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Greater Sage-Grouse and Community Responses to Strategies to Mitigate Environmental Resistance in an Anthropogenic Altered Sagebrush Landscape

Justin R. Small
Utah State University

GREATER SAGE-GROUSE AND COMMUNITY RESPONSES TO STRATEGIES TO MITIGATE ENVIRONMENTAL RESISTANCE IN AN ANTHROPOGENIC ALTERED SAGEBRUSH LANDSCAPE

by

Justin R. Small

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Approved:

Terry A. Messmer, Ph.D. Major Professor	Mark W. Brunson, Ph.D. Committee Member
Dave K. Dahlgren, Ph.D. Committee Member	Douglas R. Ramsey, Ph.D. Committee Member
Eric T. Thacker, Ph.D. Committee Member	D. Richard Cutler, Ph.D. Interim Vice Provost of Graduate Studies

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ABSTRACT

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by

Justin R. Small, Doctor of Philosophy

Utah State University, 2021

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

Sagebrush (*Artemisia* spp.) ecosystems are diverse habitats found throughout western North America. European settlement, associated agricultural practices, and altered fire regimes has resulted in the loss of over half of the sagebrush ecosystems impacting sagebrush obligate species such as sage-grouse (*Centrocercus* spp.). Federal, state, and private land managers have implemented landscape scale mechanical pinyon (Pinus spp.) and juniper (Juniperus spp.; conifer) removal projects in an effort to restore functioning sagebrush communities to benefit sage-grouse. However, few studies have strategically prioritized and quantified the potential for using large-scale conifer treatments to mitigate factors impeding sage-grouse seasonal movements and space-use in anthropogenic altered landscapes.

To address this management need, I analyzed pre- and post-treatment vegetation composition data and annual changes in percent cover for known conifer treatments completed from 2008-2014 in Box Elder County, Utah, USA. I developed a multivariate generalized linear regression model that predicts future landscape conditions for sage-grouse and projects tree canopy cover that approximated observed cover values for known treated plots at time of treatment and five years post-treatment.

Next, I analyzed five different management scenarios to predict resource selection by greater sage-grouse (*Centrocercus urophasianus*) in response to changes in habitat following conifer treatments. I used a Relative Selection Strength (RSS) framework to quantify the net habitat gain from 2017 to 2023. My top ranked treatment scenario showed net habitat gains across all categories (cumulative habitat gain; logRSS = 6398.13) and highest gain per dollar invested (logRSS = 0.2040).

Additionally, I investigated the efficacy of global position system (GPS) and very high frequency (VHF) transmitters used in range wide studies. I compared mortality rates for two separate Utah populations. Across summer and winter for sex, and spring, summer and winter for age, I documented higher mortality for sage-grouse marked with GPS transmitters.

Lastly, to assess stakeholders' perceptions of contemporary community-based conservation efforts, I conducted a case study in fall 2019 of the West Box Elder Coordinated Resource Management (CRM). Respondents reported: participation by federal and state agencies was paramount for funding and program structure, trust has been enhance, and landowner involvement is necessary for long-term stability and persistence.

(205 pages)

PUBLIC ABSTRACT

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DEDICATION

To my children, Warren, West and Grace, my greatest pride and joy. Your light gave me the strength and necessary drive to overcome the many obstacles along the road to academic success.

To my dear wife, Priscilla. Without your love and support, and continued encouragement, none of this would have come to pass.

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Broad Scale Conservation

Across ecological disciplines, conservation of an individual species has always been challenging for wildlife practitioners to implement at broad scales. As human population growth approaches eight billion, global demands on the environment for energy acquisition, agriculture and livestock production ensures the continual anthropogenic modification and development of the terrestrial biosphere (Runge et al. 2019). These land use practices have transitioned many ecosystems into unnatural states of functioning; thus causing the emergent of novel ecological patterns and processes (i.e., shifts in natural fire cycles and plant communities resistance and resilience; Ellis 2011). Estimates suggested between one-third and one-half of earth's land surface has undergone human alterations (Fedy et al. 2015). For wildlife populations to remain at healthy, sustainable levels, wildlife biologists and land managers must implement land use strategies that mitigate species resistance to human induced habitat modification(s) (Messmer 2013, Fedy et al. 2015, Ricca et al. 2018, Shirk et al. 2015).

Limited Conservation Resources

The struggle for managers to introduce and employ mechanisms on regional scales that benefit a large guild of species remains demanding; especially while trying to leverage limited funding sources for maximum ecological benefits per unit economic cost

(Messmer 2013 and Ricca et al. 2018). The principles embedded within the concept of "conservation triage" cannot be overlooked by practitioners when trying to prioritize conservation efforts while operating under the constraint of allocating finite funding resources; which are usually several orders in magnitude below what is actually needed for on-the-ground conservation to occur (Bottrill et al. 2009). The definition of triage comes from the medical field where the priority and allocation of treatment is based on the severity of patients' condition (Wilson and Law 2016). Within an ecological context and in reflection to the Endangered Species Act (ESA) of 1973, this means higher at-risk or sensitive species will receive more disbursement of limited resources for conservation actions to avert listing under the ESA (Gerber 2016).

Opponents of triage decision framework feel that the concept overvalues certain species and devalues others with the allocation of conservation funding resources being distributed to species that promote "the greater good" of conservation, while sacrificing the needs of some less focal species (Wilson and Law 2016). Although the ethics can and will continue to be debated, both sides can agree that government spending is often insufficient and ineffective and disproportionate among species when trying to accomplish conservation goals (Bottrill et al. 2009 and Gerber 2016). Therefore, employment in some form of the triage decision framework might be inevitable when trying to conserve any species under restrictive budget capacities and maximizing conservation outcomes (Gerber 2016). Furthermore, and in practice, all agencies and wildlife practitioners operate under limited budgets, where allocation of resources to certain individual species will mean that some species will receive less or no investment. Jachowski and Kesler (2009) argued this was 'sanctioning extinction in the name of efficiency'. However, proper utilization of triage by budget compression (Gerber 2016) could help agencies develop more cost-efficient frameworks for prioritizing recovery and management of threatened flagship species with a higher level of success, while operating under constrained, fixed budgets (Bottrill et al. 2009 and Gerber 2016). One possible way of ensuring a higher level of success for multiple species across taxa and ecological communities, is if the individual species, that conservation funding is being allocate to, acts as an umbrella for a suite of species (Runge et al. 2019).

Sage-grouse as an Umbrella Species

In the early 2000s, the concept of a focal or charismatic species acting as an umbrella for other species gained traction. An umbrella species can be defined when the conservation of a single species also benefits other co-occurring species with obligatory relationships to the same habitat type and similar sensitivity to disturbance regimes (Rowland et al. 2006, Hanser and Knick 2011, Dinkins and Beck 2019, Runge et al. 2019). In the mid-2000s, sage-grouse (*Centrocercus urophasianus;* sage-grouse) was identified as an umbrella and indicator species to determine the condition of sagebrush habitat across sagebrush ecosystems (Rowland et al. 2006, Knick et al. 2013, Sanford et al. 2017). Sage-grouse are an iconic species endemic to western sagebrush rangelands and are valued both for their charismatic breeding behavior and their importance to sportsman as a game bird species (Runge et al. 2019). Furthermore, the umbrella labeling was advanced due to sage-grouse being a landscape species whose habitat use, both spatially and compositionally, encapsulated enough species that resources allocated to their conservation would additionally help preserve the heterogeneity and biodiversity of less focal species throughout sagebrush ecosystems (Lambeck 1997, Runge et al

2019). Over 350 co-occurring species can be associated with sagebrush ecosystems inhabited by sage-grouse (Hanser and Knick 2011).

Across landownership boundaries (e.g., federal, state and private), this initiated the largest conservation effort for a single species in history with an unprecedented amount of research and conservation resources directed towards greater sage-grouse conservation (Rowland et al. 2006 and Hanser and Knick 2011). For example, in Wyoming alone, in sage-grouse core habitat, over $250 US million has been spent on conservation easements to protect sage-grouse habitat on private rangelands (Runge et al. 2019). Within the Great Basin in 2007, the Department of Interior's Emergency Stabilization and Burned Area Rehabilitation (ESR) spent 60 million dollars for restoration of sagebrush habitat burned by wildfires (Arkle et al. 2014).

Some recent research suggest sage-grouse might have been over-stated as an umbrella species for sagebrush ecosystems, arguing that conservation prioritization of sage-grouse does not encompass the needs of all species that occupy sage-grouse habitat (i.e., certain songbirds with small scale habitat overlap) (Hanser and Knick 2011, Copeland et al. 2014, Carlisle et al. 2018a, Dinkins and Beck 2019). Conversely, others report that despite the potential drawbacks of focusing conservation efforts at the cost of other less focal species, single surrogate species can still provide a conduit to accomplish benefits for multiple species (Copeland et al. 2014). In most instances, flagship species secure or entice more funding from sources that might have otherwise not invested in conservation actions (Runge et al. 2019). Rowland et al. (2006) tested for spatial overlap in habitat between sage-grouse and 39 co-occurring sagebrush associated vertebrate species and found the greatest overlap was with other sagebrush obligate species. For sagebrush obligate passerines, Hanser and Knick (2011) reported a moderate to strong association with sage-grouse; however, the importance of scale must be accounted for when implementing restoration efforts for sage-grouse and maintaining landscape heterogeneity within sagebrush ecosystems.

As knowledge advances in regards to scale dependency of species and hierarchically selection of habitat between species occurring with the same ecological community, alternative or complementary conservation prioritization may need to be implemented for highly localized or range limited species (Hanser and Knick 2011). For example, passerine species like grasshopper sparrow (*Ammodramus savannarum*), savannah sparrow (*Passerculus sandwichness*) and green-tailed towhee (*Pipilo chlorurus*) existing at the edge of the sagebrush habitat gradient or grassland patches within the sagebrush matrix and ecotones between shrublands. These species might not incur the same direct or ancillary benefits as obligate species or those with broad scale habitat overlap to sage-grouse (i.e., such as mule deer [*Odocoileus hemionus*] across most sage-grouse occupied habitat) (Hanser and Knick 2011, Copeland et al. 2014, Carlisle et al. 2018a, 2018b). Moreover, species like the black-footed ferret (*Mustela nigripes*) that only exist in reintroduce highly managed populations, will need specialized conservation approaches and will not likely receive appropriate protection by a surrogate or umbrella species conservation actions (Runge et al. 2019). Sage-grouse might not be the ideal umbrella species (i.e., the one species that encapsulates the collective needs of other species) across sagebrush environments (Dinkins and Beck 2019); however, the single species conservation approach using a focal umbrella species still offers encouragement for conservation (Carlisle et al. 2018b, Runge et al. 2019). Although, in the future, conservation efforts may need to be augmented with target and systematic investments to species that fall out of the umbrella of the main focal species (Hanser and Knick 2011, Runge et al. 2019).

Sagebrush and Humans: A Conservation Primer

The greater sage-grouse has been called an iconic species of the American West and has become a symbolic representation for conserving sagebrush ecosystems across western rangelands (Knick and Connelly 2011a). Sage-grouse are North America's largest endemic grouse species and are recognized for their obligatory relationship to sagebrush (Beck et al. 2003 and Knick et al. 2013). Sage grouse's historic and current distribution can be directly associated with the distribution of sagebrush, an especially, big sagebrush (*A. tridentata* ssp. *tridentata, vaseyana, wyoingensis*) and have been used as a key indicator species for sagebrush habitat health (Pattersen 1952, Wallstead 1975, Connelly and Braun 1997, Braun 1998, Schroeder et al. 1999, Schroeder et al. 2004). The first written account of sage-grouse was reported by the Lewis and Clark Expedition in 1805 at the confluence of the Marias and Missouri Rivers in present day Montana (Schroeder et al. 2004). Meriwether Lewis first described sage-grouse in great abundance on the sagebrush benches adjacent to the river banks. The historical pre-settlement distribution of sage-grouse spanned 13 states and 3 Canadian provinces (Connelly and Braun 1997, Schroeder et al. 2004). Since Euro-American settlement of western rangelands, sage-grouse populations have undergone long-term declines and have been extirpated from almost half of their historic range (Knick and Connelly 2011a, b). Range wide population declines were first reported in the early 1900s (Connelly and Braun 1997). Because of climatic conditions and over hunting reported in states that have adequate record keeping methods, Connelly and Braun (1997) estimated a 17-47% reduction in sage-grouse breeding populations since 1985, with a 2% drop in abundance annually from 1965-2003 (Connelly et al. 2004). Currently, sage-grouse occur in 11 states and 1 province and have been completely extirpated from areas on the periphery of their core habitat (Beck et al. 2003) including Arizona, Nebraska and British Colombia (Crawford et al. 2004, Connelly and Braun 1997, Schroeder et al. 2004).

Conservation Status and Threats in the Great Basin

In 1954, the Western Association of Fish and Wildlife Agencies formed the Western States Sage-Grouse Technical Committee to develop a framework for managing and monitoring sage-grouse due to concerns over the status of sage-grouse populations range wide (Stiver 2011). However, by the mid-1990s, contemporary sage-grouse management began with warranted concerns over status of sage-grouse populations and habitat forecasts (Stiver 2011, Stiver et al. 2015). State and provincial wildlife management and land management agencies began to employ conservation efforts, adjust hunting regulation and seasons, and redirect funding resources to benefit sage-grouse populations (Connelly and Braun 1997). In 1999, the first petition was filed requesting the U.S. Fish and Wildlife Service (USFWS) to list an individual population of greater sage-grouse in Washington State under protection of the Endangered Species Act (ESA) of 1973 (USFWS 2010) declaring it was distinct population. The USFWS reported that the petition presented substantial information, but it was precluded by higher priority species. In 2001 and 2005, two additional petitions were filed for the bi-state populations that reside in the Mono Basin region of California and Nevada (USFWS 2005, Stiver 2011). Although the USFWS determined that protection under the ESA was warranted, it was precluded by higher priority species as well (USFWS 2001). Unlike the 1999 petition, both the 2001 and 2005 petitions, the USFWS denied the listings on the basis that petitions did not present substantial information that warranted protection under the ESA. The decision was challenged by outside conservation groups, which sued the USFWS and initiated a long litigation process (Stiver 2011).

In 2010, due to continuing range-wide population declines, sage-grouse were determine again as a candidate species by the USFWS for protection (USFWS 2010). Just like in 2001, the USFWS reached the same decision as in prior cases: protection under the ESA was warranted but was precluded by higher priority species. Again, the USFWS was sued by multiple outside organizations citing failure to reach an acceptable decision. However, this time the USFWS was ordered by a federal judge to make a final decision and determine species status of sage-grouse. In September 2015, because of the paramount retooling and implementation of both scientific and regulatory mechanisms, the USFWS determined that greater sage-grouse did not warranted protection under the ESA and withdrew the species from the candidate species list. A reviewing of sage-grouse conservation status will occur again in 2020.

Conservation Threats

From 1803 to 1850, the federal government's land acquisition was outpacing its land disposition, and furthermore, their ability to properly manage it (Knick 2011). During the 1850s, with the ending of the Little Ice Age, came the largest anthropogenic impact that Intermountain West had undergone (Miller et al. 2019). Operating under the concept of "Manifest Destiny" and believing the endless sea of sagebrush was inexhaustible, settlers immediately started to convert rangelands to meet their domestic needs. From the period between 1870 and early 1900s, an estimated 26 million cattle and 20 million sheep was introduced to the West (West 1983). Dramatic physical changes to the landscape came primarily in the form of habitat loss, fragmentation and degradation (Braun 1998, Connelly and Braun 1997, Knick and Connelly 2011a, Miller and Eddleman 2001, Schroeder et al. 2004). Within 10 to 15 years during this period, major changes to plant communities and structure occurred with overgrazing and minimal to no grazing management (Miller and Eddleman 2001). By the 1930s, carrying capacity on rangelands for livestock operations had decreased by an estimated 60 to 90 percent (McArdle et al.1936). Connelly et al. (2004) estimated a 44% loss in pre-settlement sage-grouse habitat across the Great Basin Ecoregion from an area that once encompassed 120,048,300 ha of potential habitat to a current distribution of 66,841,200 ha. In Utah alone, sage-grouse only occupy 42% of historic pre-settlement habitat; their distribution has shrunk from 7,069,600 ha to a present 2,982,100 ha (Beck et al. 2003).

Within the Great Basin ecoregion, the main threats to sage-grouse populations are structural development and cultivation to cropland; removal of native sagebrush and herbaceous cover; introduction and propagation of invasive annuals; improper management of livestock grazing; fire suppression and conifer encroachment. Within the northwestern Utah, the main threats to sage-grouse are habitat loss from invasive annual grasses, wildfire and conifer encroachment. All of these threats are interwoven, therefore, making it paramount for management mechanisms and techniques to be holistic in their approach.

Invasive Annuals

Within sagebrush ecosystems of Utah, cheatgrass (*Bromus tectorum*), has become the most problematic of invasive annuals and stressors to native sagebrush communities. This exotic annual was introduce to western rangelands from Eurasia in the 1890s (Mack 1981) and is well suited to the Intermountain West climates. In lower Wyoming sagebrush communities, cheatgrass poses the biggest threat (Miller et al. 2011) to loss of sagebrush habitat in Sage-grouse Management Areas (SGMA) and Priority Areas of Conservation (PACs). Cheatgrass exhibits a broader ecological amplitude (i.e., existing in over a larger gradient of xeric and mesic ecological sites) than native perennial bunchgrasses and has had profound effects on the physical and effective environments of native plant assemblages and communities (Chambers et al. 2014). Cheatgrass establishment lowers an ecosystem's resilience and resistance capabilities. Subsequently, reducing an ecosystem's and individual plant species' (e.g., bluebunch wheatgrass [*Pseudoroegneria spicata*] and Idaho fescue [*Festuca idahoensis*]) ability to regain and retain its fundamental structure (both spatially and compositionally) and functionality (Miller et al. 2011). This can be further exacerbated when sagebrush communities are exposed to stressors like drought, fire and overgrazing by livestock grazing (Miller et al. 2011, Chambers et al. 2014).

Fire

Prior to European settlement, fire played an important role in sagebrush steppe ecosystems of the Great Basin. Plant communities had developed under hundreds of years of colder wetter climatic conditions, with low severity fires that increased herbaceous cover dominance while decreasing woody plant abundance (Young and

Miller 1985, Miller and Eddleman 2001). Historically, it is estimated that fire rotations in lower xeric Wyoming big sagebrush communities were 50-100 years and in higher mesic Mountain big sagebrush communities as frequently as 15 to 25 years (Baker 2006, Miller and Heyerdahl 2008 and Chambers et al. 2014).

Presently, with dryer and warmer climatic conditions being experienced across the physiographic regions of the Great Basin, and the rapid proliferation of cheatgrass in the past 50 years (Miller and Eddleman 2001), fire return intervals have decreased significantly. In in many mid to low elevation sagebrush ecosystems, fire return intervals have been tightened to < 12 years. Cheatgrass is and cool season annual, which grows in late winter and early spring and desiccates much quicker in summer at seed set; thus increasing chance of ignition during warm, dry conditions. With dryer climatic conditions occurring across the sagebrush biome of the Great Basin, it is favoring cheatgrass's growth cycle, which is in juxtaposition to native perennial bunchgrasses (Miller et al. 2011, Chambers et al. 2014). As cheatgrass reaches a certain level of persistence across a given effective environment, its shorter fire return interval becomes self-perpetuating, especially in closed monoculture understory and interspace situations (Davies et al. 2007). Thus tightening fires cycles much closer together than prior to 50 years ago (Wambolt et al. 1999, Wambolt et al. 2002, Baker 2006, Beck et al. 2009).

Some research suggests that fire might be used as an appropriate management tool in sagebrush systems to improve heterogeneity and species diversity of sage-grouse habitat (Wrobleski and Kauffman 2003). However, in light of what is occurring across western sagebrush ecosystems with establishment of invasive annuals, conifer encroachment and overall drier climatic conditions pre-exposing vegetation communities to lower resistance and resilience states, using fire to improve sage-grouse habitat warrants discretion (Baker 2006, Davies et al. 2007). Beck et al. (2009), cautioned against frequent or large prescribed burning to enhance greater sage-grouse habitat in Wyoming big sagebrush plant communities. Fire can kill sagebrush by repressing recovery time because big sagebrush species are not root sprouting shrubs. In many of the lower lying xerophytic sites that offer wintering habitat for sagebrush obligate species, prescribed fire has been shown to reduce habitat characteristics and vegetative structure to non-adequate levels. Mechanical treatments to enhance vegetative features may be more appropriate than the use of prescribe fire due to having faster recovery times (Beck et al. 2009). Concurrently, there also seems to be somewhat of a paradox occurring in the literature in that the burning practices of the last 60 years to reduce big sagebrush cover are now being stated by some managers as a tool to be used to increase the same taxa (Wambolt et al. 2001). Furthermore, even within favorable mesic conditions presented in higher elevation big mountain sagebrush habitat, prescribed fire may delay sagebrush recovery time up to 16 years when compared to unburn sites; and opportunity to increase herbaceous plant production has shown to be minimal (Wambolt et al. 2001).

In appropriate applications, some research have shown that low severity fires can actually reduce the risk of cheatgrass, especially if the resident plant community is composed of native bunchgrasses with sufficient basal cover and established root systems (Bate et al. 2009). However, the same study reported that the threshold is sharp if the fire crosses over into the severe category. High severity fires can negatively affect native bunchgrasses by killing individuals and removing dense basal cover like in densely pack culms found in Idaho fescue and Thurber's needle grass (Bates et al. 2009). Moreover, mechanical treatments (Beck et al. 2009) and appropriate grazing techniques (Beck and Mitchell 2000, Davies et al. 2014) might achieve the same benefits faster without the risk factors of using prescribe fire.

Conifer Encroachment

Across Great Basin sagebrush ecosystems, juniper (*Juniperus* spp.) and pinyon-pine (*Pinus* spp.; conifers) were historically part of dominate plant associations and alliances that resulted from spatial heterogeneity in soil types (Miller and Heyerdahl 2008). Prior to the late 1800s, low severity fires played a key role in limiting conifer expansion (establishment of tree into areas that were previously void of trees) and infill (increasing consolidation of previously sparse tree canopies) from mid to upper elevation sites into mountain big sagebrush habitat (Coates et al. 2017). Post European settlement in the 1860s within mountain big sagebrush habitat types, pinyon – juniper expansion co-occurred with livestock grazing and fire suppression regimes, which increased fire return intervals from 12-24 years to > 50 year (Crawford et al. 2004); lengthening successional stages and causing more conifer expansion and infill from distinct pre settlement habitats (Miller and Heyerdahl 2008). This mid to upper elevation conifer expansion and infill has paralleled cheatgrass's establishment on the lower elevation sites that is causing an elevational squeeze on sagebrush habitats across the Great Basin (Miller et al. 2011). Furthermore, since the late 1800s, pinyon – juniper woodlands have been expanding from their historical distributions across Great Basin rangelands at a rate exceeding any expansion during the Holocene (Bradley and Fleishman 2008, Miller et al. 2011, Knick et al. 2014). Crawford et al. (2004) estimated a 10-fold expansion in conifer woodlands, particularly juniper and pinyon-pine, in the past 130 years that has impacted 18.9 million hectares of sagebrush (*Artemisia* spp.) ecosystems. Stiver et al. (2006) estimated that 60,000-90,000 ha of sagebrush communities across the range are impacted annually because of conifer encroachment. With cheatgrass establishment on lower xeric sagebrush sites and pinyon – juniper encroachment and infill occur on mesic higher elevation sites, continued loss of contemporary sagebrush habitat could be exacerbated if mitigation techniques in the form of habitat treatments are not employed (Miller et al. 2011).

To reduce expansion and infill of pinyon - juniper into core sage-grouse habitat, the Natural Resources Conservation Service (NRCS), through its Sage-grouse Initiative (www.sagegrouseinitiative.com), has provided cost-share to landowners to mechanically remove or reduce thousands of hectares of conifers on private lands in the western U.S. Similar projects have been implemented range wide on Bureau of Land Management (BLM) and U.S. Forest Service (USFS) administered lands. In Utah alone, conifers have been removed from > 200,000 hectares of sagebrush landscapes since 2006 under the Utah Department of Natural Resources (UDNR) Watershed Restoration Initiative (WRI 2010). Large-scale mechanical conifer reduction projects are relatively low cost on a per hectare basis, and may have potential for increasing usable habitat for sagebrush obligate species (Utah Division of Wildlife Resources [UDWR] 2009, Baruch-Mordo et al. 2013, Dahlgren et al. 2016a, 2016b). This potential increase in suitable habitat could reduce the seasonal movements for certain sagebrush obligate species, such as sage-grouse populations, due to providing more continuous useable habitat; distances for an individual bird or population often directly reflect the availability of suitable habitat (Dahlgren et al. 2016a).

Role of Local Working Groups in Conservation

Because half of Utah's greater sage-grouse populations inhabit private lands at some time during their life cycle (UDWR 2002, 2005, 2009, Utah Public Lands Policy Coordination Office [PLPCO] 2019, Dahlgren et al. 2016a), successful conservation will require broad support from local communities and private landowners. In 1997, USU Extension, through the CBCP, began organizing and facilitating sage-grouse local working groups (LWGs) throughout Utah (Messmer et al. 2008, Messmer et al. 2010, Messmer et al. 2013, Messmer et al. 2016, Belton et al. 2017, Messmer et al. 2018). The CBCP has enhanced coordination and communication between community-based adaptive resource management working groups, private, and public partners. To accomplish this, the CBCP facilitated the development and implementation of "seamless" plans for designated Utah geographic areas that have contributed to the conservation of sage-grouse and other wildlife species that inhabit Utah's sagebrush ecosystems and enhance the economic sustainability of local communities (Messmer et al. 2008, Belton et al. 2009). The CBCP process embraced a unique model that not only engaged LWG participants conservation planning, but also identifying research questions, research funding, and conducting the research.

There are 11 active regional LWGs in Utah. Each LWG has developed a local conservation plan that contributed to the development Utah's sage-grouse conservation strategies. The LWG plans laid the framework for the species threat analysis and conservation strategies (Messmer et al. 2008) that were incorporated into the Utah Plan

(PLPCO 2019). Some of the LWG have morphed into Coordinated Resources Management (CRM) groups. Coordinated Resource Management is a model in which a broad base of stakeholders makes decisions by consensus, rather than by traditional voting and majority rule. The CRM groups have developed across the West to help people manage natural resources in a balanced, productive, conservation-friendly, and economical manner, for the long-term by involving the wide-ranging perspectives and interests.

In 2000, the Box Elder Adaptive Management Local Working Group (BARM) began meeting to develop and implement voluntary strategies to conserve the greater sage-grouse and the working sagebrush landscapes. In 2008, BARM published and began implementing its comprehensive sage-grouse and sagebrush comprehensive strategy. In 2011, the West Box Elder Coordinated Resources Management (CRM) Committee emerged from the early BARM efforts to further coordinate the different resource management activities by integrating local landowner's knowledge about the area, and community needs with multiple-agencies' resources, mandates, and expertise. This group further invested in and implemented impactful projects around the most crucial needs that are guided by science and advance the values of the community, agriculture, and wildlife.

Greater Sage-grouse Ecology

Breeding

Each year sage-grouse males return and congregate on traditional breeding locations called leks. Migration from winter areas to spring lekking sites usually begins in late winter between late February and early March; timing of these movements can be weather depended (Connelly et al. 2011, Robinson and Messmer 2013). These sites usually exist in relatively open areas with less herbaceous shrub cover in or adjacent to sagebrush dominant habitat types. In Utah, most leks persist in black sagebrush (*Artemisia nova*) habitat or big sagebrush (*Artemisia tridentata* ssp.) habitat types (Nisbet et al. 1983). Leks generally occur on more gentle terrain (i.e., slopes of < 10%) in comparison to surrounding habitat (Rogers 1964, Nisbet et al. 1983). Up to 400 males can occupy an individual lek, which can cover up to 20 ha once males partition off into their individual breeding territories (Scott 1942, Patterson 1952). Site fidelity among sage-grouse is strong and traditional lekking sites can persist within the same location for up to 70+ years if major disturbances do not occur (Hagen 2005). However, minimal annual disturbance (i.e., snow depth and habitat structure and composition), can cause annual temporary shifts in display sites (Gibson and Bradbury 1987, Commons et al. 1999, Connelly et al. 2011). One study reported finding bird point arrowheads used by Native American hunters on an individual lek that suggested the lek site was at least 85 years old (Dalke et al. 1963).

Sage-grouse are polygynous, meaning they participate in communal breeding behavior, where one male mates with multiple females (Patterson 1952, Connelly et al. 2011). A dominant male generally positions himself within the center of the lek, so visibility to receptive females is increased (Patterson 1952). On large leks, multiple dominant males can occur but still display within individual established breeding territories. Satellite leks (usually < 15 males) can develop near large leks during years of peak grouse populations (Connelly et al. 2003). Male sage-grouse usually begin displays prior to sunrise. During peak female attendance, males can display up to 3 to 4 hours (Patterson 1952, Walsh 2002). Females will chose males based off lek dominance and breeding displays. Females may breed the first morning of attendance or over multiple mornings. Females can also revisit leks later in the breeding season due to renesting efforts (Eng 1963). In northwestern Utah, the breeding season usually begins in early March and concludes the first week of June (BARM 2007).

Nesting

After mating concludes, individual female sage-grouse move to nest sites and remain localized until nesting occurs (Paterson 1952). Movements to pre-nesting habit usually occurs a few days after mating (Connelly et al. 2011). During this pre-nesting period, females' diets change from sagebrush to mainly forbs; this diet transfer increases levels of protein, calcium and phosphorus that may benefit initiation rates, clutch size and nest success (Drut et al. 1994). Early literature reported that most female sage-grouse nests were located within 3.2 km to lek sites (Braun et al. 1977). However, recent literature shows females can select nest sites ranging 1 to 20 km from leks, but on average range within 5 km or less to the lek where mating occurred (Connelly et al. 2000, Holloran 2005, Connelly et al. 2011). In areas of increased habitat disturbance, females may chose nest locations farther from breeding sites to optimize potential nest success (Lyon and Anderson 2003). Predator densities can also affect distance of nest site selection from leks, because of the trade-off between resource acquisition and risk of predation (Dinkins et al. 2012). These trade-offs can cause females to select less optimal nesting habitat, which may affect reproductive success (Schroeder and Baydack 2001, Coates and Delehanty 2010, Dinkins et al. 2012).

Sage-grouse nests locations may occur in a variety of sagebrush dominant habitat types. Most successful nests are placed under sagebrush plants with larger structure cover, both vertically and horizontally than contrasting nest sites of unsuccessful females or random sites (Patterson 1952, Connelly et al. 2011). In Utah, Dahlgren et al. (2006) reported that 70% of nest sites where located under big sagebrush. Multiple studies have reported that sagebrush cover was greater near successful nest sites than unsuccessful nest sites (Wallestad and Pyrah 1974, Gregg 1991). Across habitat types, Connelly et al. (2000) recommended that breeding habitats should be managed to support 15-25% sagebrush nesting canopy cover.

Across the Great Basin and Utah, nest initiation rates average 78%. Renesting rates are a direct reflection of habitat quality and climatic conditions and can vary annually and between populations (Schroeder 1997). Clutch size can range from 6 to 9 eggs, but on average females lay 7 eggs (Schroeder 1997, Connelly et al. 2011). Sage-grouse have relatively low clutch sizes in comparison to other game birds like Bobwhite quail (*Colinus virginianus*) and Sharp-tailed grouse (*Tympanuchus phasianellus*) with 12 to 14 and 11 to 12 eggs, respectively (Reese and Connelly 2011). Incubation period generally last about 27 days (Schroeder 1997). Across the range and between individual populations, Connelly et al. (2011) that nest success can vary between 15% and 85%.

Brooding

Upon hatching, females usually will move chicks away from the actual nest site, but remain within 3 km of the nest location for the first 2-3 weeks post hatching (Berry and Eng 1985). This early brood-rearing habitat is typically diverse in forbs and insects, which are protein rich and is critical for chick survival (Connelly et al. 2000). Dahlgren et al. (2006) found that higher insect abundance correlated to higher chick survival. Broods will usually make small diurnal movements to feed in areas with lower sagebrush height and density, higher rate of bare ground and increased herbaceous cover (Johnson and Boyce 1990, Holloran 1999, Connelly et al. 2011). However, these restricted movements could be extended if xeric conditions prevail early on, forb cover desiccates and insect abundance subsides prematurely.

After the first 2-4 weeks, chicks become more vigorous and mobile, and is the period when females move broods to summer and late brood rearing habitats. This period usually last from July to September and coincides with chicks switching from a heavily insect diet to one more composed of forbs (Connelly et al. 2011). Sage-grouse females will exploit a variety of habitats during this period in search of mesic areas and following vegetation phenology, that is continually forb dense. Commonly, to find wet meadow type habitat in late summer, brooding females will move up in elevation to mountain big sagebrush habitat (*A. t.* ssp. *vaseyana*). However, lower elevation irrigated croplands can serve as a surrogate mesic habitat and can compress large upslope movements if females are in relative proximity to these areas (Connelly et al. 2011).

Fall

Fall time is a period when both adults and broods begin to transition diets from forbs and insects to a diet primarily composed of sagebrush (Patterson 1952, Wambolt et al. 2002). Fall habitat used by sage-grouse populations can vary widely, reflecting landscape variables like resource availability, topography, weather and distance to overwintering habitat (Patterson 1952, Connelly et al. 1988). During this period, brood augmentation occurs with adults and larger flocks form. In addition to sagebrush, sage-grouse may still use similar habitat types to the summer period; however, movements from these habitats can occur quickly as irrigation of croplands and pastures subsides or vegetation killed by frost occurs at higher elevations (Gill and Glover 1965). As vegetation desiccates and metabolic water extraction from plants decreases, sage-grouse will key in on additional above ground water sources. Dalke et al. (1963) during a 7-year study in Idaho found that large flocks of sage-grouse near available water sources watered between 10 to 30 minutes daily. Fall migration to sagebrush dominated wintering habitat can occur from August to December, although early severe storms can shorten migration (Connelly et al. 1988). In Utah, Welch et al. (1990) found sage-grouse fall migration was independent of snow depth and generally occurred in mid-November.

Study Area

The Great Basin Ecoregion is a sub-region within the larger Intermountain West complex and spans Nevada, much of Oregon and Utah, and portions of California Idaho and Wyoming. The Great Basin is physiographic region of the largest and contiguous endorheic watershed in North America, which is delineated by a series of short fault-block mountain ranges running mostly north to south (Zamora and Tueller 1973). Across the region's ecosystems, sagebrush alliances and floristic characteristics of vegetation is a derivative and function of the climate, soil, topography and disturbance regimes (Miller and Eddleman 2001, Miller et al. 2011). Unlike most of the sagebrush steppe plant associations existing under potential natural vegetation (PNV) conditions – where sagebrush species are codominant with perennial bunchgrass species – Great Basin sagebrush are often the dominant overstory plant with a sparse grass understory (Kuchler

1970). These habitat characteristics are represented in my study area in northwestern Utah.

The study area consists of 440, 750 ha located in the Raft River Subunit Management Area, located in west Box Elder County in northwestern Utah (Fig. 1.1, UDWR 2002). The study area is bordered by the Raft River Mountains to the north, the Grouse Creek and Pilot Mountains to the west, by the Great Salt Lake to the southeast and areas of salt flats to the south (Cook et al. 2013). Land ownership within the Raft River Subunit consists of a mix of public, state and private lands; Bureau of Land Management (37%), U.S. Forest Service (7.6%), Utah School and Institutional Trust Lands Administration (5.0%) and private (50%) (Cook et al. 2013, Sanford and Messmer 2015).

The climate of the study area is emblematic of the modified continental macroclimate found throughout the Great Basin with cold winters and hot summers (Miller et al. 2019). From 1990 to 2016, the weather station (1732 m elevation) located in Rosette documented an average monthly low temperature in January of - 9.3 °C and in July an average monthly high temperature of 30.3 °C (Western Regional Climate Center 2018). Average precipitation was 29.3 cm with 14.2 cm accumulating as snowfall. At higher elevations (> 8000), snow can persist into the summer months but usually melts at lower elevations by early spring.

Vegetation structure and composition are correlated with elevation gradients (West 1983). Low elevations consist of salt desert shrub including shadscale saltbush (*Artriplex confertifolia*), greasewood (*Sarcobatus vermiculatus*) and rabbitbrush (*Chrysothamnus* spp.). Mid elevations are typical of sagebrush plant communities with

Wyoming sagebrush (*Artemisia. tridentata* spp. *wyomingensis*) and black sagebrush (*Artemisia nova*) dominating habitat characteristics. Aspens (*Populus tremuloides*) and mixed mountain shrubs stands are also present at mid to high elevation, especially in more mesic habitat. Higher elevations are represented by mountain sagebrush ((*A. tridentata* spp. *vaseyana*) and mixed coniferous forest (*Picea* spp., *Pinus* spp., and *Pseudotsuga menziesii*.) at higher elevations. Elevation throughout the study area ranged from 1300 to 2950 m above sea level.

Research Purpose

This study will focus on determining the role of mechanical conifer removal has on sage-grouse habitat utilization, seasonal movement patterns and individual brood response to mechanical conifer treatments in a landscape that exhibits a high level of anthropogenic disturbance (Gifford et al. 2014). This is the first study in West Box Elder County to document sage response to mechanically removed conifer treatments using individually marked sage-grouse with Global Position System (GPS) technology. Recent research from West Box Elder County documented positive individual sage-grouse responses to mechanical conifer treatments (Cook et al. 2017, Sanford et al. 2017); both of these studies use data gathered from individually marked sage-grouse using Very High Frequency radio applications. I also radio-marked sage-grouse chicks to study their vitals rate in response to management.

Additionally, a case study will be completed of the West Box Elder CRM to better identify the mechanisms and process used to springboard from BARM to CRM. This case study will provide other LWGs with information and insights regarding the transition of a LWG to a CRM. The West Box Elder CRM is one of the most successful local working groups in Utah— and the Intermountain West. A well documented case study could provide a template for other local working groups that desire to address local community needs beyond species conservation.

Chapter 2 will use locations from GPS to develop and evaluate models within a Resource Selection Function framework approach that will assist land managers with identifying and prioritizing implementation of conifer removal and habitat improvement areas while optimizing finite resources. This research will provide land managers with additional information regarding the role of mechanical conifer treatments in mitigating the potential effects of anthropogenic disturbances on sage-grouse movements and population fitness in the Box Elder Sage-grouse Management Area (SGMA) in northwestern Utah (Utah Public Lands Policy Coordination Office [PLPCO] 2019).

Chapter 3 will investigate the differential morality effect between individually radio-marked sage-grouse marked with a GPS backpack style transmitter or VHF necklace collar. This information with be useful to researchers and wildlife biologist in understanding mortality associated costs between the two marking techniques. Chapter 4 will report vital rates of radio-marked chicks for 2 years within the West Box Elder SGMA.

Chapter 5 will report on the findings from a case study and interview process conducted in Fall 2019 on participants from the West Box Elder CRM group. I will use this information to evaluate how well the program approximated the community based conservation framework (Berkes 2004). Chapter 6 is the conclusion of my dissertation. This chapter will summarize the results of my research on prioritizing habitat management for sage-grouse by using GPS location within a RSF framework to better mitigate resistance in a human modified landscape.

This dissertation is written in a multiple paper format using the Journal of Wildlife Management format guidelines for chapters 1, 2, 3, 4 and 6. Chapter 5 is written in format guidelines for Human – Wildlife Interactions.

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Figures

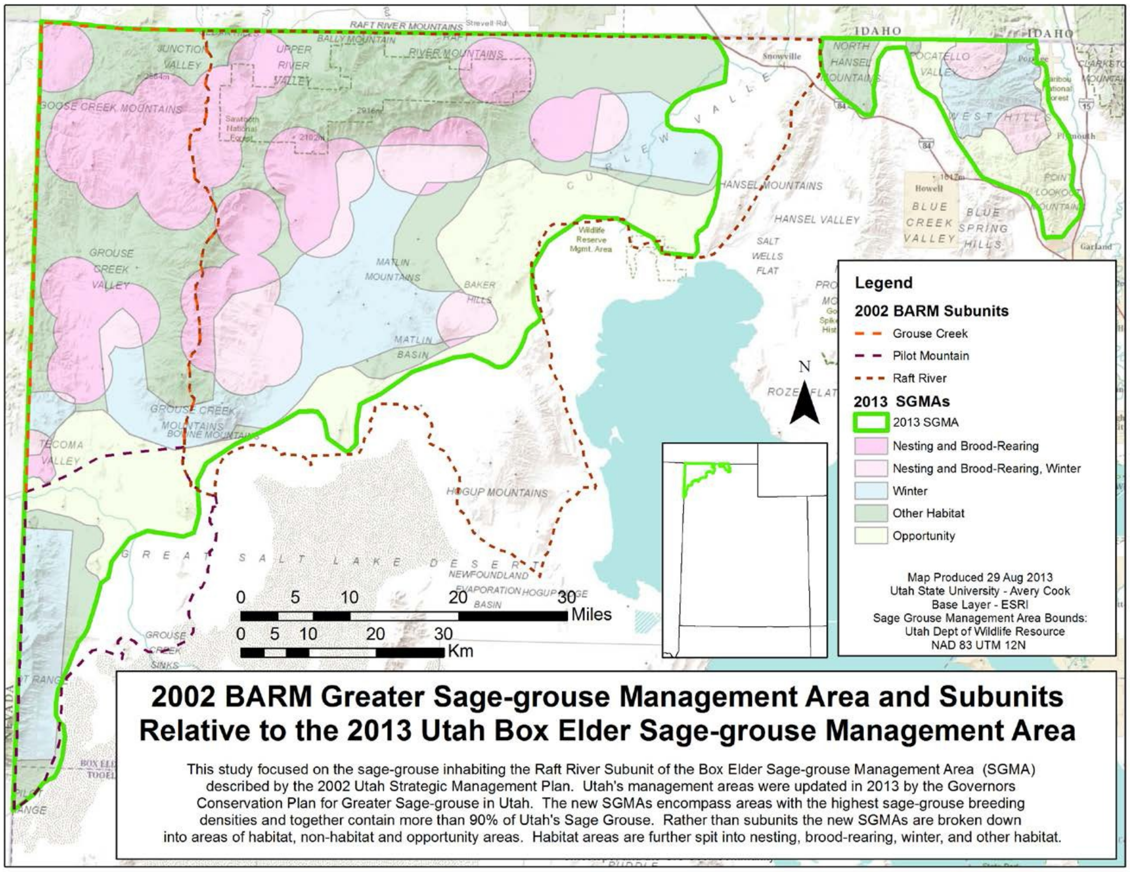

Figure 1-1. Greater sage-grouse (*Centrocercus urophasianus*) Management Area and Subunits as defined by the 2013 Utah Box Elder Sage-grouse Management Area (SGMA) and the 2002 BARM. Utah's SGMA management plans were updated in 2013 and encompass areas within the highest breeding densities of sage-grouse in the state and support > 90% of Utah's sage-grouse populations. The update SGMA classified and separated by habitat, other habitat and opportunity. Habitats are further delineated by nesting and brood-rearing, by nesting and brood-rearing and winter.

CHAPTER 2

FORECASTING VEGETATION COMPOSITION RESPONSES TO PINYON - JUNIPER TREATMENTS IN NORTHWESTERN UTAH

Abstract

Conifers (mainly Utah juniper [*Juniperus osteosperma*] and Western juniper [*Juniperus occidentalis*] and (pinyon-pine [*Pinus monophyla*] to a lesser degree by infill) are expanding across the Great Basin into sagebrush (*Artemisia* spp.) communities inhabited by the greater sage-grouse (*Centrocercus urophasianus;* sage-grouse) at rates exceeding those since the Holocene. Without active intervention, conifer encroachment is projected to convert > 75% of the remaining sage-grouse habitats into phase III woodlands over the next 40 to 50 years. Because intervention is costly, land managers desire tools that can be used to remotely quantify and evaluate the effectiveness of past pinyon – juniper removal treatments to optimize future conifer management actions. To address this information need, we analyzed pre- and post-treatment data for vegetation composition and annual changes in percent cover for known conifer treatments completed between 2008-2014 in Box Elder County, Utah, USA to develop a multivariate generalized linear regression model to predict future landscape conditions for sage-grouse. We evaluated our models by comparing predicted vegetation composition five years post-treatment to the observed composition. We subsequently predicted expected vegetation composition in 2023 based off treatments completed in 2018. Our predictive model accurately projects tree canopy cover that approximated observed cover values for known treated plots at time of treatment and five years post-treatment. Future refinement will be necessary to make the model more mechanistic so it

can accurately forecast future shrub cover along with tree encroachment for sagebrush areas outside of treatment plots. To our knowledge, our model represents the first approach to incorporate annual vegetation cover data for change detection over current and future landscapes. Our predictive model can provide land managers with a tool to prioritize conifer treatments to optimize sage-grouse habitat improvements.

Introduction

The Great Basin is the largest contiguous endorheic watershed in North America cover covers approximately 540,000 km2 (Nelson and Mayo 2014). It spans nearly all of Nevada, much of Oregon and portions Utah, and is bounded by the eastern Sierra Nevada mountain range on the western side and the Wasatch Front Range to the east. The combination of hot, dry summers and cold winters results in a characteristic vegetation dominated by aromatic, perennial shrubs such as various forms of sagebrush (Artemisia *spp*.) (Miller et al. 2019). Great Basin sagebrush communities provide important habitats for over 350 vertebrate species (Knick et al. 2014) including the greater sage-grouse (*Centrocercus urophasianus*; sage-grouse). Since European settlement, over 50% of the sagebrush communities have been lost because of anthropogenic land uses. Concomitantly, sage-grouse and other sagebrush-obligate species populations are declining (Connelly and Braun 1997, Braun 1998, Schroeder et al. 2004, Knick and Connelly 2011b, Connelly et al. 2011, Stiver 2011).

One of the most significant threats Great Basin sagebrush communities are facing is the encroachment of pinyon (primarily *Pinus monophylla*) and juniper (primarily *Juniperus osteosperma*) woodlands at a rate exceeding any expansion phase during the Holocene (Bradley and Fleishman 2008, Miller et al. 2011, Knick et al. 2014, Coates et al. 2017, Miller et al. 2019). Historically, pinyon – juniper woodlands (hereafter; PJ) were part of dominant plant associations and alliances that resulted from spatial heterogeneity in soil types across the physiographic provinces of the Basin and Range complex (Miller et al. 2008). Pre-settlement estimates suggest PJ occupied less than 3 million ha (Greenwood and Weisberg 2009). Currently, PJ woodlands are estimated to cover more than 40 million ha (Romme et al. 2009, Filippelli et al. 2020) and now constitute the third largest vegetation cover type in the United States (Huang et al. 2009).

Anthropogenic land-use changes throughout the Great Basin have also exacerbated PJ encroachment into sagebrush habitats (Miller and Rose 1999, Greenwood and Weisberg 2009). Prior to the late 1800s low-severity fires increased herbaceous cover dominance, restricted PJ expansion and infill, and influenced vegetation dynamics (composition, structure and persistence) in established sagebrush habitats (Miller and Heyerdahl 2008, Coates et al. 2017). However, resulting from increasing European settlement in the1860s, natural fire return intervals declined to levels not documented in the last 3000 years (Miller et al. 2019). Declines in fire frequency coincided with the introduction of domestic livestock in the late 1800s, which further reduced fine herbaceous fuel loads across western rangelands.

During this same period, exotic annual grasses like cheatgrass (*Bromus tectorum*), well-suited to warming trends of Intermountain West climates, were introduced to the west (Mack 1981). Within sagebrush ecosystems of Nevada and Utah, cheatgrass has become the most problematic invasive. Cheatgrass exhibits a broader ecological amplitude (i.e., existing in over a larger gradient of xeric and mesic ecological sites) than native perennial bunchgrasses (Chambers et al. 2014).

The culmination of these landscape-scale alterations disrupted natural vegetation successional pathways. The disruption of plant successional stages has facilitated PJ expansion into sagebrush habitat types that do not reflect distinct pre-settlement distributions (Miller and Heyerdahl 2008). Although PJ is a native vegetation component in the Great Basin and helps shape landscape heterogeneity, land managers are concerned that if conifer encroachment continues at accelerated rates, rangelands will become more homogeneous across defined habitat types and affect sagebrush obligate species (Rowland et al. 2006, Coates et al. 2017). Forest inventories completed in Utah, Nevada and eastern California reported that > 60 % of current PJ woodlands are less than 150 years old (Bolsinger 1989, Menlove et al. 2016, Miller et al. 2019). Furthermore, this interwoven matrix of landscape disturbance regimes has altered the physical and effective environments of native plant assemblages and communities through the reduction of an ecosystem's resilience and resistance (Chambers et al. 2014). Conifer encroachment in sagebrush communities has impacted the ecosystem's and individual native plant species' ability to regain and retain their fundamental structure and functionality across habitat gradients (Miller et al. 2011).

Sage-grouse have been identified as a key indicator species to determine the condition of sagebrush ecosystems (Rowland et al. 2006, Knick et al. 2013, Sanford et al. 2017). The species requires large intact mosaics of sagebrush dominated landscapes at large spatial scales to complete their life cycles (Rowland et al. 2006, Knick et al. 2013, Coates et al. 2017). Several studies have reported sage-grouse avoidance of PJ woodlands (Doherty et al. 2008, Knick et al. 2013, Coates et al. 2017, Sanford et al. 2017) and at different phases of encroachment. Pinyon-juniper successional processes are separated into three transitional phases: with phase I, shrubs are the dominant overstory but trees are present (> 0-10%); phase II, shrubs are codominant with trees (>10-20%); and phase III, trees are dominant (>20%) (Miller et al. 2005, Coates et al. 2017). Avoidance of trees can be linked to increased perch structure for avian predators (Coates et al. 2017). For example, predator densities can affect site selection for nesting female sage-grouse because of the trade-off between resource acquisition and risk of predation (Dinkins et al. 2012). These trade-offs can cause females to select less optimal nesting habitat, which may affect reproductive success (Schroeder and Baydack 2001, Coates and Delehanty 2010, Dinkins et al. 2012). Coates et al. (2017), documented possible fitness consequences to sage-grouse and PJ avoidance density of > 2 % canopy composition.

Beginning in the mid to late 2000s, the Natural Resources Conservation Service (NRCS) through the Sage-grouse Initiative (www.sagegrouseinitiative.com), provided cost-share to landowners to mechanically remove or reduce conifers into core sage-grouse habitats on private lands in the western U.S. Similar projects have been implemented range wide on Bureau of Land Management (BLM) and U.S. Forest Service (USFS) administered lands. In Utah alone, conifers have been removed from > 200,000 hectares of sagebrush landscapes since 2006 under the Utah Department of Natural Resources (UDNR) Watershed Restoration Initiative (WRI 2010).

Large-scale mechanical conifer reduction projects may have potential for increasing metapopulation connectivity, gene flow and usable habitat for sagebrush obligate species (Utah Division of Wildlife Resources [UDWR] 2009, Knick and Connelly 2011b), Baruch-Mordo et al. 2013, Dahlgren et al. 2016). Broad-scale intact sagebrush communities or connected networks of habitat patches that support large stable sage-grouse populations can play a vital role in maintaining isolated or satellite populations that are not self-sustaining because of low recruitment and decreased gene flow (Knick and Connelly 2011b). Moreover, potential increase in suitable habitat could reduce the seasonal movements for certain sagebrush obligate species, such as sage-grouse populations, due to providing more continuous useable habitat; distances for an individual bird or population often directly reflect the availability of suitable habitat (Dahlgren et al. 2016). Population trends of sage-grouse are likely controlled by long-term environmental factors rather than stochastic events and conservation strategies for this highly mobile species should focus on preserving existing habitat and restoring habitat that complement the species dispersal capabilities (Knick and Connelly 2011a).

The logistics required to remove encroaching conifer at the scales required to benefit sage-grouse and other sagebrush obligates has impeded land managers and agencies management efforts (Messmer et al. 2010, Messmer 2013, Ricca et al. 2018). Given current budgetary constraints, land managers desire methodologies to remotely quantify and evaluate the effectiveness of past PJ treatments to better inform future management strategies and actions that maximize ecological benefits per unit cost (Greenwood and Weisberg 2009, Messmer 2013). Quantifying land cover changes relative to PJ expansion and infilling trends using traditional inventory methods of woodland stand composition and structure would be cost prohibitive (Greenwood and Weisberg 2009, Filippelli et al. 2020). However, using remotely sensed data to evaluate and predict possible cost-benefits of future PJ treatments to sagebrush ecosystems, could provide land managers with a practical decision-making tool, while maximizing ecological benefits for sage-grouse and other sagebrush obligates.

The objective of this research was to develop a predictive model to forecast landscape conditions in response to future pinyon-juniper treatment (i.e., woodland expansion, contraction and shrubland composition) based on actual past treatments, using remotely sensed vegetation and environmental data. First, we quantified vegetation change in response to PJ treatments occurred between 2008 and 2014 across West Box Elder Sage-grouse Management Area (SGMA) in northwest Box Elder County, Utah. Then, we validated the model by comparing predicted and actual vegetation composition 5 years after treatment. Finally, we applied the model to forecast vegetation composition (e.g., woodland and shrublands) in 2023 in response to treatments performed in 2018. Our approach can be applied as a powerful conservation-planning tool to prioritize candidate treatment plots based on projected outcomes that has potential to increase habitat suitability for sage-grouse populations that reside within the West Box Elder SGMA.

Study Area

We conducted this study in Box Elder county, northwestern Utah, which is part of the Great Basin. The Great Basin is a sub-region within the larger Intermountain West complex that falls within the Northern Basin and Range ecoregion and spans across Nevada, much of Oregon and Utah, and portions of California Idaho and Wyoming. The Great Basin is a physiographic region of the largest and contiguous endorheic watershed in North America, which is delineated by a series of short fault-block mountain ranges running mostly north to south (Zamora and Tueller 1973). Across the region's ecosystems, sagebrush alliances and floristic characteristics of vegetation is a derivative and function of the climate, soil, topography and disturbance regimes (Miller and Eddleman 2001, Miller et al. 2011). Unlike most of the Sagebrush steppe plant associations existing under potential natural vegetation (PNV) conditions – where sagebrush species are codominant with perennial bunchgrass species – the Great Basin sagebrush are often the dominant overstory plant with a sparse grass understory (Kuchler 1970).

The study area consists of 440,750 ha located in the Raft River Subunit Management Area (Fig. 2.1, UDWR 2002). The study area is bordered by the Raft River Mountains to the north, the Grouse Creek and Pilot Mountains to the west, by the Great Salt Lake to the southeast and areas of salt flats to the south (Cook et al. 2013). Land ownership within the Raft River Subunit consists of a mix of public, state and private lands; Bureau of Land Management (37%), U.S. Forest Service (7.6%), Utah School and Institutional Trust Lands Administration (5.0%) and private (50%; Cook et al. 2013, Sanford and Messmer 2015).

The climate of the study area is emblematic of the modified continental macroclimate found throughout the Great Basin with cold wet winters and hot dry summers (Zamora and Tueller 1973, Miller et al. 2019). From 1990 to 2016, the weather station (1732 m elevation) located in Rosette documented an average monthly low temperature in January of - 9.3 °C and in July an average monthly high temperature of 30.3 °C (Western Regional Climate Center 2018). Average precipitation was 29.3 cm with 14.2 cm accumulating as snowfall. At higher elevations (> 8000), snow can persist into the summer months but usually melts at lower elevations by early spring. Less than

25 percent of annual precipitation accumulates in the summer (Miller et al. 2019). Temperature and precipitation are both strongly influence by elevation: for each 305 m in elevation gain, temperature decreases by 1.65 °C and precipitation increases by 12.7 cm (Oosting 1956).

Elevation throughout the study area ranges from 1300 to 2950 m above sea level. Vegetation structure and composition are correlated with elevation gradients (West 1983). Low elevations consist of salt desert shrub including shadscale saltbush (*Atriplex confertifolia*), greasewood (*Sarcobatus vermiculatus*) and rabbitbrush (*Chrysothamnus* spp.). Mid elevations are typical of sagebrush plant communities with Wyoming sagebrush (*A. tridentata* spp. *wyomingensis*) and black sagebrush (*A. nova*) dominating habitat characteristics. Aspens (*Populus tremuloides*) and mixed mountain shrubs stands are also present at mid to high elevation, especially in more mesic habitat. Higher elevations are represented by mountain sagebrush (*A. t.* spp. *vaseyana*) and mixed coniferous forest (*Picea* spp., *Pinus* spp., and *Pseudotsuga menziesii*).

Methods

We used pre- and post-treatment vegetation composition data for known treatment plots in Box Elder County, UT, to train a predictive model of the effects of PJ treatments on vegetation composition. We evaluated this model by comparing predicted vegetation composition five years after treatment to the observed composition in plots that were treated between 2008 and 2014. We then used the validated model to predict expected vegetation composition in 2023 as a result of treatments to be performed in 2018. We conducted all analyses in R version 3.6.2 (R Core Team 2019) using the packages *raster*

(Hijmans 2020), *rgdal* (Bivand et al. 2019), *rgeos* (Bivand and Rundel 2019), *tidyverse* (Wickham et al. 2019), and *DirichletReg* (Maier 2015).

Treatment Data

We downloaded data on PJ treatments in Box Elder County from the WRI database (https://wri.utah.gov/wri). These data included information on date and location of treatments completed between 2006 and 2019. For this analysis, we selected ten representative plots among those treated before 2014, so that we could later evaluate our predictions by comparing predicted status five years after treatment with the observed status. We chose the 10 plots so as to encompass the spectrum of variation in areal extent, geographical location, and year of treatment found in the full dataset. We also chose plots that were sufficiently isolated as to minimize noise resulting from concurrent treatment in surrounding areas that we would not account for in our model.

Vegetation Composition Data

We used percent annual cover data at a 30m resolution from the Rangeland Analysis Platform (RAP; https://rangelands.app/data/) to quantify annual vegetation composition in each of the treated plots from the year prior to treatment to five years post-treatment. We did the same for the surrounding untreated area, defined by adding 10km in each direction to the rectangular extent of the treatment plot. The RAP data included six bands corresponding to tree cover, shrub cover, annual grasses and forbs, perennial grasses and forbs, litter, and bare ground. Although tree cover is not explicitly split between deciduous and conifer cover, tree cover in our study area can be assumed to be mainly constituted by conifer in the majority of cases (Cook et al. 2017, Miller et al.

2019); similarly, we were unable to distinguish sagebrush from other shrubs based on the available data. Despite these shortcomings, the RAP data is the highest-spatial-resolution available data of vegetation cover in our study area that is available on an annual basis.

Environmental Variables

Vegetation dynamics, including responses to treatments, are influenced by topographic characteristics of the landscape (Miller et al. 2008). These variables are also important in determining the susceptibility of an area to pinyon-juniper encroachment in the first place (Miller et al. 2000, Miller et al. 2019). We associated topography data to each of the treatment plots in our dataset to account for the effect of these variables in shaping vegetation dynamics in response to treatment. We downloaded elevation, aspect, and slope layers from the Landscape Fire and Resource Management Planning Tools project (Landfire version 1.3.0; www.landfire.gov).

Sampling Design

For each of the 10 treatment plots in our sample, we randomly selected 10 points within the treated area and 10 outside of it. For each of these points, we intersected data on vegetation composition in each year from the year prior to treatment to five years after, as well as topography data. The model dataset therefore consisted of 1200 points (20 in each year for 6 years and 10 polygons). Thinning the data by randomly sampling a random subset of points ensured that each data point could be reasonably treated as independent, thus accounting for spatial autocorrelation inherent to our data and process of interest.

Data Analysis

We used Dirichlet regression to model vegetation composition in response to treatment as a function of prior composition, controlling for topography characteristics. Dirichlet regression is appropriate for the analysis of compositional variables, because it accounts for covariance between components of the response variable and it ensures that they add up to one. We modeled vegetation composition in each year, from the year of treatment to five years after, as a function of A) vegetation composition in the previous year (starting from the year prior to treatment until four years after) in interaction with a binary treated/untreated variable and the number of years from treatment, B) elevation, C) slope, D) aspect sine, E) aspect cosine. We scaled and centered all variables before fitting the model. We evaluated predictive performance of our model by comparing spatially explicit model predictions of tree and shrub cover with the observed data five years after treatment for the ten plots in our sample. We used parametric bootstrapping to calculate confidence intervals around mean model predictions.

Results

The set of treatment plots we selected among the WRI dataset included one plot treated in each of the years 2008-2010 and 2014, and two plots treated in 2011-2014; the area of the chosen plots ranged between 1 and 45 square kilometers (Fig. 2.1). The Dirichlet regression indicated that tree cover was lower in each year post-treatment in treated plots compared to untreated surrounding areas, and that it decreased faster through time within treated plots versus untreated surrounding areas (Fig. 2.2). Shrub cover was also greater in treated plots when compared to untreated adjacent areas in the first year after treatment, although it appeared to decrease through time in both (Fig. 2.2).

The longer after treatment, the smaller the difference we detected in shrub cover between treated and untreated areas (Fig. 2.2). Treated plots also had higher percent cover of litter, annual, and perennial grasses and forbs than untreated plots (Fig. 2.2); the percent cover of these vegetation classes also increased faster in treated compared to untreated surrounding areas (Fig. 2.2). Conversely, percent bare ground decreased faster after treatment in treated plots compared to untreated ones (Fig. 2.2). Overall, we did not observe any reversal of trends through time between treated and untreated plots, i.e., each vegetation class either increased in both or decreased in both through time (Fig. 2.2). The effect of treatment on tree cover was strongest than for all other vegetation classes (Fig. 2.2; see non-overlapping confidence intervals).

Model predictions for PJ canopy cover in relation to topographical covariates indicated a positive correlation with elevation and slope: higher elevations and steeper slopes were associated with greater values of percent tree cover (Fig. 2.3). Moreover, north-facing slopes were associated with the highest values of percent tree cover (Fig. 2.3). These relationships were stronger in untreated than in treated plots (Fig. 2.3). Shrub cover was also positively correlated with elevation and, less so, with slope, as well as with north-facing slopes (Fig. 2.4). However, we did not observe any interactive effect of treatment with topographic variables (i.e., no difference in trends between treated and untreated plots; Fig. 2.4).

Our model performed well in predicting changes in percent tree cover through time as a result of treatment. Projected values of tree cover for plots treated between 2008 and 2014 closely matched the actual observed values five years after treatment (Fig. 2.5). In most cases, the model also performed satisfactorily in predicting tree cover in areas where trees were already present and that were not subject to treatment (surrounding but outside of treatment plots; Fig. 2.5). However, the model performed poorly at predicting new tree encroachment outside of treatment plots (Fig. 2.5; see especially plot E).

The model did not perform as well in predicting changes in shrub cover as a result of treatment as it did for tree cover. Shrub cover values within some predicted plots matched the patterns actually observed five years after treatment (Figure 2.6; see especially plots B, G, and I, where model predictions most closely follow the spatial configuration of the changes observed after treatment). However, predictions in the untreated portions of the landscape were generally not accurate (Fig. 2.6). In some cases, predictions were far from what actually observed five years after even within treated plots (Fig. 2.6, plots F and J) plots.

Discussion

Our predictive model presents a unique approach in forecasting vegetation composition change in response to PJ treatments for future landscapes that are currently being encroached by pinyon-juniper. To our knowledge, using newly developed RAP data, our study represents the first to use annual vegetation data from remote sensing to build a predictive model that forecasts the effect of projected PJ treatments on vegetation response and composition. Although previous research have investigated vegetation change detection in response to PJ treatments (Falkowski et al. 2017, Coates et al. 2017, Reinhardt et al. 2017, Ricca et al. 2018, Reinhardt et al. 2020), it was performed without using annual data. Our model gives land managers a conservation planning tool that could be employed to prioritize candidate treatment sites and forecast treatment effected and possible ecological net gains.

Our Dirichlet regression results paralleled those reported by other studies (Miller et al. 2011, Boyd et al. 2017) that tree cover was lower for treated plots versus untreated surrounding areas in each of the five years post-treatment. Our model achieved high predictive power within treated plots, producing spatially explicit predictions of percent tree cover that closely matched the observed values five years post-treatment. However, model performance was lower outside of treatment plots, where predictions often did not capture new encroachment where it occurred. This result was to be expected, given that we did not incorporate any mechanistic component for tree encroachment within the model. Topography likely plays a role in determining the susceptibility of different areas to PJ encroachment, and we captured this susceptibility by including elevation, slope, and aspect within the model. However, other factors ultimately determine where new encroachment will occur. These factors may include the spatial proximity of the leading edge of current encroachment, the density of PJ in surrounding encroached areas, or the spatial configuration of existing encroachment across the landscape. Overall, our mechanistic understanding of the drivers of encroachment is still limited. Until the mechanistic drivers of PJ encroachment are identified and accounted for, any model of vegetation change in affected areas will be purely phenomenological and thus unable to accurately predict the emergence of new encroachment across the landscape. Our model performed well at the task we designed it for (i.e., predicting vegetation change within treated plots) and as well as it could with the information it was given when predicting vegetation change outside of treatment plots.

Within treated plots, the most consistent signal we detected in the data was a decrease of tree cover in response to treatment (Fig. 2.2). However, we found high variability in responses of the rest of the vegetation community to PJ removal treatment. Although treatments are meant to reduce tree cover in favor of shrub, and specifically sagebrush, the responses we observed did not show a consistent increase of shrub cover in all treated plots (Figure 2.3). This variability was reflected in poor performance of the model when predicting shrub cover for treated plots (Fig. 2.6). Additional factors that were not captured within our model could modulate vegetation community responses to treatment and determine whether tree removal will result in an increase of shrub cover. These factors may include abiotic characteristics such as climate and soil composition, as well as biotic ones such as dominant shrub and/or grass species at the time of treatment. Future attempts to improve our model should thus elucidate the mechanisms driving the variability in vegetation community responses to treatment besides the mechanisms driving tree encroachment in previously unaffected areas. At this point, our primary objective was achieved in developing a predictive model that forecast vegetation change in response to future pinyon-juniper treatments with reasonable accuracy considering knowledge gaps. To our knowledge, this is the first instance of a model that leverages annual remotely sensed data at a fine spatial resolution to quantify vegetation responses to conifer removal treatments across broad scales.

Predictive models that incorporate annual remotely sensed data could be employed as a cost-effective planning tool and solution to prioritize candidate pinyon – juniper treatments at regional and local scales, consequently giving land managers pre-interpretive strength of forecasting site-by-site outcomes. Additionally, this information could provide managers a valuable spatially and temporally explicit visualization mechanism that identifies the effect of treatment on individual encroachment phases of pinyon – juniper within candidate treatment sites. For example, forecasting the top-down effects of PJ encroachment phases (I, II and III) of candidate treatment sites on vegetation composition could be paramount in practitioners achieving the highest net ecological return on investment (Falkowski et al. 2017).

Miller et al. (2008) reported that without natural disturbances (e.g., natural occurring wildfire) or continued intervention, pinyon – juniper encroachment would transition by 75% into phase III over the next 40 to 50 years throughout the Great Basin, which will put sagebrush habitat types and obligate species at increased risk. Model frameworks, which can predict future management outcomes at local and region scales, will be principal in prioritizing future restoration sites to mitigate or prevent ecological thresholds from being breeched by the successional transition of sagebrush habitat types into late phase PJ woodlands (Baruch-Mordo et al. 2013). For example, we used our model to predict expected vegetation composition for 2025 plots as a result of hypothetical treatments to be performed in 2020 to gain knowledge of what additional habitat resources candidate treatment sites could provide in the future. Our study demonstrates the strength of using annual remote sensed data to detect vegetation response and composition change at temporal and spatial scales that could maximize economic investments and minimize impacts to sagebrush obligate species.

Management Implications

Pinyon – juniper management is costly and restoration efforts may just be keeping pace with estimated expansion rates. Our study demonstrated that vegetation response to future treatment can be accurately quantified and forecasted. Predictive model flexibility that can forecast future landscapes gives conservation partners upfront knowledge of project implementation outcomes before on-the-ground work occurs and helps mitigate unknown treatment variables (e.g., post treatment clean-up because of PJ regrowth). Importantly, knowledge of how vegetation responds to treatment across the landscapes allow managers to target specific sites or phases of PJ encroachment, balance cost and benefit trade-offs of different treatment techniques (e.g., mastication, chaining, lop-and-scattered, etc.) and maximize biological return on investment. Land practitioners that can leverage planning tools to predict future vegetation response to treatment will be more effective and mitigating impacts of PJ encroachment across broad landscapes that could provide additional resources to sage-grouse and other sagebrush obligate species. We anticipate future refinement of our model to be used in concert with a RSF using GPS-derived sage-grouse location data. Intersecting our predictive model with a RSF could be valuable for detecting female sage-grouse behavioral response, space use and nesting habitat for candidate treatment sites that are currently encroached by pinyon-juniper.

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Figures

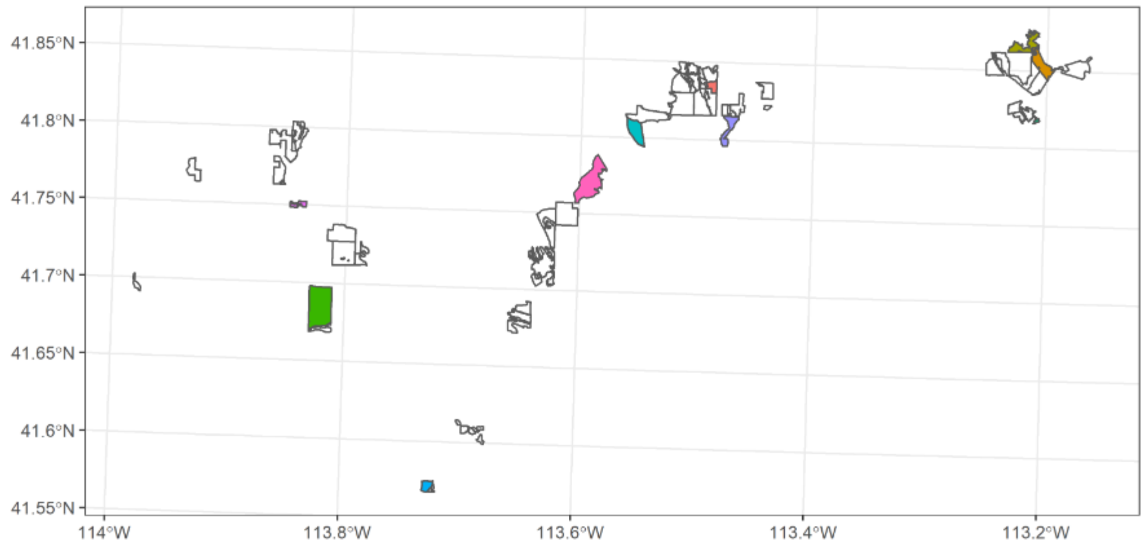

Figure 2-1. Map of the ten treatment plots chosen within the Watershed Restoration Initiative database as a representative sample among the plots treated between 2008 and 2014 in Box Elder County, Utah, USA.

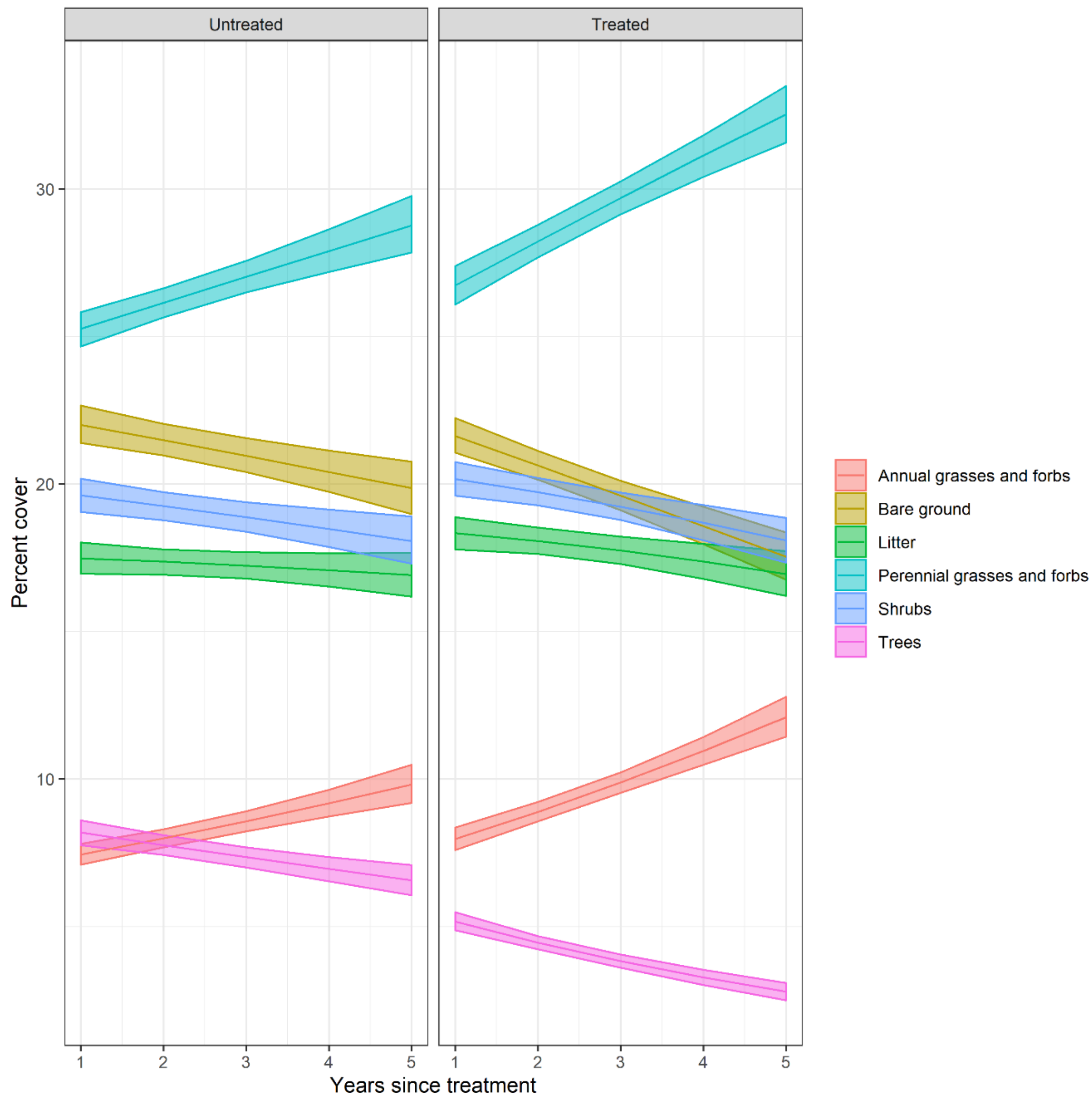

Figure 2-2. Model predictions for Dirichlet regression of vegetation composition as a function of treatment status and time (years since treatment). Topographic variables and percent vegetation cover prior to treatment were held fixed at their mean value. The solid line depicts mean predictions of percent cover for each of the six vegetation classes, while the shaded ribbon around it shows 95% confidence intervals.

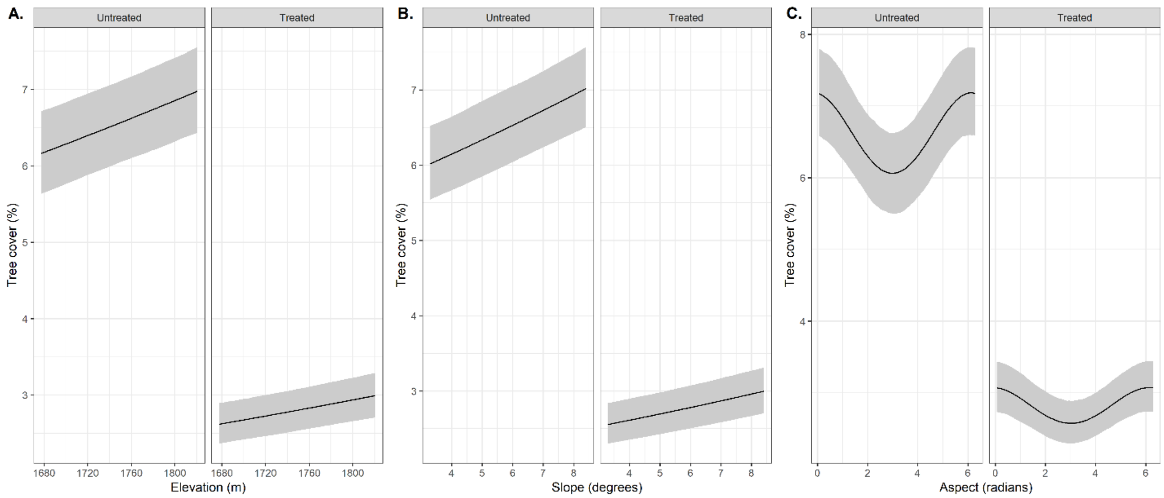

Figure 2-3. Model predictions for percent tree cover five years after treatment as a function of treatment status and topographic variables (A: elevation; B: slope; C; aspect). Percent vegetation cover prior to treatment was held fixed at their mean value. The solid line depicts mean predictions for percent tree cover, while the shaded ribbon around it shows 95% confidence intervals.

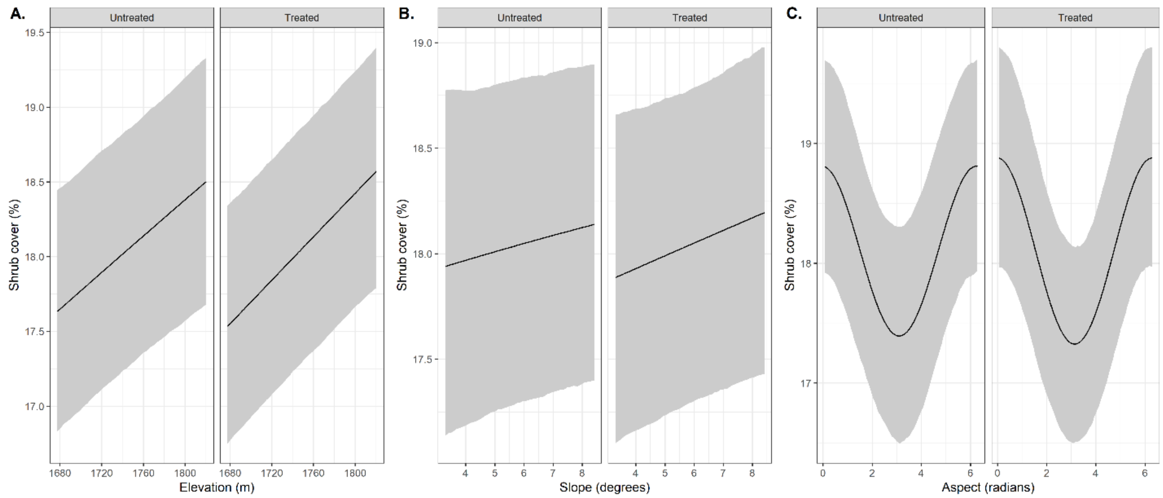

Figure 2-4. Model predictions for percent shrub cover five years after treatment as a function of treatment status and topographic variables (A: elevation; B: slope; C; aspect). Percent vegetation cover prior to treatment was held fixed at their mean value. The solid line depicts mean predictions for percent shrub cover, while the shaded ribbon around it shows 95% confidence intervals.

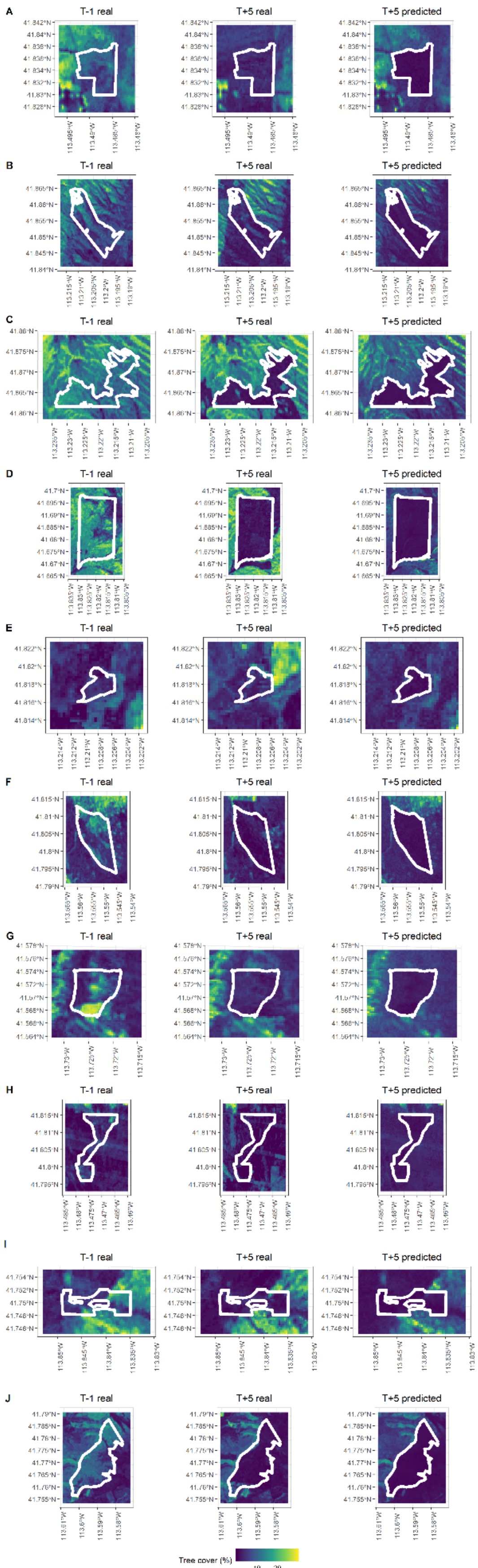
A
T-1 real
T+5 real
T+5 predicted
B
C
D
E
F
G
H
I
J
Tree cover (%)
10
20

Figure 2-5. Maps of observed percent tree cover prior to treatment, observed percent tree cover five years after treatment, and predicted percent tree cover five years after treatment for the ten example plots treated between 2008 and 2014 in Box Elder County (A through J). Comparing observed and predicted percent tree cover five years after treatment side by side provides a visual evaluation of the model's predictive performance.

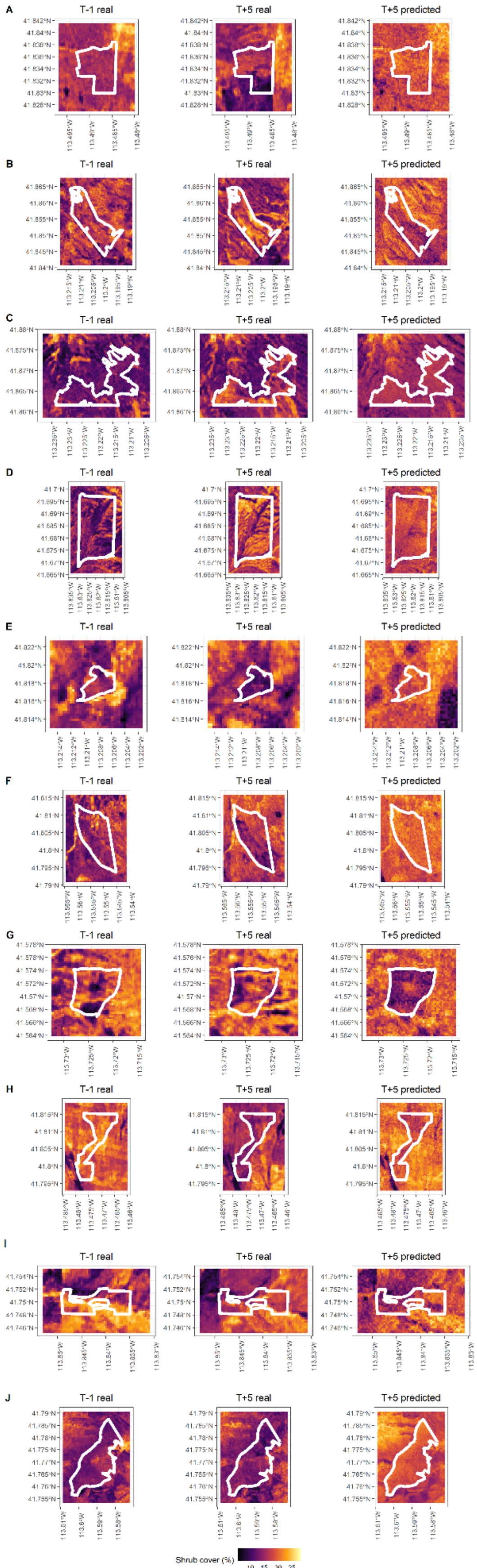
A
T-1 real
T+5 real
T+5 predicted
B
T-1 real
T+5 real
T+5 predicted
C
T-1 real
T+5 real
T+5 predicted
D
T-1 real
T+5 real
T+5 predicted
E
T-1 real
T+5 real
T+5 predicted
F
T-1 real
T+5 real
T+5 predicted
G
T-1 real
T+5 real
T+5 predicted
H
T-1 real
T+5 real
T+5 predicted
I
T-1 real
T+5 real
T+5 predicted
J
T-1 real
T+5 real
T+5 predicted
Shrub cover (%)
10 15 20 25

Figure 2-6. Maps of observed percent shrub cover prior to treatment, observed percent shrub cover five years after treatment, and predicted percent shrub cover five years after treatment for the ten example plots treated between 2008 and 2014 in Box Elder County (A through J). Comparing observed and predicted percent shrub cover five years after treatment side by side provides a visual evaluation of the model's predictive performance.

CHAPTER 3

PRIORITIZING CONIFER REMOVAL TREATMENTS TO OPTIMIZE GREATER SAGE-GROUSE HABITAT BENEFITS IN NORTHWESTERN UTAH

Abstract

Federal and state agencies responsible for managing landscapes to conserve sensitive wildlife species desire adaptive planning mechanisms to optimize project costs with ecological benefits. Advances in wildlife monitoring technology and movement data analyses now provide managers with modeling approaches that can be used to better predict species space use at temporal and spatial scales relevant to management. Herein, we describe a composite modeling approach used to predict resource selection by greater sage-grouse (*Centrocercus urophasianus*) in response to changes in habitat vegetation composition subsequent to conifer (i.e., pinyon pine (*Pinus* spp.) and juniper (*Juniperus* spp.) removal projects in northwestern Utah. We modeled predicted changes in vegetation composition across our study area from 2017 (pre-treatment) to 2023 (five years post-treatment) under five different management scenarios, compared sage-grouse habitat selection for each scenario pre- and post-treatment, and then ranked the scenarios using three criteria (i.e., change in suitability of nesting and summer habitats, and cumulative net habitat gain per dollar invested). We used a Relative Selection Strength (RSS) framework to quantify the net habitat gain from 2017 to 2023 for each treatment scenario. Net habitat gain for dollar spent on each treatment differed by scenario. Our top ranked treatment scenario showed net habitat gains across all categories (cumulative habitat gain; logRSS = 6398.13) and highest gain per dollar invested (logRSS = 0.2040).

Our analysis can provide managers with a framework that can be used to prioritize conifer removal projects based on habitat benefits accrued per unit economic cost.

Introduction

As anthropogenic landscape modifications accelerate in response to the global growth in human populations, conservation planners desire adaptive and effective tools to maintain biodiversity, improve ecosystem services, conserve landscape heterogeneity and recover at-risk species (Pressey and Bottrill 2009). Concomitantly, agencies responsible for mitigating impacts and facilitating recovery of imperiled species often have limited resources to implement the strategies necessary to achieve on-the-ground conservation (Bottrill et al. 2009).

Contemporary conservation planning methods often produce undesirable outcomes relative to resource allocation and anticipated ecological benefits (Schindler et al. 2020). The desire for more efficient resource allocation methods has led managers to seek and develop quantitative yet tractable planning mechanisms that identify and prioritize restoration areas for habitat improvement, while maximizing ecological benefits per unit economic cost for targeted wildlife species (Messmer 2013, Gerber 2016, Ricca et al. 2018, Schindler et al. 2020). Recent studies have reported that conservation planning strategies that incorporate spatial distributions of ecological benefits and economic costs upfront can achieve sizeable net ecological gains even while operating under limited budgets (Naidoo et al. 2006, Schindler et al. 2020).

Technological developments that facilitate more intensive monitoring of seasonal movements of illusive and remote wildlife species, coupled with analytical improvements, have opened the door for researchers to integrate multiple modeling approaches and data to better inform future management actions across habitat types at temporal and spatial scales relevant to managers (Knick et al. 2014, Sanford et al. 2017). Incorporating composite model frameworks into planning strategies can provide managers with greater predictive ability to identify suitable habitats, spatially predict the distribution of focal species, and target the most biologically relevant areas for habitat restoration, (Doherty et al. 2016, Coates et al. 2016, Ricca et al. 2018). Integrating demographic models with habitat models is not new, but integrating models to translate projected landscape change into actual habitat gain is new.

Recent studies combined species distribution models with remotely sensed vegetation composition data to predict space use and resource selection (including functional responses) for target species' populations across multiple spatiotemporal scales (Guisan et al. 2013, Coates et al. 2017, Ricca et al. 2018). Incorporation of species distribution ensures model outputs do not identify or support treatment implementation in areas that provide suitable habitat improvements, but where actual habitat use is unlikely because target species occurrence is low or source populations are distant (Ricca et al. 2018).

Using an integrative model approach to spatially prioritize habitat treatment areas could facilitate the strategic management of species such as the greater sage-grouse (*Centrocercus urophasianus;* hereafter sage-grouse). Sage-grouse have been designated as umbrella and indicator species of the condition of sagebrush (*Artemisia* spp.) habitat because they require large continuous tracts of sagebrush-dominated ecosystems to complete their life cycle (Rowland et al. 2006, Knick et al. 2013, Coates et al. 2017). The umbrella label was advanced due to sage-grouse being a species whose habitat use (both spatially and compositionally) encompassed enough other species that resources directed to their conservation would additionally benefit and preserve the heterogeneity and biodiversity of less focal species throughout sagebrush dominant ecosystems (Lambeck 1997, Runge et al 2019). In most instances, umbrella species secure or entice more funding for species conservation within a particular ecosystem from sources that might have otherwise not invested in conservation actions (Runge et al. 2019).

Beginning in the late 1990s, sage-grouse range-wide population declines and coupled with habitat loss and fragmentation (Connelly et al 2004, Stiver 2011), have contributed to the species being identified as a candidate species by the U.S. Fish and Wildlife Service (USFWS) for listing and protection under the Endangered Species Act (ESA) of 1973 (USFWS 2010). However, in September 2015, because of the paramount retooling and implementation of both scientific and regulatory mechanisms, the USFWS determined greater sage-grouse did not warrant protection under the ESA and withdrew the species from the candidate species list (USFWS 2015).

In the Great Basin and Utah, conifer expansion and infill, in particular by pinyon pine (primarily *Pinus monophylla*) and juniper (primarily *Juniperus osteosperma*), has been identified as a major threat to sage-grouse population persistence and long-term stability (Crawford et al. 2004, Bradley and Fleishman 2008, Miller et al. 2011, Knick et al. 2013). Conifer encroachment contributes to sagebrush ecosystem destabilization by reducing associated shrub, grass and forb species, further resulting in the contraction of large continuous sagebrush mosaics across the landscape (Chambers et al. 2014, Coates et al. 2017, Miller et al. 2019).

Stiver et al. (2006) estimated 60,000-90,000 ha of sagebrush habitat are impacted annually because of conifer encroachment. Sage-grouse have been reported to avoid landscapes where conifer canopy densities are as low as 2% (Coates et al. 2017). Pinyon-juniper successional processes are separated into three transitional phases: phase I, shrubs are the dominant overstory but trees are present (> 0-10%); phase II, shrubs are codominant with trees (>10-20%); and phase III, trees are dominant (>20%) (Miller et al. 2005, Coates et al. 2017). The U.S. Fish and Wildlife Service (USFWS) in the Conservation Objectives Team Report identified that mitigating conifer expansion into occupied sage-grouse habitat in core conservation areas was a potentially important species conservation strategy (USFWS 2013). To reduce expansion and infill rates of conifers into core sage-grouse habitat, the Natural Resources Conservation Service (NRCS), through its Sage-grouse Initiative (www.sagegrouseinitiative.com), has provided cost-share to landowners to mechanically remove or reduce thousands of hectares of conifers on private lands in the western U.S. Similar projects have been implemented range wide on Bureau of Land Management (BLM) and U.S. Forest Service (USFS) administered lands. In Utah alone, starting in 2006 under the Utah Department of Natural Resources (UDNR) Watershed Restoration Initiative has funded project that have removed or reduced conifer encroachment from > 200,000 hectares of sagebrush ecosystems (WRI 2010).

Managers increasing seek methodologies to quantify ecological gains from restoration projects in terms of functional response and space use by the target species that also can be used to prioritize management actions (Utah Public Lands Policy Coordination Office [PLPCO] 2019). Coates et al. (2017) and Sandford et al. (2017)

used species distribution models with spatial environmental data to document positive fitness consequences for certain life history stages of sage-grouse in areas where conifers were removed. Coates et al. (2017) used a two-stage Bayesian model in concert with a remotely derived conifer cover map to document sage-grouse avoidance at different phases of conifer cover and increased survival for individual sage-grouse that exhibited avoidance of the lowest conifer class (e.g., sparsely scattered to isolated trees). Sandford et al. (2017) used a Resource Selection Function (RSF) with conifer treatment data to document individual fitness consequences for nesting female sage-grouse. They reported that females selected for nesting and brooding sites in closer proximity to conifer treatment areas and the probability of nest and brood success decreased for females that selected sites farther from conifer treatments. Although these studies documented fitness consequences for sage-grouse at distinct life history stages within conifer treatment areas, there remains a knowledge gap on how the future placement of projects relative to costs may affect resource selection and space use. The net habitat gain for a conifer treatment may also depend on the surrounding landscape configuration (Cook et al. 2017). With land management agencies placing increased importance on restoration projects, planning frameworks that offer predictive capabilities, and incorporate landscape variability with future management actions, will be important for the long-term conservation of sage-grouse while balancing use of finite economic resources.

Herein, we employ a composite modeling approach to develop a landscape prioritization tool to guide management actions for placement of conifer treatment areas that will optimize ecological and habitat gains relative to finite resources. Our approach combines the use of a predictive model of vegetation community responses to treatment with a RSF that estimates how these changes translate in terms of habitat gain (i.e., usable space) for sage-grouse. This framework allows us to quantify expected outcomes of management actions in terms of habitat gain, thus evaluating the functionality of the treatment rather than just the structural changes it produces. Furthermore, our approach allows us to evaluate each treatment within the broader landscape context, by accounting for functional responses of sage-grouse to changes in availability given the surrounding landscape configuration. Besides allowing managers to comparatively evaluate the effectiveness of different treatments in bringing a functional benefit, our framework also allows for the inclusion of costs into a final computation of ecological gain relative to economic expense. Inclusion of associated economic data into the preliminary planning stages could attract increased rates of participation by private landowners into incentive-based programs (e.g., SGI and WRI) where costs are upfront and compensation is possible (Schindler et al. 2020). Our tool provides managers a highly flexible planning mechanism to prioritize conifer treatment sites that allows for the most efficient distribution of resources and conservation efforts, while maximizing ecological potential across the landscape for sage-grouse (Schindler et al. 2020).

Study Area

This study was conducted in Box Elder County of northwestern Utah. The county is located in the northeastern portion of the Great Basin. The Great Basin is a sub-region within the larger Intermountain West complex that falls within the Northern Basin and Range ecoregion and spans across Nevada, much of Oregon and Utah, and portions of California, Idaho and Wyoming (Miller et al. 2019). The Great Basin is a physiographic region of the largest and contiguous endorheic watershed in North America, which is delineated by a series of short fault-block mountain ranges running mostly north to south (Zamora and Tueller 1973). Across the region's ecosystems, sagebrush alliances and floristic characteristics of vegetation is a derivative and function of the climate, soil, topography and disturbance regimes (Miller and Eddleman 2001, Miller et al. 2011). Unlike most of the sagebrush steppe plant associations existing under potential natural vegetation (PNV) conditions – where sagebrush species are codominant with perennial bunchgrass species – the Great Basin sagebrush are often the dominant overstory plant with a sparse grass understory (Kuchler 1970).

The study area consists of 440, 750 ha located in the Raft River Subunit Management Area (Fig. 3.1, Utah Division of Wildlife Resources [UDWR] 2002). The study area is bordered by the Raft River Mountains to the north, the Grouse Creek and Pilot Mountains to the west, by the Great Salt Lake to the southeast and areas of salt flats to the south (Cook et al. 2013). Land ownership within the Raft River Subunit consists of a mix of public, state and private lands; Bureau of Land Management (37%), U.S. Forest Service (7.6%), Utah School and Institutional Trust Lands Administration (5.0%) and private (50%) (Cook et al. 2013, Sanford and Messmer 2015).

The climate of the study area is emblematic of the modified continental macroclimate found throughout the Great Basin with cold wet winters and hot dry summers (Zamora and Tueller 1973, Miller et al. 2019). From 1990 to 2016, the weather station (1732 m elevation) located in Rosette documented an average monthly low temperature in January of - 9.3 °C and in July an average monthly high temperature of 30.3 °C (Western Regional Climate Center 2018). Average precipitation was 29.3 cm with 14.2 cm accumulating as snowfall. At higher elevations (> 8000), snow can persist into the summer months but usually melts at lower elevations by early spring. Less than 25 percent of annual precipitation accumulates in the summer (Miller et al. 2019). Temperature and precipitation are both strongly influence by elevation: for each 305 m in elevation gain, temperature decreases by 1.65 °C and precipitation increases by 12.7 cm (Oosting 1956).

Elevation throughout the study area ranges from 1300 to 2950 m above sea level. Vegetation structure and composition are correlated with elevation gradients (West 1983). Low elevations consist of salt desert shrub including shadscale saltbush (*Atriplex confertifolia*), greasewood (*Sarcobatus vermiculatus*) and rabbitbrush (*Chrysothamnus* spp.). Mid elevations are typical of sagebrush plant communities with Wyoming sagebrush (*A. tridentata* spp. *wyomingensis*) and black sagebrush (*A. nova*) dominating habitat characteristics. Aspens (*Populus tremuloides*) and mixed mountain shrubs stands are also present at mid to high elevation, especially in more mesic habitat. Higher elevations are represented by mountain sagebrush (*A. t.* spp. *vaseyana*) and mixed coniferous forest (*Picea* spp., *Pinus* spp., *Juniperus* spp., and *Pseudotsuga menziesii*.).

Conifer removal projects in West Box Elder began in 2007. Since then, projects implemented to reduce the canopy cover have ranged from 10 ha to 2428 ha in size. Mechanical removal methods have included lop-and-scatters, pull-and-pile, one and two-way chaining (Cain 1971, Cook et al. 2017, Miller et al. 2019) and mastication (shredding) (Fecon Bull Hog, Lebanon, OH). Currently, mastication is the predominant method to removal conifer encroached areas where landscape and topography conditions are accommodating, with one and two-way chaining being the second most common (Miller et al. 2019). Conifer treatments have occurred across all successional stages and are separated into three distinct transitional phases: with phase I, shrubs are the dominant overstory but trees are present (> 0-10%); phase II, shrubs are codominant with trees (>10-20%); and phase III, trees are dominant (>20%) (Miller et al. 2005, Coates et al. 2017, Cook et al. 2017, Miller et al. 2019).

Methods

We used a composite modeling approach to forecast the effects of conifer treatments on habitat gain and resource selection by sage-grouse. We compared alternative proposed treatments based on their expected outcomes and projected costs. For the purpose of this study, we evaluated our approach by conducting a post-hoc analysis on conifer treatment implemented in 2018, based on their predicted outcomes in 2023 and the known cost for each project.

We employed a previously validated predictive model (see Chapter 2) to forecast the effects of conifer treatments on vegetation composition. The model predicts future vegetation composition in response to treatment as a function of vegetation composition prior to treatment and topographic variables (elevation, slope, and aspect). We obtained vector layers delimiting plots treated in 2018 in Box Elder County from the Utah Watershed Restoration Initiative database (https://wri.utah.gov/wri). These included five treatment plots. We used annual percent cover data at a 30m resolution from the Rangeland Analysis Platform (RAP 2020; https://rangelands.app/data/) to quantify vegetation composition in each of the treated plots in the year prior to treatment (i.e., 2017). We downloaded elevation, aspect, and slope data for each of the five plots from the Landscape Fire and Resource Management Planning Tools project (Landfire version 1.3.0; www.landfire.gov). We used the Dirichlet regression model described in Chapter

2 to predict vegetation composition five years after treatment (i.e., in 2023) for each of the plots. We then constructed five alternative treatment scenarios, each of which included one of the five polygons as treated and the other four as not treated. We sought to compare the gain in sage-grouse habitat resulting from vegetation change five years after treatment under each of these five scenarios.

Then we used an existing statewide RSF model of sage-grouse habitat selection developed by Kohl and Messmer (2020) for the Bureau of Land Management's Habitat Assessment Framework to predict sage-grouse habitat selection under each of the five treatment scenarios. The RSF model was built using location data from female sage-grouse individually marked with geographic positioning system transmitters (Microwave Telemetry, Columbia, Maryland, USA and GeoTrak, Apex, North Calorina, USA) from across the state. The GPS transmitters were distributed evenly across the study area to ensure the entire population was represented (Small and Messmer 2016). The RSF was formulated as a Generalized Linear Mixed Model (GLMM) with a logistic link function, and it included functional response terms to account for regional variation in habitat availability (Kohl and Messmer 2020). Incorporating the functional response helps ensure model transferability across spatial and temporal contexts (Matthiopoulos et al. 2011). Therefore, we were able to directly apply this model to obtain predictions of sage-grouse habitat selection in a subset (i.e., West Box Elder County) of the original spatial domain (i.e., the state of Utah). We obtained model predictions for sage-grouse habitat selection in 2017 and in 2023 under each of the five treatment scenarios.

To quantify the gain in habitat from 2017 to 2023 under each of the five scenarios, we used Relative Selection Strength (RSS; Avgar et al. 2017). The RSS quantifies effect size in habitat selection models by expressing relative selection for a spatial unit with respect to any arbitrary reference conditions (Avgar et al. 2017). We summed logRSS values for nesting and summer into a cumulative value of logRSS, i.e., habitat gain. We expressed habitat gain in each of our five 2023 scenarios by taking the ratio of RSF under that scenario to the RSF under the starting conditions in 2017. This value quantifies the RSS between the pre-treatment landscape and the post treatment landscape, consequently giving us a measure of habitat gain. We expressed the resulting values on the log scale (logRSS), so that a value greater than 1 indicates an increased selection strength compared to reference conditions, while values lower than 1 indicate decreased selection strength. By summing values of logRSS across the landscape for each of the five scenarios, we obtained a cumulative measure of expected habitat gain as a result of treating each of the five candidate plots.

Lastly, to obtain a measure of habitat gain per unit cost, we divided cumulative habitat gain in each scenario by the total cost of the corresponding treatment. Total cost data for pinyon – juniper treatment plots used within the model were downloaded from Utah's Water Resource Initiative database (https://wri.utah.gov/wri). We ranked the polygons based on expected habitat gain per unit cost.

Results

The five plots where conifer removal treatments were completed in 2018 in West Box Elder County included Cedar Creek, Keg Springs, Crystal Hollow, Road Canyon, and Warm Spring Hills. Based on the vegetation data recorded in 2017, our predictive model of vegetation change produced five alternative treatment scenarios for 2023, one for each of the treatment plots (Fig. 3.1 and 3.2). Predictions from the vegetation model showed that the treatments altered vegetation composition differently across the five plots.

The average predicted tree cover in 2023 was lower than the average observed tree cover in 2017 in Keg Springs Bullhog (13% to 11%; Fig. 3.3), Crystal Hollow (8% to 7%; Fig. 3.3), and Road Canyon (13% to 12%; Fig. 3.3), but not in the other treatment plots. The range of variation of predicted tree cover values in 2023 was smaller than the range of values observed in 2017 in Road Canyon and Warm Spring Hills (despite a larger average tree cover value in 2023 compared to 2017 for the latter). This suggests that treatment may sometime homogenize tree cover across a treated area even when the overall average tree cover does not change. Predicted average shrub cover in 2023 was higher than observed average cover in 2017 in all treatment plots except for Road Canyon (29% to 24%; Fig. 3.3). The range of variation of predicted shrub cover values in 2023 was smaller than the range of observed values in 2017 in all plots. Average percent cover values for all other vegetation components were consistently higher in 2023 than in 2017 according to model predictions (Fig. 3.3).

Predictions from the RSF expressed in term of RSS indicated the Keg Springs Bullhog treatment as yielding the highest habitat gain in 2023 with respect to starting conditions in 2017 (logRSS nesting habitat = 5791.71, logRSS summer habitat = 606.42 and cumulative logRSS = 6398.13; see Table 3.1). The Road Canyon treatment was also predicted to result in gains in both nesting and summer habitat, albeit smaller (logRSS nesting habitat = 877.73, logRSS summer habitat = 47.65, cumulative logRSS = 925.38). Cedar Creek was the only treatment for which the RSF predicted a gain in nesting habitat (logRSS = 2679.23) and a loss in summer habitat (logRSS = -864.93), which still resulted in a net habitat gain when looking at both seasons cumulatively (logRSS = 1814.30). For both Crystal Hollow and Warm Spring Hills, we predicted negative logRSS values for both nesting (logRSS = -28.07 and -8949.31, respectively) and summer habitat (logRSS = -1370.97 and -15059.13, respectively), with Warm Spring Hills resulting in the worst outcome across the board.

When accounting for total cost of each treatment, the five treatments were ranked as follows: Keg Springs Bullhog, Road Canyon, Cedar Creek, Crystal Hollow, and Warm Spring Hills (Table 3.1). Accounting for costs resulted in Road Canyon being ranked higher than Cedar Creek despite having a lower value of cumulative habitat gain. Keg Springs Bullhog was ranked as the top treatment based on all possible criteria (nesting, summer, or cumulative habitat gain, as well as gain per unit cost).

Discussion

Implementing systematic conservation planning to prioritize future management actions across the landscape, that interprets habitat gain in terms of species functional response and the associated economic costs of restoration efforts, will be paramount for recovering and maintaining at risk species. Our prioritization tool presents a quantitative yet tractable approach to help guide land management decisions for selecting future pinyon – juniper treatment areas used by sage-grouse, while maximizing habitat gain per unit economic cost in the most ecological relevant areas. Employing a composite model approach, to our knowledge, this research was the first to incorporate a predictive model using annual vegetation data in concert with an RSS framework to quantify habitat gain through time as a result of treatment, and the associated cost per treatment to quantify habitat gain per dollar invested. The RSS offers an easily interpretable measurement of the effect of treatment that could be used as an important planning tool to better understand landscape changes and their possible effects on sage-grouse distributions and habitat selection. Because large portions of home ranges for sage-grouse often occur on private land, including associated economic cost data could prove important to attract private landowners participation into voluntary incentive-based programs where costs and benefits can be evaluated upfront and outcomes are quantified (Schindler et al. 2020).

Our prioritization tool suggests that habitat gain does not increase equally across all pinyon-juniper treatment areas for each dollar spent, nor do sage-grouse functionally respond to treatment areas similarly across the landscape. Furthermore, these model results allow us to leverage expected outcomes of habitat gain in terms of functional response by sage-grouse rather than just structural changes to vegetation composition. Our research shows the effectiveness of ranking individual restoration efforts based on their predicted outcomes, and that strategic conservation planning can be achieved at the landscape scale in order to distribute limited economic resources in a way to maximize ecological returns on conservation investments (Schindler et al. 2020). However, a limitation of our approach is that, while we were able to validate results of the vegetation model, we did not have the data to validate the RSF. This is an important future direction because showing if the RSF predicts habitat gain for a given treatment accurately, more sage-grouse would be found there in 2023 than were in 2017.

Among the five alternative treatment scenarios we considered to predict habitat gain from 2017 to 2023, the Keg Springs Treatment ranked the highest in all categories and the Warm Springs Phase 3 Treatment ranked the lowest (Table 3.1). Note that the habitat gain per unit cost is independent of area; therefore the different outcomes we predicted for the five treatments cannot be explained by the size of the treatment area. Rather, these different outcomes are likely a result of different landscape configuration surrounding each candidate treatment. Because sage-grouse respond to broad-scale landscape features, the configuration of habitat around the treatment area contributes in determining the outcome we predict in terms of resource selection. For example, the Keg Springs treatment was implemented in an area that already represented high quality surrounding habitat with necessary seed banks for native grasses, forbs and sagebrush (*Artemisia* spp.) to reestablish back into the treatment area and promote primary succession of native plants (Chambers et al. 2014). Treatments sites with surrounding habitat that exhibits high bird use (i.e., functional response) and intact native plant assemblages often signifies higher resistance (i.e., ability to block expansion of exotic species) and resilience (i.e., ability to reorganize and retain fundamental structural and functioning capacity after disturbance) (Chambers et al. 2014, Miller et al. 2017, Reinhardt et al. 2017). Conversely, the Warm Springs Phase 3 Treatment was placed within a landscape context that was surrounded largely by later successional phase two and phase three pinyon – juniper stands where sage-grouse occurrence was low and distribution was sparse. The treatment's surrounding habitat may exhibit less productivity because invasive annuals are further established, resistance and resilience thresholds are lower, and the local plant community has already transitioned to a novel ecological state of functioning; e.g., cheatgrass has emerged as the dominant understory grass and fire regimes have been altered (Baker 2006, Chambers et al. 2014, Miller et al. 2017; Miller et al. 2019).

Furthermore, many of the pinyon – juniper encroached areas within our study location often occur between lower over-wintering and spring breeding habitat and higher late-brooding rearing summer habitat. Having prior knowledge of bird abundance and space use (e.g., telemetry location data) within site-specific areas could promote identification of "pinch points" and open additional connective pathways to other high functioning adjacent habitats (Coates et al. 2017, Reinhardt et al. 2017, Ricca et al. 2018). Knowing the importance of adult female survival, nest success and chick survival to long-term stability for sage-grouse populations (Taylor et al. 2011, Reinhardt et al. 2017), increasing accessibility to habitat that benefit these life history stages should be targeted (Coates et al 2017, Sanford et al. 2017, Severson et al. 2017). Inclusion of an RSS framework within our model gives managers the ability to not only obtain the probability of space use and selection to available habitat(s) by sage-grouse, but to measure strength of selection to individual treatments (Avgar et al. 2017). Our model framework can be flexibly adjusted to a variety of criteria; for example, to show gain in nesting habitat, gain in brooding habitat, cumulative gain per unit cost, winter habitat gain per dollar, etc. In principle, researchers or managers could use the criteria that best captures the objective according to their restoration goals.

With knowledge of the surrounding landscape, coupled with the selection strength of treatment sites, managers can now synergistically apply restoration efforts to the most biological appropriate areas for local sage-grouse populations. Ricca et al. (2018) used an integrative model approach for developing a conservation-planning tool and reported that implementing management actions based on resource selection, abundance and space use indices was important, so restoration efforts did not occur in areas where sage-grouse occurrence was low or larger connective populations were too distant. However, only employing species distribution models without knowledge of selection strength by sage-grouse to landscape features (e.g., structural changes in vegetation composition and habitat gain) could lead to unoptimized placement of treatments. Equipping managers in planning stages with knowledge of selection strength could alleviate implementing treatments in areas that offer limited habitat improvements and ecological benefits for sage-grouse. For example, pinyon – juniper treatment sites that border phase two and phase three woodlands (e.g., Warm Springs Phase 3 Treatment) could have survival consequences, in that, they might be avoided by sage-grouse because of increased available perch habitat for avian predators (Coates et al. 2017) and additional risk factors to navigating surrounding pinyon – juniper mosaics (Prochazka et al. 2017). Using an RSS-based approach may prevent management actions where the functionality of the treatment is low, selection by sage-grouse was weak and overall net ecological returns on economic resources is not maximized.

From a socioeconomic perspective, incorporating the associated cost per treatment to quantify habitat gain per dollar invested could prove to be the critical link in the planning process that attracts participation by stakeholders with beforehand limited involvement in restoration efforts. Within the West Box Elder SGMA, a large majority of intact, high functioning winter, nesting and brood-rearing habitat for sage-grouse reside on private rangelands. Economic transparency of habitat gain per dollar invested may be the lynchpin to encourage private landowners to enroll into incentive-based programs and restore ecologically important areas that benefit both land-use practices as well as local sage-grouse populations (Connelly et al. 2011, Schindler et al. 2020). For example, the ranking of treatments changed when we accounted for cost compared to the ranking that does not account for cost, which could be the desired information needed to attract landowner participation into restoration programs. Of our five scenarios, Keg Springs (as with habitat gain) returned the best cost to benefit ratio from per dollar spent (Table 3.1). Road Canyon and Cedar Creek treatments both showed net benefits in cumulative habitat gain per dollar as well (Table 3.1). Whereas, Crystal Hollow and Warm Springs Phase 3 treatments both showed negative cumulative habitat gain per dollar (Table 3.1). Having knowledge of cumulative habitat gain per dollar could prevent inefficient implementation of time and resources in locations that net minimal ecological benefits. Moreover, gains in treatment efficiency is possible if spatial distributions of cost are consider early in the decision-making process (Naidoo et al. 2006). For example, several studies have shown that conservation strategies that include species data with spatial distributions of cost were likely to conserve up to two times more species than strategies that only consider species data alone (Balmford et al. 2000). Schindler et al. (2020) in developing a decision-support tool to benefit lesser prairie chicken (*Tympanuchus pallidicinctus*) habitat in Kansas, reported including economic data helped managers evaluate trade-offs between ecological and economic inputs and identify habitat areas that were not currently considered for conservation.

Landscape scale conservation does not occur for free, therefore, if systematic conservation planning attempts to solve ecological questions for target species, cost-effectiveness and cost-benefits must be included to achieve net ecological gains from limited economic resources (Naidoo et al. 2006). Just as habitat types are not homogeneously distributed evenly across the landscape, spatial variability of costs can differ widely and should be explicitly considered at the outset of the planning process (Ferraro 2003, Newburn et al. 2005, Naidoo et al. 2006). Several studies report a consistent message: target species conservation can be achieved at a lower cost, or net higher biological gain for the same cost, if spatial heterogeneity of economic cost of conservation efforts are considered in the planning framework (Faith et al. 1996, Polasky et al. 2001, Stewart and Possingham 2005). Our model ranking of habitat gain per dollar invested offers a robust approach that enables stakeholders to directly compare between cost and benefits and help direct management actions on where to implement pinyon – juniper treatments.

The sagebrush dominant ecosystems sage-grouse inhabit at multiple spatiotemporal scales are dynamic, thus land managers approach to adaptive management must include the necessary biological and economic data to be successful at implementing conservation efforts that optimizes ecological returns for per dollar invested. Our prioritization tool offers managers and stakeholders a predictive framework that can be incorporated into early planning stages to evaluate ecological and cost related factors. Using our RSS framework, could give managers added confidence to leverage expected outcomes of habitat gain in terms of functional response by sage-grouse to guide treatment locations. We demonstrate a highly tractable planning mechanism to prioritize conservation efforts across the landscape that maximizes the ecological potential for target species for per unit cost of economic investments.

Management Implications

Modifying habitat features by removing conifer encroachment into historic sagebrush dominant ecosystems remains one of the few tools land manager and researchers can use to increase habitat productivity and benefit local sage-grouse populations in a relatively short duration of time. With limited economic resources, planning and decision strategies for implementing landscape scale habitat improvement projects, that seek highest habitat increase for resource expenditures, must implement projects in the most biological relevant areas. We built on recent work of prioritizing large-scale conservation efforts by including species distributions (Coates et al. 2017, Reinhardt et al. 2017, Ricca et al. 2018) and economic cost (Schindler et al. 2020). We demonstrate that using selection strength to interpret functional response to habitat gain in concert with treatment cost data could guide managers to choose the most biologically relevant areas to increase sage-grouse habitat and stabilize local populations. Just as important, our model can highlight areas that do not warrant treatment because habitat potential is low, species selection is weak and returns on investment are minimal. Lastly, we envision our model to be an adaptive framework that can be applied to different taxa and systems that identifies candidate treatment sites, allows for most efficient distribution of resources, and achieves the highest biological potential across the landscape.

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Tables and Figures

Table 3-1. Relative Selection Strength ranking values from highest to lowest in terms of sage-grouse (*Centrocercus urophasianus*) habitat gain (nesting, summer and cumulative) and gain per dollar cost for five 2023 predicted treatment plot scenarios based from starting conditions in 2017 within the Box Elder Sage-grouse Management Area, Box Elder County, Utah.

	Plot Id	**Nesting habitat gain**	**Summer habitat gain**	**Cumulative habitat gain**	**Dollars**	**Gain per dollar**
1	Keg Springs Treatment	5791.71434	606.42260	6398.1369	31354.24	0.20405970
2	Road Canyon Treatment	877.72942	47.65135	925.3808	22554.00	0.04102956
3	Cedar Creek Treatment	2679.22976	-864.92614	1814.3036	150264.90	0.01207403
4	Crystal Hollow Treatment	-28.06792	-1370.96800	-1399.0359	81606.00	-0.01714379
5	Warm Springs Treatment	-8949.31381	-15059.12876	-24008.4426	1357016.47	-0.01769208

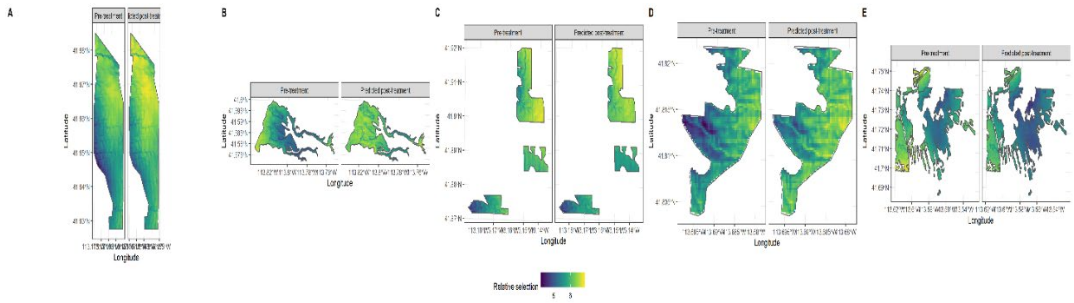

Figure 3-1. Sage-grouse (*Centrocercus urophasianus*) nesting habitat conditions for 2017 pre-treatment and 2023 predicted post treatment plots scenarios within the Box Elder Sage-grouse Management Area, Box Elder County, Utah.

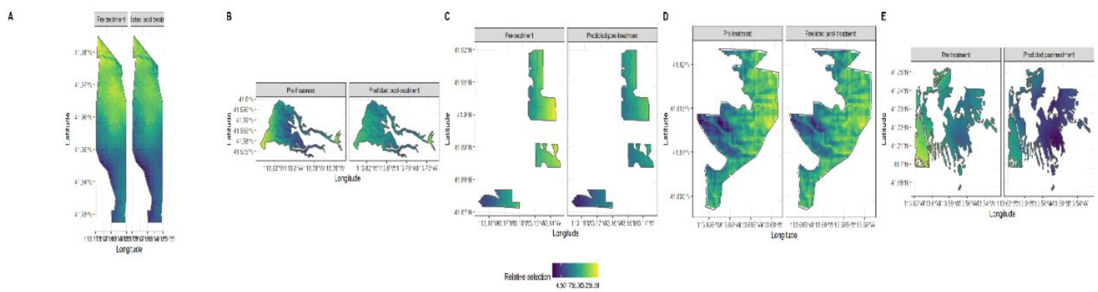

Figure 3-2. Sage-grouse (*Centrocercus urophasianus*) summer habitat conditions for 2017 pre-treatment and 2023 predicted post treatment plots scenarios within the Box Elder Sage-grouse Management Area, Box Elder County, Utah.

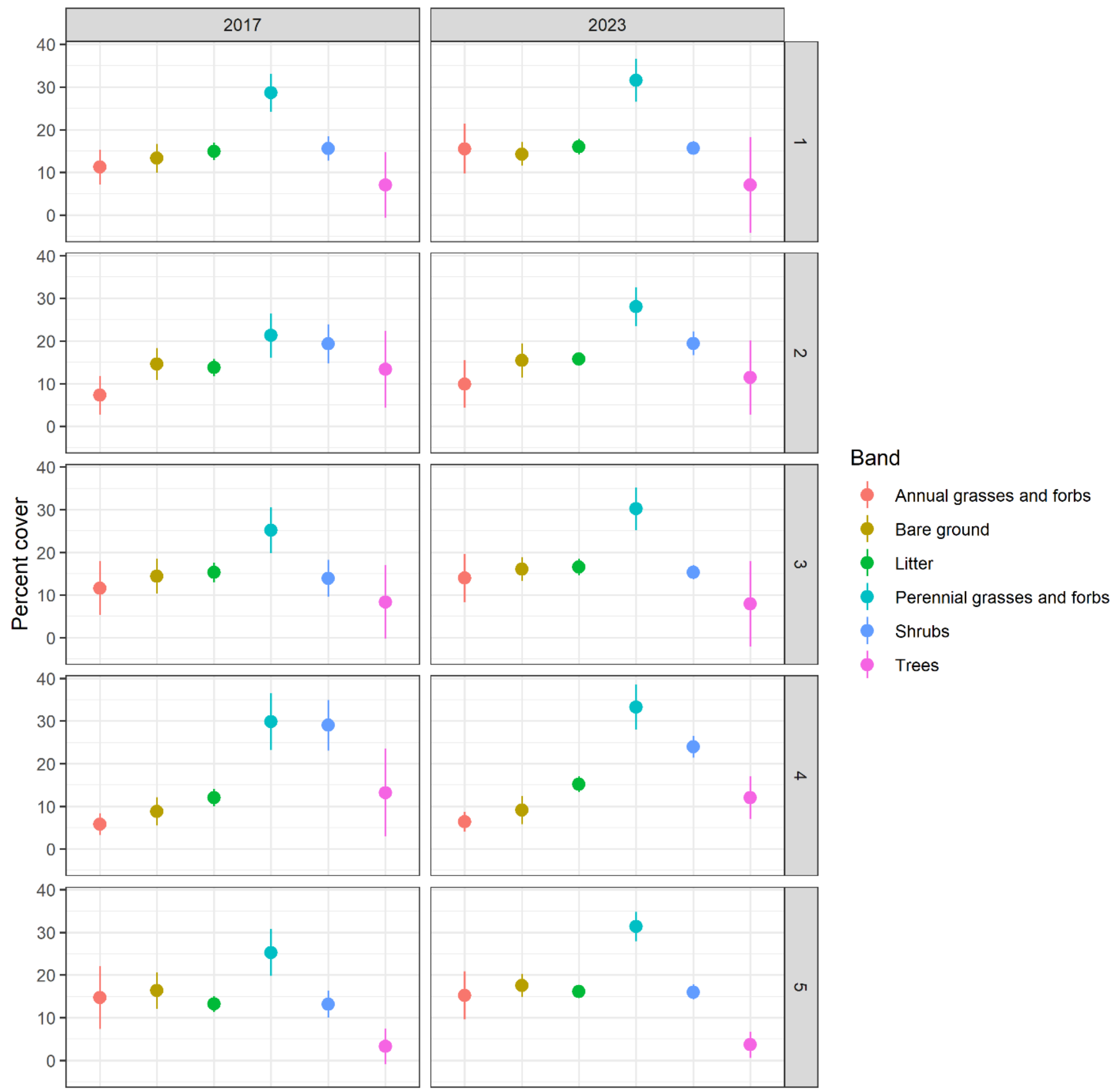

Figure 3-3. Percent vegetation cover of annual grasses and forbs (red), bare ground (gold), litter (green), perennial grasses and forbs (turquoise), shrubs (blue) and trees pink based from 2017 pre-treatment conditions and 2023 predicted treatment plots within the Box Elder Sage-grouse (*Centrocercus urophasianus*) Management Area, Box Elder County, Utah.

CHAPTER 4

DIFFERENTIAL MORTALITY IN GREATER SAGE-GROUSE MARKED WITH GLOBAL POSITIONING SYSTEM AND VERY HIGH FREQUENCY RADIO TRANSMITTERS

Abstract

Radio telemetry revolutionized wildlife ecology science by giving researchers the ability to monitor free-ranging animal populations occupying diverse landscapes and record movement and interactions within their habitats. Technological advancements in global positioning system (GPS) tracking platforms have allowed wildlife researchers to remotely acquire more precise location data when compared to the traditionally used very high frequency (VHF) radio-transmitters. However, concerns regarding the potential effects of the increased weight and positioning of GPS transmitters on individual mortality in comparisons to traditional VHF transmitters have caused some public stakeholders to question the ethical use of the technology particularly for avian research applications. To investigate these concerns, we compared mortality rates between 2016 and 2019 for 96 greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) marked with GPS rump-mounted transmitters to 156 sage-grouse marked with VHF necklace-style transmitters in two populations from central and northwestern Utah, USA. Across summer and winter for sex, and spring, summer and winter for age, we documented higher mortality for sage-grouse marked with GPS transmitters. The higher mortality rates documented for GPS marked sage-grouse may be attributed to posterior positioning (i.e., weight location) of payload box (i.e., boundary layer disruption causing increased

aerial drag), attachment type (i.e., rump-mounted harness), solar panel reflectivity, and a possible artifact of the increased stress related to additional handling time. In a post-hoc analysis for female sage-grouse only, we assessed the interactive and additive effects between transmitter unit mass and GPS and VHF devices as a proportion of body mass (PBM). Our top additive model demonstrated that a combination of device mass + solar panel or attachment as being the causative mechanisms leading to lower survival. The device only model was a close second and supported the solar panel or attachment as being a major factor for increased mortality for birds marked with GPS transmitters. One other aspect affecting the differential mortality for birds marked with GPS transmitters may be sublethal effects related to the additional stress caused by prolonged handling and physical manipulation to deploy the transmitters. Although a lack of standardization of deployment times between research sites impeded this analysis, the effect may have been captured by the covariate attachment. Researchers should assess the benefits and trade-offs of using current animal tracking radio transmitters and appropriately consider the most ethical marking technique for avian ecological research applications. Future research on impacts to post capture behavior (i.e., long-term stress), condition upon capture release (i.e., and movement patterns would better inform ergonomic refinements/improvements to current GPS platform designs.

Introduction

Radio telemetry advanced wildlife research by giving practitioners the ability to monitor free-ranging animal populations and document interactions with their respective environments (Fuller et al. 2005). Knowledge of marked individual's locations provides greater inference and interpretation of species movement patterns, habitat selection, behavior, survival, energetics and demographic estimations (Balmori 2016, Kolzsch et al. 2016). Although radio transmitters have continuously improved (Balmori 2016), stakeholder concerns over marking devices biasing survival estimations and causing added disturbance to marked individuals has remained constant across study applications (Cotter and Gratto 1995, Winterstein et al 2001, Caudill et al. 2014). However, to obtain reasonable survival estimates for populations from radio-marked individuals, the method of marking must not create added disturbance or stress (Cook 2015) and/or increase the mortality risks (e.g., for marked individuals (Pollack et al. 1989, Tsai et al. 1999, Elser et al. 2000, Caudill et al. 2014, Severson et al. 2019).

For avian species, the effects of tracking devices on survivorship of marked individuals is a valid question that can have population level consequences. Survival estimates derived from a transmitter attachment styles that decrease survival may lead to inaccurate population projections and inappropriate management actions (Millspaugh and Marzluff 2001, Caudill et al. 2014, Severson et al. 2019). Furthermore, if a particular attachment type in causing decreased survival rates caused from increased predator efficiency (i.e., ability of ground-based and/or aerial predators to locate prey at abnormally higher rates), these attachments must be further evaluated so the welfare of marked individuals is not forfeited (Balmori 2016). For example, most galliforms do not have predators that specialize in selecting them as a prey base, but usually remain susceptible as a prey from egg to adult (Hagen 2011); thus causing attachment type of transmitter to be suspicious if increased levels of mortality occurs across a given study period. If transmitter effects on study species is misinterpreted, improper adjustments to predator management may occur without warrant (Bergerud 1988).

Very-high frequency (VHF) radio transmitters have been widely used across wildlife studies for the last 35 years (Fuller et al. 2005, Tomkiewicz et al. 2010), with adjustments made over time to ensure the least effect on the study species (Barren et al. 2010, Dixon 2011, Balmori 2016). Conventional ground-based VHF marking devices require data to be manually collected using triangulation techniques, making location data more limited and statistical inference restricted (Tomkiewicz et al. 2010).

Global positioning system (GPS) transmitter technological advancements have allowed researchers to obtain additional and real-time movement and mortality data to answer increasing complex conservation issues. Location data collected by GPS transmitters are more accurate, than VHF radio transmitters. Additionally, GPS transmitters can record and transmit larger data strings of high-resolution 24-hour coverage with animal positional updates in time sequences that enable greater quantitative interpretations as animals move through and interact with their environments (Cagnacci et al. 2010, Tomkiewicz et al. 2010, Severson et al. 2019). Although GPS transmitters are fitted to animals based on a size-to-weight ratio. Additional accessories and components adhered to GPS platforms to increase functionality could compromise study species ability to remain cryptic and maintain natural movements (i.e., associated with ground and flight) (Severson et al. 2019). For example, additional small VHF button attachments that allow ground tracking could decrease original design ergonomics by adding weight and balance issues. In addition, bright colored reflective solar panels used to increase battery life may reduce the animal's ability to remain camouflaged, therefore becoming more noticeable to predators (e.g., a ground nesting bird's location being compromised to aerial or ground based predators). Lastly, little information is available on the potential sublethal and behavioral effects related to the additional stress an animal may experience after GPS transmitter deployment (Lamb et al. 2020).

In the late 2000s, GPS backpack style transmitters were widely incorporated in greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) studies to better understand movement patterns, space use, population connectivity, resource acquisition, behavior and energetic requirements. Sage-grouse are the largest grouse species endemic to North America and been designated as an indicator species of the condition of sagebrush (*Artemisia* spp.) habitat because they require large continuous tracts of sagebrush-dominated ecosystems to complete their life cycle (Rowland et al. 2006, Knick et al. 2013, Coates et al. 2017). Sage-grouse have been labeled an umbrella species because their habitat use, both spatially and compositionally, encapsulates enough other species distributions that resources allocated to their conservation would additionally help preserve the heterogeneity and biodiversity of less focal species throughout sagebrush ecosystems (Lambeck 1997, Runge et al. 2019). Over 350 co-occurring species can be associated with sagebrush ecosystems inhabited by sage-grouse (Hanser and Knick 2011). Unbiased estimations of sage-grouse population trends are important because they remain a species of concern and policy involving western rangelands is based around their conservation (Connelly et al. 2011, Stiver 2011).

Sage-grouse have been studied since the 1960s using VHF transmitters (Brander and Cochran 1969), but attachment styles have evolved, with VHF necklace-style transmitters becoming the preferred attachment type after several early studies linked backpack style VHF transmitters with increased grouse mortality (Small and Rusch 1985, Marks and Marks 1987, Caudill et al. 2014). However, recent improvements in design have allowed researchers to use GPS backpack style transmitters appropriately scaled to size from the manufacturer (Microwave Telemetry, Inc. 22g PTT-100 Solar Argos GPS Transmitter, Columbia, Maryland, USA and GeoTrak, Inc. 22g PTT Solar Argos GPS Transmitter, Apex, North Carolina, USA). These technological advancements for GPS transmitters came at the time when additional finer temporal and spatial resolution data were necessary to make population level policy and management decisions surrounding sage-grouse movements and resource acquisitions at the scale of western sagebrush landscapes. Wildlife investigators that marking any animal with tracking devices in not a neutral action, additional concerns over marking sage-grouse with GPS transmitters (especially with additional items to increase equipment functionality) have begun to arise.

Severson et al. (2019) reported the results of comprehensive differential survival analysis on GPS and VHF radio-marked sage-grouse from the Bi-state population of California and Nevada and Central Nevada's Great Basin population. They reported increased mortality for sage-grouse marked with currently available GPS transmitters across sexes, ages and seasons than individuals marked with VHF transmitters. They used a 5% criterion of the bird's weight as a cutoff for deploying of both device types (Kenward 2001, Fair et al. 2010). The spring average weights of the birds they deployed GPS transmitters on were lower than range wide averages (Connely et al. 2011). They also recaptured VHF-marked birds and fitted them with GPS transmitters and attempted to account for these situations as a time-dependent variable in the modeling process.

We used Severson et al. (2019) analyses framework to determine if mortality rates differed for two separate Utah sage-grouse populations marked with GPS and VHF transmitters from 2016 to 2019 that inhabit the eastern edge of the Great Basin sagebrush ecosystems of northwestern and central Utah. The population we studied exhibited higher average weights (up to 400 grams) than did Severson's Bi-state Nevada populations (Severson et al. 2019.). We used a 3% criterion of the bird's weight as a cutoff for deploying of both device types.

Furthermore, both sage-grouse populations we studied occupy areas that exhibit higher annual precipitation regimes and is expressed through higher productive vegetation communities (i.e., cover types) that are more similar to sagebrush steppe habitats types than Great Basin sagebrush habitat types (Miller et al. 2019). Predator communities also differed from Severson et al. (2019) study area in that Utah's populations exhibit lower densities of common raven (*Corvus corax*; Coates et al. 2017), but higher densities of red fox (*Vulpe vulpes*), an invasive human subsidized olfactory predator (Hagen 2011).

A treatment and control experimental design incorporating unmarked or leg-banded sage-grouse would be optimal (Murray and Fuller 2000, Hagen et al 2018); however, estimating demographic rates remains logistically difficult for unmarked sage-grouse. With most sage-grouse studies using VHF transmitters to collect demographic data, we used them as a control for this study as did Severson et al. (2019). We hypothesized that the GPS marked sage-grouse we studied would have higher mortality rates relative to the VHF marked birds, however the effects would be less pronounced for heavier individuals marked with currently equipped GPS platforms (i.e., females ≥ 1200g). We envision this analysis framework to give researchers better interpretations for the best use of current GPS platforms in areas inhabited by different visual and olfactory predators (Conover 2007), to alleviate added disturbance to marked sage-grouse, and offer guidelines on possible ergonomic improvements that could promote increase survival outcomes for future projects.

Study Area

We conducted our study in Box Elder County, northwestern Utah, and Tooele and Juab counties, central Utah, which are part of the eastern edge of the Great Basin. The Great Basin is a sub-region within the larger Intermountain West complex that falls within the Northern Basin and Range ecoregion and spans across Nevada, much of Oregon and Utah, and portions of California, Idaho and Wyoming. Across the region's ecosystems, sagebrush community floristic characteristics are a derivative and function of the climate, soil, topography and disturbance regimes (Miller and Eddleman 2001, Miller et al. 2011). Unlike most of the sagebrush community plant associations existing under potential natural vegetation (PNV) conditions – where sagebrush species are codominant with perennial bunchgrass species – the Great Basin sagebrush are often the dominant overstory plant with a sparse grass understory (Kuchler 1970).

The study areas consisted of 440, 750 ha located in the West Box Elder Sage-Grouse Management Area (SGMA) in Box Elder, County, Utah and 247, 315 ha located in the Sheeprock SGMA in Tooele and Juab Counties, Utah. Land ownership within the West Box Elder SGMA and the Sheeprock SGMA encompasses a mosaic Bureau of Land Management, U.S. Forest Service, Utah School and Institutional Trust Lands Administration, Utah Department of Natural Resources and private (Cook et al. 2013, Small and Messmer 2016, Chelak and Messmer 2019).

The climate of the study area is emblematic of the modified continental macroclimate found throughout the Great Basin with cold wet winters and hot dry summers (Zamora and Tueller 1973, Miller et al. 2019). Less than 25 percent of annual precipitation accumulates in the summer (Miller et al. 2019). Temperature and precipitation are both strongly influence by elevation: for each 305 m in elevation gain, temperature decreases by 1.65 °C and precipitation increases by 12.7 cm (Oosting 1956). Study sites average monthly low temperatures in January of - 9.9 °C and in July an average monthly high temperature of 31.4 °C (Western Regional Climate Center 2018). Average precipitation was 27.6 cm.

Elevation throughout the study areas averaged 1400 to 2950 m above sea level. Vegetation structure and composition are correlated with elevation gradients (West 1983). The dominant vegetation consisted Wyoming sagebrush (*A. tridentata* spp. *wyomingensis*) and black sagebrush (*A. nova*) at low to mid elevations and mountain sagebrush (*A. t.* spp. *vaseyana*) at higher elevations. Aspens (*Populus tremuloides*) and mixed mountain shrubs stands of serviceberry (*Amelanchier alnifolia*), common snowberry (*Symphoricarpos albus*), antelope bitterbrush (*Purshia tridentata*) were also present at mid to high elevations. Pinyon (primarily *Pinus monophylla*) and juniper (primarily *Juniperus osteosperma*) woodlands, along with Dougals fir (*Pseudotsuga menziesii*) and limber pine (*Pinus flexilis*), were present at mid to high elevations.

A diverse predator community of both visual (i.e., aerial-based) and olfactory predators (i.e., ground-based) inhabits the study areas. The most common avian predators are ravens (*Corvus corax*), black-billed magpies (*Pica hudsonia*), golden eagles (*Aquila chrysaetos*), red-tailed hawks (*Buteo jamaicensis*), ferruginous hawks (*Buteo regalis*), northern harriers (*Circus hudsonius*), swainson’s hawks (*Buteo swainsoni*), prairie falcon (*Falco mexicanus*), great horned owls (*Bubo virginianus*). The most common mammalian predators are red fox (*Vulpes vulpes*), coyote (*Canis latrans*), American badger (*Taxidea taxis*), Uinta ground squirrel (*Urocitellus armatus*), and long-tailed weasel (*Mustela frenata*).

Methods

We deployed two types of solar-powered, platform transmitter terminal (PTT) GPS transmitters across the study sites. Each factory equipment model weighed 22 g before additional accessories were attached (33.3 g after) and had a top positioned solar panel. All GPS transmitters were painted similar to the vermiculation patterns of sage-grouse's back feathers to help blend with the bird's natural profile. The solar panels remained the factory semi reflective color of dark gray or medium blue. We used a the rump-mounted design method to attach GPS units (Bedrosian and Craighead 2007), which has become the established method used for sage-grouse research and monitoring. Brown Teflon ribbon was used to create an attachment harness with elastic sewn into portions to insure appropriate pressure, but still allow for bird growth and flexibility. Round lightweight copper crimps were used for clamping the harnesses into position once the GPS transmitter was fitted correctly. Excessive Teflon was cut-off after crimping and ends were sealed using super glue to prevent fraying. A foam neoprene pad was glued to the bottom of each transmitter to ensure comfort for the bird and prevent chaffing. Beginning in 2018, GPS transmitters received an additional small ~3 g VHF button type transmitter to the side to aid in ground tracking and unit location in case the factory UHF signal malfunctioned.

The VHF radio transmitter we deployed were the 22 g avian style necklace model A4060 from Advance Telemetry Systems (Isanti, Minnesota, USA). Battery life was

~869 days with a pulse rate of 40 pulse per minute (ppm). Transmitters came from the factory with a dark gray rubberized coating. When transmitters remain stationary for 8 hours, a mortality sensor would cause the pulse rate double to 80 ppm. Transmitters were attached around the neck with a steel cable housed inside black plastic tubing and secured with steel crimps. Each collar was fitted around the bird's neck loose enough to allow movement, but tight enough to prevent the transmitter to slip over the bird's head. Each antenna was bent downward to contour the backline of individual sage-grouse.

Field Methods

We captured and marked 257 (i.e., 158 VHF and 99 GPS) sage-grouse in spring and late summer 2016-2019 using all-terrain vehicles (ATVs) with the spotlight method (Wakkinen et al. 1992). In central Utah's Sheeprock SGMA, sage-grouse were translocated from other populations within the state to prevent extirpation of the remaining population. Each sage-grouse was weighed to the nearest gram with handheld scales. Sex and age was determined for each individual. Ages included juveniles (hatch year), yearlings (second year), and adult (>second year) (Crunden 1963). Captured sage-grouse were fitted with a gender specific aluminum leg band and then were marked with a GPS or VHF transmitter. We used the 3% cut-off criterion for bird's unmarked weight for attaching both GPS and VHF transmitters. Although no current protocol exists for handling time, we tried to keep marking durations under ≤ 10 minutes for sage-grouse marked with VHF necklace transmitters and ≤ 15 minutes for GPS rump-mounted transmitters. Base on previous field capture observations, the longer handling time and manipulation of the individual bird, the greater likelihood of capture induced stress increasing (Cook 2015). The GPS transmitters were programmed to record location updates on 4 to 6-hour intervals, and location data was downloaded weekly from Movebank (movebank.org). The VHF and GPS marked birds were located 1 to 3 times weekly for spring and summer and monitored for survival in some areas throughout fall and winter, if accessible. Any missing birds, malfunctioned transmitters, or presumed mortalities, were right censored because actual end fate of the individual could not be determined; right censoring was assumed unbiased and random (Severson et al. 2019).

Mortality Analysis

We used Bayesian shared frailty models due to their ability to account for intraclass correlation independently by random effects and estimate mortality risk across age, sex and transmitter type (Halstead et al. 2012, Severson et al. 2019).

We parametrized two separate models for sex-based (female and male) and age-based survival, where the differing age classes were divided into the aforementioned classes: yearlings (second year), and adult (>second year) (Crunden 1963), across the differing attachment types (VHF & GPS). Each model was divided amongst four seasons, biologically significant to the species: Spring = March 15 - June 14, Summer = June 15 – September 14, Fall = September 15 – December 14, and Winter = December 15 – March 14. Season and age/sex were treated as interacting variables with each bird, site, and year acting as random additive effects to the models.

The frailty model for the change in unit hazard (UH) was expressed as the following:

$$UH_{hijkl} = \exp(\lambda_{kl} + \beta_{kl}G + \beta T + \kappa_h + \eta_i + \varsigma_j)$$

The interaction between sex/age and season is denoted as λ, with β_{kl} being the expected change of magnitude of age or sex and season when G (a variable for attachment type) equaled 1. A third interaction βT incorporated the expected change in magnitude β for the overall effect of T (a binary variable for residency status—translocated or resident). This enabled us to control for the overall translocation effect across translocated individuals in the model because the purpose of this model was not to look at the differences in survival between residency status but was instead to look at the effect of VHF versus GPS. The three variables, κ, η, and ς, denote the random additive effects of each bird, site, and year, respectively. Subscripts $h, i, j, k,$ and l refer to the individual bird, site, year, age/sex, and season, with age, season, and year delineated as time-varying variables, as well as device type. Because individuals graduate to a higher age class if they reached subsequent seasons (adult or age class 3 being the max) and could switch between VHF or GPS if their transmitter was changed during the study, we feel this was appropriate for the analysis. March 15 of each year was designated as each subsequent year because this is the approximate date when lekking begins. At this date, a given individual would progress to a higher age class if alive and younger than the adult age class (i.e. juvenile or yearling). The study spanned for 176 weeks from March 09, 2016 – July 26, 2019, with the start date based on the date the first individual in the study was captured. All subsequent capture weeks were derived from that initial start week until the ending date.

Because the UH estimates the unit hazard at any one time, we can acquire seasonal hazards by the addition of each weekly (w) UH across approximately 13 time intervals (T) to give us four separate seasons. This is denoted as the cumulative unit hazard (CH) and shown below:

$$CH_{whijkl} = \sum_{w=1}^{T=13} UH_{1:w,hijkl}$$

From a cumulative hazard model, to extract the survival parameter (S), we use an identity function for relating hazard functions to survival that gives us the following:

$$S_{whijkl} = e^{-CH_{whijkl}}$$

We ran 3 MCMC chains of 30,000 iterations following a burn-in period of 45,000 iterations thinned by a factor of 5. Model convergence was assessed visually based on MCMC mixing and the R statistic, where, if the upper bounds of the 95% credible interval on R is lower than 1.1, the MCMC chain most likely converged to the stationary distribution (Gelman 2014). Posterior probability distributions for each model procedure were estimated using R 4.0.2 (R Core Team 2020) in the package *rjags* (Plummer 2019).

We then ran analyses to assess the effect of the transmitter weight on survival for female sage-grouse only, to eliminate any effect of the difference in behavior that would confound differences between males and females. Using the capture weight of the individual and the transmitter weight including all supplementary attachments (Teflon ribbon, copper crimps, and a 3-gram VHF button, for some), we determined percent body mass (PBM) of the transmitter to the individual upon which it was attached. We ran four models, in addition to a null, to assess the potential effects it might have upon the individuals: 1) device type only, 2) PBM only, 3) device type plus PBM additive effect, and 4) device type by PBM interaction. Across all models, we controlled for season and residency status, as the principal goal was not to explore the differences across either.

We hypothesized that the first model would represent the effect of the solar panel or of the rump-mount/necklace differential attachment types, the second model to represent the effect of the weight of the device without the specific difference between the devices, the third model to represent a weight effect in addition to the solar panel or attachment type, and the fourth to represent a weight effect different for GPS than VHF. Severson et al. (2019) hypothesized that heavier weights placed on the rump of the bird were more likely to reduce survival and that there might be a threshold of PBM in which this effect might be more substantial. Similarly, we predict that there might be this effect and, through replicating their analysis, would like to assess the difference in thresholds found in their publication.

The PBM portion of our post-hoc analysis contained 74 and 67 VHF and GPS transmitters, respectively. Because our data were censored (0 or 1 based on if a bird was a mortality or went missing, experienced a transmitter failure, or survived past the end date, respectively), we modeled the function as a logistic regression model owing to the binary response variable in the Bayesian framework. We ran 3 MCMC chains of 10,000 iterations with a burn-in period of 30,000 iterations with a thinning factor of 10. To compare competing models, we used the Watanabe-Akaike information criterion (WAIC; Watanabe 2010) and considered models with WAIC < 2 from the top model to have support and WAIC < 1 from the top model to be highly competitive.

Results

We attached GPS transmitters on 80 female and 19 male sage-grouse and attached VHF transmitters to 122 females and 36 males from 2016-2019. Sample sizes by age class for females were 102 yearlings, and 97 adults; for male sage-grouse there were 10 yearlings, and 45 adults (Table 4.3). There were 74 confirmed VHF-marked individual mortalities and 67 confirmed GPS-marked individual mortalities across the 4 years of the study (Table 4.3).

In our shared frailty analysis differentiated according to age class and season, we found several differences in survival related to device type. For yearlings in spring and adults in summer and winter, the hazard ratios' 95% credible intervals were all >1, meaning that there was an increased effect on mortality for these age classes marked with GPS transmitters. Their median ratios were 1368, 2.76 and 462 times greater, respectively, than that of mortalities for VHF-marked individuals (Table 4.1). All other age classes by season in this analysis exhibited 95% credible intervals that crossed 1 with median ratios ranging from 3.10E-10 to 9.23 (Table 4.1).

Survival by sex across seasons did not differ by age class. Female's summer and winter hazard ratios had 95% credible intervals that crossed 1, where the median GPS hazard was 2.21 and 376 times than the VHF hazard (Table 4.1). Other sex-based hazard ratios across seasons had median credible intervals that ranged from 3.85E-08 to 7.55 (Table 4.1).

Our logistic regression analysis for assessing the effect of GPS transmitters on individual females by the percent body mass showed that the additive model, where device mass + solar panel and attachment, was the highest predictor for the survival of individuals with the lowest WAIC (PBM table). The device only model, where we assessed the solar panel or attachment, and the interactive model were both highly competitive, being <1 away from the lowest WAIC (Table 4.2).

Discussion

To answer landscape scale ecological questions for sensitive species, such as sage-grouse, recent advancements in GPS technologies have allowed researchers to remotely acquire finer temporal and spatial resolution data to develop robust analytical frameworks to guide management actions. However, our results demonstrated that contemporary weighted rump-mounted GPS platforms used to mark sage-grouse increased mortality costs compared to VHF transmitters (e.g., female sage-grouse showed increases in mortality in summer and winter, yearlings in spring, and adults in summer and winter compared to VHF transmitters). If data bias exist for sage-grouse carrying current weighted and designed GPS transmitters, this could have consequences for broad demographic based management guidelines were inferences are being made in regards to movement, resource selection and survival estimates. Our additive model results highlighted a combination of device mass plus solar panel or attachment, and our device only model supported solar panel or attachment as being the leading mechanism that increased mortality for birds marked with GPS transmitters. Our post hoc analyses is a continued step in a forward direction to better understand and identify the exact combination of marking effect on sage-grouse that will lead to reevaluation and the necessary ergonomic (e.g., lighter, reduced solar panel reflectivity and smaller payload box) refinements to current GPS platform designs. These outcomes will help researchers assess the benefits and trade-offs of using current animal tracking radio transmitters and appropriately consider the most ethical marking technique for individual studied taxa.

Posterior mounted transmitter designs and attachment methods on galliforms to gather location data have raised prior concerns over whether the device itself impedes the flight performance and body mechanics of the species, and overall locomotion across life history stages (Small and Rush 1985, Marks and Marks 1987, Pennycuick et al. 2012). Marks and Marks (1987) tested early designed rump mounted VHF transmitters on male Columbia sharp-tailed grouse (*Tympanuchus phasianellus columbianus*) and reported that posterior (i.e., rump) mounted transmitters altered the appearance of the bird, sound of flight (e.g., antenna slap), and solar panel reflection that allowed possible detection by avian predators. Other recent studies have substantiated that size and shape of the rump-mounted GPS devices can impede body movements, increase aerial drag coefficients and restrict ground movements (Pennycuick et al. 2012, Severson et al. 2019, Kircher et al. 2020).

Barron et al. (2010) in a comprehensive meta-analysis reported, despite the widely accepted heuristic that transmitters must weigh ≤ 5% of the animal's body mass, there was no empirical evidence existing in peer-reviewed literature for which the rule is predicated on. Below 5%, design features (i.e., aerodynamic effects and proportional surface) may play a stronger role than unit mass alone (Obrecht et al. 1988, Barron et al. 2012). Attachment method and material used could further exacerbate and influence movement patterns, aerial sound, and most skin abrasions caused from surface chaffing (Marks and Marks 1987, Pennycuick et al. 2012, Kircher et al. 2020). Currently, there is no peer reviewed standardized protocol of attachment method for marking Galliformes species with GPS rump-mounted transmitters; most methods currently used have either been informally shared between research collaborators to improve harness designs, attachment material and modifications, or relying on data from unpublished reports (Kircher et al. 2020).

Our study used 2 different transmitter attachment styles: VHF front mounted necklace and GPS rump-mounted transmitters, with major difference between the tracking unit styles being placement, weight, color and attachment location. The VHF necklace transmitters (22g) were attached around the neck bird, where feathers may obscure some or most of the radio, and were a cryptic dark gray allowing for improved camouflage. Whereas, both GPS style transmitters were heavier (33.3 g), mounted on the rear of the birds back (although we tried to mount GPS units as high as possible to improve balance and prevent slipping of the unit post-capture) and displayed semi-reflective solar panels. Our top additive model demonstrated the device mass + solar panel or attachment as the cause of increased mortality for GPS marked sage-grouse. Pennycuick et al. (2012) observed additional mass and placement to the posterior portion of the bird could have adverse effects. Consequently, when the frontal area of the payload box is placed on the rear of the bird, the boundary layer over the posterior end of body is disrupted, which increases the drag coefficient by possibly a large amount (Pennycuick et al. 1996, Pennycuick et al. 2012). The combination effect of device mass and attachment could be the leading cause of the disproportionately lower survival of GPS marked female sage-grouse compared to VHF necklace marked birds (Pennycuick et al. 2012, Severson et al 2019). We have noticed that once the harnesses are cinched down on to the rump of the bird, there is an immediate adjustment phase with most sage-grouse to acclimate to the harness tension and new center of balance from rearward placement of the unit mass upon release of individuals. Further investigations need to be conducted to detect if these acclimations to GPS transmitters alter behavior for an extended post capture period compared to VHF marked birds (Dennis and Shah 2012).

Our device-only model (solar panel or attachment) ranked closely with the additive model, indicating that solar panel or attachment was casual for decreased survival in females, with device mass being independent. Although we did not evaluate the impacts of solar panel directly, it may be a major causative factor for increasing predator efficiency on sage-grouse marked with bright reflective solar panels. Marks and Marks (1987) reported that solar panel glare could increase avian predation to grouse species occupying open habitats, especially during breeding season when birds are more visible and vegetation is still relatively low. In a post-fire sagebrush landscape, Foster et al (2018) found that dorsal positioned solar panels could have increased visibility of sage-grouse to predators, causing the 5% lower annual survival demonstrated by female sage-grouse marked with rump-mounted GPS transmitters compared to VHF necklace transmitters. Conversely, Hines and Zwickel (1985) found that dusky grouse (*Dragapus obscurus*) marked with VHF rump-mounted transmitters had similar survival rates to non-radio marked birds. Compared to sage-grouse carrying-out life history stages in open habitat types, dusky grouse are more solitary, make shorter flights to thicker, consolidated cover when attacked by predators, which may prevent aerial predators to detect solar glare effectively (Hines and Zwickel 1985, Marks and Marks 1987).

Several studies have reported that tracking devices can have sublethal deleterious effects to behavior of avian species (Pyrah 1970, Amstrup 1980, Marks and Marks 1987, Pietz et al. 1993, Esler et al. 2000, Gibson et al. 2013, Fremgen et al. 2017), which could lead to negative effects on survival and reproduction. Pietz et al. (1993) found that female wild mallards (*Anas platyrhynchos*) marked with VHF rump-mounted transmitters, exhibited decrease feeding, preen and rested more frequently, initiated nests later and had smaller clutches than unmarked females. Furthermore, rump mounted transmitters may influence flight behavior and cause marked individuals reluctant to flush when detected by predators (Marks and Marks 1987). For sage-grouse, several studies have reported negative effects of VHF necklace collars on male lek attendance and vocal displays because of esophageal air sac restriction (Pyrah 1970, Amstrup 1980, Fremgen et al. 2017). However, to our knowledge no study has performed a comprehensive analysis on the behavior effects of sage-grouse marked with rump-mount GPS transmitters. If current designed rump-mounted transmitters are negatively affecting marked sage-grouse, this could manifest through resource selection, body condition and critical life history stages (e.g., nesting and brood rearing) and migration patterns.

The use of GPS transmitter have allowed researchers more precise movement data on sage-grouse to better interpret movement corridors and space use (Fedy et al. 2012), response to landscape features (Prochazka et al. 2017) and habitat manipulation conservation actions (Coates et al. 2017). GPS transmitters have reduced the necessary fieldwork required to manually collect location data from VHF transmitters, which in some instances where terrain ruggedness increases and technician skill decreases, signals from VHF marked birds can be entirely lost (Severson et al 2019). Marks and Marks (1987) reported that, although rump-mounted VHF transmitters increased conspicuousness of sharp-tailed grouse, the tracking device did not impede body mechanics and movement patterns compared to non-radioed led banded birds. Conversely, Pietz et al. (1993) indicated that female wild mallards wearing rear harness mounted VHF transmitters had constricted movements compared to non-marked birds. Although the use of GPS rump-mounted devices in fairly new (Barron et al. 2010), these findings are similar to the contrasting literature on effects of VHF necklace transmitters, where some studies indicate negative effects (Gibson et al. 2013, Fremgen et al. 2017) and others report no effects (Small and Rusch 1985, Thirgood et al. 1995, Hagen et al. 2006).

Our hypothesis was supported by the results, in that, sage-grouse showed increased mortality when marked with GPS rump-mounted transmitters compared to VHF necklace transmitters. With our results reflecting similar findings by Severson et al (2019), appropriate research and analysis steps are being taken to better interpret the necessary refinements to transmitter attachment, design, placement and unit mass. We were unable to produce minimum PBM threshold or recommendation, however, we envision this being attainable in future analyses. Since the 1980s, VHF necklace transmitters have been commonly fitted to sage-grouse across research applications (Amstrup 1980), and continual improvements were made to limit impacts on survival and behavior, and remove as much bias as possible (Fuller et al. 2005, Hagen et al. 2006). Continual improvements must be made to current GPS rump-mounted platforms so that effects on life history stages of sage-grouse approximate those marked with VHF necklace transmitters.

Because of lack of standardization of deployment times between the VHF and GPS transmitter deployment by study sites, we were unable to access handling time as a covariate in our model. Cook (2015) reported a possible sublethal effect to added stress attributed to handling time in deploying poncho and necklace-style VHF transmitters. However, the added sublethal effects of stress due to handling time may have been accounted for in our model by method of attachments. The potential for GPS palatiform deployment to add sublethal stress and the effect so the added stress on individual bird mortality and behavior warrants additional research (Lamb et al.2020).

Management Implications

Future mark and recapture studies using VHF marked sage-grouse as a control, could prove beneficial to understand hormonal effects (i.e., before and after cortisol levels), body condition and energy deposition for GPS marked birds. Additional research on behavioral responses of sage-grouse marked with GPS rump-mounted platforms in regards to resource selection, movement patterns, lek attendance and reproduction should be further investigated. We further recommend that handling time for each study be evaluated and restricted as much as possible for GPS marked sage-grouse to minimize capture induced stress and negative post capture behavior responses. We recommend that future research applications using current GPS platforms adhere to current guidelines for mitigating unnecessary chaffing and abrasions that can be caused by current attachment and harness designs. Lastly, we recommend that researchers publish all results (e.g., reporting parameter estimates for GPS and VHF marked birds, so estimates can be used in future meta-analyses) on effects of sage-grouse mark with GPS platforms so that quicker refinements can be made to current models.

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Tables and Figures

Table 4-1. Hazard ratios for sage-grouse (*Centrocercus urophasianus*) for sex- and age- based shared frailty models across seasons. Bolded values highlight a hazard ratio 95% credible interval greater than one indicating the GPS transmitters' increased mortality for that age or sex in that season.

				Hazard Ratio (GPS:VHF) Quantile Values				
Model	Sex	Age	Season	2.50%	25%	Median	75%	97.50%
A) Sex	Female	All	Spring	0.95	1.36	1.64	1.98	2.81
	Male	All	Spring	0.69	1.46	2.11	3.00	5.91
	Female	**All**	**Summer**	**1.02**	**1.69**	**2.21**	**2.88**	**4.82**
	Male	All	Summer	0.19	0.89	1.78	3.36	11.65
	Female	All	Fall	0.61	3.23	7.55	19.42	224.61
	Male	All	Fall	1.51E-30	3.98E-15	3.85E-08	0.01	1783.48
	Female	**All**	**Winter**	**1.78**	**35.45**	**376.47**	**4139.96**	**137577.93**
	Male	All	Winter	2.65E-30	3.77E-15	3.57E-08	0.01	2325.59
B) Age	**All**	**Yearling**	**Spring**	**2.37**	**105.08**	**1368.47**	**20640.08**	**835669.03**
	All	Adult	Spring	0.92	1.27	1.51	1.79	2.48
	All	Yearling	Summer	7.35E-32	9.94E-17	3.10E-10	2.16E-05	0.25
	All	**Adult**	**Summer**	**1.31**	**2.13**	**2.76**	**3.60**	**6.14**
	All	Yearling	Fall	2.92E-30	2.59E-15	1.47E-08	0.003	839.59
	All	Adult	Fall	0.81	3.95	9.23	24.03	285.71
	All	Yearling	Winter	4.81E-31	1.89E-15	1.86E-08	0.004	876.29
	All	**Adult**	**Winter**	**2.51**	**50.64**	**462.23**	**4447.06**	**94737.66**

Table 4-2. Comparison of models affecting sage-grouse (*Centrocercus urophasianus*) survival to 60 days post-marking by device type (GPS or VHF) and weight as a percent body mass (PBM)

Model	Hypothesized Mechanism	Penalty	WAIC	ΔWAIC
Additive	Device mass + Solar Panel or Attachment	4.03	235.94	0.00
Device only	Solar Panel or Attachment	4.03	236.43	0.49
Interactive	Device mass + Mass Placement	3.83	236.65	0.71
PBM Only	Device mass only	3.63	313.25	77.31
Null	No effect	3.15	315.37	79.43

Table 4-3. Sample sizes for sage-grouse (*Centrocercus urophasianus*) for the two study areas by attachment type (GPS or VHF), sex, age (adult (=> 2 years) or yearling (1 year) including the number of mortalities per attachment type.

Map Symbol	Site Name	Total	GPS Female Adult	GPS Female Yearling	GPS Male Adult	GPS Male Yearling	VHF Female Adult	VHF Female Yearling	VHF Male Adult	VHF Male Yearling	VHF Mortalities	GPS Mortalities
SR	Sheeprock Mountains	167	14	32	15	1	37	36	25	7	52	45
BE	West Box Elder	85	13	19	0	2	33	14	4	0	20	20
	Total	252	27	51	15	3	70	50	29	7	72	65

CHAPTER 5

ENHANCING LOCAL GOVERNANCE THROUGH COMMUNITY-BASED CONSERVATION WITHIN THE WEST BOX ELDER COORDINATED RESOURCE MANAGEMENT GROUP

Abstract

Because home ranges for many sensitive wildlife species often extend beyond private and public property boundaries and agencies jurisdictions, successful conservation typically requires collaborative efforts engage multiple stakeholders. The West Box Elder Coordinated Resource Management (CRM) group is one example of a process to create a governance across jurisdictional boundaries that has been well-known for completing landscape scale management projects when compare to other CRM groups throughout Utah. The CRM has used community-based collaborative adaptive management (CAM) techniques to engage multiple public and private partners in landscape and species conservation. In 2019, we conducted a case study of the West Box Elder CRM. Seventeen (8 private, 6 state and 3 federal) stakeholder participants were interviewed in person. The purpose of the interviews was to identify the operational mechanisms of governance that enabled the group to implement projects, which contributed to the long-term sustainability of the local community and enhanced species conservation. Each interview consisted of a similar of questions from a predetermined list. The questions were developed to assess respondents' perceptions and beliefs about the CRM governance process. The topics covered were divided into 6 sections: 1) CRM Initiation/Origin 2) CRM Support and Synergy 3) Program Administration 4) Communication 5) Program Outcomes 6) Making Improvements. Our qualitative analysis

of the response revealed some common themes. These themes were: 1) participation by representatives of federal and state government agencies was paramount for funding and program structure, 2) landowner involvement is necessary for long-term stability and persistence, and 3) intergroup communication has improved and trust of local landowners between state and federal agencies has been enhanced. However, respondents also expressed concerns that the CRM governance process should be re-evaluated periodically to mitigate stakeholder burnout and group cohesion deterioration. The re-evaluation could help temper unrealistic expectations relative to sustaining the momentum the CRM has achieved over the last decade and establish new goals to better address current conservation issues. The results of our case study may be applicable by other local working groups who desire enhanced local governance. Local governance can be achieved by a introspective review of the intergroup organizational program dynamics of successful CRMs. These periodic reviews will enhance group understanding the role of adaptive collaborations in local governance and how setting realistic objectives and goals in dynamic environments can contribute to overall group effectiveness and long-term sustainability.

Introduction

Home ranges for many imperiled wildlife species often extend beyond federal and state agency jurisdictions to encompass habitats within private ownership boundaries (Polasky et al. 1997) Thus, for species conservation and restoration efforts to be successful they must employ integrative and collaborative adaptive management strategies to define objectives and achieve both intermediate and long-term goals (Brunson et al. 1996). Concomitantly, the singular definitive decision frameworks historically used to develop and implement past species conservation strategies that often excluded local public involvement, collaborative stewardship and the ignored economic consequences that followed resource decisions. Endter-Wada et al. (1998) reported that ecosystem management frameworks that exclude social considerations and public involvement into the decision-making process, and focus only on the biophysical aspects, could often polarize people and make the policy process more contentious and divisive.

Collaborative adaptive management (CAM) emerged into natural resource management arena in the early 1970s out of necessity to better engage stakeholders in conservation processes. The addition of affected stakeholders in these new process increased monitoring capacities and facilitated continual improvements, the identification of provisional strategies to bridge information gaps, and the application of incremental adjustments to the management process when needed (Susskind et al. 2012). However, these new processes encountered opposition. Early opposition to the inclusion of public and local collaboration into ecosystem management often framed their assumptions or arguments in terms of biocentrism or anthropocentrism (Endter-Wada et al. 1998). The biocentrism view espoused the primary goal of ecosystem management was to maintain the ecological integrity of native species assemblages and that human influences were harmful to natural function ecosystems, and balancing economic, social and ecological concerns was not possible (Grumbine 1994, Endter-Wada et al. 1998). Conversely, the anthropocentrism view promoted that humans were an intrinsic part of the landscape and could not be separated from maintaining ecological processes and that ecosystems were resilient to human influences and social dynamics must be considered when establishing management paradigms (Norton 1991, Ludwig et al. 1993, Noss and Cooperrider 1994, Stanley 1995, Endter-Wada et al. 1998).

However, by the late 1990s and early 2000s, it was becoming clear that resistance to or critiques of CAM were largely unwarranted and many landscape scale conservation efforts had been achieved by employing adaptive management strategies into policy, ecological and economic decisions (Keough et al. 2006). For example, the Malpai Borderland Group in 2001 applied integrative CAM techniques to bridge differences between ranchers and environmentalist and conserved 323,749 ha of public and private land in southern Arizona. The Red Cliff Desert Reserve formed in 2004 and leveraged CAM to protect critical threatened desert tortoise (*Gopherus agassizii*) habitat and resolved conflicting interest between recreationalist, environmental groups and local communities in southwestern Utah (Keough et al. 2006). However, these were only conservation primers to what would become the largest modern landscape scale conservation effort to prevent a single species, the greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse), from being listed as threatened under the Endangered Species Act (ESA) of 1973 (United States Fish and Wildlife Service (USFWS) 2010).

In 1997, Utah State University (USU) Extension, through the community-based conservation program (CBCP) (developed in the early 1990s), began organizing and facilitating sage-grouse local working groups (LWGs) throughout Utah to increase local governance (Messmer et al. 2008, Messmer et al. 2010, Messmer et al. 2013, Messmer et al. 2016, Belton et al. 2017, Messmer et al. 2018). Governance has been defined as "the totality of instruments and mechanisms available to collectively steer society (Khan 2010, Kronsell et al. 2010). Governance is the means or process used by governments, agencies, organizations, and individuals to direct their actions. The processes include the laws, rules, regulations, policies, and standard operating procedures, which collectively guide their actions (Rudolph et al. 2012).

Thus, governance is not only under the purview of established governments. More and more, the authority and resources for governance of wildlife is being shared through cooperative agreements, coordination, and cooperation with entities outside of traditionally recognized governmental structures.

The CBCP recognized early in the planning stages that with half Utah's sage-grouse populations inhabiting private rangelands at some time during their life cycle (Utah Division of Wildlife Resources 2002, 2009, State of Utah 2013, Dahlgren et al. 2016), successful conservation will require broad support and employment of CAM strategies from local communities and private landowners. The initial objectives of the CBCP was to enhance local governance through the coordination and communication between community-based adaptive resource management working groups, private, and public partners. The CBCP accomplish this by facilitating the development and implementation of "seamless" plans for designated Utah geographic areas that contributed to the conservation of sage-grouse and other wildlife species that inhabit Utah's sagebrush ecosystems, while enhancing the economic sustainability of local communities (Messmer et al. 2008, Belton et al. 2009). The CBCP process embraced a unique model framework that not only engaged LWG participants into conservation planning and decision-making, but also identifying research questions, research funding, and research implementation.

Throughout Utah in the late 1990s and early 2000s, regional LWGs were developed in geographical appropriate locations. Individual LWGs developed a local conservation plan through CAM that contributed to the development Utah's sage-grouse conservation strategies. The LWG plans laid the framework for the species threat analysis and conservation strategies (Messmer et al. 2008) that were incorporated into the Utah Plan (Utah Public Lands Policy Coordination Office (PLPCO) 2019). Currently, there are 11 active LWGs. Some of the LWG have transitioned into Coordinated Resources Management (CRM) groups.

Coordinated Resource Management is a unique model that builds on CAM strategies and invites stakeholders from diverse backgrounds to make decisions by consensus, rather than by method of traditional voting and majority rule. Coordinated Resources Management groups have developed and advanced local governance across the West to assist stakeholders with managing wildlife related issues and natural resources in a balanced, productive, conservation-friendly, and economical manner, for the long-term by involving the wide-ranging perspectives and interests.

One of the best known, integrative and collaborative based CRM's in Utah at implementing landscape scale conservation efforts, to help long-term stabilization of local sage-grouse populations, is the West Box Elder CRM in remote northwestern Box Elder County, Utah. The predecessor to the West Box Elder CRM was the Box Elder Adaptive Management Local Working Group (BARM). In 2000, BARM began meeting to develop objectives and implement voluntary restoration strategies to promote sage-grouse conservation and the working sagebrush (*Artemisia* spp.) landscapes they inhabited. In 2008, BARM published and began implementing its comprehensive sage-grouse and sagebrush strategic framework. Then, in 2011, the West Box Elder CRM Committee was established to further coordinate and link local landowner's knowledge with state and federal agencies to consolidate conservation efforts, balance land-use practices and maintain socioeconomic viability.

The CRM partnership strives to integrate the management of public and private lands that is integral to preserving the sagebrush landscape for wildlife and sustain the communities that depend on the services provided by the ecosystem (Messmer et al. 2008, Belton et al. 2009, Messmer et al. 2016, Belton et al. 2017, Messmer et al. 2018). The partners have committed to collectively tackling conifer encroachment and invasive grasses (e.g., cheatgrass; *Bromus tectorum*) and forbs (e.g., spotted knapweed; *Centaurea stoebe ssp.micranthos*), through a proactive, cooperative management approach. Since 2006, partners have removed over 10,000 ha of conifer dominated and encroached areas. These efforts set the stage for the WBE CRM to be effective when, in 2010, due to continuing range-wide population declines, sage-grouse were determined a candidate species by the USFWS for protection (USFWS 2010).

The threat of federally listing the sage-grouse was originally the catalyst for local conservation coordination and infusion of new money from incentive-based programs (e.g., NRCS Sage Grouse Initiative and Utah Department of Natural Resources Water Resource Initiative). The community has collaborated around projects to remove conifers in areas of encroachment, and restore wet mesic meadows using innovative approaches (e.g., beaver reintroductions and dam analogues). With using science to guide management, these community-driven restoration efforts are improving rangeland health on both private and public lands.

Recently, the West Box Elder CRM identified the need for increased capacity to implement rangeland improvement projects, so in 2016 they supported the founding of the Sagebrush Ecosystem Alliance (SEA) in partnership with the Bureau of Land Management, Intermountain West Joint Venture, Utah State University Extension, and other partners (SEA Annual Report 2019). The SEA is now a 450,000 ha effort focused in West Box Elder County, with the potential to expand across public and private jurisdictional boundaries. The SEA provides technical and partnership assistance to implement conservation practices that benefit long-term sustainability of sagebrush steppe ecosystems. This primarily includes restoring wet meadows, mitigating encroachment, reducing fire risk and invasive species, range structural improvements and coordinating the planning and implementation of appropriate livestock grazing practices (SEA Annual Report 2018 and 2019). These collaborative-based efforts built on decades of private landowner leadership, conservation, and strong relationships established with neighboring landowners and agency personnel.

Beginning in the early fall of 2019, we conducted an in-depth case study of the transformation of the West Box Elder CRM to provide insight into the mechanisms and processes used to transform from BARM to CRM. This case study will provide other LWGs and communities with information and insights regarding how and why they might consider transitioning of an LWG to a CRM format. Furthermore, the transferring of this information to other LWGs and CRMs in the form of a template can help interested stakeholders to better understand the process needed for the landscape scale conservation successes (e.g., mechanical conifer treatments, beaver (*Castor canadensis*) reintroductions, wildlife habitat and livestock range improvements) that have been demonstrated by the West Box Elder CRM since its inception.

Study Area

The study area encompasses the Raft River subunit found in Box Elder County Adaptive Resource Management Local Working Groups (BARM) (Fig. 5.1). The Raft River subunit is located in a remote low population density area of northwestern Utah. Geographically, the core of the study area is bordered by the Raft River Mountains to the north, the Grouse Creek and Pilot Mountains to the west, by the Great Salt Lake to the southeast and areas of salt flats to the south (Cook et al. 2013). Approximately 440,750 ha are encompassed within the study area. Land ownership within the Raft River subunit is a mixture of public and private lands consisting of: Bureau of Land Management, U.S. Forest Service, Utah School and Institutional Trust Lands Administration and private (Cook et al. 2013; Sanford and Messmer, 2015). The study area is commonly referred to as the Box Elder Sage-grouse Management Area (SGMA) as defined in the Utah Conservation Plan for Greater Sage-grouse (PLPCO 2019).

Communities in West Box Elder, like much of the rural western U.S., have experienced a significant population loss over the past century, accompanied by a decrease of available public services and economic opportunities and stability. Payments in Lieu of Taxes (PILT) for 2019 for Box Elder, County was $3,324,840 for 486,138 ha of federal land (United States Department of Interior 2020). Although the largest amount of federal land is located in the western part of the county, the majority of PILT dollars go to the more populous areas in the eastern part of the county. The public lands in the area provide value for grazing, wildlife, and recreation opportunities—all central to the local economy and keeping families together and in business.

Methods

Sampling Frame

We developed a list of known participants in the West Box Elder CRM through one-on-one interactions with the CRM members spanning a four-year period. Our interactions provide the information we used to identify key informants. A key informant can provide valuable information to aid in structuring the initial evaluation process and help obtain access to the research setting (Singleton and Straits 2010). One of our key informants was the longest sitting and well-connected West Box Elder CRM paid coordinator. Research in organization theory showed having a paid coordinator to organize meetings at the group level can be highly effective and that those individuals often times had highly beneficial information and insight into the group's interlayers (Curtis et al. 2000). The coordinator's insights helped facilitate the development of the initial list of CRM's interviewees that included private, state and federal stakeholders.

We initially identified 8 ranchers / private landowners, 6 state employee stakeholders and 3 federal employee stakeholders for possible inclusion within the interview process. We conducted the interviews in person and recorded each interview with an Olympus model 541PC handheld digital recorder (Olympus America Inc., Center Valley, PA). This list included participants that were involved in the CRM from its inception as a local working group. These key participants help mitigate information redundancy. Within the context of social research, the framework of grounded theory reports concept of "information saturation" as a point in the interview process where no new information is being obtained (Murphy et al 2016).

Before any interviews were conducted, all recommended participants were contacted to set-up date and time of interview. To address areas of concern prior to implementation in the field, all survey questions and instruments and were pretested. The survey methods used were reviewed and approved for use by the Utah State University Institutional Review Board (IRB) process; Protocol # 10509.

Private Landowners and Agency Personnel Interviews

We completed the interviews September 1 – November 1 2019 using a semi-structured interview protocol. The interview participants were asked a series of question from a predetermined list of questions (Table 5.1) divided into 6 sections: 1) CRM Initiation/Origin 2) CRM Support and Synergy 3) Program Administration 4) Communication 5) Program Outcomes 6) Making Improvements.

The participants in each group (e.g., private, state and federal) do not strictly fit in a definitive category, meaning groups are not mutually exclusive. For instance, the long-standing paid coordinator for the CRM is also a livestock producer, landowner and schoolteacher. However, having prior knowledge of interview participants, an effort was made to have as low as categorical overlap as possible between interviewees.

Data Analysis

After completion of individual interviews, recordings were individually transcribed, printed, and initially read post-interview to eliminate any bias possibly arising from other participants' answers. To gain a general interpretation of stakeholders' answers to interviews, a second reading of transcripts was conducted within a week of the first reading to enable development of an outline of key points for each interview. Then, with the use of these outlines, within a month following the interviews, a third review of the interview transcripts entailed hand coding to identify consistency in common themes identified for each group (private, state and federal participants) with the six sections mentioned beforehand. These themes were used to describe the similarities and differences from each group of interview participants.

Response percentages of questions that produced common themes was derived for each group by taking the individual interviewee response divided by the total participants for each group (individual response / total group number). Consensus was considered to have been reached when all 3 groups of participants combined produced a common theme of ≥ 75%.

Results

Common themes that emerged from interviews of federal, state and local landowners during the interview process from fall 2019 were separated into the six sections (Table 5.1) below:

CRM Initiation and Origin

Federal (100%) state (100%) and landowner stakeholders (75%) agreed that the Natural Resource Conservation Service (NRCS) was paramount in forming the CRM through funding resources to help with establishment and that USU Extension was important to help guide science-based issues. A state interviewee stated, "having a federal agency's presence, not only financial support but also individual managers attendance at early stage meetings, really was a catalyst for early momentum". However, USU Extension's initial involvement was perceived differently than other state agencies. Extension's presence was interpreted as being more neutral, without an agenda, other than to promote science directed research that had potential to synergistically benefit the local community and wildlife. A landowner interviewee that was involved from the early stage of the CRM stated, "USU Extension was critical with support for wildlife conservation issues". All respondents (100%) agreed that sage-grouse habitat improvement and concern of being as threatened under the Endangered Species Act had created the momentum to form the CRM. A landowner interviewee stated, "the single biggest issue that help form early involvement was the possible listing of sage-grouse".

CRM Support and Synergy

Federal and state employees (both 100%) and landowners (88%) believed that landowner involvement was necessary for long-term stability and persistence of the CRM. Federal, state, and landowners interviewees all stated that local landowner involvement had decreased since 2015 when the USFWS determined that listing of sage-grouse for ESA protection was not warranted (USFWS 2015). A federal interview respondent stated, "landowner involvement definitely has decreased after the 2015 listing of sage-grouse as threatened under the ESA was prevented". Furthermore, respondents (federal (100%) state (95%) landowners (88%)) stated that federal and state money has been substantial and will be necessary for future participation from local landowners.

Program Administration

Most federal (70%), state (90%) and local (75%) respondents reported that having a paid coordinator was beneficial. They felt a designated paid coordinator advanced the CRM group in facilitating meetings, maintaining group organization throughout the non-meeting periods (e.g., currently the CRM is meeting every three months), and keeping the group connected across stakeholders through email updates that relay local related news and scientific research taking place across West Box Elder. A landowner interviewee stated, “having a paid coordinator in the early stages of the CRM helped keep the group connected”. Many local landowners in the West Box Elder CRM district rely on emails to stay current on local information, however seldom are physically present or participate in CRM meetings; this is especially true for local residents that reside in Grouse Creek or Lynn Valley areas.

Communication

There was a strong consensus across respondent groups (federal (100%), state (100% and local (88%) that intergroup communication has improved between local and state and federal agencies since the forming of the CRM, leading to a more diverse group of stakeholders than before the CRM existed. One landowner interviewee stated, “communication efficiency has increased greatly from intergroup participation within the CRM between stakeholders”. Additionally, trust increased between groups for federal, state, county, university extension and local community members. University extension was parsed out from other state institutions (e.g., Utah Division of Wildlife Resources) because trust for it changed the least, but was higher initially than the other state agencies. Most interviewees reported a 25% to 50% increase in trust between stakeholders because of direct intergroup collaboration and support. A federal employee interviewee stated, “having a district field manager from the BLM attend the meetings help set a positive attitude towards their involvement”. A landowner interviewee stated, “having BLM managers at meetings help not see them as the enemy that makes decision from far off”.

Program Outcomes

Federal state, and landowners agreed unanimously (100%) that the CRM has been critical in habitat improvement projects (e.g., conifer treatments, seedings, firebreaks and beaver restoration) being implemented across the landscape. All three groups stated that conifer removal projects would have not likely occurred at the current scale in West Box Elder County without the CRM being used as a conduit to access to the necessary economic resources. A landowner interviewee stated, “without federal and state involvement, conifer treatments would have never happened at the level they have over the last decade across West Box Elder”.

Making Improvements

The respondents agreed (federal 100%, state 100% and landowners 75%), that for the CRM to remain effective, landowner participation must increase such that other individuals take the lead to prevent burnout by individuals who have remained highly involved from the inception of CRM. Interviewees reported (federal 100%, state 83% and landowners 75%) that the CRM group must reevaluate goals and objectives and refocus on current issues or else the CRM will be non-effective or defunct in five years. One landowner interviewee stated, “for the CRM to remain effective relevant conservation concerns must be identified". A state employee interviewee that was highly involved with the CRM until recently stated, "there has to be a frank conversation between the agencies and the landowners. There is money to continue but the landowners must want to carry-on with current issues and be involved in order for the CRM to remain effective going forward. A reset of goals and objectives might be necessary". They stated further that the accomplishment of past goals would not maintain the incentive or momentum to remain effective into the future.

Discussion

The West Box Elder CRM has been highly effective throughout its duration in employing CAM techniques that have been expressed through a synergistic approach in tackling and achieving complex conservation issues (e.g., sage-grouse conservation, conifer removal projects, firebreaks and rangeland improvement projects) relative to the local West Box Elder community (Belton et al. 2017, Messmer et al. 2018). Our case study presents a tractable qualitative view of intergroup structure within the West Box Elder CRM and of the collaborative adaptive mechanisms that have been employed to achieve the level of conservation success thus far. However, our study also provides a further view into the necessary actions and maintenance of the CRM that will be paramount for it to remain effective without having a locally perceived conservation crisis to rally local stakeholder participation. The results from this case study provides a template for other LWGs to apply necessary actions to block deterioration of group structure, maintain the required synergy and support, and to maintain local participation over the long-term.

Our respondents concurred that the initiation phase of forming a CRM group will need broad support from outside stakeholders (e.g., federal, state and region planning bodies) with a upfront supportive institutional framework and outside funding resources to help establish group structure and provide the required economic means to implement early conservation projects (Curtis et al. 2002). For example, the NRCS's ability, largely from State Conservation Sylvia Gillen's efforts, to contribute over $125,000 in the initial planning phase was largely responsible for the CRM's ability to attract local stakeholders involvement into incentive based programs, implement initial phase habitat restoration projects, create local jobs, and cover management costs (e.g., hire a coordinator). Furthermore, USU Extension transitional involvement and support from the West Box Elder LWG to the CRM was paramount in offering group mentorship and guidance regarding sage-grouse conservation, policy navigation of other sensitive species conservation issues and understanding how to employ community-based adaptive management strategies at the landscape scale.

Additionally, early-phase involvement by federal and state institutions can lead to higher levels of trust and group cohesion that have over-arching benefits throughout the LWGs meeting process (Curtis et al. 2002, Alvarez 2011, Susskind et al. 2012). All eight landowners interviewed stated that working with federal personnel, especially the Bureau of Land Management (BLM), and being able to speak to agency representatives (e.g., Salt Lake field office manager) was responsible for increasing trust by a magnitude that had not been attainable before the CRM. Early group cohesion between government and locals sets the stage for on-the-ground accomplishments in comparison to groups that do not demonstrate early phase intergroup collaboration and comradery (Susskind et al. 2012).

Curtis et al. (2002) reported that it is an unrealistic expectation for a locally based collaborative group to become established, and remain effective, without substantial representation and direct investment by government institutions that provide early-phase program management, group coordination, and cost sharing for on-the-ground project implementation. Without the early commitment and representation of the NRCS and USU Extension for financial support and program oversight, the early-perceived benefits of broad stakeholder participation could have been forfeited (Endter-Wada et al. 1998, Curtis et al. 2002, Keough and Blahna 2006).

A common theme across respondent groups was that continued support and synergy and open communication within the group would require broad landowner participation; not just a few involved landowners carrying the weight of responsibility. All groups stated that since the listing of sage-grouse as threaten under the ESA was averted in 2015, landowner involvement has steadily decreased. This type of senescence is common in local groups that have rallied around a landscape-scale conservation effort and operated under a historically high-level of momentum for a long duration (Curtis 2000). For example, efforts to conserve and restore sage-grouse habitat in the West Box Elder Sage-Grouse Management Area (SGMA) has been in full momentum since 2011; from 2008, over 20,000 acres of pinyon (*Pinus* spp.) – juniper (*Juniperu*s spp.) have been removed in the West Box Elder SGMA alone. Long-term sustainability of this level of momentum has not been attainable for most LWGs or CRMs (Curtis et al. 2000).

To maintain landowner involvement and prevent individual and group burnout, a reevaluation period must be implemented (Bryon and Curtis 2002). Reflection and evaluation of past objective and goals that have been accomplished, and setting of new realistic goals, may be the linchpin that allows CRMs to transition into a new era of stakeholder involvement (Curtis and De Lacy 1998, Curtis et al. 2000, Keough and Blahna 2006, Susskind et al. 2012). Most state and federal personnel interviewed suggest that a reevaluation period could be necessary for the West Box Elder CRM to transition into a new era of stakeholder involvement, realistic goal setting in light of the current context of conservation needs, and forming a clear future direction to prevent group dissolution over the next five years.

This case study demonstrates the effectiveness of collaborative resource management within the local community context. Early phase involvement of government institutions (i.e., both state and federal) will remain necessary for initial group structure and cohesion, guidance, access economic resources and project implementation. However, with most CRM's formation being in response to larger conservation issues than can be handled by the local landowner community (i.e., smaller-scale grassroots working groups), it is also unrealistic for groups member to envision that wave of momentum lasting indefinitely. A reevaluation phase will be necessary for higher functioning LWGs or CRMs to segment group achievements, adjust current expectations and goals in light of present landscape issues to remain effective in the interim (i.e., between larger conservation issues). The West Box Elder CRM remains an exemplary community based group that can report successful accomplishments of its mission, and our results could be a useful template to assist other CRMs to remain effective over the long-term with all size and scale of conservation issues.

Management Implications

Coordinated resource management (CRM) groups can be a highly effective community-based collaborative mechanism to meet landscape-scale conservation challenges. Based on results from the West Box Elder CRM case study, we recommend early inclusion of state and federal institutions structure to promote group organization, build trust and cohesion among stakeholders and gain access to necessary funding resources. A reevaluation phase will be paramount before landowner participation decreases and momentum subsides. Long-term momentum established on the premise of large-scale conservation issues (e.g., sage-grouse initiative) is not maintainable indefinitely. Midterm evaluation of early phase objectives, goals and project successes could prevent group senescence or decreased landowner involvement during the interim periods of lesser scale conservation issues.

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Tables and Figures

Table 5-1. Survey Questionnaire for interviews of case study conducted in the fall 2019 in the West Box Elder Coordinated Resources Management (CRM) in Box Elder County, Utah.

Background Question

1. How did you first learn about the West Box Elder Coordinated Resource Management Group (CRM) process?
2. What does the word CRM mean to you? Have you been involved in other LWGs or CRMs?
3. Why did you become involved in the WBE CRM?
4. What was your role and level of participation in the CRM and when did you become involved?
5. What were your expectations?
6. Have your expectations been met?
    a. If so, how?
7. If you could do it over again, what might you change?

CRM Initiation/Origin:

1. How did the WBE CRM start? What helped launch the effort? (agencies, institutions, individuals, etc.)?
2. What were the main issue(s) that the CRM was trying initially to address?
    a. Sage-grouse habitat improvement?
    b. Did the initial momentum to start the CRM begin within the WBE ranching community or from an outside group or agency?

CRM Support and Synergy?

1. Are the main agencies or partners represented at the CRM?
    a. Are there any groups or individuals absent? Why?
2. Who are the agencies or partners who currently work with landowners to help facilitate partnerships and/or projects?
    a. Are there others who should be participating?
3. Are you satisfied with the level of landowner and/or agency activity within the CRM?
    a. Yes, no, why not?
    b. What could be done to increase landowner involvement?
4. What have been the greatest benefit of the CRM process?
    a. More money, more access to the political or policy process, provide a list
5. Has partner support for the CRM increased or decreased, or remained the same?
    a. Can you provide some examples to support your assessment?
6. What is the most important need of the CRM to sustain its momentum?
7. Has funding CRM sources changed throughout your involvement?
8. How does the CRM recruit new members?

9. How does the CRM conduct its business? Are the committees effective? Is so why or why not?

Program Administration:

1. Who should be responsible for coordinating and organizing meetings within the CRM?
2. How has this responsibility changed since the inception of the CRM?

Communication:

1. Since the forming of the CRM, has local communication among ranchers, agency personnel and collaborators improved?
2. If so, how has increased communication has opened doors for funding sources and projects?
3. Were do you get your information from regarding issues surrounding WBE?
4. How have the sources for information changed since the forming of the CRM?
5. Please rate the level of trust you had for the following entities. 1 being low and 5 being high:
    a. Federal
    b. State
    c. County
    d. University Extension
    e. Local
6. Now, using a 1 to 5 scale with 1 being low and 5 being high, rate your level of trust for the same entities after the being involved in the CRM process.

Program Effects:

1. Since the establishment of the CRM, how has the efficiency of project implementation improved?
2. Since the forming of the CRM, which desired futures conditions (DFCs) of the landscape that were originally identified have been achieved? Here are some examples.

    Rangeland and Agriculture?
    Socioeconomics?
    Water Resources?
3. What projects do you believe have be implemented since the establishment of the CRM that would have otherwise never happened? Here are some examples.

    Pinyon-Juniper projects?
    Habitat improvement for both livestock and wildlife?
    Sage-grouse research?
    Fire Breaks?
    Seedings?
    Invasive Plant Control?

Making Improvements:

1. What are some of the biggest achievements the CRM has made since its establishment?

Securing funding?
Intergroup communication?
Stakeholder participation?

2. How do you think the CRM needs to improve to remain effective moving forward?
3. What are some of the largest hurdles/obstacles the CRM needs to overcome to remain effective?
4. How has the CRM has been effective at helping ranchers and landowners in WBE get projects implemented?
5. On a scale of 1 to5, with 1 being low, how satisfied to you think the ranchers and landowners in WBE with the CRM?
6. Where do you see the CRM in 5 years?

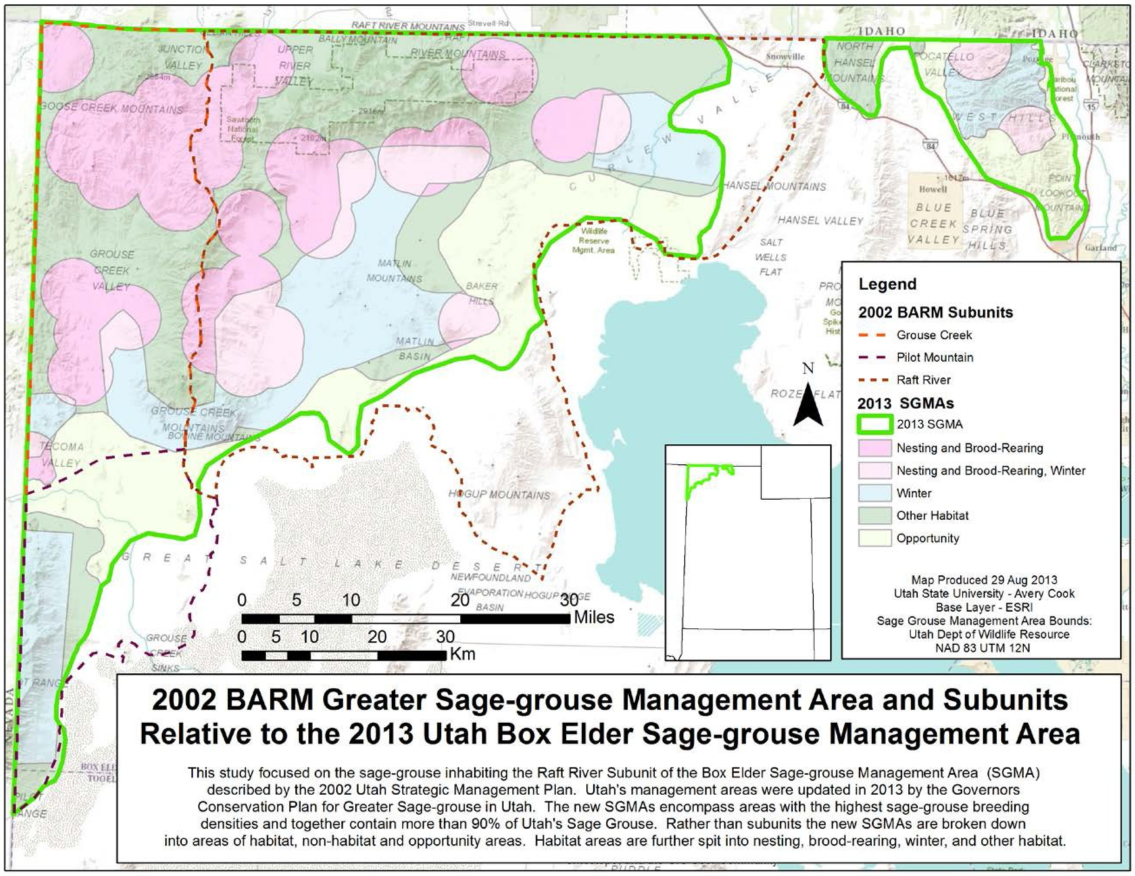

Figure 5-1. Greater sage-grouse (*Centrocercus urophasianus*) Management Area and Subunits as defined by the 2013 Utah Box Elder Sage-grouse Management Area (SGMA) and the 2002 BARM. Utah's SGMA management plans were updated in 2013 and encompass areas within the highest breeding densities of sage-grouse in the state and support > 90% of Utah's sage-grouse populations. The update SGMA classified and separated by habitat, other habitat and opportunity. Habitats are further delineated by nesting and brood-rearing, by nesting and brood-rearing and winter.

CHAPTER 6

CONCLUSION

Without active management, pinyon (*Pinus* spp.) and juniper (*Juniperus* spp.; hereafter conifer) encroachment is projected to transition over 75% of the remaining sagebrush habitats into phase III woodlands within the next 40 to 50 years (Miller et al. 2008). Because intervention and management actions are costly, land managers desire quantitative yet tractable tools that can be used to remotely quantify and evaluate the effectiveness of past conifer removal treatments to optimize future management decisions that will benefit greater sage-grouse (*Centrocercus urophasianus;* sage-grouse) and other sagebrush obligate species. Model frameworks that can predict future management outcomes at local and regional scales relative to managers will play a principal role in prioritizing future restoration sites to mitigate the successional transition of sagebrush habitat types into late phase conifer woodlands (Baruch-Mordo et al. 2013, Miller et al. 2019). Recent advancements of global positioning system (GPS) radio-transmitter technology has given managers access to substantial movement data streams (Fuller et al. 2005), which can be harnessed to interpret and predict sage-grouse responses to conservation actions (e.g., space use and resource selection) across broad landscapes (Balmori 2016, Kolzsch et al 2016).

To address this information gap, I developed a predictive model by analyzing pre- and post-treatment data for vegetation composition and annual changes in percent cover for known conifer treatments completed between 2008-2014 in Box Elder County, Utah. Treatment data was downloaded from Utah's Water Resource Initiative database (WRI 2019; https://wri.utah.gov/wri) and vegetation composition data from Rangeland Analysis

Platform (RAP 2020; https://rangelands.app/data/). I used Dirichlet regression to model vegetation composition in response to treatment as a function of prior composition, controlling for topography characteristics. I evaluated the models by comparing predicted vegetation composition five years post-treatment to the observed composition. Subsequently, I predicted expected vegetation composition in 2023 based of hypothetical treatments completed in 2018. The final model, model achieved high predictive power within treated plots, producing spatially-explicit predictions of percent tree cover that closely matched the observed values five years post-treatment. To my knowledge, this model is the first that leverages annual remotely sensed data at a fine spatial resolution to quantify vegetation responses to conifer removal treatments across broad scales.

Then, I employed a composite modeling approach to develop a landscape prioritization tool to guide management actions for placement of conifer treatment areas that will optimize ecological and habitat gains relative to economic investments. Using the predictive model from Chapter 2, under five different management scenarios, I modeled predicted changes in vegetation composition across West Box Elder Sage-grouse Management Area (SGMA) from 2017 (pre-treatment) to 2023 (five years post-treatment). Subsequently, I combined the predicted outcomes with an existing statewide resource selection function model of sage-grouse habitat selection (Kohl and Messmer 2020) and compared sage-grouse habitat selection for each scenario pre- and post-treatment. I ranked the scenarios using three criteria: change in suitability of nesting and summer habitats, and cumulative net habitat gain per dollar invested. Lastly, I used a Relative Selection Strength (RSS) framework to quantify the net habitat gain from 2017 to 2023 for each treatment scenario. Net habitat gain for per dollar invested on each treatment differed by scenario. My top ranked treatment scenario showed net habitat gains across all categories (cumulative habitat gain; logRSS = 6398.13) and highest gain per dollar invested (logRSS = 0.2040). Besides allowing managers to comparatively evaluate the effectiveness of different treatments in bringing a functional benefit to sage-grouse, this prioritization framework also allows for the inclusion of costs into a final computation of ecological gain relative to economic investments. Incorporating associated economic data into initial planning stages could attract increased rates of participation by private landowners into incentive-based programs (e.g., SGI and WRI) where costs are upfront and compensation is possible (Schindler et al. 2020).

To gain a better understanding of the differential mortality effects between marking sage-grouse with global positioning sensor (GPS) backpack style transmitters and Very high frequency (VHF) radio transmitters, I compared mortality rates for two separate sage-grouse populations from central and northwestern Utah. Between 2016 and 2019 I marked 96 greater sage-grouse with GPS rump-mounted transmitters to 156 with VHF necklace-style transmitters. I used Severson et al. (2017) analyses framework to quantify if Utah's sage-grouse populations would demonstrate similar mortality effects marked with GPS transmitters. Results showed across summer and winter for sex, and spring, summer and winter for age, higher mortality for sage-grouse marked with GPS transmitters. Posterior positioning of payload box (i.e., boundary layer disruption causing increased aerial drag), attachment type (i.e., rump-mounted harness) and solar panel reflectivity, and a possible artifact of the increased stress related to additional handling time, may be the main causal factors contributing to lower survival of GPS marked sage-grouse. A post hoc analysis for female sage-grouse only, supported an additive model demonstrating a combination of device mass + solar panel or attachment as being the causative mechanisms leading to lower survival. However, possible sublethal effects related to the additional stress caused by prolonged handling and physical manipulation to deploy the GPS transmitters needs to be further investigated. This information will help researchers assess the benefits and trade-offs of using current animal tracking radio transmitters and make the necessary improvements to current GPS rump-mounted platforms so that effects on sage-grouse approximate those marked with VHF necklace transmitters.

Lastly, I conducted a case study of the West Box Elder Coordinated Resource Management (CRM) group to identify the mechanisms of governance that have enabled the group to maintained long-term success and remain engaged going forward (Belton et al. 2017, Messmer et al. 2018). In 2019, I interviewed seventeen (8 private, 6 state and 3 federal) stakeholder participants. Interviews of respondents consisted of similar questions from a predetermined list. Common themes that emerged from the study were early phase and continued participation by representatives of federal and state government agencies was salient for funding and program structure, landowner involvement is necessary for long-term stability and persistence, and intergroup communication has improved and trust of local landowners between state and federal agencies has been increased. Respondents also expressed concerns that the CRM governance process should be re-evaluated periodically to mitigate stakeholder burnout and group cohesion deterioration. The re-evaluation could help temper unrealistic expectations relative to sustaining the momentum the CRM has achieved over the last decade and establish new goals that address current conservation issues.

As human modifications continue to alter Utah's sagebrush environments, managers will remain with the demanding task of employing mechanisms on regional scales that benefit sage-grouse populations, balance land-use practices and maintain local socioeconomic viability. My research gives managers a flexible prioritization framework that can be leveraged to predict resource selection by sage-grouse in response to changes in vegetation composition subsequent to conifer removal projects. The ability to predict species space use at temporal and spatial scales relevant to regional conservation actions for future treatments, allows managers to prioritize restoration areas that optimize ecological returns on finite economic investments for sage-grouse, and other targeted wildlife species, in conifer encroached sagebrush habitats.

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Miller, R., J. Chambers, L. Evers, C. Williams, K. Snyder, B. Roundy and F. Pierson. 2019. The ecology, history, ecohydrology, and management of pinyon and juniper woodlands in the Great Basin and Northern Colorado Plateau of the western United States. General Technical Report. RMRS-GTR-403. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO, USA, p. 284.

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APPENDIX

Survey Questionnaire

Background Question

8. How did you first learn about the West Box Elder Coordinated Resource Management Group (CRM) process?
9. What does the word CRM mean to you? Have you been involved in other LWGs or CRMs?
10. Why did you become involved in the WBE CRM?
11. What was your role and level of participation in the CRM?
12. What were your expectations?
13. Have your expectations been met?
    a. If so, how?
14. If you could do it over again, what might you change?

CRM Initiation/Origin:

3. How did the WBE CRM start? What helped launch the effort? (agencies, institutions, individuals, etc.)?
4. What were the main issue(s) that the CRM was trying initially to address?
    a. Sage-grouse habitat improvement?
    b. Did the initial momentum to start the CRM begin within the WBE ranching community or from an outside group or agency?

CRM Support and Synergy?

10. Are the main agencies or partners represented at the CRM?
    a. Are there any groups or individuals absent? Why?
11. Who are the agencies or partners who currently work with landowners to help facilitate partnerships and/or projects?
    a. Are there others who should be participating?
12. Are you satisfied with the level of landowner and/or agency activity within the CRM?
    a. Yes, no, why not?
    b. What could be done to increase landowner involvement?
13. What has been the greatest benefit of the CRM process?
    a. More money, more access to the political or policy process, provide a list
14. Has partner support for the CRM increased or decreased, or remained the same?
    a. Can you provide some examples to support your assessment?
15. What is the most important need of the CRM to sustain its momentum?
16. Has funding CRM sources changed throughout your involvement?
17. How does the CRM recruit new members?
18. How does the CRM conduct its business? Are the committees effective? Is so why or why not?

Program Administration:

3. Who should be responsible for coordinating and organizing meetings within the CRM?
4. How has this responsibility changed since the inception of the CRM?

Communication:

7. Since the forming of the CRM, has local communication among ranchers, agency personnel and collaborators improved?
8. If so, how has increased communication opened doors for funding sources and projects?
9. Where do you get your information from regarding issues surrounding WBE?
10. How have the sources for information changed since the forming of the CRM?
11. Please rate the level of trust you had for the following entities before your involvement with the CRM. 1 being low and 5 being high:
    a. Federal
    b. State
    c. County
    d. University Extension
    e. Local
12. Now, using the same 1 to 5 scale, with 1 being low and 5 being high, rate your level of trust for the same entities after the being involved in the CRM process.

Program Effects:

4. Since the establishment of the CRM, how has the efficiency of project implementation improved?
5. Since the forming of the CRM, which desired futures conditions (DFCs) of the landscape that were originally identified have been achieved? Here are some examples.
    Rangeland and Agriculture?
    Socioeconomics?
    Water Resources?
6. What projects do you believe have be implemented since the establishment of the CRM that would have otherwise never happened? Here are some examples.
    Pinyon-Juniper projects?
    Habitat improvement for both livestock and wildlife?
    Sage-grouse research?
    Fire Breaks?
    Seedings?
    Invasive Plant Control?

Making Improvements:

7. What are some of the biggest achievements the CRM has made since its establishment?
    Securing funding?
    Intergroup communication?
    Stakeholder participation?
8. How do you think the CRM needs to improve to remain effective moving forward?
9. What are some of the largest hurdles/obstacles the CRM needs to overcome to remain effective?
10. How has the CRM has been effective at helping ranchers and landowners in WBE get projects implemented?
11. On a scale of 1 to5, with 1 being low, how satisfied to you think the ranchers and landowners in WBE with the CRM?
12. Where do you see the CRM in 5 years?

CURRICULUM VITAE

Justin R. Small
Department of Wildland Resources
5230 Old Main Hill
Utah State University
Logan, UT 84322

Education

Ph.D.

August 2015 – November 2020
Utah State University, Logan, UT
Major: Wildlife Biology
GPA: 4.0

Bachelor of Science

August 2010 - May 2013
Washington State University, Pullman, WA
Major: Wildlife Ecology

Experience

Utah State University, Logan, UT. July 2015-present. Graduate Research Assistant – PhD Candidate, Defended November 2020.

- Successful completion of 4 field season / 18 months of field research. Managed a 1800 sq. mi. research project in northwestern Box Elder, County Utah. Used MoveBank animal tracking web interface to track and locate sage-grouse remotely before actual field locations occur.
- Developed monitoring databases via CyberTracker animal tracking systems. Marked greater sage-grouse using GPS backpack style transmitters and VHF necklace radio collars.
- Marked greater sage-grouse chicks by suturing on small VHF backpacks.
- Monitored both GPS and VHF radio marked sage-grouse adults and chicks (VHF only for chicks) daily using UHF/VHF receivers and Yagi antennas throughout the breeding, nesting and brood rearing life stages.
- Conducted nest and brood vegetation surveys using the Robel Pole, Daubenmire Frame and Line Intercept methods.
- Interacted daily with local landowners, residents and stakeholders for land access and describe research objectives. Daily operation/utilization of 4wd truck and ATV in extremely remote and rugged environments and varied weather conditions. Quarterly presentations and project updates at local CRM group public meetings.

- Developed a predictive prioritization tool using GPS location data from marked sage-grouse to forecast vegetation composition response to conifer treatments and sage-grouse habitat selection at the scale of the landscape. The priority tool can provide land managers with a tool to prioritize conifer treatments to optimize sage-grouse habitat improvements.
- Analyzed differential mortality of sag-grouse marked with GPS and VHF transmitters.
- Conducted and case study of the West Box Elder Coordinated Resource Management Group.
- All graduate course work was completed with a 4.0 GPA.
- Successfully defended PhD in November 2020
- Final dissertation edits in progress.

Forester / Natural Resource Consultant / Wildland Firefighter. Northwest Management, Inc., Moscow, ID. April 2014-present.

- Completed forest stands inventory and analysis. Daily usage of Trimble handhelds and GPS units. Plot inventory and analysis includes: tree DBHs, heights, taper heights, ages, defect %, region (includes all conifer species under 4.5" DBH) and using proper BAFs for individual stands. Prescribed burning duties: drip torch handling, lighting proper burn lines, line control, reading fire behavior, fire tools and equipment and mop-up. Incident Command System training and Firefighter 2 training completed.

Range Technician Supervisor/Team Leader. University of Idaho and Natural Resource
Conservation Service (NRCS). May 2013-Aug2013

- Performed detailed NRCS protocol. Collected vegetation analysis from federal, state, and private rangelands of Idaho. Hiked into remote locations using Trimble GPS units and map coordinates. Worked with ranchers/farmers/landowners to collect analysis on private rangelands. Operation of 4x4 vehicles in extremely remote, rugged environments.

Water Resource Lead Field Compliance Technician. Turlock Irrigation District, Turlock, CA. July 2004- Dec. 2005.

- Successfully managed a district-wide Tail-Water Run-Off state grant program. Mapped, photo documented, and Global Position System (GPS) logged several hundred unknown field drains. Scheduled and organized meetings with farmers and ranchers to help them bring their field drains and non-compliant water discharges into compliance with state regulations. Mitigated social conflicts with landowners over compliance issues. Oversaw the installation of positive shut-off valves to non-compliance discharge sites, and distributed reimbursement checks to landowners at project completion.

Other Work Experirence

Operator/Lumber Grader/Laborer. Bennett Lumber, Inc., Princeton, Idaho. Dec. 2013-Mar. 2014.

- Graded lumber for quality scale. Operated various mill line machines. Cleaned machinery for operation functionality and efficiency.

Assistant Manager. C & S Mini Storage, Pullman, WA. July 2010 to May 2013.

- Meet and help customers. Keep facilities clean and maintained storages.

Project Forman. Hilton Construction Inc., Merced, CA and Pinedale, WY. Aug 2007-Dec. 2009.

- Completed custom homes in Pinedale, Wyoming and in Central Valley, California.

Building Superintendent. Mid Valley Framing, Atwater, CA. Dec. 2005- July 2007.

- Completed 20 custom homes from 2000 to 4200sqft in 10 months. Homes were built from bare lot to completion. Also, manage other company commercial projects. Met regularly with homeowners. Met weekly with city building inspectors for inspections of construction compliance. Interacted daily with subcontractors until job completion.

Presentations

Small, J. Helping Sage-Grouse and Land Managers See the Forest for the Trees. Presented at the Sagebrush Summit, Salt Lake City, UT, February 2019.

Small, J. Greater Sage-Grouse Response to Pinyon Juniper Removal: Mitigating Resistance in an Anthropogenic Altered Landscape. Presented at the West Box Elder Community Resource Management Group meeting. A research review and summary. Park Valley UT, Fall 2019.

Small, J. Greater Sage-Grouse Response to Pinyon Juniper Removal: Mitigating Resistance in an Anthropogenic Altered Landscape. Presented at the Annual Utah Wildlife Society Meeting in Bryce, UT, March 2017.

Small, J. Greater Sage-Grouse Response to Pinyon Juniper Removal: Mitigating Resistance in an Anthropogenic Altered Landscape. Presented at the Student Research Symposium, Department of Wildland Resources, Utah State University, April 2016.

Small, J. Seasonal home range sizes and habitat selection for Owyhee pronghorn. Undergraduate senior research project. Presented in the Department of Natural Resources at Washington State University, Pullman, WA, May 2013.

Collaborative Presentations

Picardi, S. and J. Small. 2020. Helping sage-grouse and land managers see the forest for the trees. Presented to Utah's Statewide Local Working Groups. Virtual Meeting, October 2020.

Messmer, T., S. Picardi and J. Small. 2020 Are we making a difference and effectiveness of fuel/vegetation treatments and restoration within Utah BLM? Presented to Utah bureau of Land Management Fire and Fuels Workshop. Virtual Meeting, November 2020,

Messmer, T., D. Stoner, S. Picardi, H. Wayment and J. Small. 2020. Deseret Land Livestock research update. Presented to Deseret Land Livestock wildlife and livestock mangers group. Virtual Meeting. December 2020.

Small, J and N. McKellar. Seasonal home range sizes and habitat selection for Owyhee pronghorn. Undergraduate senior research project. Presented in the Department of Natural Resources at Washington State University, Pullman, WA, May 2013.

Poster Presentation

Small, J. 2019. If it's not good for the community; it's not good for wildlife: sage lessons from Grouse Creek, Utah. Poster session at the Wildlife Society's National Conference, Reno, Nevada, September 2019.

Small, J. 2019. Greater sage-grouse response to pinyon – juniper removal: prioritizing habitat manipulation across Utah. Poster Session at the Sagebrush Summit, Salt Lake City, UT, February 2019.

Publications

Chelak, M., **J. Small** and D. Dahlgren. 2020. North American Forest Grouse Harvest Regulations. Jack Berryman Institute, Utah State University Extension. https://www.usugrouserange.com/

Technical Reports

Small, J. and T. Messmer. 2018. Greater Sage-Grouse Responses to Pinyon - Juniper Removal: Mitigating Resistance in an Anthropogenic Altered Landscape. 2018 Annual Report

Small, J. and T. Messmer. 2017. Greater Sage-Grouse Responses to Pinyon - Juniper Removal: Mitigating Resistance in an Anthropogenic Altered Landscape. 2017 Annual Report

Small, J. and T. Messmer. 2016. Greater Sage-Grouse Responses to Pinyon - Juniper Removal: Mitigating Resistance in an Anthropogenic Altered Landscape. 2016 Annual Report

Teaching

Wildland Resources 2400 undergraduate course. Instructed a telemetry workshop for undergraduates on the proper techniques for using telemetry to track for animal species marked with both GPS and VHF transmitters. Utah State University, Logan, UT, September 2019.

Natural Resource 2000 undergraduate course. Participated in instructing undergraduates on the proper techniques for using radio telemetry to track animal species marked with Very High Frequency (VHF). Utah State University, Logan, UT, September 2019.

Professional Training

May 2013

Natural Resource Conservation Service Vegetation Protocol Training
State Office, Boise, Idaho
Instructor: Brendan Brazee

February 2014

Forest Stand Inventory and Analysis Training
Northwest Management Inc. Moscow, Idaho
Instructors: Mark Stutzman

April 2014

Red Card Certified Wildland Firefighter Training
Northwest Management Inc. Moscow, Idaho
Instructor: Karl Radcliffe

March 2016

Resource Selection Function Workshop
Utah State University, Logan, Utah
Instructors: Michel Kohl and Peter Mahoney

Professional Memberships

The Wildlife Society (2018)
The Wildlife Society – Utah Chapter (2016)