing for daily acquisition of location data throughout the study. Unfortunately, a study of only female spatial distribution and habitat use does not paint a full picture. This study was unable to monitor brood data because no females monitored showed exhibited successful nests. Males and non-brooding females will select habitat more supportive of adult survival while brooding females will select habitat to support juvenile survival (Smith et al. 2018). Many studies focus on both female and male grouse to fully explain the habitat selection of the sage-grouse population (Cook 2015, Gibson et al. 2018, Dahlgren et al. 2016). Further research monitoring a larger sample size containing both female and male grouse will greatly increase the understanding of sage-grouse habitat use within pinyon juniper removal treatment projects.

Sage-grouse pellet surveys revealed that sage-grouse were present within the pinyon juniper removal treatment area throughout the year. While the bird dog and
walking surveys showed some detections, they should be run in tandem with pellet
counts. Monthly pellet counts allowed for detections without sage-grouse needing to be
present during the survey while bird dog surveys can give a more accurate number of
grouse present (Hansen et al 2011).

Within this study sage-grouse were seen to be present within conifer removal
treatment areas. While the majority of the sage-grouses’ estimated home ranges was
dominated by conifer woodlands this gives opportunity for further conifer removal to
bolster sage-grouse habitat. Additionally, newly established treatments are more likely to
be occupied by sage-grouse. With further studies into seasonal habitat and use of conifer
treatments there is the opportunity to maintain sage-grouse population at its’ southern
edge.

MANAGEMENT IMPLICATION/CONCLUSIONS

Pinyon juniper removal projects to restore sage-grouse habitat have been conducted
within the Panguitch SGMA for more than 16 years. During my study, sage-grouse were
found in areas recently treated to remove woodland cover more often than other
vegetation communities. Past studies indicate that forb and grass species density increase
sharply in the few years following a treatment, often as a result of seeding (Abella et al.
2012, Herron et al. 2013). After the initial disturbance grasses and forbs decrease over
time as shrubs out competed them. My study of vegetation growth after a tree removal
treatment indicated that in southern Utah, this does indeed occur (Chapter 2).

Continued research is needed to determine the frequency in which pinyon juniper
removal should be conducted to support sage-grouse habitat restoration as climate change
continues to alter southern Utah. The current frequency of monitoring every 10 to 15 years for pinyon juniper removal treatment conducted to support sage-grouse may need to be shortened or supplemented with monitoring percent grass and forb cover to maintain sage-grouse habitat. Further monitoring of sage-grouse within the Panguitch SGMA will allow for a better understanding of seasonal habitat which may cause a change in the map of seasonal habitat within the SGMA.
REFERENCES


and brood success in greater sage-grouse. Ecology, conservation, and

Christiansen, T. 2012. Sage-grouse (Centrocercus urophasianus). Pages 12-1–12-55 in
S. A. Tessman and J. R. Bohne, editors. Handbook of biological techniques. Third
edition. Wyoming Game and Fish Department, Cheyenne, USA

Coates, P. S., B. G. Prochazka, M. A. Ricca, K. B. Gustafson, P. Ziegler, and M. L.
Casazza. 2017. Pinyon and juniper encroachment into sagebrush ecosystems
impacts distribution and survival of greater sage-grouse. Rangeland Ecology and
Management 70:25-38.

Connelly, J. W., K. P. Reese, and M. A. Schroeder. 2003. The monitoring of greater sage
 grouse habitat and populations. College of Natural Resources Field Station,
Publication 80. University of Idaho, Moscow, Idaho, USA.

Cook, A. 2015. Greater sage-grouse seasonal habitat models, response to juniper
 reduction and effects of capture behavior on vital rates, in northwest Utah. Thesis,
 Utah State University, Logan Utah, USA.

 mechanical conifer reduction treatments in Northwest Utah. Wildlife Society

Dahlgren, D. K., T. A. Messmer, and D. N. Koons. 2010. Achieving better estimates of
greater sage-grouse chick survival in Utah. The Journal of Wildlife Management
74:1286-1294.


ESRI, 2022. Arc GIS Pro (Version 3.0) [Computer software]. ESRI.


LANDFIRE, 2020, LANDFIRE 2020 Existing Vegetation Cover (EVC) CONUS 2022
Capable, Edition: LF 2020, Earth Resources Observation and Science Center
http://www.landfire.gov

McIver, J., and M. Brunson. 2014. Multidisciplinary, multisite evaluation of alternative
sagebrush steppe restoration treatments: the Sage STEP project. Rangeland

Biology, ecology, and management of western juniper (Juniperus occidentalis).
Oregon State University Agricultural Experiment Station Technical Bulletin 152,
Corvallis, USA.

of greater sage-grouse lek data: Trends in peak male counts 1965-2015. Western
EcoSystems Technology, Inc., Cheyenne, Wyoming, USA.

J. Altmann, P. C. Antunes, J. L. Belant, D. Beyer, N. Blaum, K. Böhning-Gaese,
L Cullen, R. Cunha, J. de Paula, J. D.-L, Dekker, N. Farwig, C. Fichtel, C.
Fischer, A. Ford, J. R. Goheen, R. Janssen, F. Jeltsch, M. Kauffman, P.M.
Kappeler, F. Koch, A. Scott LaPoint, C. Markham, E. P. Medici, R. G. Morato, R.
Nathan, G. R. Luiz, K. A. Oliveira-Santos, B. D. Olson, A. P. Patterson, E. E.
Ramalho, S. Röesner, D. Schabo, N. Selva, A. Sergiel, M. Xavier, O. da Silva, P.


Accessed 1 June 2023.

responses to mechanical treatment of pinyon-juniper in northwestern Colorado.


Utah Division of Wildlife Resources (UDWR). 2019. Strategic management plan for sage-grouse. Utah Department of Natural Resources, Publication 02-20. Salt Lake City, Utah, USA.

Utah’s Watershed Restoration Initiative (WRI). 2021 Utah Department of Natural Resources Project Database. https://wri.utah.gov/wri/project/search.html


Table 3.1. Percent of seasonal home ranges of sage-grouse females within pinyon juniper treatment project areas fall winter, (Oct-Feb), breeding (Mar-May), summer (June-Sept) Panguitch SGMA Utah 2020-2021.

<table>
<thead>
<tr>
<th>Season</th>
<th>Bird ID</th>
<th>% Core within</th>
<th>% Extended within</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall Winter</td>
<td>1414_Ah_2020</td>
<td>32.43239</td>
<td>23.81406</td>
</tr>
<tr>
<td>Fall Winter</td>
<td>1415_Ah_2020</td>
<td>41.52405</td>
<td>41.86103</td>
</tr>
<tr>
<td>Fall Winter</td>
<td>1415_AH_2021_Fall</td>
<td>74.31591</td>
<td>47.46417</td>
</tr>
<tr>
<td>Fall Winter</td>
<td>1822_Ah_20</td>
<td>26.88793</td>
<td>26.12411</td>
</tr>
<tr>
<td>Fall Winter</td>
<td>1823_Ah_2020</td>
<td>67.95232</td>
<td>51.50722</td>
</tr>
<tr>
<td>Fall Winter</td>
<td>1824_Ah_2021</td>
<td>44.68688</td>
<td>39.73225</td>
</tr>
<tr>
<td>Fall Winter</td>
<td>1825_2_Ah_2020</td>
<td>33.25524</td>
<td>32.80328</td>
</tr>
<tr>
<td>Fall Winter</td>
<td>Average</td>
<td>45.86496</td>
<td>37.61516</td>
</tr>
<tr>
<td>Breeding</td>
<td>1414_Ah_2020</td>
<td>47.42306</td>
<td>30.4167</td>
</tr>
<tr>
<td>Breeding</td>
<td>1822_Ah_20</td>
<td>27.07398</td>
<td>20.11334</td>
</tr>
<tr>
<td>Breeding</td>
<td>1823_Ah_2020</td>
<td>61.84475</td>
<td>43.48173</td>
</tr>
<tr>
<td>Breeding</td>
<td>1824_Ah_2021</td>
<td>19.24252</td>
<td>17.77514</td>
</tr>
<tr>
<td>Breeding</td>
<td>1825_2_Ah_2020</td>
<td>37.263</td>
<td>20.67785</td>
</tr>
<tr>
<td>Breeding</td>
<td>Average</td>
<td>38.56946</td>
<td>26.49295</td>
</tr>
<tr>
<td>Summer</td>
<td>1414_Ah_2020</td>
<td>62.83361</td>
<td>42.33189</td>
</tr>
<tr>
<td>Summer</td>
<td>1822_Ah_20</td>
<td>22.24549</td>
<td>25.80821</td>
</tr>
<tr>
<td>Summer</td>
<td>1823_Ah_2020</td>
<td>41.00118</td>
<td>39.84611</td>
</tr>
<tr>
<td>Summer</td>
<td>1824_Ah_20</td>
<td>39.22207</td>
<td>35.47757</td>
</tr>
</tbody>
</table>
Table 3.2. Percentage of land type found within extended and core seasonal sage-grouse home ranges within the Panguitch SGMA based on locations from October 2020 – December 2021

<table>
<thead>
<tr>
<th>Land Type</th>
<th>Fall/Winter Extended</th>
<th>Breeding Extended</th>
<th>Summer Extended</th>
<th>Fall/Winter Core</th>
<th>Breeding Core</th>
<th>Summer Core</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shrubland</td>
<td>32.8</td>
<td>28.2</td>
<td>28.8</td>
<td>40.5</td>
<td>36.5</td>
<td>35.6</td>
</tr>
<tr>
<td>Conifer</td>
<td>55.4</td>
<td>54.6</td>
<td>59.5</td>
<td>45.7</td>
<td>44.9</td>
<td>53.8</td>
</tr>
<tr>
<td>Developed</td>
<td>3.5</td>
<td>3.8</td>
<td>3.2</td>
<td>4.0</td>
<td>4.6</td>
<td>3.0</td>
</tr>
<tr>
<td>Invasive Herbaceous</td>
<td>1.3</td>
<td>1.0</td>
<td>1.5</td>
<td>1.4</td>
<td>1.0</td>
<td>1.6</td>
</tr>
<tr>
<td>Invasive Shrub/Tree</td>
<td>3.3</td>
<td>3.0</td>
<td>2.9</td>
<td>4.8</td>
<td>3.0</td>
<td>1.8</td>
</tr>
<tr>
<td>Grassland</td>
<td>1.3</td>
<td>1.2</td>
<td>1.6</td>
<td>1.2</td>
<td>0.9</td>
<td>1.4</td>
</tr>
<tr>
<td>Agricultural</td>
<td>0.6</td>
<td>2.2</td>
<td>0.8</td>
<td>1.1</td>
<td>5.2</td>
<td>1.3</td>
</tr>
<tr>
<td>Other</td>
<td>1.7</td>
<td>6.0</td>
<td>1.7</td>
<td>1.3</td>
<td>3.9</td>
<td>1.5</td>
</tr>
</tbody>
</table>
Figure 3.1. Locations of the study area, indicating conifer treatment areas, surveys, lek, and coalmine, Sink Valley, Utah 2020-2021.
Figure 3.2. Location and age of conifer removal treatments completed within the Panguitch SGMA treatments are shaded from black 2006 to white 2021. Utah.2021
Figure 3.3. Seasonal habitat of Panguitch SGMA by the Utah sage-grouse management plan including nesting brood rearing, nesting brood rearing and winter, non-specified habitat, winter, opportunity and non-habitat southern Utah 2020-2021.
Figure 3.4. Core home ranges of sage-grouse females during the breeding season, 5 individual females, conifer removal treatments shade from black 2006 to white 2021 Panguitch SGMA Utah 2020-2021
Figure 3.5. Core home ranges of sage-grouse females during the summer season, five individual females, conifer removal treatments shade from black 2006 to white 2021. Panguitch SGMA southern Utah 2020-2021
Figure 3.6. Core home range of sage-grouse females during the fall winter season, seven individual females, conifer removal treatments shade from black 2006 to white 2021 Panguitch SGMA southern Utah 2020-2021
Figure 3.7. Extended home ranges of sage-grouse during the breeding season for five individual females, conifer removal treatments shade from black 2006 to white 2021. Panguitch SGMA Utah 2020-2021
Figure 3.8. Extended home range of sage-grouse females during the summer season five individual females, conifer removal treatments shade from black 2006 to white 2021, Panguitch SGMA 2020-2021
Figure 3.9. Extended home range of sage-grouse females during the fall winter season, seven individual females, conifer removal treatments shade from black 2006 to white 2021 Panguitch SGMA southern Utah 2020-2021
CHAPTER IV
CONCLUSIONS

Conifer encroachment has been a major concern impacting Greater sage-grouse
(*Centrocercus urophasianus*; hereafter sage-grouse) throughout the state of Utah and the
entire sage-grouse range (Baruch-Mordo et al. 2013, Pyke et al. 2015, Coates et al. 2017).
Conifer removal treatments have been implemented throughout Utah by the Utah
Watershed Initiative and other government agencies. It is important to address the
effectiveness of these conifer removals and determine changes needed to continue to
support sage-grouse populations. The conclusions addressed throughout this thesis
provide essential information concerning sagebrush habitat restoration after conifer
removal treatment in Sink Valley and sage-grouse use of conifer removal treatment areas
within the Panguitch Sage-Grouse Management Area (SGMA) in Southern Utah. To
gather vegetation information pertaining to the restoration of the treatment area in the
Sink valley I conducted vegetation surveys in 2021 and 2020 and compared them to
vegetation surveys from 2007 and 2009 to determine change in vegetation including
shrub cover, shrub height, grass cover and forb cover. To obtain sage-grouse locational
data over the course of my study I captured 8 females, and released them with Global
Positioning System transmitters monitoring their locations from October of 2020 to
December of 2021. I used this data to determine extended (95%) and core (65%) home
ranges of sage-grouse within conifer removal treatments and selected locations to
conduct further vegetation surveys to compare to the vegetation surveys conducted in
Sink Valley.
In Chapter 2 I addressed the results of the comparisons between vegetation surveys conducted in 2020 and 2021 within a 2005 conifer removal treatment to vegetation surveys conducted in 2007 and 2009 within the same treatment area to determine the change in vegetation and to determine if the treatment area had been restored to sage-grouse management guidelines. I analyzed the results by conducting ANOVAs comparing, average shrub height, average shrub intercept cover, percent shrub cover, percent grass cover, and percent forb cover between surveys conducted in 2007 and 2009 to those taken in 2020 and 2021. I found that sage-average shrub height shows no significant variance. Additionally, I compared the vegetation surveys conducted at sage-grouse locations in 2021 to vegetation within the conifer removal treatment from 2020 - 2021 and nearby intact sagebrush to determine the difference between habitat within the treatment area and habitat selected by sage-grouse females during the brooding period.

Chapter 3 focused on sage-grouse use of the pinyon juniper removal treatments conducted through the Watershed Restoration Initiative of Utah within the Panguitch Sage-Grouse Management Area (SGMA). Within the Panguitch SGMA 71 pinyon juniper removal projects across 945.0 km² were carried out through the Watershed Restoration Initiative of Utah in the support of sage-grouse habitat restoration (WRI 2021). These projects were completed between 2006 and 2021. I conducted estimated core and extend home ranges of each individual female monitored from 2020 - 2021 split into three time periods of breeding, summer, and fall/winter and determine the proportion that was within pinyon juniper removal projects. While the percent within each treatment ranged from season to season and amongst different individual females, the lowest
observed was 19.24 % and 17.78 % within the core and extended sage-grouse home ranges estimations. The highest percentage of pinyon juniper removal treatment within the core and extend habitat utilization estimations were 90.63 and 82.86.

To determine if age of treatment had an impact on sage-grouse estimated home ranges, I analyzed the seasonal core and extended utilization distributions to determine the percent area of treatments separated by age spanning 15 years to less than 1 year old. I found that extend seasonal home ranges consisted of 57.3%, 62.9%, and 76.1% of treatments 5 years old or less during breeding, fall winter, and summer seasons respectively. Furthermore, the core seasonal home ranges consisted of 57.9%, 66.9%, and 66.7% of treatments 5 years old or less during breeding, fall winter, and summer seasons respectively. That data supports that sage-grouse are utilizing of sage-grouse locations were found within treatments 5 years old or less.

The Utah Sage-Grouse Management plan mapped out the seasonal and opportunity habitat within each SGMA (UDWR 2019). I analyzed the sage-grouse extended and core home ranges to determine sage-grouse use of seasonal and opportunity sage-grouse habitat within the Panguitch SGMA. I found that sage-grouse predominantly used sage-grouse designated habitat though extend seasonal home ranges consisted of 15.4%-17.8% opportunity habitat. The extend seasonal home ranges did not line up within the SGMA designated habitats. Of the extended seasonal home range areas 44.1% - 60.1% was outside of their associated SGMA designated habitat. The core home ranges were found to contain 78.5%-95.0% sage-grouse habitat and 3.3% to 14.0% opportunity. Core seasonal home ranges for winter fall, breeding, and summer were found to be
outside of their seasonal designated habitat 52.7%, 34.6 %, and 7.4 % of the time respectively.

The consensus of this study supports the restoration of sage-grouse habitat through pinyon juniper removal treatments. These results provide important information regarding the restoration of sage-grouse habitat that occurred within pinyon juniper treatment areas and the impact age of treatment has on sage-grouse use of the pinyon-juniper removal treatment areas. The continued changing climate of southern Utah and constant pressure from conifer encroachment continue to threaten sage-grouse survival within the most southern portion of its range (Kleinhesselink and Adler 2018, Renwick et al. 2018). My results support existing management guidelines for sage-grouse management with the exception of increasing the minimal for forb and grass cover to better support sage-grouse during the breeding and brood rearing periods (UDWR 2019). Additionally, continuing to support forbs and grasses post treatment to maintain higher coverage may greatly support sage-grouse survival. Additional studies determining the impact age of pinyon juniper removal treatment has on sage-grouse use will help managers develop new programs to better support sage-grouse within the Panguitch Sage-Grouse Management Area.
REFERENCES

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 Reese, K. P. 2013. Saving sage-
grouse from the trees: a proactive solution to reducing a key threat to a candidate

Coates, P. S., B. G. Prochazka, M. A. Ricca, K. B. Gustafson, P. Ziegler, and M. L.
Casazza. 2017. Pinyon and juniper encroachment into sagebrush ecosystems
impacts distribution and survival of greater sage-grouse. Rangeland Ecology and
Management 70:25-38.

tridentata) to interannual climate variation changes across its range. Ecology
99:1139-1149.

Doescher, E. W. Schupp, B. A. Roundy, M. Brunson, and J. D. McIver. 2015.
Restoration handbook for sagebrush steppe ecosystems with emphasis on greater

Renwick, K. M., C. Curtis, A. R. Kleinhesselink, D. Schlaepfer, B. A. Bradley, C. L.
Aldridge, B. Poulter, and P. B. Adler. 2018. Multi-model comparison highlights
consistency in predicted effect of warming on a semi-arid shrub. Global Change

Utah Division of Wildlife Resources (UDWR). 2019. Strategic management plan for
sage-grouse. Utah Department of Natural Resources, Publication 02-20. Salt Lake City, Utah, USA.
Appendices
Appendix A
Chapter 2 Supportive Information
Summary Statistics for vegetation composition (+/- SD) for sage-grouse locations (G2021) based on individual grouse collected in June and July of 2021, Panguitch sage-grouse management area, Utah.

<table>
<thead>
<tr>
<th>Individual</th>
<th>N</th>
<th>Shrub Height</th>
<th>Shrub Intercept</th>
<th>Shrub Percent Composition</th>
<th>Forb Percent Composition</th>
<th>Grass Percent Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>20</td>
<td>31.30 ± 22.52</td>
<td>9.41 ± 8.30</td>
<td>7.58 ± 9.05</td>
<td>5.38 ± 7.57</td>
<td>28.86 ± 27.65</td>
</tr>
<tr>
<td>H2</td>
<td>18</td>
<td>33.9 ± 15.99</td>
<td>10.00 ± 5.21</td>
<td>10.88 ± 4.78</td>
<td>1.34 ± 1.19</td>
<td>6.57 ± 2.91</td>
</tr>
<tr>
<td>H3</td>
<td>2</td>
<td>32.78 ± 10.21</td>
<td>9.93 ± 12.86</td>
<td>9.79 ± 10.90</td>
<td>0.21 ± 0.30</td>
<td>31.25 ± 22.38</td>
</tr>
</tbody>
</table>
Appendix B
Chapter 2 Supporting Information

Vegetation ANOVA comparisons conducted within this study organized by vegetation factor for the pinyon juniper treatment removal conducted in 2005 in sink valley, nearby untreated sage-brush area and sage-grouse locations. All surveys were conducted in the months of June and July of their associated years. T2020 represents transect surveys conducted within pinyon juniper removal treatment in 2020/2021. I2020 represents transect surveys conducted within untreated sagebrush in 2020/2021. T2007 represents transect surveys conducted within the pinyon juniper treatment in 2007 and 2009. G2021 represents locations selected from female sage-grouse in 2021. GR2021 represents random locations within the pinyon juniper removal surveyed in 2021.

<table>
<thead>
<tr>
<th>Comparison (N/N)</th>
<th>Vegetation Measurement</th>
<th>F - value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2020/I2020 (10/10)</td>
<td>Percent Shrub cover</td>
<td>9.1775</td>
<td>0.007208</td>
</tr>
<tr>
<td>I2020/T2007 (10/10)</td>
<td>Percent Shrub cover</td>
<td>72.84</td>
<td>9.64E-08</td>
</tr>
<tr>
<td>G2021/GR2021 (40/40)</td>
<td>Percent Shrub cover</td>
<td>5.3485</td>
<td>0.02338</td>
</tr>
<tr>
<td>T2020/T2007 (10/10)</td>
<td>Percent Shrub cover</td>
<td>5.7771</td>
<td>0.02723</td>
</tr>
<tr>
<td>T2020/GR2021 (10/40)</td>
<td>Percent Shrub cover</td>
<td>0.4454</td>
<td>0.5077</td>
</tr>
<tr>
<td>G2021/T2020 (40/10)</td>
<td>Percent Shrub cover</td>
<td>4.1011</td>
<td>0.04844</td>
</tr>
<tr>
<td>G2021/I2020 (40/10)</td>
<td>Percent Shrub cover</td>
<td>34.798</td>
<td>3.58E-07</td>
</tr>
<tr>
<td>I2020/GR2021 (10/40)</td>
<td>Percent Shrub cover</td>
<td>21.138</td>
<td>3.13E-05</td>
</tr>
<tr>
<td>T2020/GR2021 (10/40)</td>
<td>Percent Grass Cover</td>
<td>15.252</td>
<td>0.000294</td>
</tr>
<tr>
<td>T2020/I2020 (10/10)</td>
<td>Percent Grass Cover</td>
<td>1.6009</td>
<td>0.2219</td>
</tr>
<tr>
<td>I2020/T2007 (10/10)</td>
<td>Percent Grass Cover</td>
<td>6.846</td>
<td>0.01748</td>
</tr>
<tr>
<td>G2021/GR2021 (40/40)</td>
<td>Percent Grass Cover</td>
<td>17.581</td>
<td>7.21E-05</td>
</tr>
<tr>
<td>Sample Description</td>
<td>Property</td>
<td>Value</td>
<td>Standard Error</td>
</tr>
<tr>
<td>--------------------</td>
<td>-------------------</td>
<td>---------</td>
<td>----------------</td>
</tr>
<tr>
<td>G2021/T2020 (40/10)</td>
<td>Percent Grass Cover</td>
<td>2.4417</td>
<td>0.1247</td>
</tr>
<tr>
<td>T2020/T2007 (10/10)</td>
<td>Percent Grass Cover</td>
<td>3.1884</td>
<td>0.09102</td>
</tr>
<tr>
<td>G2021/I2020 (40/10)</td>
<td>Percent Grass Cover</td>
<td>3.4641</td>
<td>0.06884</td>
</tr>
<tr>
<td>I2020/GR2021 (10/40)</td>
<td>Percent Grass Cover</td>
<td>2.7671</td>
<td>0.1027</td>
</tr>
<tr>
<td>T2020/T2007 (10/10)</td>
<td>Percent For Cover</td>
<td>18.47</td>
<td>0.000433</td>
</tr>
<tr>
<td>T2020/GR2021 (10/40)</td>
<td>Percent For Cover</td>
<td>27.031</td>
<td>0.000433</td>
</tr>
<tr>
<td>T2020/I2020 (10/10)</td>
<td>Percent For Cover</td>
<td>2.0283</td>
<td>0.1715</td>
</tr>
<tr>
<td>I2020/T2007 (10/10)</td>
<td>Percent For Cover</td>
<td>24.068</td>
<td>0.000114</td>
</tr>
<tr>
<td>G2021/GR2021 (40/40)</td>
<td>Percent For Cover</td>
<td>7.8759</td>
<td>0.006324</td>
</tr>
<tr>
<td>G2021/T2020 (40/10)</td>
<td>Percent For Cover</td>
<td>0.0797</td>
<td>0.779</td>
</tr>
<tr>
<td>G2021/I2020 (40/10)</td>
<td>Percent For Cover</td>
<td>0.8769</td>
<td>0.3537</td>
</tr>
<tr>
<td>I2020/GR2021 (10/40)</td>
<td>Percent For Cover</td>
<td>5.9044</td>
<td>0.01889</td>
</tr>
<tr>
<td>I2020/T2007 (10/10)</td>
<td>Percent Shrub Intercept</td>
<td>54.672</td>
<td>7.39E-07</td>
</tr>
<tr>
<td>G2021/GR2021 (40/40)</td>
<td>Percent Shrub Intercept</td>
<td>6.6275</td>
<td>0.01193</td>
</tr>
<tr>
<td>G2021/T2020 (40/10)</td>
<td>Percent Shrub Intercept</td>
<td>2.3928</td>
<td>0.1285</td>
</tr>
<tr>
<td>T2020/T2007 (10/10)</td>
<td>Percent Shrub Intercept</td>
<td>3.1702</td>
<td>0.09188</td>
</tr>
<tr>
<td>T2020/GR2021 (10/40)</td>
<td>Percent Shrub Intercept</td>
<td>2.00E-04</td>
<td>0.9903</td>
</tr>
<tr>
<td>T2020/I2020 (10/10)</td>
<td>Percent Shrub Intercept</td>
<td>8.7211</td>
<td>0.008508</td>
</tr>
<tr>
<td>G2021/I2020 (40/10)</td>
<td>Percent Shrub Intercept</td>
<td>33.332</td>
<td>5.55E-07</td>
</tr>
<tr>
<td>T2020/T2007 (10/10)</td>
<td>Shrub Height</td>
<td>2.0415</td>
<td>0.1702</td>
</tr>
<tr>
<td>T2020/I2020 (10/10)</td>
<td>Shrub Height</td>
<td>2.3843</td>
<td>0.14</td>
</tr>
<tr>
<td>T2020/GR2021 (10/40)</td>
<td>Shrub Height</td>
<td>0</td>
<td>0.9982</td>
</tr>
<tr>
<td>I2020/T2007 (10/10)</td>
<td>Shrub Height</td>
<td>0.0294</td>
<td>0.8659</td>
</tr>
<tr>
<td>G2021/GR2021 (40/40)</td>
<td>Shrub Height</td>
<td>0.1737</td>
<td>0.678</td>
</tr>
<tr>
<td></td>
<td>Shrub Height</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------</td>
<td>--------------</td>
<td>-------</td>
<td>-----</td>
</tr>
<tr>
<td>G2021/T2020 (40/10)</td>
<td>0.0512</td>
<td>0.8219</td>
<td></td>
</tr>
<tr>
<td>G2021/I2020 (40/10)</td>
<td>0.3084</td>
<td>0.5813</td>
<td></td>
</tr>
<tr>
<td>I2020/GR2021 (10/40)</td>
<td>3.1974</td>
<td>0.1448</td>
<td></td>
</tr>
</tbody>
</table>