Owyhee Rangeland Fire Protection Association:
Geoplanning for Future Landscape Management Efforts

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In Partnership With:

NSF · GEM3 Genes by Environment Modeling · Mechanisms · Mapping · Idaho EPSCoR · University of Idaho

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Approval

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Master's Project Committee Members

Daniel Cronan, Master's Project Chair

Master's Project Chair Approval

Date: ______________________ Signature: _________________________________

Abstract

This project employs stakeholder-driven scenarios identified in the National Science Foundation's (NSF) Established Program to Stimulate Competitive Research (EPSCoR) Genes by Environment: Modeling, Mechanisms, and Mapping (GEM3) program's Owyhee site (in southwest Idaho) to determine plausible alternative futures with respect to fire regime change and best management practices (BMP's) in the region. The mixed-methods approach of this project makes use of spatiotemporal Geographical Information System (GIS) data, local knowledge and ideals, as well as statistical modeling, specifically forest-based forecasting, to create a clearer picture of what the future of the region could look like given stakeholder-driven scenarios of future land use and land cover change. Results provide a framework for disseminating the process as well as potential solutions to address fire uncertainty. It is hoped the outputs of this project will help lead to a more cohesive and effective overall management strategy for wildfire in the rangelands of the northwestern US that begets a reduction in the prevalence and intensity of large ecosystem-altering fires in the future resulting in the better protection of existing, and the creation of new, healthy sustainable sagebrush steppe ecosystems for the benefit of the native fish and wildlife that rely on them as well as for the benefit of current and future generations of recreators and land users.

Acknowledgements

First and foremost, I would like to thank my unbelievably supportive and understanding wife, Alyssa Vincent. She has been my rock and guiding light throughout this entire endeavor. She was always there whenever my hysteria needed quelling, whenever I needed a shoulder to cry on, whenever I needed critiques every 15-20 minutes over the course of entire work days for writing or during design studios, and whenever I needed her sight for ensuring my "broken eyes" didn't color water purple or grass some horrid yellow color I mistook for green. Regardless of what I needed from her, she has always been there; and all while she too was slogging through the exact same Landscape Architecture Masters program no less! Alyssa, thank you. I love you more than you can know.

Secondly, I would like to thank my major professor Dan "The Man" Cronan. His constant guidance, encouragement and friendship have helped me stay sane and shed the ever-present feeling of "imposter syndrome" throughout this entire labyrinthine journey. I not only see you as a good friend, but as the greatest mentor I have ever had the pleasure and honor of learning from; one whose example I intend to emulate and hopefully one day live up to. Dan, I would never have been able to complete this program without you. Thank you so much for helping Alyssa and I find our way.

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Section Overviews

Introduction

This chapter introduces the motivation for the project and will give historic, current and spatial context about the chosen study site in addition to an overview of its overall goals, objectives and integration into both the grant which funded it’s efforts and into the field of geodesign as it relates to landscape architecture.

Methodology

Here, the robust methodology used in the completion of this project is outlined in detail; beginning with introductions to the selected scenarios of future landscape change moving through the forecasted future data, zone delineation and finally the creation of treatment method geospatial layers.

Results

Next, the findings of the methodology are laid out section by section as they relate to each of the selected scenarios of future landscape change.

Discussion

Finally, in this chapter after restating the goals and objectives of the project, the implications of the previously outlined results are presented, the resultant HUB application will be described, suggestions for its use are given and will ultimately conclude with a brief reflection of possible future applications, limitations encountered, and next steps.

Introduction

Project Motivation

Wildfire regimes in the western US have changed drastically post Euro-American settlement of the area (Abatzoglou & Williams, 2016; Miller et al., 2011; Westerling, 2016). Wildfire activity, amount of area burned, number of large fires per season and fire season length have all seen a marked increase beginning in the mid 1890's; a trend that has only continued through to today with stark increases to that upward trajectory occurring in the past half century (Abatzoglou & Williams, 2016; Westerling, 2016). This increase in wildfire prevalence, intensity and length of the burn season has helped lead to the drastic alteration of sensitive habitats, instances of widespread forest mortality, increases in carbon emissions, growing periods of degraded air quality, and a substantial increase in fire suppression expenditures (Abatzoglou & Williams, 2016; Chambers et al., 2014, Miller, 2011). Being that the majority of this increase has occurred in the ecoregions of the Northwestern US, steps must be taken to help better understand and manage the region both pre- and post-fire throughout the complex mosaic of land ownerships in the region to either lessen the occurrence of detrimental ecosystem-altering fires or mitigate their effects (Abatzoglou & Williams, 2016; Westerling, 2016). We hypothesize that if fire regime change in the ecoregions of the Owyhee area, driven by externalities from contributing variables, could be better understood and managed then a combination of regional and site specific robust and adaptive best management practices (BMPs) can be developed. These practices can be achieved through a socio-ecological system (SES) scenario-driven alternative futures framework to aid in long-term fuels reduction and rangeland restoration in the chosen study area as well as similar, but spatiotemporally unconnected ecoregions.

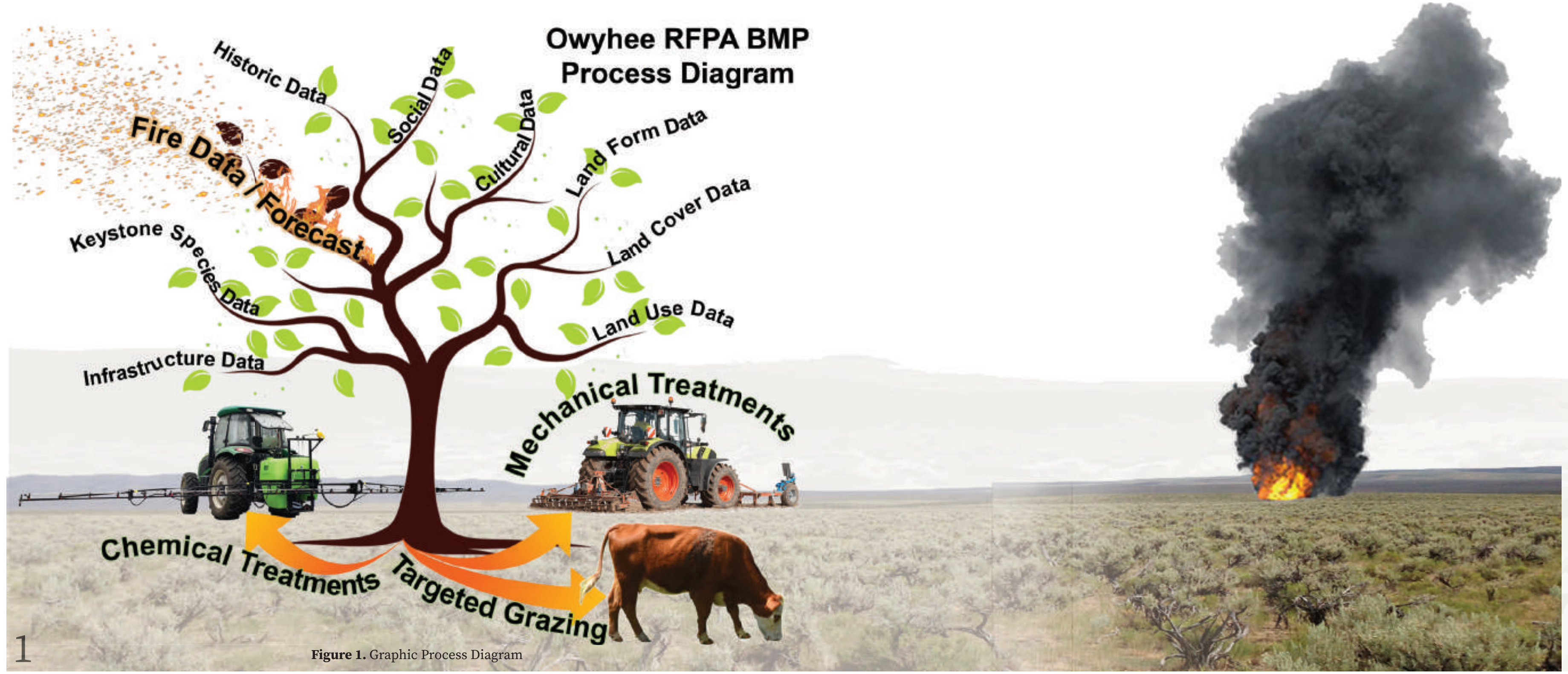


Figure 1. Graphic Process Diagram

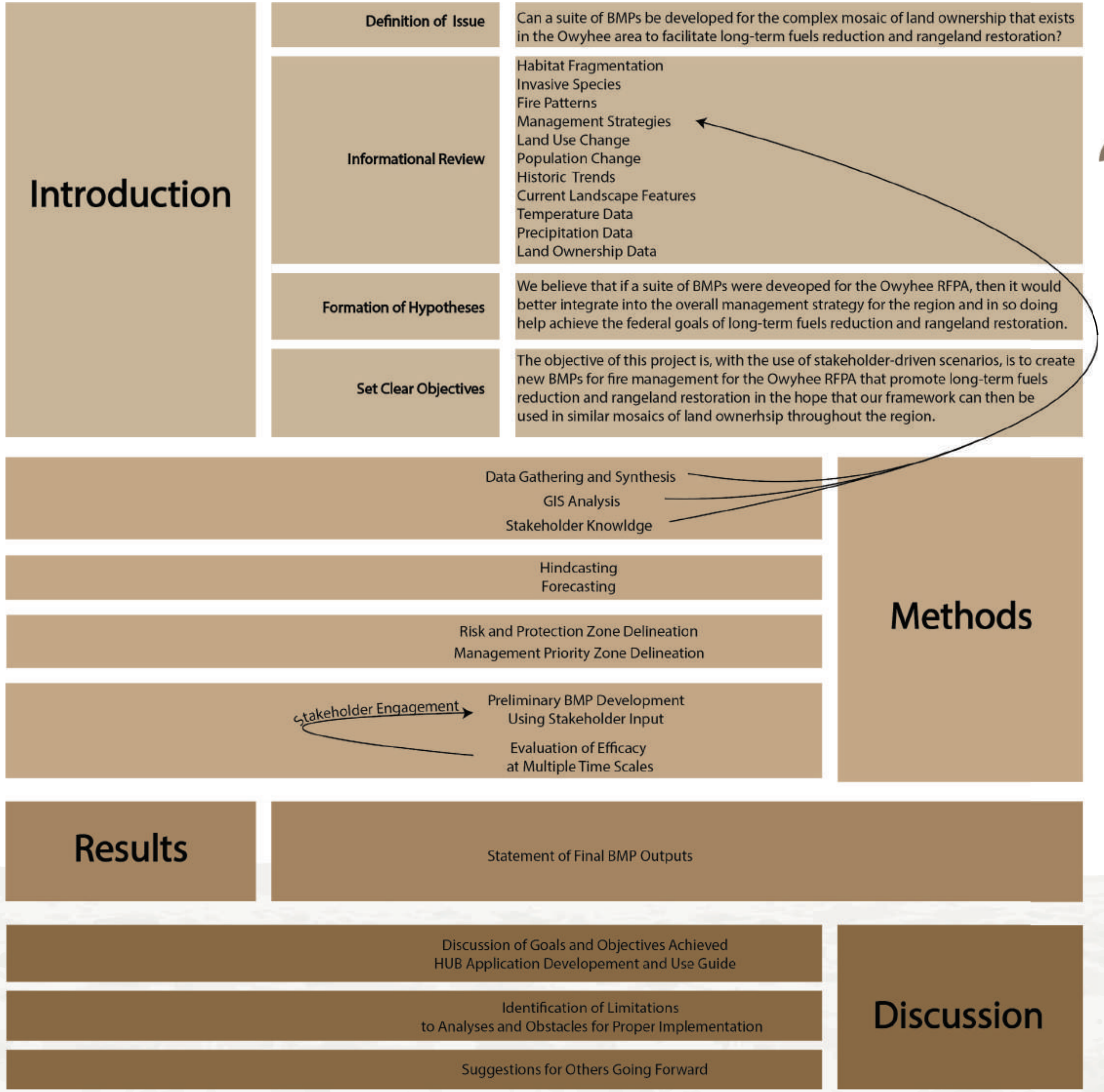


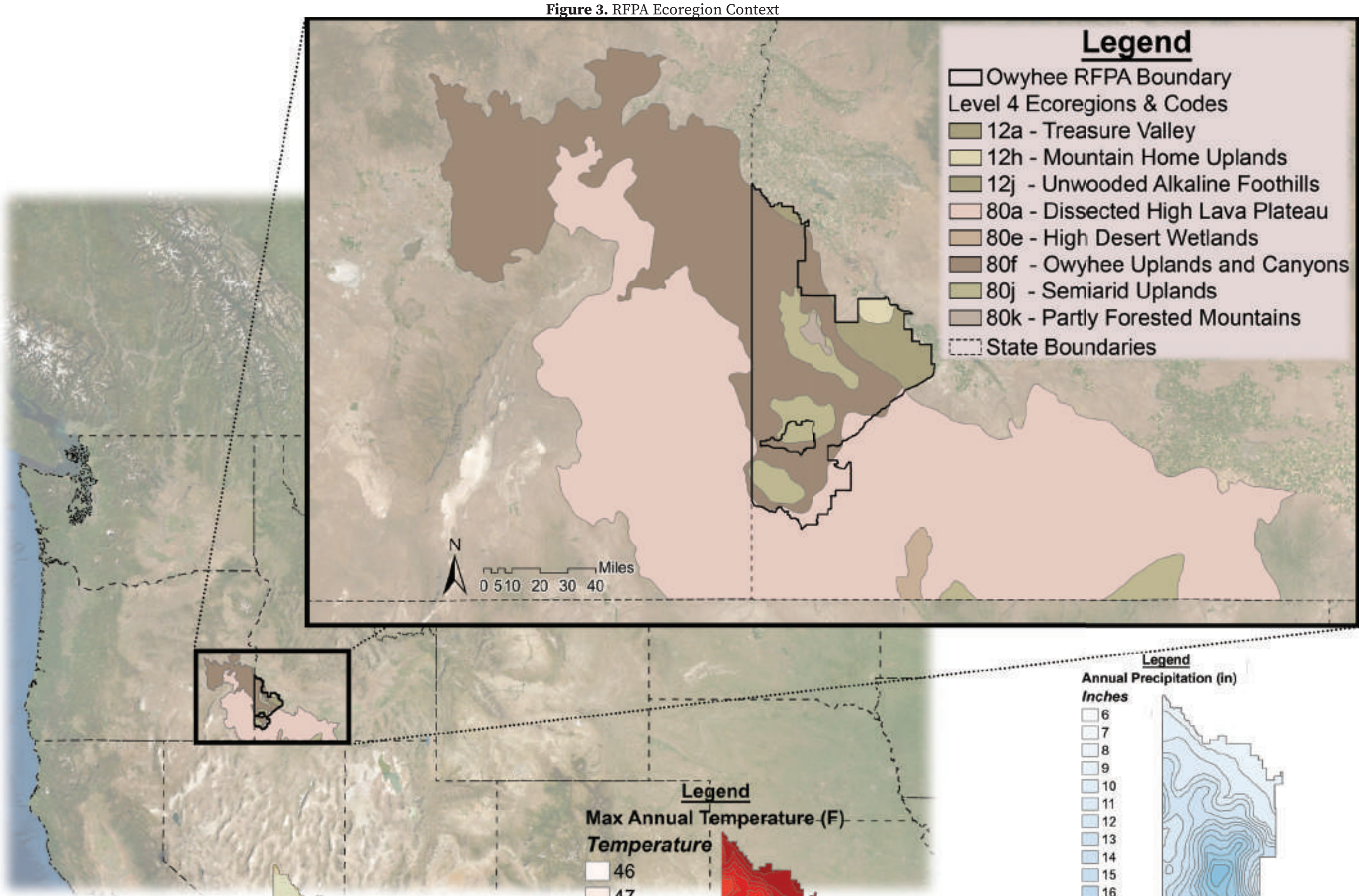
Figure 2. Process Diagram

Study Site

The overarching area that has been chosen to conduct this project consists of the level 4 ecoregions of the Dissected High Lava Plateau (80a), High Desert Wetlands (80e), Owyhee Uplands and Canyons (80f), Semiarid Uplands (80j) and Partly Forested Mountains (80k) together make up the “Owyhee area” and span southwestern Idaho, southeastern Oregon and, for the purposes of this study, are bordered by northern Nevada. Moreover, the regional BMPs of this project were refined down to a more site-specific scale within the overarching Owyhee area to aid in the generation of more cohesive and comprehensive management practices throughout the mosaic of land ownerships found in the region. To that end, the primary study site of the project was chosen as the area encompassed by the Owyhee Rangeland Fire Protection Association (Owyhee RFPA). The Owyhee area is characterized by its high desert plant and animal communities, which live in a landscape that is dominated by deep canyons, plateaus, and tall mountain ranges (Fesenmyer & Dauwalter, 2014). Historically, in areas of lower elevation the dominant land cover has been sagebrush steppe. This transitions to montane forests of conifer in the higher elevations (Fesenmyer & Dauwalter, 2014). While there is a large amount of private land throughout the area, most of the land ownership in the Owyhee area is public (roughly 85%) and so is diverse in its overall use types with an emphasis on mining and grazing in addition to the recreational aspects of the area (Fesenmyer & Dauwalter, 2014). Furthermore, with such large remote and tracts of land being primarily managed by single entities, management actions within the Owyhee area may be able to be implemented more comprehensively than elsewhere if the knowledge, equipment and manpower of the local rangeland working community is properly integrated into the federal management plans for detection, prevention and suppression efforts. This has clear implications for the efficacy of the management actions imposed. To that end, the Owyhee area with its diverse management structure and increased fire prevalence over the recent decades, commensurate with the increase in fire regimes of the rest of the northwestern US, represents a unique opportunity for developing new and innovative management techniques to help prevent and mitigate the detrimental effects of these ever-increasing fires in similar habitats (Fesenmyer & Dauwalter, 2014).

Image 1. The Owyhee Landscape. *Image Credit*: Mark W. Lisk

Figure 3. RFPA Ecoregion Context



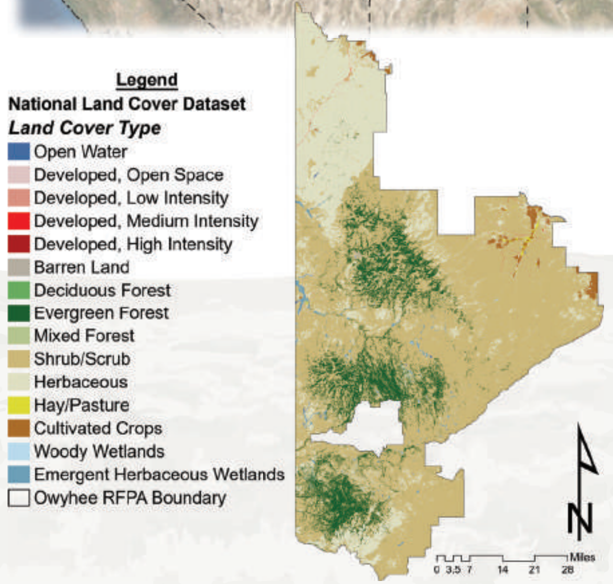


Figure 4. RFPA National Land Coverr Dataset (NLCD)

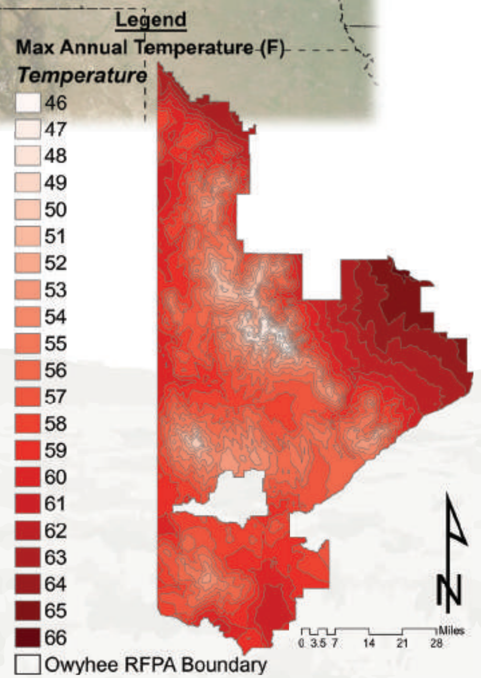


Figure 5. RFPA Max Average Annual Temperature

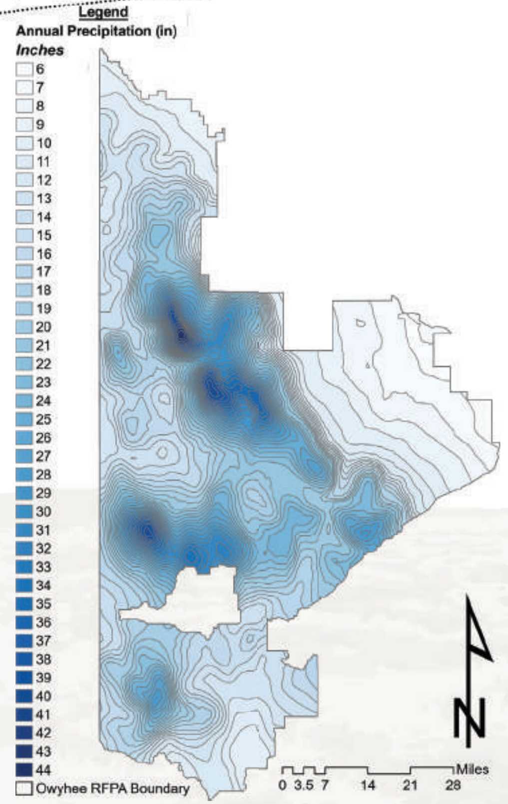


Figure 6. RFPA Average Annual Precipitation

Literature Review

Fire Ecology Overview

To begin this discussion, it is first important to gain an understanding of fire ecology, fire regimes, and the past and present management strategies within the United States. To that end, this document begins with fire ecology. Fire ecology is a complex area of study focusing on the natural processes of fire on the landscape. It can be broken into two distinct lenses for assessment: fire regime and fire risk. These two categories can be further explained through a multitude of dynamic factors including, but not limited to, changes in climate, weather, fire hazard and vulnerability, anthropogenic interaction, fuel loads, moisture content, heat and sources of ignition as well as how interactions between these factors can come together in an interconnected web to influence the scope, size, intensity, prevalence and benefits or detriments of when and where fires occur (Abatzoglou & Williams, 2016; Wildland Fire Leadership Council, 2012; Calviño-Cancela et al., 2016; Fischer et al., 2016; Hulse et al., 2016; Stephens et al., 2012; Taylor et al., 2013; USDA Forest Service, 2022b).

In this study the framework developed by the Institute for a Sustainable Environment Lab (Hulse et al., 2016) was built upon to map the fire risk of where and when surprising fires are predicted to occur. This initiative helped tailor the management proposals to the study area. Working from C.S. Holling's definition of surprise from his 1986 paper (Holling, 1986), which stated surprise is, "when perceived reality departs qualitatively from expectation", Hulse et al. determined that a surprise fire was equal to the size of the largest fire to occur within the study area in the 50 years directly preceding his study. The authors also determined that the key factors that must typically all be present to initiate a large fire are extreme fire weather, an ignition, a sufficient amount and arrangement of flammable fuels, and topography that, coinciding in time in space, allow the fire to spread rapidly and far (Hulse et al., 2016). These parameters were used as the basis for how this project modeled when and where fires are predicted to occur within the study area in the coming decades. The following sections will provide an overview of relevant research for variables that were examined as well as the current conditions of the study area.

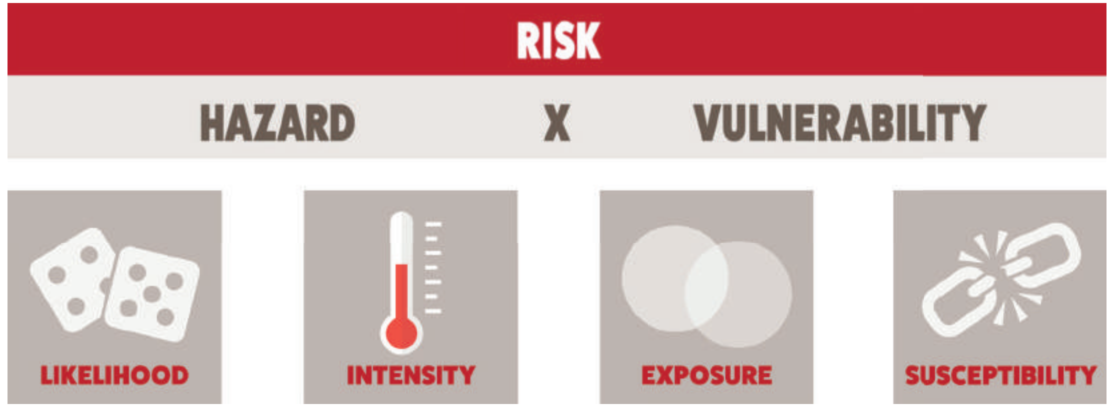


Figure 7. Wildfire Risk. *Adapted From:* USFS (2020)

Fire Regimes

Fire regimes are defined as, "the general characteristics of fires found within any specified area of interest" (Skinner and Chang, 1996). They can be described through five characteristics typically represented through the median of data points derived from (1) frequency, (2) rotation, (3) spatial extent, (4) magnitude, and (5) seasonality to adequately represent the wide variation in each of these factors (Skinner and Chang, 1996). See Figure 8 for a visual representation of the fire history of the area. Fire regime frequency, or return interval, refers to the length of time between fires on a given landscape. Rotation is the length of time it takes for an area within and equal to the size of the area encompassed by a given landscape to burn. This does not mean every square inch of land within the given landscape must burn, rather it refers to the amount of time it would take for fires within the area of interest to burn enough land to equal that of the total area of the site. Spatial extent is expressed as the mappable extents of a given fire on the landscape. Magnitude is a combination of a given fires intensity and severity where intensity is a measure of energy released and severity is a measure of the impacts the given fire has on changing ecosystem processes and functionality. Lastly, seasonality demarks the timing of a given fire throughout the year. This is important as the timing of a fire will affect the other factors determining regime since moisture regimes change as the year progresses and ecosystems are either receptive or averse to fire depending on when they occur temporally (Skinner and Chang, 1996).

Figure 8. Fire History of the Owyhee Area 1950 - 2020

Evolution of U.S. Fire Policy

Fire management policy in the United States has been, and at this point in time still is, undergoing a shift in priorities for the better part of the past half century (Abrams et al., 2021; Dombeck et al., 2004; North et al., 2015). Prior to that, the prevailing objective of federal firefighting agencies was complete suppression of wildfires wherever and whenever they occurred (Dombeck et al., 2004). This policy originated out of a nationwide disdain for wildfire after a series of large destructive fires occurred in the late 1800's and early 1900's (Dombeck et al., 2004). Two fire years, in particular, served to galvanize this public opinion. First, in 1871, the Peshtigo Fire in northern Wisconsin killed roughly 1500 people and scorched over 486,000 ha of land (Pyne, 1982). See Image 2 for artist Mel Kishner's famous depiction of the event; painted in 1968. Then in the year 1910, also known colloquially as the "Year of the Great Fires", over 2 million hectares in the American northwest were burned, towns were lost, and 78 firefighters, in addition to many civilians, lost their lives (Pyne, 2001). Driven by the destruction wrought by these and other large fires during the era, in 1935 the "all fires out by 10 a.m." policy was adopted by the federal government (Pyne, 1982). This goal of complete suppression was not realized, however, until the end of the second World War when the United States finally had the necessary workforce and equipment available to do so (Dombeck et al., 2004). While in the short term the results were favorable, fuels that normally would have burned during lower-intensity fires began to build up across the country and in 1988 the massive Yellowstone Fires were the some of the first to produce the fruit of the federal government's labors and in-so-doing sparked national debate over the nations fire policy (Dombeck et al., 2004). See Figure 9 for a visualization of the size of the 1988 fire as well as ones that have occurred since in that area.

In their recently published paper, Abrams et al. (2021) conducted an in-depth analysis of the past and present management structure and strategies of the largest wildland firefighting force in the United States the United States Forest Service (USFS) (Abrams et al., 2021; North et al., 2015). This federal agency currently is responsible for the care and management of over more than 193 million hectares of forests and grasslands throughout the United States (Abrams et al., 2021; USDA Forest Servcie, 2022a). Their analysis of USFS management strategies began with the National Forest Management Act of 1976. Through this legislation the goals and objectives of the USFS were incentivized to achieve quantifiable results that were resource output-oriented (Abrams et al., 2021). Integral to meeting those benchmarks, which were and still are necessary to ensure continued funding of the agency, was the continued implementation of a policy of all-out suppression of fires (Abrams et al., 2021; Dombeck et al., 2004; North et al., 2015). This modus operandi began to clash with environmental protection laws as well as with a shift in the mindsets of much of the American public around the turn of the century (Abrams et al., 2021; Dombeck et al., 2004). At that point, the rules governing the agency started to move away from this timber production-centered ideology towards a more wholistic ecosystem management approach which stressed the incorporation socio-ecologic systems (SES) into the planning process (Abrams et al., 2021; Dombeck et al., 2004; Koontz and Bodine, 2008).

Since the turn of the century, this shift in ideology has been painfully slow. For example, both Dombeck et al. (2004) and North et al. (2015) have shown that 98% of wildfires in the United States are extinguished before they exceed 120 ha in size. This might seem cost effective until one understands that the 2% that escape containment account for the vast majority (97%) of firefighting costs and total area burned in the United States (North et al., 2015). These costs are not minuscule either and are only growing more costly. This is evidenced when one looks at how the costs related solely to the suppression of fires have reached an average of over $1.9 billion in the past ten years and an average of over $2.3 billion in the past 5 years with an all-time high of $3,143,256,00 in 2018 (National Interagency Fire Center, 2020).

Image 2. Peshtigo Fire I: Refuge in a Field. *Image Credit*: Mel Kishner - 1968

This progress has been slow despite the passing of multiple legislative shifts in policy including the National Fire Plan in 2000, the FLAME Act of 2009, the National Forest Management Act of 2012 and the National Cohesive Wildland Fire Management Strategy of 2014; all of which stress the need for implementation of more adaptive management strategies emphasizing the use of mechanical thinning treatments, prescribed burns and necessity of managed fire on the landscape (Abrams et al., 2021; Dombeck et al., 2004; North et al., 2015). This at first may seem counterintuitive, but when one looks at the issue through the lens of an SES perspective things begin to come into focus. While, from a policy standpoint, the building blocks for adaptive management are currently in place, these policy changes have failed to also bring down the institutional barriers that exist at multiple scales (Abrams et al., 2021; Dombeck et al., 2004; Koontz and Bodine, 2008; North et al., 2015). These include, but are not limited to, the need to maintain existing mandates for saleable timber volume, conflicts with existing environmental laws, ambiguity or complexity of overarching goals, conflicting agendas of involved stakeholders, limited budgets, liability and or casualty risks, little tolerance for management errors and bureaucratic infighting (Abrams et al., 2021; Dombeck et al., 2004; Koontz and Bodine, 2008; North et al., 2015).

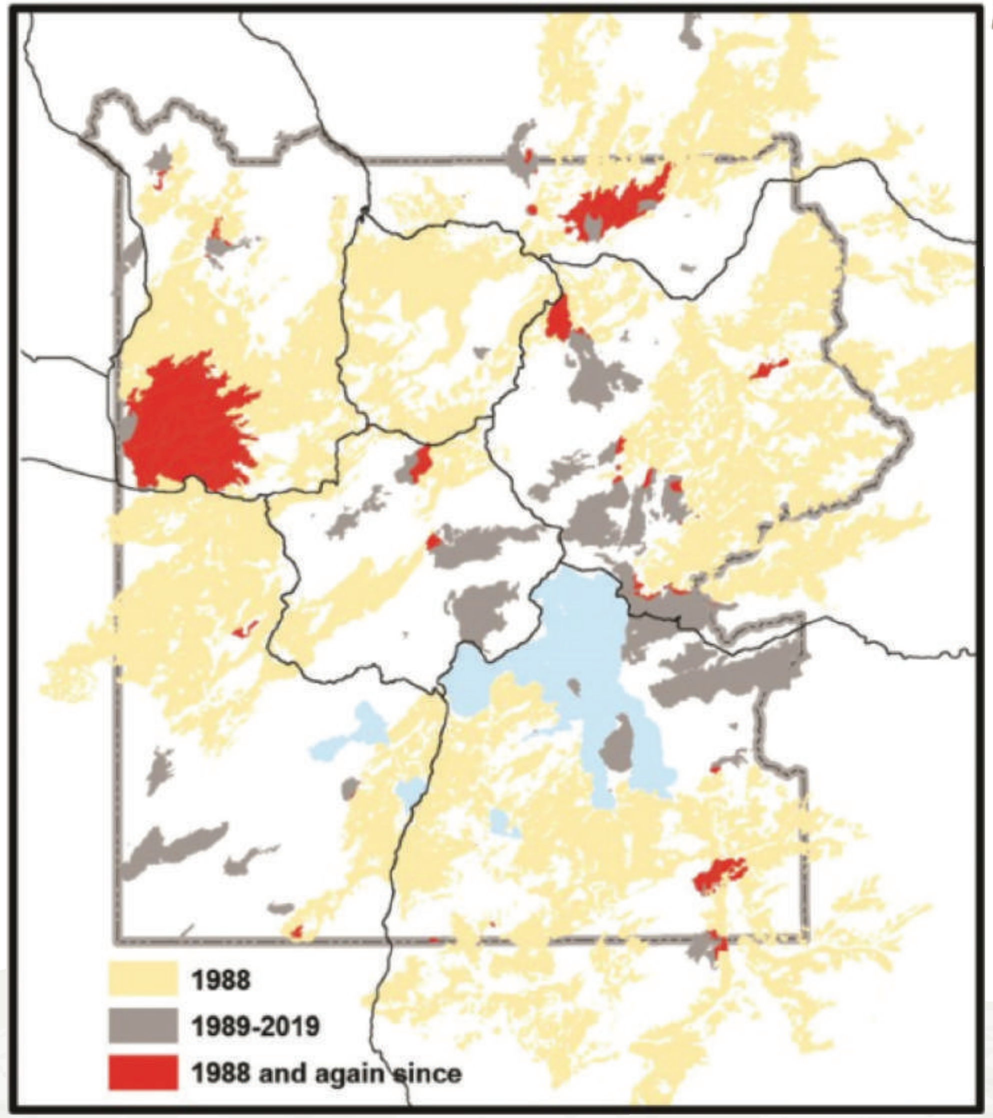


Figure 9. Graphic Illustrating Burned Areas in Yellowstone from 1988 to 2019. *Figure Credit*: U.S. National Parks Service

Invasives and Fire: A Global Assessment

In addition to, and in conjunction with, maladaptive management practices such as the ones that were just evidenced, throughout the world a litany of peer-reviewed literature has also shown a clear connection between many invasive plants and altered fire regimes (Calviño-Cancela et al., 2016; Chambers et al., 2014; D'Antonio, 1992; D'Antonio et al., 2000; Diamond et al.; Dubinin et al., 2011; Rahlao et al., 2009; Setterfield et al., 2010; St. Clair & Bishop, 2019; Wildland Fire Leadership Council, 2012; Wagner and Fraterrigo, 2015; Woods et al., 2013). For instance, in the arid shrublands of South Africa, Rahlao et al. (2009) found that the invasive "fountain grass" (*Pennisetum setaceum*) has been driving novel fire cycles in the once seldom burned Karoo ecosystem. In Australia, Setterfield et al. (2010) showed how gamba grass (*Andropogon gayanus*) has resulted in altered fire regimes in the northern savannas of the continent. Even in southern Russia the invasive grass *Stipa capillata* has been found by Dubinin et al. (2011) to have contributed to the increase in burned area after the fall of the Soviet Union in 1991. North America as well has not been spared from the havoc invasive species can wreak on natural fire regimes. In the hardwood forests of the eastern United States the invasive camas species *Microstegium vimineum*, originally from southeastern Asia, has been instrumental in the increases in fire seen there, where it creates dense "lawns" of flammable material throughout the understory (Wagner and Fraterrigo, 2015). Additionally, multiple studies have shown the clear connection between *Bromus tectorum* (hereafter cheatgrass) and the creation of positive feedback loops between it and fire as well as the increased fire risk associated with encroachment of single-leaf piñon pine (*Pinus monophyla*), two-needle piñon pine (*Pinus edulis*), western juniper (*Juniperus occidentalis*), Rocky Mountain juniper (*Juniperus scopulorum*) and Utah juniper (*Juniperus osterosperma*) (hereafter piñon-juniper woodlands) in the Great Basin of the American West (D'Antonio, 1992; Williamson et al., 2020; Chambers et al., 2014; D'Antonio et al., 2000; Woods et al., 2013).

Image 4. A House Burning in Lake Conjola, New South Wales, on New Years Eve. *Image Credit*: Matthew Abbott

Image 3. Unburned (Left) and Burned (Right) South African Veldt at the "Mills Site" Three Years Post-Fire. *Image Credit*: Justin Christopher Okesdu Toit - 2015

The Owyhee Area Fire Regime: *Prehistoric and Current*

Prehistoric Fire Regime

To gain a greater understanding of fire ecology on the landscape of the chosen study area it is important to also understand both the past and present conditions and drivers of fire regime within the region. This prompted this project to investigate the distant past of the Great Basin of the western United States. For at least the past 13,000 years prior to Euro-American settlement of the region the landscape was inhabited, modified and stewarded by the peoples of many different Native American tribes including, but not limited to, the Shoshone, Bannock, Paiute, Washoe and Ute peoples (Griffin, 2002; Kitchen, 2016). See Figure 10, originally from Grayson (1993), used in Griffin (2002). It is understood that many of the nomadic peoples of this area utilized fire over millennia for a multitude of reasons ranging from growth promotion of key plant species to driving game during hunting practices as well as out of spiritually driven stewardship motivations (Griffin, 2002; Kitchen, 2016). Sadly, information detailing the extent to which these methods were employed as well as a concrete consensus among the scientific community on the degree of their subsequent effects on the landscape is currently lacking. However, from the information that does exist it can be inferred that, in addition to the prevailing climatic and non-anthropogenic drivers of fire that existed during prehistoric times, human-caused fire events in the region have been to some extent a natural part of the ecosystem for millennia (Griffin, 2002; Kitchen, 2016). As such, current and future wildfire management efforts should continue to embrace prescribed burns not only as an anthropogenic management technique, but as a natural part of the fire regime of the landscape where applicable.

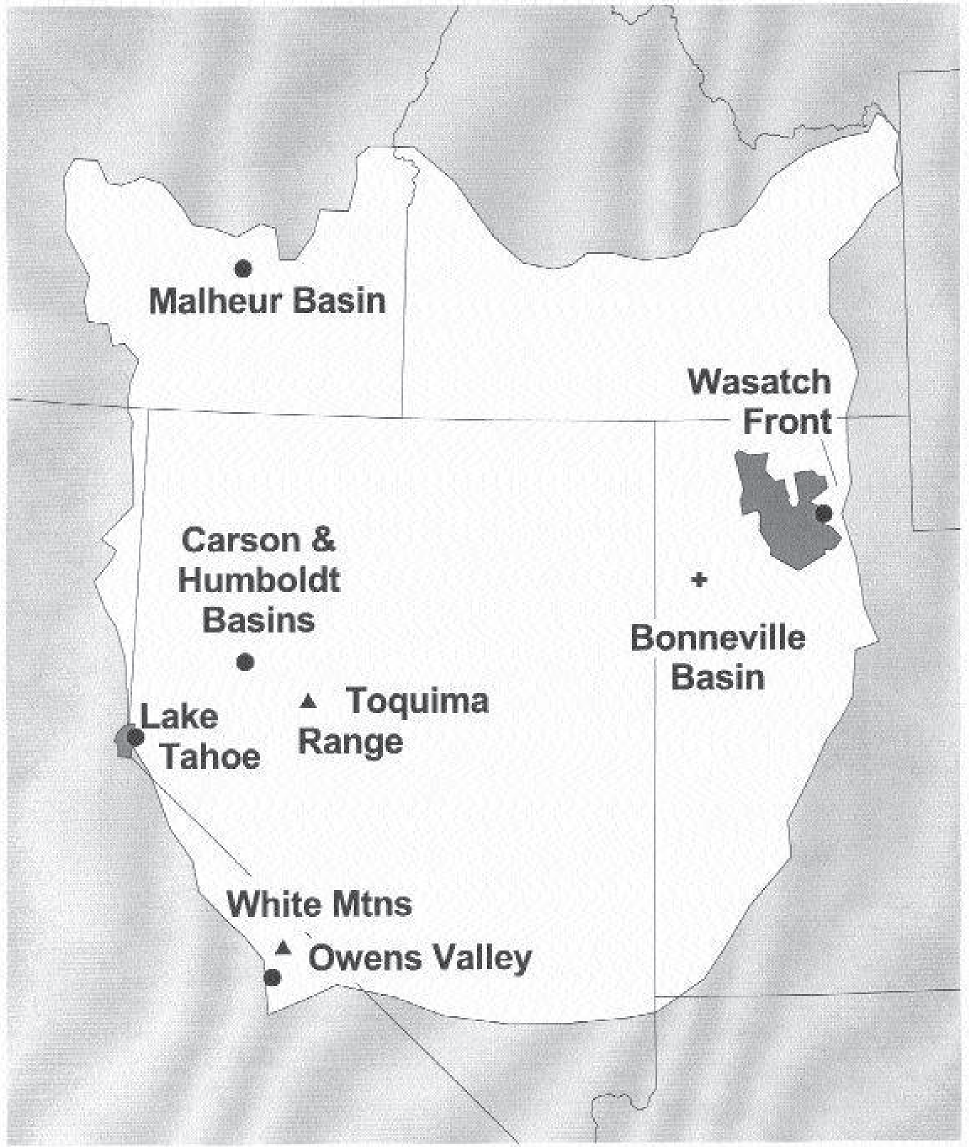


Figure 10. Locales Where Human Populations are Known to Have Been Concentrated in Prehistoric Times. *Figure Credit*: Grayson (1993)

In terms of historic non-anthropogenic drivers of fire in the Great Basin, the prevailing scientific literature indicates fire regimes were products of the interplay between fluctuations in the Pacific Ocean surface temperature cycles, specifically the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) (which are the main drivers of precipitation cycles in the American West) as well as more locally explicit drivers such as site burn history, elevation, plant community makeup and prevailing soil conditions (Griffin, 2002; Kitchen, 2016). In their 2016 study of prehistoric fire regimes Kitchen, found that regionally a cycle of ENSO and PDO driven years of "wet" environmental conditions typically begot an increased abundance in fine fuels. Those years were then succeeded by years of "dry" environmental conditions that promoted predominantly late-season surface-level burns of these higher abundances of fine fuels (Kitchen, 2016; Miller et al., 2011). See Figures 11 and 12 for graphic representations of these concepts.

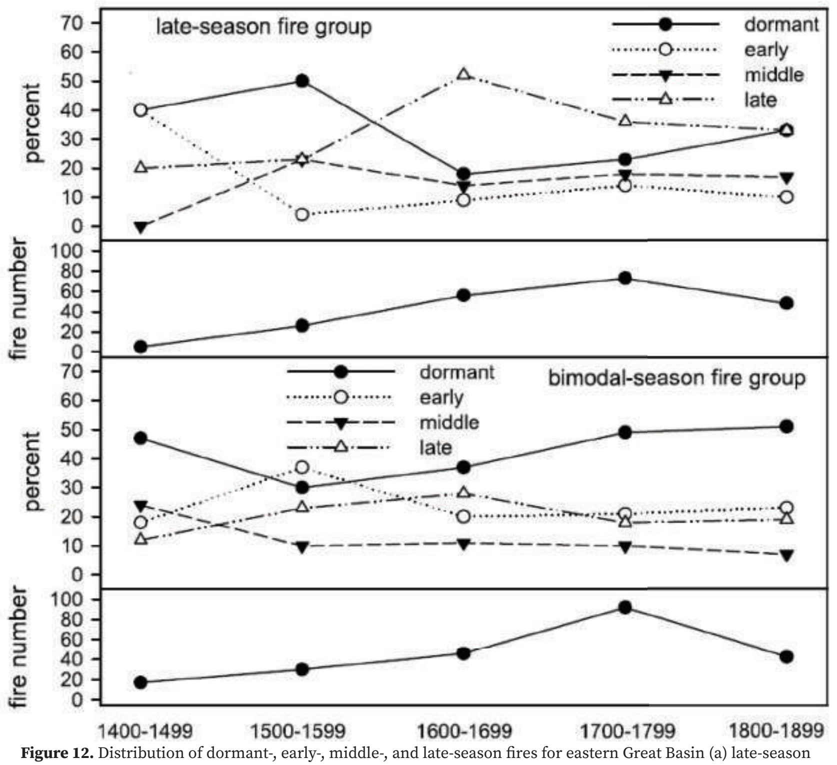


Figure 12. Distribution of dormant-, early-, middle-, and late-season fires for eastern Great Basin (a) late-season dominant and (b) bimodal-season sites across five centuries (1400–1900). Individual site fires were pooled in 100-year bins for each group/season combination. *Figure Credit*: Kitchen (2016)

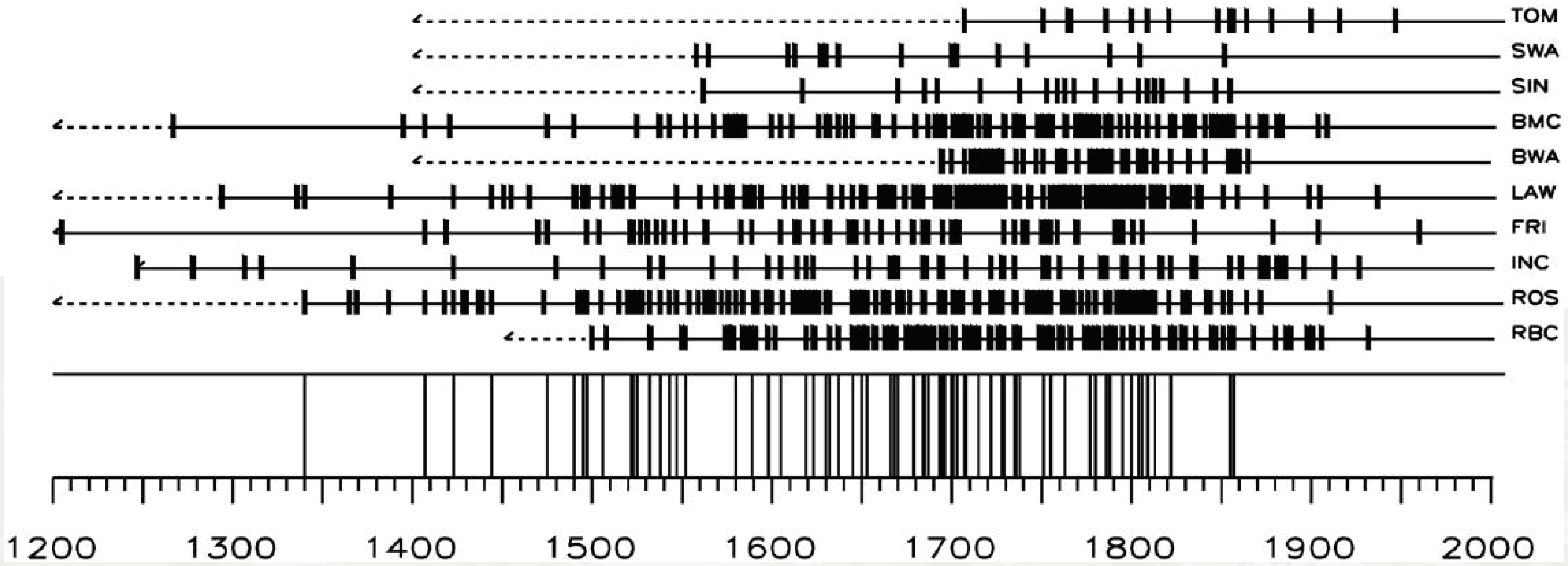


Figure 11. Fire chronologies for 10 eastern Great Basin sites arranged from north (top) to south. Horizontal lines are composite records of fire for each site. Solid lines indicate at least one tree is in recording status. Short vertical lines mark fire dates. Long vertical lines indicate timing of regional fire years in which >33% of recording sites recorded fire. *Figure Credit*: Kitchen (2016)

Within these overarching wet and dry climatic cycles, at more of a site scale, historic fire return intervals can be better approximated through delineation of the prevailing soil moisture and temperature regimes that make up the particular area of interest (Griffin, 2002; Miller et al., 2011). See Figure 13 taken from Miller et al. (2011) for a representation of this concept. Through analysis of these different communities, it has been found that xeric (very dry) soil as well as wetter high-elevation forest communities had typical fire return intervals surpassing 100 years (Griffin, 2002). In the xeric communities this was a result of the sparse vegetation being too spread apart to normally carry fire and in the high-elevation forests it was a result of a combination of the wetter conditions coupled with the rocky makeup of the soil typical at those altitudes (Griffin, 2002). Sagebrush communities were found to have had a wide range of fire return intervals depending its specific soil temperature and moisture regime that ranged from over 100 years in the more lowland xeric communities consisting of predominantly Wyoming big sagebrush (*Artemisia tridentata ssp. wyomingensis*) to under 20 in wetter mid-elevation sites mainly composed of mountain big sagebrush (*Artemisia tridentata ssp. vaseyana*) with the bulk of intervals being found to have occurred between 20 and 50 years (Griffin, 2002; Miller et al., 2011). Grasslands in the region were found to have return intervals of 10 years or less and piñon-juniper woodlands exhibited return intervals between 10 and 30 years (Griffin, 2002; Miller et al., 2011). This interval in the piñon-juniper woodlands was determined to be optimal to the promotion of open "savanna-like" ecosystems relegated to steep or rocky terrain (Griffin, 2002; Miller et al., 2011).

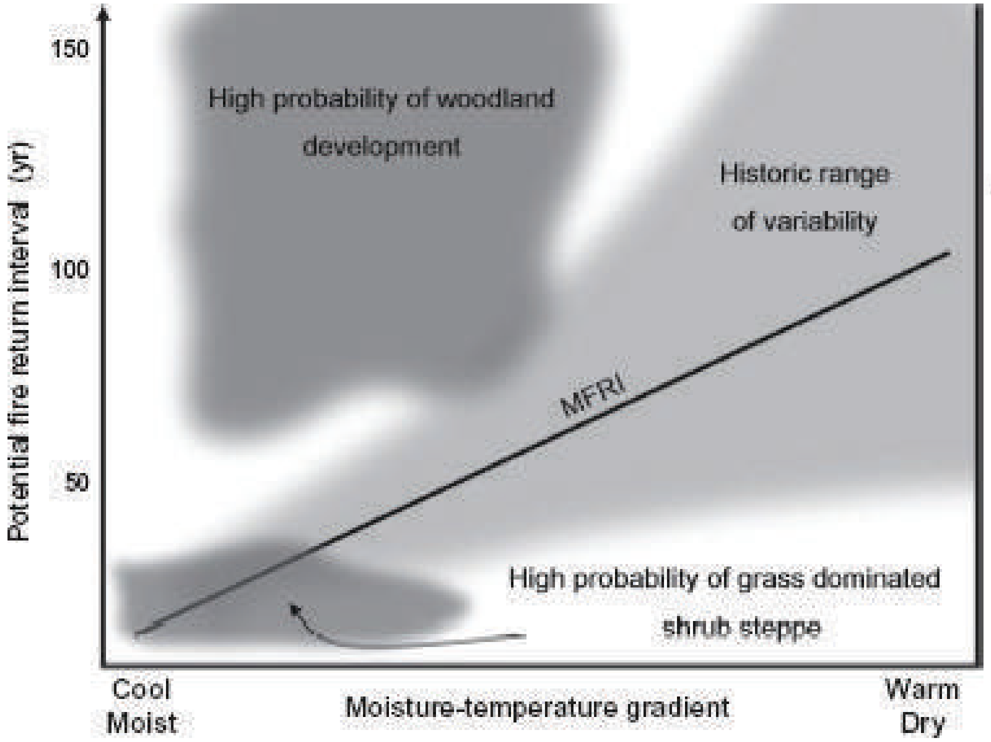


Figure 13. Conceptual model illustrating the historic potential mean fire return interval (MFRI) and historic range of variation (light gray area) in sagebrush steppe as it relates to temperature and moisture, resulting in a change in structure, composition, and abundance of fuels. Persistent vegetation that occupies the light gray area would likely be a sagebrush herbaceous mix, although herbaceous vegetation would occupy the site immediately following fire until the sagebrush stand redeveloped. *Derived By*: S. C. Bunting and R. F. Miller

To better understand what these return intervals meant on the landscape, the difference between fire return and rotation intervals must be considered. For example, in the sagebrush ecosystems of the Great Basin, it has been estimated that the time it takes for many sagebrush canopies to recover to pre-disturbance levels fluctuates anywhere between 15 and 50 years; 30-35 years in cooler, moister sites (Miller et al., 2014). This already long timespan is vastly extended when addressing pre-disturbance recovery of canopy in Wyoming big sagebrush communities, where estimates of recovery time are, "very slow to nearly nonexistent" (Miller et al., 2014). While, upon cursory examination of these statistics, fire return intervals might seem relatively short in many areas when compared to the time it takes for these communities to return to pre-disturbance levels this does not mean that the entirety of each sagebrush community burns during every fire event. Here is where rotation intervals become more relevant. Fire rotation in these ecosystems pre-Euro-American settlement has been estimated to be >200 years in little sagebrush (*Artemisia arbuscula*), 150-300 years in mountain big sagebrush, 40-230 years in montane grasslands that contain patches of mountain big sagebrush with these rotational times extending where sagebrush and forests intermix, and 200-350 years in the slow-to-recover Wyoming big sagebrush communities (Baker, 2011). This can be better understood through the information presented in Table 1. Thus, while the fire return intervals in these sagebrush ecosystems were relatively short and comprised of infrequent large, high-severity fires succeeded by long temporal periods of intermittent lower-severity fires occurring on the landscape, the long prehistoric fire rotation intervals in these ecosystems allowed for these slow-recovering shrubs to recolonize areas lost to burns (Baker, 2011; Miller et al., 2014).

In terms of the historic seasonality of these fires on the landscape, evidence gathered through analysis of tree ring boundary fire scars going back hundreds of years indicates that the typical fire season of the prehistoric Great Basin region was what would be considered currently to be “late-season” dominant, with most fires occurring from August on (Kitchen, 2016). This late-season dominant cycle persisted, with some intermittent bimodal (early- as well as the typical late-season burns) patterns that have been attributed to anthropogenic (Native American) causes, until the late 1800’s (Kitchen, 2016). From there, the fire regimes of the region broke from this previous trajectory and the fire-scar-based record exhibits a reduction across the region (Kitchen, 2016). This shift has been attributed to the effects livestock had on the fuels of the region as well as changes in human burning practices as the traditional burning practices of the Native Americans of the area were replaced by those of the Euro-American settlers (Kitchen, 2016).

		Original sources			Corrected estimates			
Taxon		Source	Setting	Estimate	After 3.6 mult. corr.	After 16.0 mult. corr.	Small sagebrush areas after no adj. corr.	Large sagebrush areas after 0.57 adj. corr., if needed
Little sagebrush	Young and Evans (1981)	Scars	Adjacent	95	342	1,520	—	195–866
	Miller and Rose (1999)	Scars	Intermix	138	497	2,208	497–2,208	—
	Bauer (2006)[a]	Rotation	Intermix	427	—	—	427	—
	Summary						>425	>200
Wyoming big sagebrush	Young and Evans (1981)	Scars	Adjacent	95	342	1,520	—	195–866
	Floyd et al. (2004)[b]	Rotation	Intermix	~400	—	—	~400	—
	Bauer (2006)[a]	Rotation	Both	427	—	—	427	243
	Shinneman (2006)	Rotation	Both	400–600	—	—	400–600	228–342
	Mensing et al. (2006)	Charcoal	Expanses	200–500[c]	—	—	—	200–500
	This chapter	Recovery	Expanses	Uncertain	—	—	—	Uncertain
	Summary						400–600	200–350
Mountain big sagebrush								
Fast track	This chapter	Recovery	Expanses	>50–70	—	—		>50–70
Slow track	This chapter	Recovery	Expanses	>150–200	—	—		>150–200
	Jacobs and Whitlock (2008)	Charcoal	Expanses	150–200	—	—	—	150–200
	Nelson and Pierce (2010)	Charcoal	Expanses	183	—	—	—	183
Near piñon-juniper	Burkhardt and Tisdale (1976)	Scars	Adjacent	>30–40	>108–144	>480–2,304	—	>62–1,313
	Wangler and Minnich (1996)[a]	Rotation	Intermix	480	—	—	480	—
	Floyd et al. (2008)[b]	Rotation	Intermix	400–600	—	—	400–600	—
	Bauer (2006)[a]	Rotation	Both	427	—	—	427	243
	Shinneman (2006)	Rotation	Both	400–600	—	—	400–600	228–342
Near Douglas fir	Heyerdahl et al. (2006)	Rotation	Intermix	160[d]	—	—	160	—
	Summary						160, 400–600	150–300
Mountain grass-lands/patchy sagebrush	Houston (1973)[b]	Scars	Both	20–25	72–90	320–400	72–400	41–228
	Arno and Gruell (1983)	Scars	Both	<35–40	<126–144	<560–2304	<126–2,304	<72–1,313
	Miller and Rose (1999)	Scars	Intermix	12–15	43–54	192–864	43–864	—
	Summary						Uncertain	40–230

Table 1. Estimates in years for pre-Euro-American fire rotations and mean fire interval in sagebrush. *Table Credit*: Baker (2011)

Post 1880’s Fire Regime

From here, more concrete and diligent record keeping allows this discussion of fire regime to shift from its regional focus on the Great Basin down to the specific ecoregion of interest for the project, the Owyhee Area of southern Idaho and Western Oregon. Within the Owyhee area there have been three overarching drivers of fire regime change that have served to drastically change the dynamics of fire on the landscape since the mid-late 1800s; climate change, invasive species, and maladaptive management practices (Baker et al., 2011; Chambers et al., 2014; Knick et al., 2011; Miller et al., 2011; Miller et al., 2014; Miller and Rose, 1999; Williamson et al., 2019). With the end of the climatic era known as the “Little Ice Age” in the mid-1800’s, the overall climate of the region entered a prolonged period of increased precipitation and historically mild winters that persisted until roughly the 1920’s (Miller and Rose, 1999). This change in climate entered the region into a period of reduced fire frequency and size due to changes in fuel structure; a reduction that was then (post 1920’s) elongated via maladaptive fire management practices (Abrams et al., 2021; Chambers et al., 2014; Dombeck et al., 2004; Miller and Rose, 1999). The changes seen in the fuel structure were a product of the expansion of woody species throughout the landscape catalyzed by the novel optimal climatic conditions in conjunction with maladaptive grazing practices, which reduced the biotic resistances of predominantly sagebrush ecosystems to woody plant invasion and subsequently begot a reduction of the occurrence of fire on the landscape (Chambers et al., 2014; Miller and Rose, 1999). This period of reduced fire was further prolonged into the late half of the 20th century by the efforts of the federal government as well as local land managers to impose their will of all-out fire suppression on the landscape (Abrams et al., 2021; Chambers et al., 2014; Dombeck et al., 2004; Miller and Rose, 1999; North et al., 2015). As was discussed in previous sections, this policy of all-out fire suppression in conjunction with the rapid changes in climate seen today (which have moved away from those seen between the late 19th and early 20th centuries) along with infiltrations of invasive species have served to produce the explosive and highly devastating fire seasons that have occurred regularly for the past few decades (Abrams et al., 2021; Chambers et al., 2014; Dombeck et al., 2004; Miller and Rose, 1999; North et al., 2015).

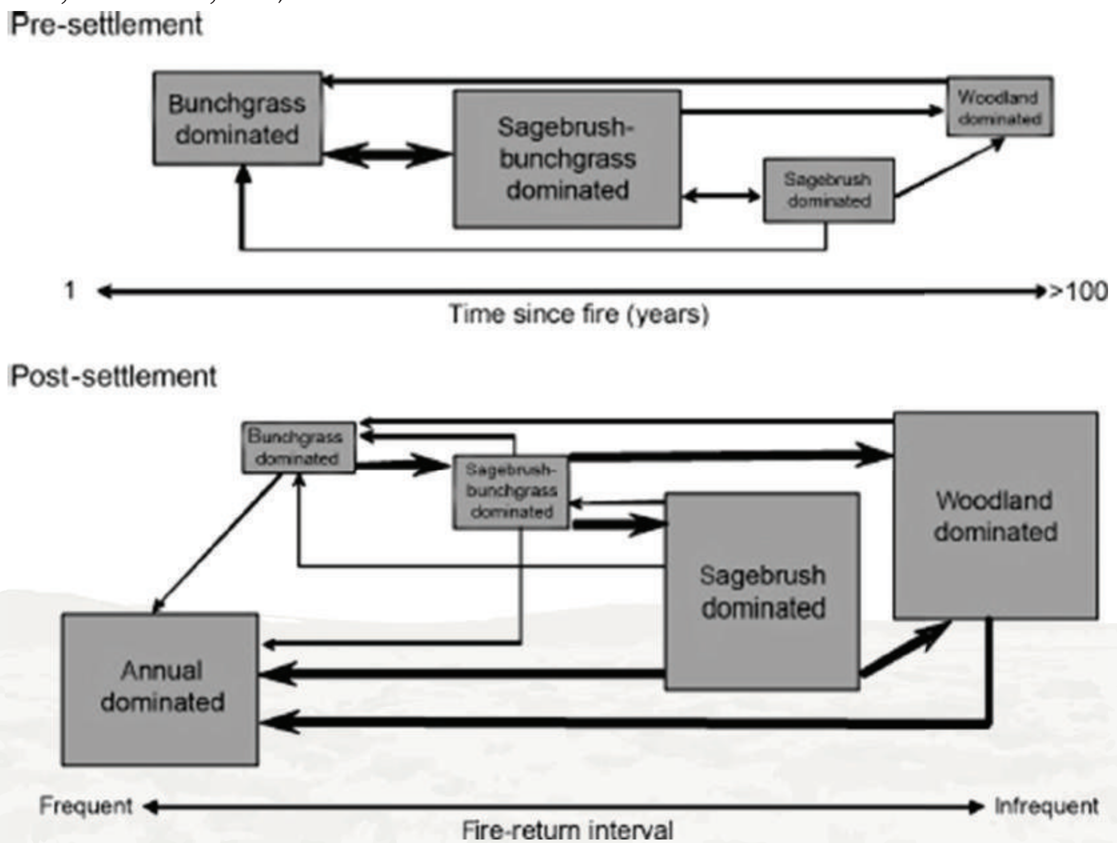


Figure 14. Conceptual model of pre- and post-settlement dynamics for plant communities in the Sage-Grouse Conservation Area. Differences in box and arrow sizes imply a difference in proportion of phases and transition from one phase to another within and across steady states. *Figure Credit*: Miller et al. (2011)

Owyhee Invasives and Fire

As previously stated, a key driver of the drastic change in fire regime that has been seen in the Owyhee area has been the infiltration and expansion of a plethora of invasive native and non-native species on the landscape. See Table 2 for a listing of common vegetation cover types within the study area and their relative susceptibility to common invasive nonnative plant species. For the purposes of this project, the two invasive plant communities of greatest concern were investigated. The first of which are invasive non-native annual grasses such as cheatgrass, medusahead (*Taeniatherum caput-medusae*), and whitetop (*Lepidium draba*) that are prevalent in the lower elevations and secondly the native piñon-juniper woodland encroachment that is occurring as these woodlands make their way down from many of the higher elevation areas of the region (Chambers et al., 2014; Diamond et al., 2009; Lehnhoff et al., 2019; Miller and Rose, 1999; Miller et al., 2011; Miller et al., 2014; Pilliod et al., 2017; Taylor et al., 2013; Wilder et al., 2019; Williamson et al., 2019; Woods et al., 2013).

Invasive Species Susceptibility

Major vegetation cover types within the Sage-Grouse Conservation Area and their susceptibility to invasion by nonindigenous plant species. Susceptibility to invasion is defined by four categories: (H) high, (M) moderated, (L) low and (U) unknown.

Invasive Species	Basin big sagebrush, Wyoming big sagebrush, three-tip sagebrush	Mountain big sagebrush	Low sagebrush, black sagebrush	Wheatgrass, bunchgrass
Cheatgrass (*Bromus tectorum*)	H	M	M	H
Musk Thistle (*Carduus nutans*)	U	M	U	M
Whitetop (*Cardaria spp.*)	M	M	M	M
Diffuse Knapweed (*Centaurea diffusa*)	M	M	M	H
Spotted Knapweed (*Centaurea maculosa*)	M	M	U	H
Russian Knapweed (*Centaurea repens*)	M	M	U	M
Yellow Starthistle (*Centaurea solstitialis*)	M	M	M	H
Squarrose Knapweed (*Centaurea virgata*)	M	M	M	M
Rush Skeletonweed (*Chondrilla juncea*)	M	M	U	M
Oxeye Daisy (*Chrysanthemum leucanthemum*)	U	U	U	M
Canada Thistle (*Cirsium arvense*)	M	M	M	H
Bull Thistle (*Cirsium vulgare*)	M	M	M	M
Poison Hemlock (*Conium maculatum*)	L	L	L	L
Common Crupina (*Crupina vulgaris*)	L	M	L	M
Leafy Spurge (*Euphorbia esula*)	M	L	M	M
Halogeton (*Halogeton glomeratus*)	M	M	M	M
Orange Hawkweed (*Hieracium aurantiacum*)	L	M	L	L
Meadow Hawkweed (*Heiracium pratensis*)	L	L	L	L
Dyer's Woad (*Isatic tinctoria*)	H	L	H	H
Perennial Pepperweed (*Lepidium latifolium*)	L	L	L	L
Dalmation Toadflax (*Linaria dalmatica*)	M	H	M	H
Yellow Toadflax (*Linaria vulgaris*)	M	M	U	M
Purple Loosestrife (*Lythrum salicaria*)	L	M	L	L
Scotch Thistle (*Onopordum acanthium*)	M	L	U	M
Sulfur Cinquefoil (*Potentilla recta*)	U	M	U	H
Mediterranean Sage (*Salvia aethiopis*)	H	M	U	H
Russian Thistle (*Salsola kali*)	M	M	L	M
Tansy Ragwort (*Senecio jacobaea*)	U	U	U	U
Sowthistles (*Sonchus spp.*)	M	M	M	M
Medusahead (*Taeniatherum caput-medusae*)	M	M	L	M

Table 2. Major vegetation types within the Sage-Grouse Conservation Area and their susceptibility to invasion by nonindigenous plant species. *Table Derived From*: Miller et al. (2011)

Owyhee Invasive Annual Grasses and Fire

The Owyhee area is heavily dominated by stands of sagebrush that have been well documented to have had their historic fire regimes be affected by the invasion of non-native annual grasses (Chambers et al., 2014; Diamond et al., 2009; Lehnhoff et al., 2019; Miller and Rose, 1999; Miller et al., 2011; Pilliod et al., 2017; Taylor et al., 2013; Williamson et al., 2019; Woods et al., 2013). In fact, it was estimated that by 2018, cheatgrass, the most pervasive of these annual grasses, had achieved at least 15% land cover of just under half the total land area of the entire Great Basin; an area encompassing over 425,000 km^2 (Bradley et al., 2017; Williamson et al., 2019). This percent coverage holds true when assessing both focal areas of this project; the overall Owyhee ecoregion as well as that of the Owyhee RFPA; see Figure 15. Stands of sagebrush in these focal areas, like much of the rest of the western US, have seen drastic decreases in the return intervals of large wildfires over the past century as a direct result of this invasion (Chambers et al., 2014; Diamond et al., 2009; Lehnhoff et al., 2019; Miller and Rose, 1999; Miller et al., 2011; Pilliod et al., 2017; Taylor et al., 2013; Williamson et al., 2019; Woods et al., 2013). These stands, which used to burn on centurial time scales, are now burning in some cases on sub-decadal time scales due to cheatgrass invasion (Chambers et al., 2014; Diamond et al., 2009; Lehnhoff et al., 2019; Miller et al., 2011; Pilliod et al., 2017; Williamson et al., 2019).

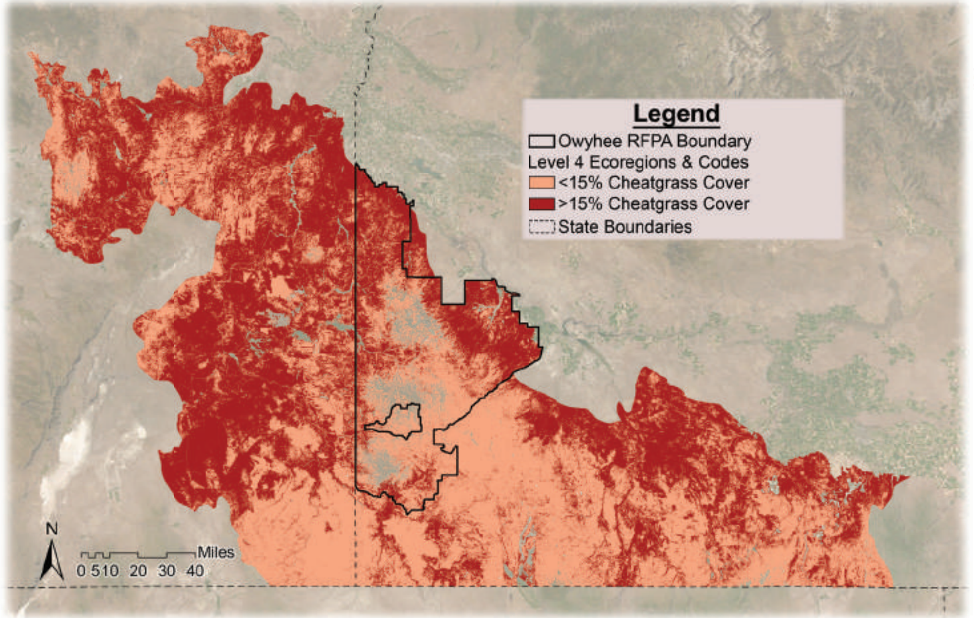


Figure 15. Areas throughout the Owyhee ecoregion with and without at least 15% cover of cheatgrass in July 2021.

Image 5. A wildfire that started in invasive annual grass adjacent to a railroad track and burned upslope into a mountain big sagebrush and Jeffery pine ecosystem in northeast Nevada. *Image Credit*: Nolan E. Preece

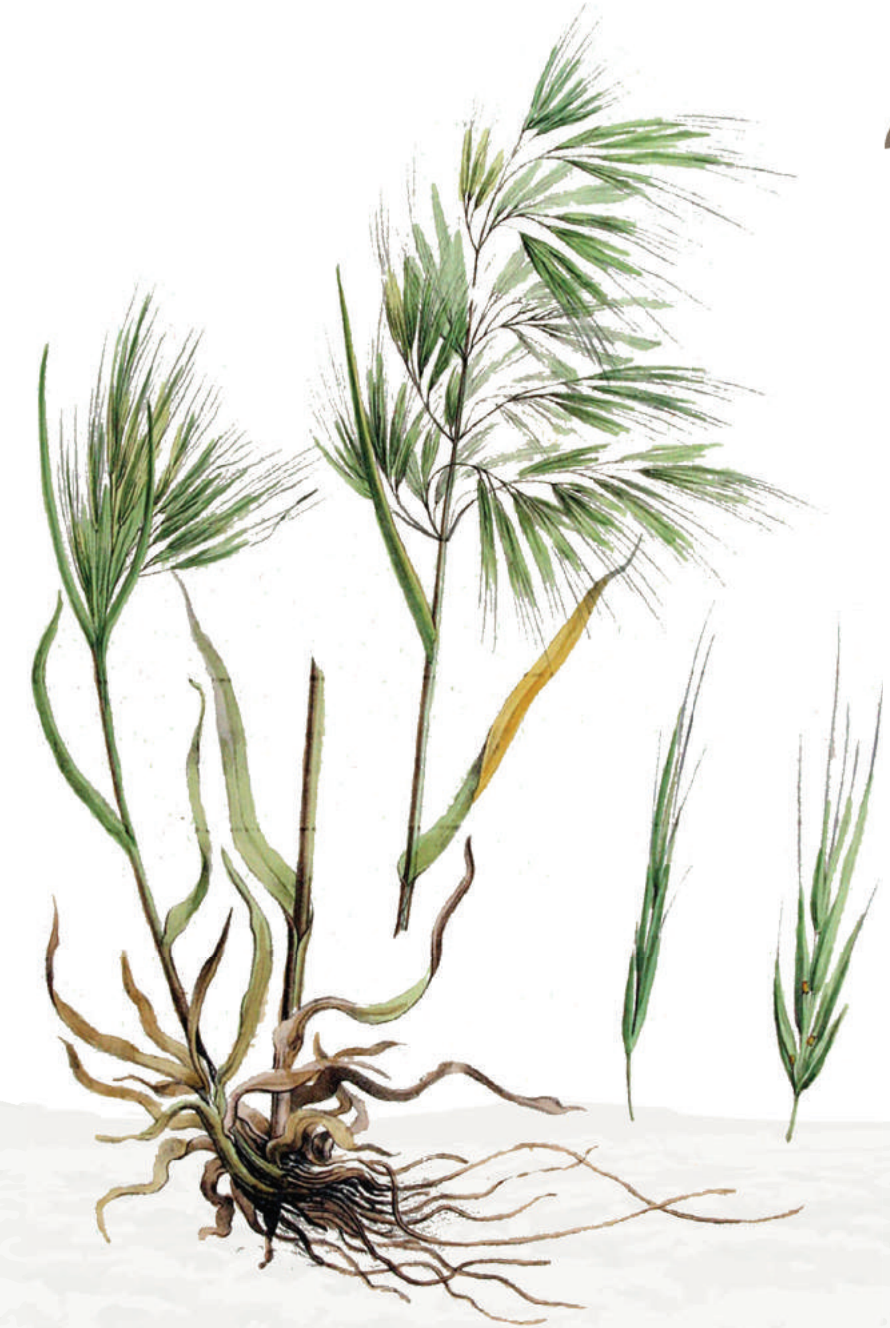
Image 6. A big sagebrush ecosystem that has been converted into invasive annual grass in north central Nevada. *Image Credit*: Nolan E. Preece

How did the region become invaded by a grass native to Eurasia? Research into the subject suggests that invasion in the intermountain northwest began in the 1890's through importation of contaminated grain shipments (Chambers et al., 2014; Miller et al., 2011; Pilliod et al., 2017). This grass was subsequently allowed to invade throughout the region by way of regional transportation routes that led it to find prime habitat for itself in the vast areas of habitat that had already been degraded by years of maladaptive livestock grazing through the disturbance of the protective biological soil crusts of the region and reduction of native perennial plants these large ungulates caused (Chambers et al., 2014; Miller et al., 2011; Williamson et al., 2019). This low biotic resistance was subsequently augmented by the suitable climatic conditions of the region with its wet winters and relatively dry summers (Miller et al., 2011). Through this combination of low biotic resistance on the part of the degraded rangelands and the fact that the life cycle of cheatgrass, which is heavily reliant on winter precipitation to fuel its early (relative to competing native perennial bunchgrass species) germination, growth, viable seed production and senescence (that in turn leads to greater burn potential), the climate of the intermountain northwest offered the perfect suite of conditions to allow for it to outcompete the already degraded native perennial grasses and forbs and thus fuel its rapid expansion, which has in turn, in many areas, led successionally to the invasion of medusahead and whitetop (Chambers et al., 2014; Lehnhoff et al., 2019; Miller et al., 2011; Pilliod et al., 2017; Williamson et al., 2019).

On a more in-depth level, once cheatgrass enters an area with these already favorable conditions its spread is almost assured without intervention through its multipronged assault on the area's natural community structure as well as its ecological function and relationships (Chambers et al., 2014; Miller et al., 2011). These alterations take place on multiple levels and timesteps. Perhaps most noticeable from an on-the-ground perspective is the change in structure that will be seen throughout the understory of these communities as they are invaded; where the traditional community makeup of sparsely arranged native perennial grasses and forbs is replaced by a denser and more contiguous mat of invasive grasses (Chambers et al., 2014; Miller et al., 2011). This loss of native discontinuity and increase in fuel structure then begets decreased fire return intervals and generates larger more intense and comprehensive fires on the landscape (Chambers et al., 2014; Lehnhoff et al., 2019; Miller et al., 2011; Pilliod et al., 2017). This combination is fatal for most sagebrush communities due to their extreme intolerance to fire coupled with their methods of reestablishment and the long time it takes for those methods to succeed (Miller et al., 2011; Williamson et al., 2019). Most sagebrush species require seeds within the soil seed bank or those deposited by nearby plants to fuel their regeneration, the temporality of which depends on the species of sagebrush in question, but as stated previously can range anywhere between 15 and 50 years for complete canopy cover regeneration (Miller et al., 2011; Miller et al., 2014). Reestablishment through either of these avenues is unlikely in most cases after fires resulting from cheatgrass invasion due to the creation of positive feedback loops between it and fire, which leads to shortened return intervals typified by the all-encompassing, contiguous nature of the fires often produced as well as the short periods of viability that exist in the seeds of most sagebrush (Chambers et al., 2014; Diamond et al., 2009; Lehnhoff et al., 2019; Miller et al., 2011; Pilliod et al., 2017). For example, while the seeds of mountain big sagebrush can maintain viability in the soil seed bank for multiple years after a burn, those of Wyoming big sagebrush are only viable for one year unless covered by a layer of protective soil (Miller et al., 2011). Therefore, when these large fires occur, especially in the lower-elevational communities of Wyoming big sagebrush, there is little chance of natural regeneration; leading to the self-sustaining monocultures of cheatgrass seen throughout the area.

Additionally, the ability of the pockets of sagebrush left unburned to recolonize adjacent burned areas can be further hindered by the changes that occur in the nutrient cycle and organic matter content of the soil due to changes in the mycorrhizal and root makeup brought about by cheatgrass invasion (Miller et al., 2011). The nutrient cycles and organic matter content of soils associated with cheatgrass invasion differ from those of native sagebrush communities in that they are characterized by comparatively shallow root structures as well as fewer mycorrhizal associations and therefore contain more organic material near the surface that can be easily decomposed (Miller et al., 2011). This is in contrast to those of native sagebrush communities, which have complex mycorrhizal associations as a result of their diverse root structures leading to organic matter that is more well distributed throughout the soil horizons and is thus less susceptible to rapid decomposition (Miller et al., 2011). This creates not only the physical barrier to reestablishment brought about by the highly competitive nature of cheatgrass for the resources of the soil as well as that of the limited dispersion ability of the seeds of these primarily wind-dispersed plants (typically within 9-12 m from the parent plant), but also a barrier to reestablishment on a more molecular level in that the nutrients necessary for reestablishment simply no longer exist in the soil environment (Chambers et al., 2014; Miller et al., 2011).

In terms of changes to the ecological functions brought about by conversion to cheatgrass dominated environments the chief concern is the redistribution of the temporal availability of water. This is because cheatgrass lowers the availability of water in surface soils and increases surface temperatures, which increases stress on native plants by promoting more severe summer drought conditions (Chambers et al., 2014; Lehnhoff et al., 2019; Miller et al., 2011). This differs from the water availability and soil surface temperatures exhibited in the patchy arrangement typical of native sagebrush communities in which surface temperatures are reduced and water availability is greater and more concentrated under these patches leading to more drought tolerant communities (Miller et al., 2011). Thus, through these pathways, the changes to the community structure and ecological function of sagebrush systems brought about by their conversion to cheatgrass can eventually lead to complete prohibition to reestablishment by native communities without anthropogenic intervention (Chambers et al., 2014; Miller et al., 2011).



Cheatgrass (*Btomus tectorum*)

Owyhee Piñon-Juniper Woodland Encroachment

A secondary threat to sagebrush ecosystems is the expansion of piñon-juniper woodlands that is occurring in many higher elevational stands and is proceeding down-slope; a process that in conjunction with invasive annual grass spread at lower elevations is effectively squeezing out sagebrush in all directions (Chambers et al., 2014; Miller et al., 2011; Miller and Rose, 1999; Woods et al., 2013). This expansion is exhibited through two pathways, encroachment and infill; where encroachment is the colonization of new, previously conifer-free, habitat and infill is the closure of canopy within stands of conifers (Chambers et al., 2014; Miller et al., 2011). This overall expansion has been found to have begun, as with the invasion of cheatgrass, in the late 1800's and coincides with the period of favorable climatic conditions that occurred after the end of the Little Ice Age as well as the changes in land use and management brought to the landscape by Euro-American settlement (Chambers et al., 2014; Miller et al., 2011; Miller et al., 2014; Miller and Rose, 1999; Woods et al., 2013).

Prior to these changes on the landscape, fire regimes in these higher elevations consisted of shorter return intervals of low and medium severity fires; typically on the order of less than 15 years in many areas with an upper limit of roughly 40 years in some sites (Miller and Rose, 1999, Woods et al., 2013). This effectively inhibited the expansion of conifers as they can take upwards of 45 years to become large enough to be resilient to low or medium intensity fires (Miller et al., 2011; Miller and Rose, 1999). These preventative conditions were altered, however, by the changes in land use and management brought to the landscape by Euro-American settlement as well as the favorable shift in climatic conditions that brought more precipitation and milder winters to the region (Chambers et al., 2014; Miller et al., 2011; Miller and Rose, 1999).

Principal among the factors augmenting the newly favorable climate was the advent of large amounts of livestock on the landscape. As they did in the lower elevations of the region, these novel large hooved ungulates also altered the environment in the higher elevation mountain big sagebrush communities they encountered (Chambers et al., 2014; Miller et al., 2011; Miller and Rose, 1999). This occurred through three separate avenues that all compounded to bring about widespread fire suppression; (1) the reduction of fine fuels (2) the alteration of plant community structure and (3) the reduction of competition from herbaceous species (Chambers et al., 2014; Miller et al., 2011; Miller and Rose, 1999; Woods et al., 2013). Furthermore, the advent of fire suppression efforts by land managers in the early 1900's prolonged this livestock-induced exclusion of fires on the landscape and allowed these encroachments of piñon-juniper woodlands that could have otherwise been reduced with the return of fire to persist and continue their expansion (Abrams et al., 2021; Chambers et al., 2014; Dombeck et al., 2004; Miller et al., 2011; Miller and Rose, 1999).

These co-occurring factors served to release piñon-juniper woodlands from the historic inhibitors to their expansion long enough for them to alter and in many cases completely dominate large swathes of what was historically sagebrush steppe ecosystem. Their invasion has been occurring at rates above that of any previous expansion seen in the scientific record of the Holocene and has been widespread throughout the high elevational sagebrush communities throughout the Great Basin (Miller and Rose, 1999; Miller et al., 2011; Miller et al., 2014). However, this expansion has not been uniform in its severity due to differences in conditions at site-specific levels (Miller and Rose, 1999; Miller et al., 2011; Miller et al., 2014).

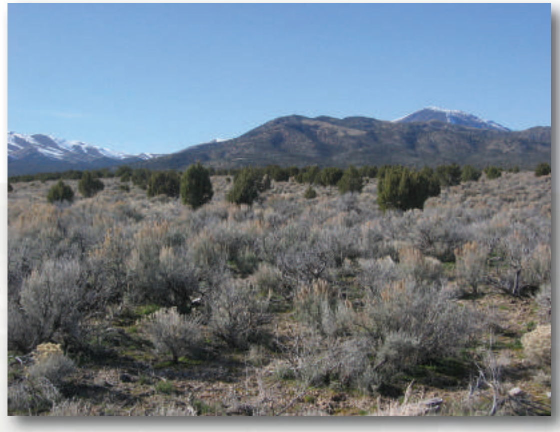


Image 7. Progressive infilling of juniper into mountain big sagebrush that has led to exclusion of native understory species. *Image Credit*: Bruce A. Roundy

Image 8. Expansion of Utah juniper trees into a mountain big sagebrush ecosystem in east central Utah. *Image Credit*: Bruce A. Roundy

Currently, the expanded extents of piñon-juniper woodlands have grown to between two and six times what their previous historic extents were, and many of these areas are predicted to completely infill and exhibit canopy closure within the next 50 years (Chambers et al., 2014; Miller et al., 2011; Woods et al., 2013) The peak of this encroachment occurred between 1885 and 1925, but did not have significant effects on the alteration of local fire regimes themselves until infill began to occur on sufficiently invaded sites by the 1950's (Miller et al., 2011; Miller and Rose, 1999). This is because piñon-juniper woodland invasion occurs in three distinct phases that were delineated by Miller et al. (2005) in their book, "Biology, ecology, and management of western juniper (*Juniperus occidentalis*)" where Phase I is characterized by relatively low piñon-juniper woodland canopy cover and overall dominance of typical sagebrush community structure, Phase II sees a reduction in the herbaceous understory of the historic sagebrush community and becomes codominant with the invading piñon and/or juniper, and finally Phase III is defined as a landscape that is dominated by a canopy of piñon-juniper woodland with little-to-no sagebrush understory (Coates et al., 2017; Miller et al., 2005).

While habitat degradation does occur at levels high enough to disrupt native species such as greater sage-grouse (*Centrocercus urophasianus*) during Phases I & II of encroachment and infill, distinct fire regime change does not often occur until Phase III (Chambers et al., 2014; Coates et al., 2017; Miller et al., 2011; Woods et al., 2013). In this final phase, sites exhibit a further reduction in fire frequency as a result of their reduced fine fuel loads, but are prone to much higher severity fires when they do occur (Chambers et al., 2014). Being that the rate of encroachment has seen a reduction since the 1960's, due to a lack of suitable habitats within the invadable range of piñon-juniper woodlands that have not already been invaded, more and more areas are either entering or are slated to enter this final phase (Chambers et al., 2014; Coates et al., 2017; Miller et al., 2011). This, in combination with the increase in fire seen in the lower elevations brought on by the invasion of cheatgrass, is helping to fuel the large, high severity fires currently seen across the west and only serves to further complicate and reduce the efficacy of management and restoration efforts in these sensitive sagebrush habitats.

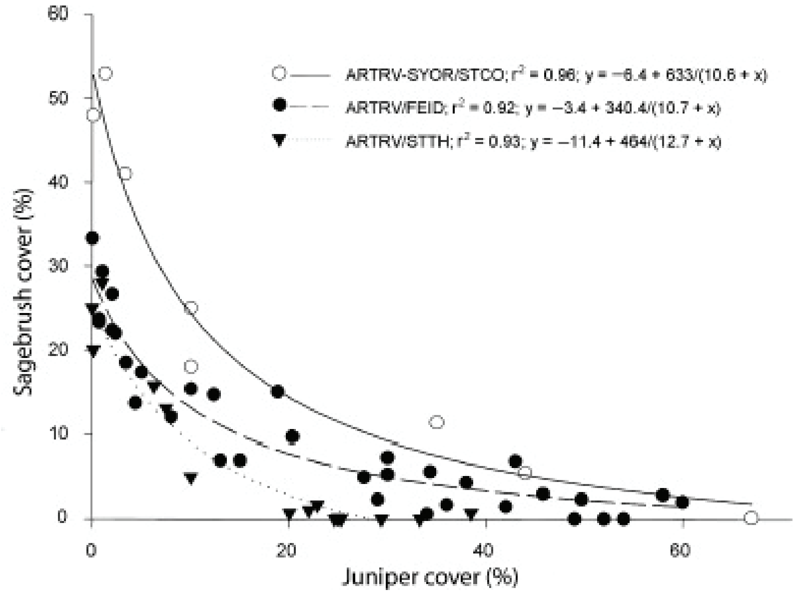


Figure 16. Relationship between juniper and mountain big sagebrush canopy cover in three plant associations: *Artemisia tridentata ssp. vaseyana-Symphoricarpos oreophilus/Stipa columbiana* (ARTRV-SYOR/STCO), *A. tridentata ssp. vaseyana/Festuca idahoensis* (ARTRV/ FEID), and *A. tridentata ssp. vaseyana/Stipa thurberiana* (ARTRV/STTH). *Figure Credit*: Miller et al. (2011)

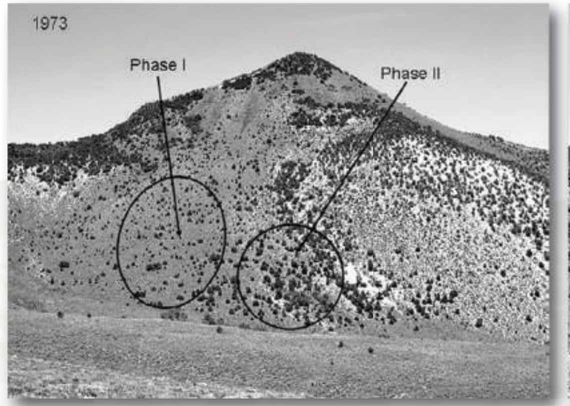


Image 9. Phases I and II of Piñon-Juniper Woodland Encroachment. *Image Credit*: Robin Tausch

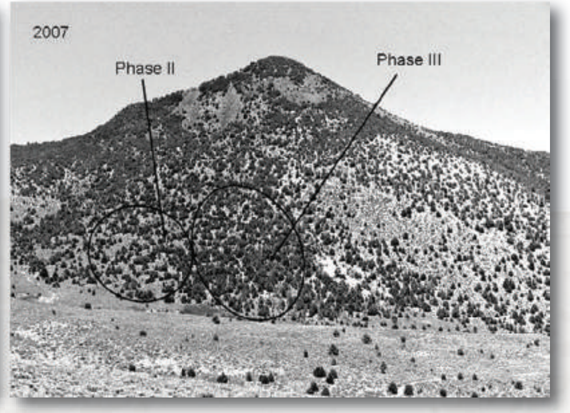


Image 10. Phases II and III of Piñon-Juniper Woodland Encroachment. *Image Credit*: Robin Tausch

Fragmentation and Habitat Viability

From this point, it is important to bring the concepts of fragmentation and connectivity into the discussion. For the purposes of this study, fragmentation refers to the reduction, degradation or destruction of habitat to a point at which it can no longer viably support the plant and animal communities it historically has been able to, which for this study is represented by the habitat needs associated with the greater sage-grouse (Chambers et al., 2014; Driscoll et al., 2021). Furthermore, connectivity refers to the level of ease and ability of this chosen keystone species to live in and move between suitable habitat patches within its ranges (Chambers et al., 2014; Fesenmyer & Dauwalter, 2014). To better understand these terms, the ways in which fire and habitat fragmentation interact must first be understood. For analysis of this concept, this project turns again to Driscoll et al. and their 2021 article “How fire interacts with habitat loss and fragmentation”. Through their meta-analysis of 162 peer-reviewed papers discussing the interactions between fire and fragmentation, Driscoll et al. (2021) found that this occurs on three separate levels: (1) where fire influences fragmentation, (2) where fragmentation influences fire and (3) where the two do not influence each other, but fire interacts with fragmentation to affect environmental responses. In instances where fire influences fragmentation it does so through one of two mechanisms, either destroying or fragmenting existing habitat or through the creation of new habitat leading to better connectivity. When fire is influenced by fragmentation, it is a result of a previously contiguous habitat being fragmented through varying means including anthropogenic suppression, increased edge flammability and increased obstruction to fire spread, which lead to an alteration of historic fire regimes. Conversely, where the two do not influence each other, they still interact to amplify each other’s effects on the ecosystem (Driscoll et al., 2021). See Figures 17 and 18 for graphic representations of these pathways. For example, in instances where fire burns through land that has been heavily grazed the intensity of the fire and area burned by the fire will typically be greater than if the historic land use had not been altered. Additionally, these types of interactions have been shown to promote the establishment of feedback loops that can ultimately lead to ecosystem conversion (Driscoll et al., 2021).

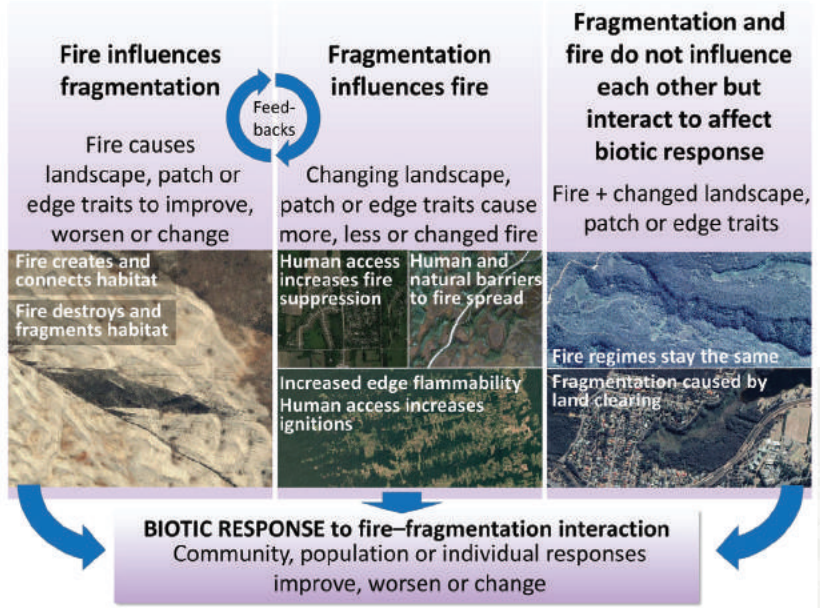


Figure 17. The three main pathways fire interacts with fragmentation. *Figure Credit*: Driscoll et al. (2021)

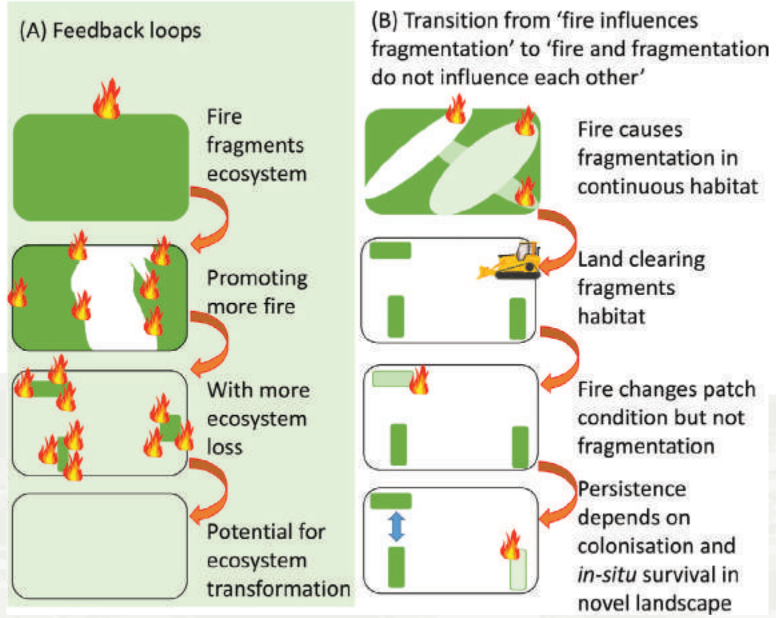


Figure 18. How feedback loops interact with fire and fragmentation. *Figure Credit*: Driscoll et al. (2021)

The Owyhee area as well as the Owyhee RFPA within it are prime examples of all three of these types of interactions between fire and fragmentation. As has been evidenced above, increasingly severe fires, brought on by a litany of mechanisms, have burned through much of the Owyhee area in the past century leading to the fragmentation of its once massive contiguous sagebrush steppe habitats (Bradley et al., 2017; Chambers et al., 2014; Miller et al., 2011; Miller and Rose, 1999). Some of those mechanisms, such as the invasion of cheatgrass, have led to the formation of novel positive feedback loops with fire that are only serving to exacerbate the issue and accelerate the habitat degradation and loss occurring (Bradley et al., 2017; Chambers et al., 2014; Miller et al., 2011; Miller and Rose, 1999). In fact, areas with ≥15% cover of cheatgrass, an increasingly large portion of this project’s primary study site of the Owyhee RFPA, have been shown to have twice the likelihood of burning as those with lower coverage percentages and were four times as likely to burn again between 2000 and 2015; grim statistics for a habitat with the exceedingly low recovery rates like those found in sagebrush steppe ecosystems (Bradley et al., 2017; Miller et al., 2014).

But how does one determine and quantify the effect this fragmentation has on the landscape? For the purposes of this project, the lead of the majority of those researching sagebrush steppe ecosystems was followed and, as illuded to previously, habitat requirements for greater sage-grouse were used as a gauge both for the effects of fragmentation and connectivity as well as a goal to strive for through the management practices that were developed. Greater sage-grouse are what is known as a “keystone species” within sagebrush ecosystems. They are a sagebrush obligates once found widely throughout the Great Basin, but whose range has been drastically reduced over the past century (Chambers et al., 2014; Coates et al., 2017; Knick et al., 2011; Knick and Connelly, 2011; Miller et al., 2011). Historically, the range of the greater sage-grouse encompassed a massive area spanning 11 western states and two Canadian provinces (Knick and Connelly, 2011). See Figure 19 for a representation of their current and former range with respect to the study site of this project. In their 2011 study of sage-grouse and their habitat Knick and Connelly found that, at the time, sage grouse were absent from nearly half their historic range; a decline that was slated to only continue in the coming decades (Chambers et al., 2014; Knick and Connelly, 2011; Miller et al., 2011).

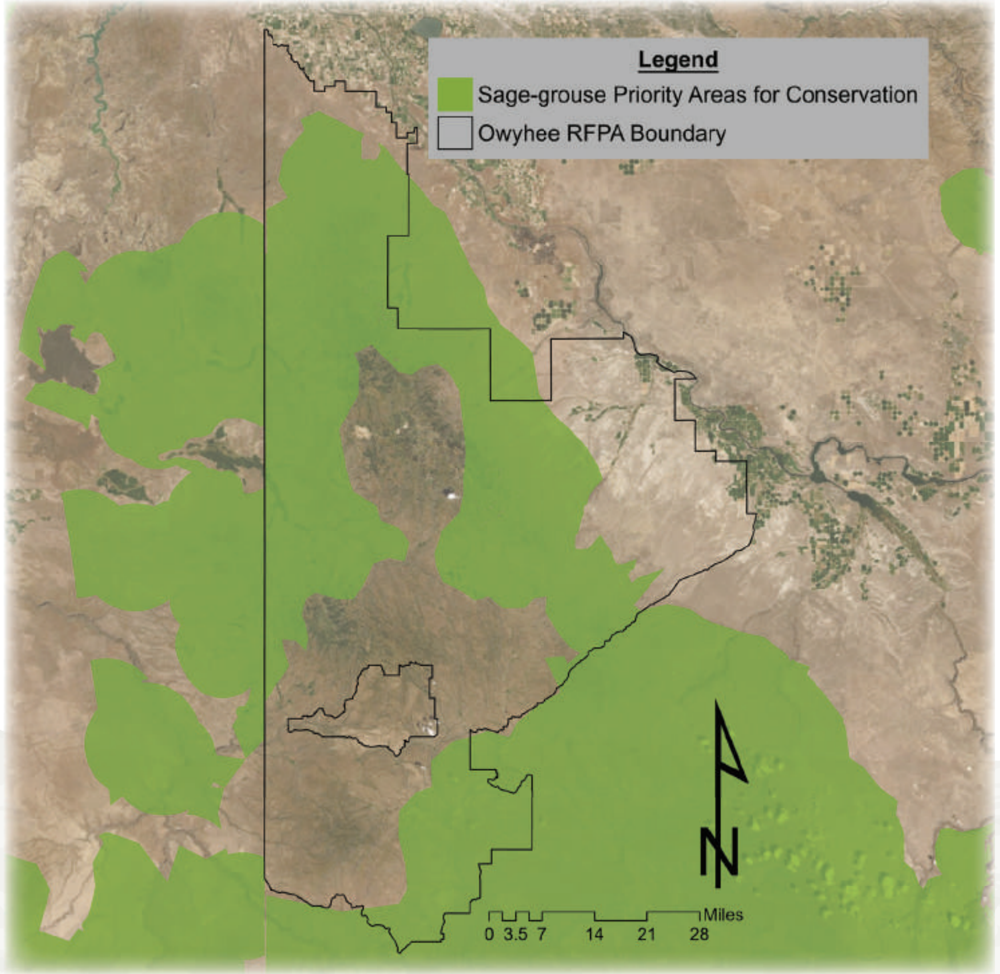


Figure 19. Sage-grouse Priority Areas for Conservation Determined by the USFWS and outlined in Chambers et al. (2014).

These iconic birds require large areas of intact yet varying habitat to meet their needs (Knick and Connelly, 2011; Chambers et al., 2014). In fact, throughout the year it has been shown that they can utilize over 2,700 km^2 of habitat mainly consisting of sagebrush, but will also utilize shrublands with interspersed grassland at certain times of year (Knick and Connelly, 2011). Unfortunately, these birds are highly susceptible to the changes in their environment brought about by habitat fragmentation, loss and degradation (Chambers et al., 2014; Coates et al., 2017; Knick and Connelly, 2011; Miller et al., 2011). For example, greater sage-grouse nest and lek (where they do their mating displays) selection has been negatively correlated with the presence of cheatgrass as well as with that of piñon-juniper woodland cover; a trend which begins its decline at relatively low land coverage percentages (Chambers et al., 2014; Coates et al., 2017; Miller et al., 2011). These birds have also been found to actively avoid areas where sagebrush cover is <25% and tend to favor areas with >65% cover; a cover percentage that is becoming exceedingly harder to find throughout the study site of the Owyhee RFPA as well as the rest of the Great Basin (Chambers et al., 2014). This preference of habitat type can be seen in Figure 20.

Due to this species' decline brought on by habitat fragmentation, loss and degradation the past decade has seen an increasing effort to protect it both on a local and federal level. Regrettably, efforts to protect and preserve greater sage-grouse have become a politically charged issue with the federal government in 2010 issuing a statement that while the species warrants protection under the Endangered Species Act (ESA) of 1973, it was precluded from this listing by "higher priority listing actions" (FWS 75 FR 13909). This has led to endless litigation attempting to reverse this decision all to no avail at this time; see (*Wild Earth Guardians* (*WEG*) *vs. U.S. Fish and Wildlife Service* (*FWS*); *Center for Biological Diversity* (*CBD*) *vs. FWS*; *State of Colorado vs. FWS*).

As has been stated previously, for reasons relating to the rationale detailed above, the specific habitat requirements as well as inhibitors of these birds were used as an indicator for overall ecosystem health throughout this project. This decision allowed the project to use a well-recognized keystone species of the dominant native environment as a proxy to evaluate how fire, invasives, and fragmentation could be better managed on the landscape and in so doing prevent and mitigate the further deterioration of sagebrush ecosystems as well as serving as a means to identify pathways to restore those that have already been degraded.

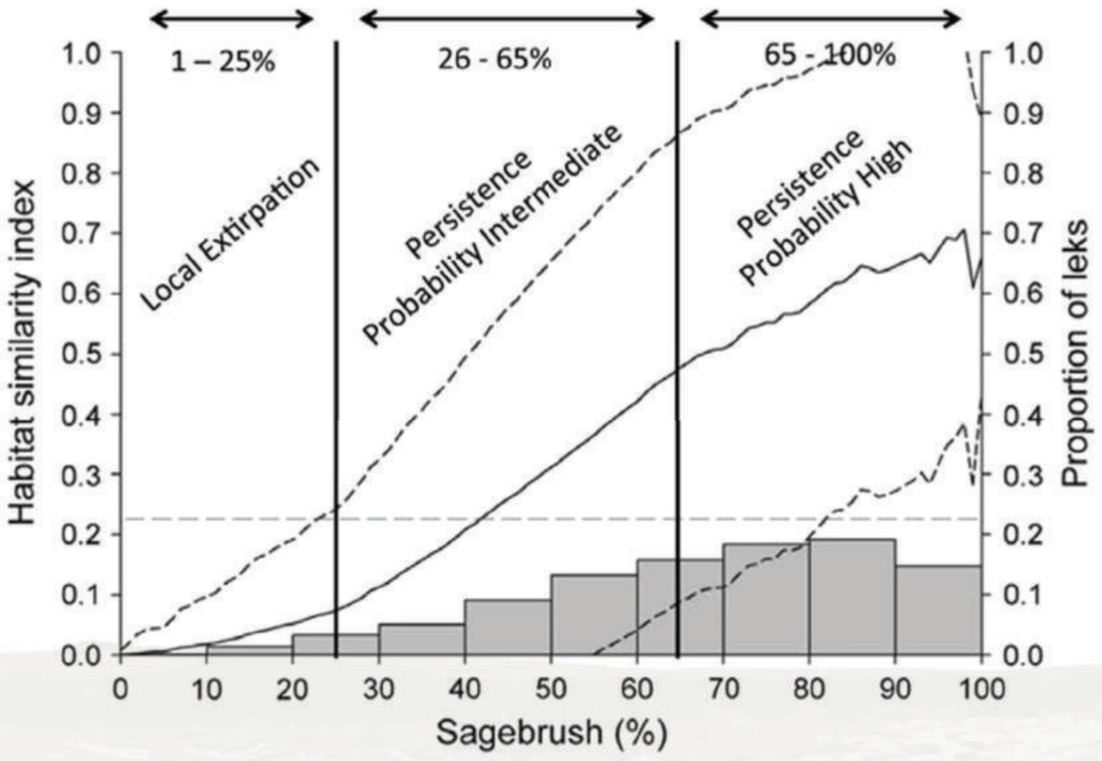


Figure 20. The proportion of sage-grouse leks and habitat similarity index (HSI) as related to the percent landscape cover of sagebrush. The HSI indicates the relationship of environmental variables at map locations across the western portion of the range to minimum requirements for sage-grouse defined by land cover, anthropogenic variables, soil, topography, and climate. HSI is the solid black line ± 1 SD (stippled lines). Proportion of leks are the grey bars. Dashed line indicates HSI values above which characterizes 90% of active leks (0.22). The categories at the top of the figure and the interpretation of lek persistence were added based on Aldridge et al. 2008; Wisdom et al. 2011; and Knick et al. 2013. *Figure Modified From*: Knick et al. (2013)

Federal Sagebrush Steppe Management Practices

2020 Bureau of Land Management PEIS Overview

In terms of current federal land management practices pertinent to the Owyhee RFPA, on November 27, 2020, the United States Bureau of Land Management (BLM) released their Final Programmatic Environmental Impact for Fuels Reduction and Rangeland Restoration in the Great Basin (PEIS) that will serve to guide the agency's approach to fuels reduction and rangeland restoration in the Great Basin for the foreseeable future (BLM, 2021). The area encompassed in the PEIS covers approximately 223 million acres, of which the BLM directly administers about 90 million acres (BLM, 2021). Through a process that involved scientific review, interagency collaboration as well as stakeholder input the BLM chose one project directive from a suite of proposed action plans (BLM, 2021). See Appendix 1 for descriptive table of all possible management directives. Once the project description was chosen, the potential treatment area within the project boundary was first refined to encompass those BLM lands with current and historically documented presence of sagebrush, then was further refined by excluding from treatment areas defined in Table 3 (BLM, 2021). After these refinements, the potential treatment area covered 38.5 million acres and contained a smaller "emphasis area" in which the BLM expects the bulk of projects to take place that encompasses roughly 26.3 million acres (BLM, 2021). Since the majority of public land within the Owyhee RFPA is owned and managed by the BLM and because the potential treatment area encompassed by this plan covers the bulk of the project site, their PEIS, augmented with a litany of peer-reviewed relevant research, was used as a basis for developing the proposed best management practices (BMPs) of this project. A visual representation of the BLM's project boundary, potential treatment area, and emphasis area can be seen in Figure 21.

In the BLM's final PEIS the selected project directive, "Alternative B", was chosen as it was the most robust and adaptable of the suggested alternatives and offered the largest potential treatment and emphasis areas for the BLM to work within to achieve their goal of long-term fuels reduction and rangeland restoration throughout the Great Basin (BLM, 2021). The predicted long-term goals of the project are intended to be met out through a lengthening fire return intervals and

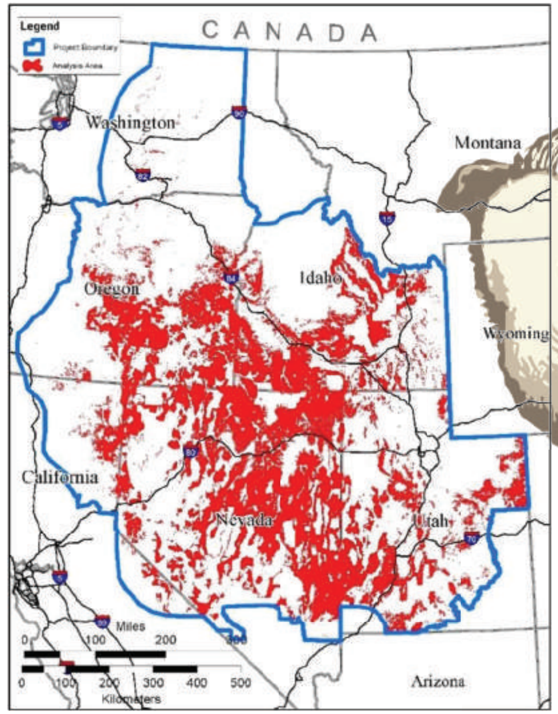


Figure 21. Project Boundary and Analysis Area for their 2020 PEIS for Fuels Reduction and Rangeland Restoration in the Great Basin. *Figure Modified From*: BLM (2021)

Analysis Exclusion Areas

Treatments associated with this analysis are not being proposed for the following areas.
If treatments are propcsed to be constructed in these areas, site-specific analysis will be required.

	Riparian Exclusion Areas	Other Exclusion Areas
Perennial Streams	300 feet on each side of the active channel, measured from the bank full edge of the stream, or the outer extent of riparian vegetation, whichever is greater.	- Areas within mapped Canada lynx distribution and/or wolverine primary habitat - Wilderness - Wilderness Study Areas - Lands with wilderness characteristics that are managed to maintain or enhance those characteristics, includ ing natural areas managed to preserve their wilderness character - National Conservation Areas and National Monuments - Areas designated through the John D. Dingell Jr. Conservation, Management, and Recreation Act, Pub. L. 116-9 (2019) -Visual Resource Management Class I areas - Areas within a quarter-mile of a Wild and Scenic River (including rivers found eligible and/or suitable) - Within National Scenic and Historic Trails and trail rights-of-way (ROWs)/corridors as identified in the Trailwide Comprehensive Plan and applicable land use plans - Pinus edulis – Juniperus osteosperma / Cushion plant woodland
Seasonally Flowing Streams	Includes intermittent and ephemeral streams with riparian vegetation. 150 feet on each side of the active channel, measured from the bank full edge of the stream, or the outer extent of riparian vegetation, whichever is greater.	
Streams in Inner Gorge	Defined by adjacent stream slopes greater than 70 percent gradient. Top of Inner Gorge	
Special Aquatic Features	Includes lakes, ponds, playas, seasonal wetlands, wetlands, seeps, wet meadows, vernal pools, and springs. 300 feet from the edge of feature or the outer extent of riparian vegetation, whichever width is greater.	

Table 3. 2020 BLM PEIS Analysis Exclusion Areas. *Table Derived From*: BLM (2021)

mosaic burn patterns, a shifting of fire regimes toward more historical conditions as well as a reduction of fine fuels and reestablishment of perennial grasses, forbs and sagebrush to reverse the overall environment's current departure from "desired vegetative states"; where desired vegetative states are defined as, "a natural mosaic of two perennial vegetation states: perennial grasses, forbs and shrubs and perennial grasses and forbs" (BLM, 2021). Visual representations intended to be utilized by local management offices in the selection process of proper treatment methods for use in their specific project areas to achieve desired vegetative states can be seen for current shrub and grassland vegetation states in Figure (Shrub and Grassland Map) and for current piñon-juniper woodland states in Figure (Piñon-juniper Map). These overall management goals are slated to be achieved through site specific utilization of manual, mechanical and chemical treatments, the use of prescribed fire as well as targeted grazing practices (BLM, 2021). The next few sections will cover these treatment methods in greater detail as they not only will be used by the federal government, but also largely align with the suggested management actions proposed by this project.

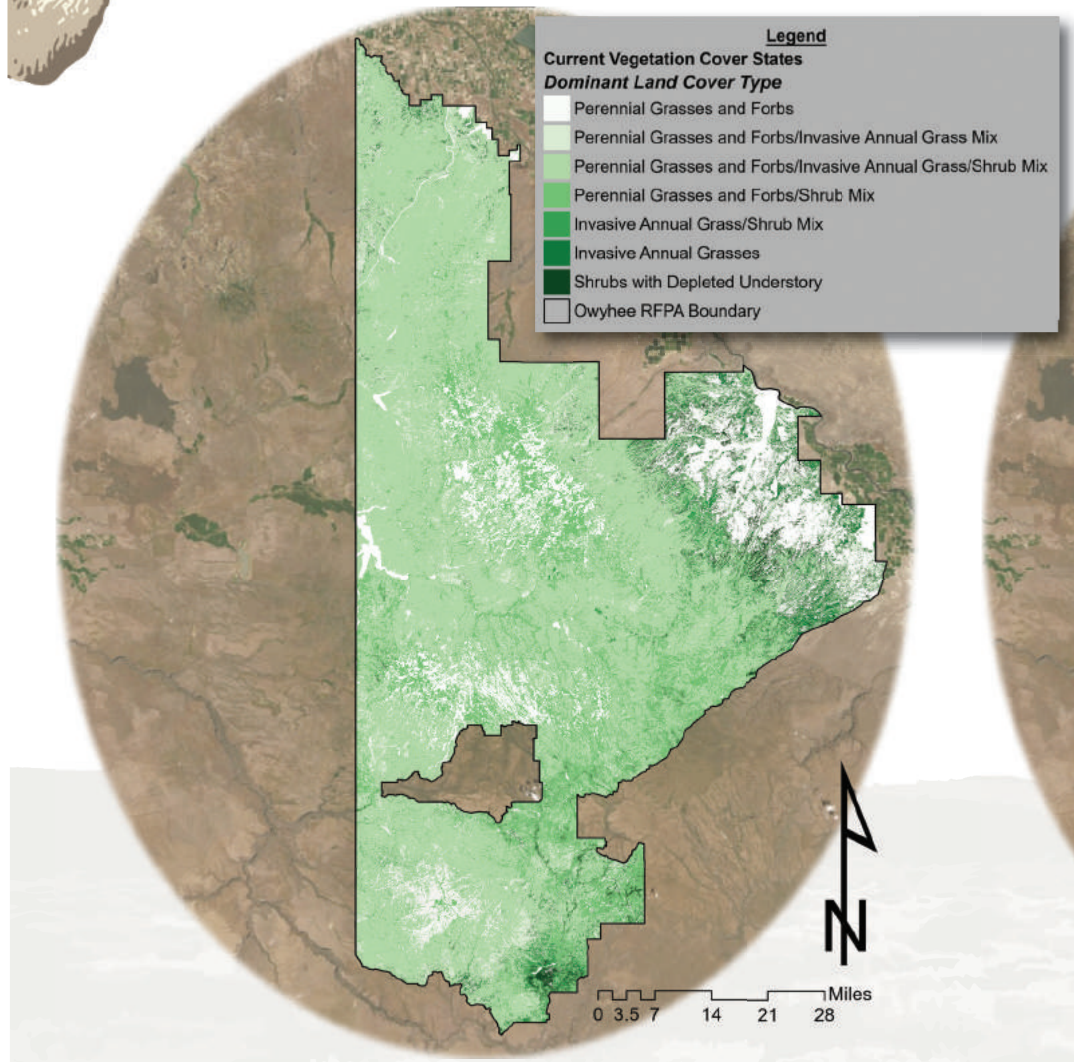


Figure 22. States of Vegetation within the Owyhee RFPA. *Figure Derived From*: BLM (2021)

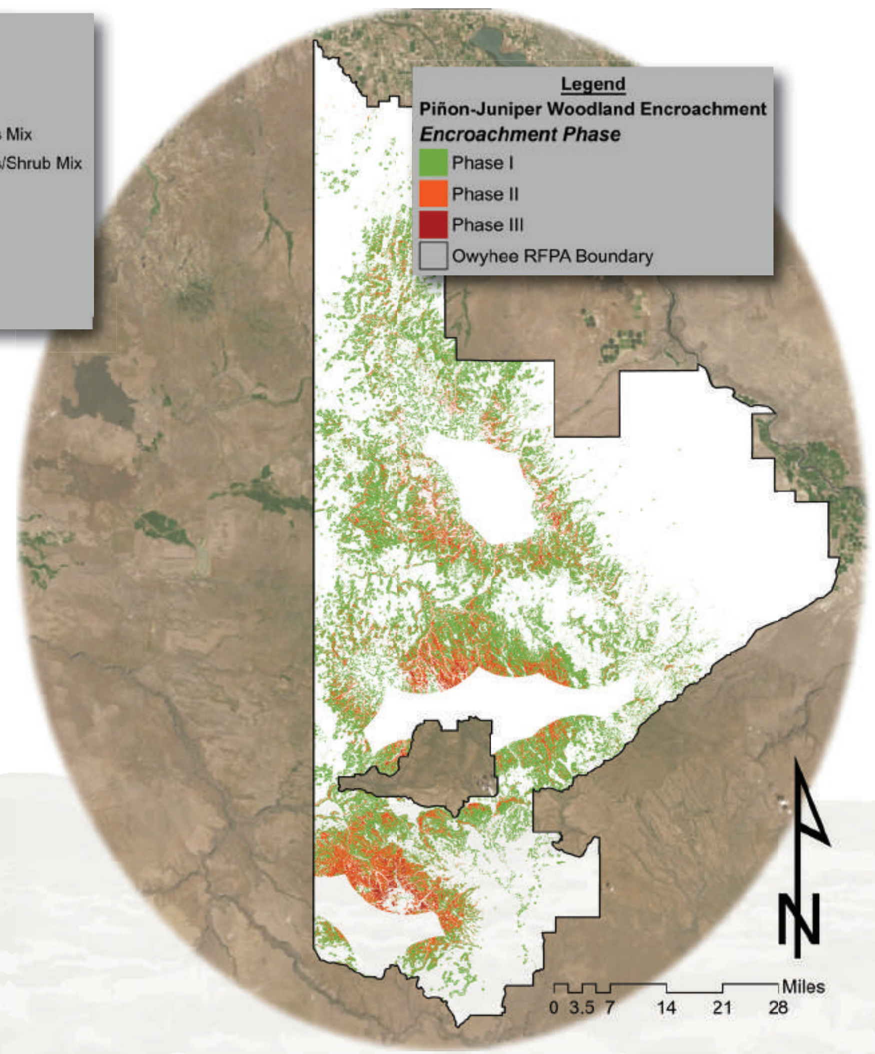


Figure 23. Piñon and Juniper Encroachment Phases within the Owyhee RFPA. *Figure Derived From*: BLM (2021)

Approved Manual and Mechanical Methods

Manual and mechanical methods typically go hand-in-hand, but in certain circumstances can be implemented separately (BLM, 2021). Manual methods consist of, "the use of hand tools and hand-operated power tools, hand planting of bareroot or container stock, and hand broadcasting [of] seed" (BLM, 2021). Whereas mechanical methods involve, "the use of vehicles such as wheeled tractors, crawler-type tractors, specially designed vehicles with attached implements designed to cut, uproot, or chop existing vegetation" (BLM, 2021). The BLM further groups mechanical treatments into three subgroups according to the delineations defined by Monsen et al. (2004), which are: (1) seedbed preparation equipment, (2) seeding equipment and (3) special use equipment (BLM, 2021). A quick breakdown of some of the types of treatments found within these three broader subgroups of mechanical treatments can be found in Tables 4, 5 and 6 and a comprehensive breakdown of all types can be found in Appendices 2, 3 and 4.

Common Seedbed Preparation Mechanical Treatments

Mechanical treatment involves the use of vehicles designed to cut, uproot, or chop existing vegetation. The selection of a particular mechanical method is based upon characteristics of the vegetation, seedbed preparation and re-vegetation needs, topography, terrain and soil characteristics

Equipment	Description	Primary Area of Use	Limitations
Disk Plow	Consists of a single gang of a few to several disks on a frame supported by wheels. Each disk is slanted at an angle to the vertical, with a separate bearing and frame attachment.	Deep plowing of rock-free and debris-free soil. Controls deep rooted plants.	Restricted to fairly rock-free and large debris-free sites. Slow speed. Large amount of power required to operate.
Ely-anchor Chain	Anchor chain weighing 40 to 160 lb per link, 90 to 350 ft long, with steel bars or railroad rails welded cross ways to chain links. Swivels are attached at either end and throughout.	Uproots and breaks off trees and shrubs. Releases understory vegetation. Percent kill of shrubs and trees is higher than with a smooth chain. Does an excellent job of scarifying soil surfaces and covering seed. Can be operated on rough, rocky terrain. Cost to operate is moderate.	Has tendency to hook and drag trees and shrubs to the middle of the chain. this lifts the chain off the ground, resulting in poor soil scarification. Can uproot and kill some understory vegeatiation.
Off-set Disk	Two rows of gangs of disks are set at an angle to each other. Angles are adjustable. Disks cut in two different directions, turning soil and vegetation both ways. Disks can be smooth or cutout.	First gang of disks turn soil and vegetation. second gang turns soil and vegetation in opposite directions. Vegetation is cut up and broken. Controls most grasses, forbs and small non-sprouting shrubs. Works well on dry, heavy and moderately rocky soils.	Cannot be operated in soil with large rocks and on slopes over 30 percent. Fairly slow operational speed.

Table 4. Common Seedbed Preparation Equipment for Use in Mechanical Treatments on Rengelands. *Table Derived and Adapted From*: Monsen et al. (2004)

Common Seeding Equipment for Mechanical Treatments

For more in-depth descriptions of the equipment types detailed below see Monsen et al., 2004.

Equipment	Description	Primary Area of Use
Drills	They are large heavy pieces of equipment typically pulled behind tractors, dozers or other large machines. Drills dispense and place various types of seed in the most ideal situations for germination and establishment.	Depends on type of drill, but most are suited for rough, rocky terrain where dense litter has not accumulated.
Ground Broadcasting	This is a method for uniformly broadcasting seed from handheld or vehicular mounted seeders. Seed is generally distributed by means of a rotary wheel. Ground broadcasters can be operated manually by a tractor's track or by hydraulic, gasoline, or electric motors. They can be mounted on trucks, trailers, or tractors and other prime movers, and attached to various types of seedbed preparation equipment.	Broadcast seeders are used to seed areas that are inappropriate for drill seeding, such as rocky or rough terrain, rocky soils, areas with large amount of debris, and small, irregularly shaped areas. Broadcast seeders can be used alone or in conjunction with seedbed preparation equipment. Broadcast seeding coupled with anchor chaining, disk-chaining, pipe harrowing, land imprinting, drilling, scalping, harrows, or other seed coverage treatments is often preferred over drill seeding. Costs are generally much lower than for drilling. Variable planting depths are achieved by broadcasting which often favors mixed species plantings. Sagebrush, rabbitbrush, forage kochia, and a number of other species do best with surface seeding on a disturbed surface. Broadcast seeders have been designed to facilitate surface seeding. With proper equipment, multiple species mixtures with differing seeding requirements can be seeded simultaneously.
Aerial Broadcasting	Aerial broadcasting is achieved through use of fixed-wing aircraft as well as helecoptors and is usually the most economical method for seeding large acreages. Typically, aerial broadcasting requires between 33 and 50 percent more seed than drilling, but its ability to uniformly distribute seed over short time periods throughout areas that would be otherwise inaccessable make it a useful tool to be employed in a variety of conditions.	Aerial boradcasting is used on sites with large areas that must be planted in small windows of time as well as on sites where terrain, access or enviornmental qualities make the use of other means of seeding impractical or impossible. Helicopters are usually selected over fixed-wing aircraft if irregular-shaped sites and variable terrain are seeded and when air strips are unavailable. Helicopter seeding is recommended for planting high elevation sites, streambanks, and roadways where fixed-wing planes do not operate as safely or satisfactorily.
Seed Dribblers	Seed dribblers deposit selected seed onto crawler tractor tracks. The seed is carried forward, dropped onto the soil, and pressed into a firmed seedbed. Tractor-pulled seed dribblers deposit seed directly into prepared seedbeds.	Dribblers are ideal for planting species that require firm seedbeds or whose seed is in short supply or extremely costly. Generally, seedling establishment of shrubs and forbs is greater when seeded through a dribbler than when broadcast or drilled. Species that require minimal coverage, like rabbitbrushes, sagebrushes, asters, and forage kochia establish much better when dribbled than when drilled. Dribblers are generally used in conjunction with other operations like chaining, cabling, and pushing trees and shrubs.

Table 5. Common Seeding Equipment for Use in Mechanical Treatments on Rengelands. *Table Derived and Adapted From*: Monsen et al. (2004)

Common Special Use Equipment for Mechanical Treatments

For more in-depth descriptions of the equipment types detailed below see Monsen et al., 2004.

Equipment	Description	Primary Area of Use
Herbicide Sprayers	Liquid herbicides are most commonly applied on rangelands by broadcast spraying. Application is by ground rigs, fixed-wing aircrafts, helicopters, and hand sprayers	Application of herbicide by ground rigs has several advantages over aerial application: small acreages can be sprayed, no landing strip is required (fixed-wing only), there is less drift, application is not restricted by fog or wind, equipment is generally less expensive, and applicators are safer. Aerial application does have some advantages over ground rigs: application rate (acres per hour) is greater and large areas can be sprayed during short periods of time when conditions are ideal. For this reason, aircraft are commonly used to spray large acreages. Aerial application is also well adapted to spraying wet, rough, steep, and rocky terrain. Cost of application is less, vegetation and soil are not disturbed, and dense, tall brush stands can be treated more effectively.
Roller Chopper	Roller choppers consist of a steel, 5 ft by 12 ft (1.5 m x 3.7 m) diameter drum with 12 grader blades evenly spaced and welded vertically around the outside of the drum and is pulled behind large equipment. Intake and drain plugs are installed to allow the drum to be filled with 800 to 900 gallons (3,000 to 3,400 L) of water. Steel frames, tongue, and hitch are attached to both ends of the drum.	Roller choppers are used to (1) push over, uproot, and chop up trees and shrubs with the main trunk at ground level less than 6 inches (15.3 cm) diameter, (2) create seedbeds, (3) cover seed, (4) create water catchment basins, and (5) to stimulate shrubs by pruning to 12 inches (30 cm) above ground level. When piñon and juniper have invaded grasslands, shrublands or chained areas, the roller chopper has been used successfully to remove them.
Dozers and Blades	Dozers and blades typically are used in one of 5 different configurations: **(1) Standard** - a straight concave blade solidly mounted to a crawler or rubber tired tractor **(2) Three-way Dozer** - a multi-purpose dozer blade that is adjustable for height, tilt, angle, and pitch **(3) Brush/Forest Rake** - consists of a special blade with vertical teeth generally with replaceable tips, or a vertical toothed implement that is attached to a standard or three-way blade **(4) Hula Dozer** - a standard dozer blade with hydraulic side tilt and pitch that is often equipped with four removable digger teeth spaced along the blade **(5) Shearing/Clearing** - a straight or V-shaped solid blade with straight or sharpened cutting edges along the bottom	Blades are used to uproot, cut off, move, pile, and windrow trees and shrubs; build or clean roads, fences, and fire lines; construct trenches, basins, and terraces; move and pile rocks and debris; prepare seedbeds and planting sites; and grade and carry out general excavation.

Table 6. Common Special Use Equipment for Use in Mechanical Treatments on Rengelands. *Table Derived and Adapted From*: Monsen et al. (2004)

Approved Chemical Treatments

Approved chemical treatments (herbicides) are included in Table 7 and their methods of application and conditions for use are derived from the Vegetation Treatments Using Herbicides on Bureau of Land Management Lands in 17 Western States Programmatic Environmental Impact Statement (EIS) and the Final PEIS on using Aminopyralid, Fluroxypyr, and Rimsulfuron (BLM 2007a, pp. 4-1 to 4-11, and 2016, pp. 4-1 to 4-6) (BLM, 2021; USDOI Bureau of Land Management, 2019). These chemicals can be used alone or alongside other treatment methods to manage plants that depart from the desired vegetative state of the site and applications may require additional treatments due to the dynamic environmental characteristics of each application site (BLM, 2021).

Herbicides Approved for Use in Chemical Treatments on BLM Land

For more in-depth descriptions of these chemicals and thier appoved subsequent formulation(s) see: BLM Approved Herbicide Formulations - April 4, 2019 and associated Environmental Assessments

		Approved for:	
Active Ingredient	Common Trade Names	*Aerial Application*	*Ground Application*
2,4-D	2,4-D Amine, 2,4-D LV 4/6; Aqua-Kleen; Barrage HF; Clean Amine; D-638; Five Star; Hi-Dep; Opti-Amine; Platoon; Salvo; Solve 2,4-D; Weedone LV-4	X	X
Aminopyralid	Milestone	X	X
Bromacil	Alligare Bromacil 80; Cennard Bromacil 80DF; Hyvar X; Hyvar XL	X	X
Chlorsulfuron	Alligare Chlorsulfuron 75; Chlorsulfuron E-Pro 75 WDG; Nufarm Chlorsulf SPC 75 WDG Herbicide; Telar XP	X	X
Clopyralid	Alligare Clopyralid 3, CleanSlate, Pyramid R&P, Reclaim, Spur, Stinger, Transline	X	X
Dicamba	Alligare Cruise Control; Banvel; Clarity; Diablo; Kam-Ba; Rifle; Sterling Blue; Topeka; Vanquish; Vision	X	X
Diflufenzopyr + Dicamba	Distinct; Overdrive		X
Diquat	Alligare Diquat Herbicide; Diquat E-AG 2L; Diquat E-Pro 2L; Diquat SPC 2L Herbicide; Nufarm Diquat 2L Herbicide; Reward	X	X
Diuron	Alligare Diuron 4L; Direx; Karmex DF; Parrot DF	X	X
Fluridone	Alligare Fluridone; Avast!; Fluridone 4L; Sonar AS; Sonar Precision Release	X	X
Fluroxypyr	Alligare Flagstaff; Alligare Floroxypyr; Comet Selective; Vista XRT	X	X
Glyphosphate	Accord Concentrate; Aqua Neat; Auqa Star; Aquamaster; Buccaneer; Credit Xtreme; Foresters; Honcho; Imitator Aquatic; KleenUp Pro; Mirage; Razor; Rodeo; Roundup; Showdown	X	X
Hexazione	Pronone; Velosa; Velpar	X *(when not combined with Sulfometuron Methyl)*	X
Imazapic	Alligare Panoramic; Nufarm Imazapic; Open Range G; Plateau	X	X
Imazapyr	Alligare Rotary; Arsenal; Chopper; Habitat; Polairs; SSI Maxim Arsenal; Stalker	X *(when not combined with Sulfometuron Methyl)*	X
Metsulfuron Methyl	Alligare MSM 60; AmTide MSM; Cimarron MAX - Part A; Escort XP; Patriot; PureStand; Romestol	X	X
Picloram	Alligare Picloram 22K; Grazon PC; OutPost 22K; Tordon; Triumph; Trooper	X	X
Rimsulfuron	Alligare Laramie 25DF; Hinge; Matrix SG	X	X
Sulfometuron Methyl	Alligare SFM 75; Oust; Spyder		X
Tebuthiuron	Alligare Tebuthiuron; Spike; SpraKil S	X	X
Triclopyr	Alligare Boulder; Alligare Triclopyr; Element; Forestry Garlon; Garlon; Pathfinder II; Relegate; Remedy; Renovate; Tahoe 3A/4E; Triclopyr RTU; Trycera; Vastlan	X	X

Table 7. List of Approved Herbicides for Use on BLM Lands and their Accepted Application Methods. *Table Derived and Adapted From*: BLM Approved Herbicide Formulations (2019)

Approved Targeted Grazing Applications

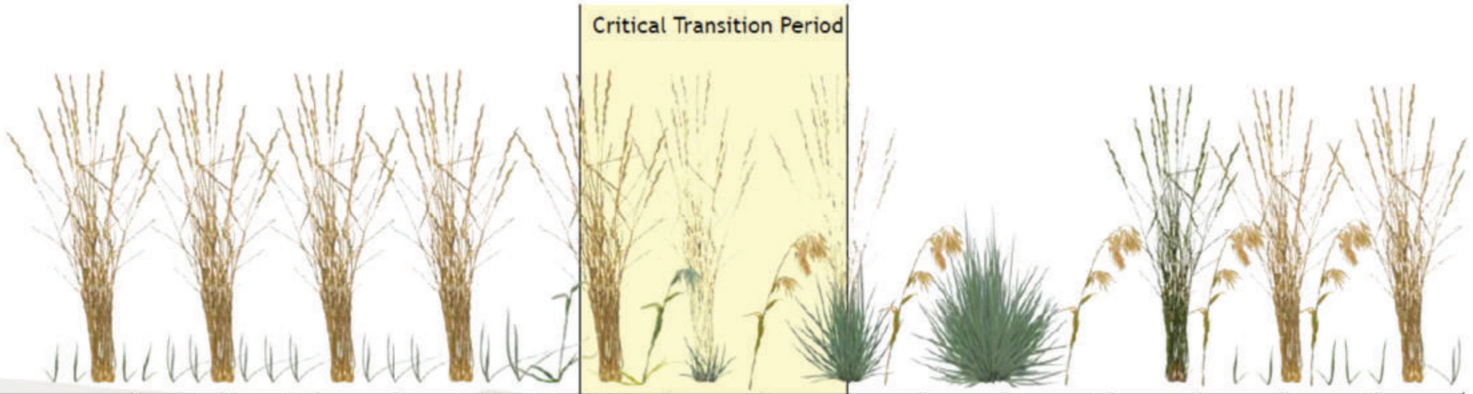
Although historic maladaptive grazing practices throughout the Great Basin have aided in the infiltration and encroachment of invasive species over the past century, when used strategically and under intensive management supervision by grazing operators, targeted livestock grazing can be an extremely useful tool in achieving the management goals of: (1) reducing fine fuel loads, (2) reducing cover and seed bank of invasive annual grasses to decrease competition against native plants and (3) preparation of a site for seeding through removal of biomass (BLM, 2021; Chambers et al., 2014; Miller et al., 2011; Miller and Rose, 1999; Woods et al., 2013). In terms of achieving those first two goals targeted grazing, "manipulates vegetation (composition, fuel continuity, or fuel loading) in areas with over 10 percent invasive annual grass or nonnative perennial grass cover and when native perennial bunchgrass cover is below 20 percent" (BLM, 2021). When utilized as a preparation method for future seeding application, targeted grazing, "reduces cover in the treatment area through [consumption] and trampling of above-ground biomass" (BLM, 2021). These practices are to be implemented throughout the project area at the discretion of individual land managers on a site-specific basis that takes into account various factors including, "vegetation type, desired vegetation objectives, terrain and current growing year conditions" (BLM, 2021). Figure 24 adapted from Smith et al., 2012 illustrates the timing considerations to be taken into account when implementing targeted grazing actions.

"Green and Brown"

Grazing Strategy for Invasive Annual Grasses

Use this chart to help you manage invasive annual grasses such as medusahead and cheatgrass.

In the table below, grazing periods are imposed based on the actual plant growth stage for both desired perennial grasses and annual grasses. The calendar months are only to be used as a general reference, **always graze by plant growth stage paying close attention to early green-up of perennials**. This also illustrates the critical transition period for removing livestock.



Grazing Period	Yes	Yes	Yes	Yes	Yes	Maybe	No	No	No	Maybe	Maybe	Maybe	Yes	Yes	Yes
Perennial Grasses	Senescence		Dormancy				Growth initiation	Leaf growth	Boot stage & seed head emergence		Flowering & seed development		Seed hardening & scatter & senescence		
Annual Grasses	Germination		Growth initiation			Leaf growth	Boot stage	Flowering & seed development		Seed hardening & scatter		Death	Germination & growth initiation		
Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec

Figure 24. "Green and Brown" Grazing Strategy for Invasive Annual Grasses. *Figure Adapted From:* Smith et al. (2012)

Idaho Rangeland Fire Protection Associations (RFPAs)

Introduction to the Owyhee RFPA

While the PEIS produced by the BLM sets forth a robust set of measures to adaptively manage the lands under their administration, the remote and rural nature of the Owyhee RFPA as well as the large tracts of private land throughout the selected project area create issues that must be addressed to ensure comprehensive fuels reduction and restoration of rangelands in the area. To that end, with the management issues created by the increase in fire severity and prevalence seen in the sagebrush steppe rangelands of southern Idaho being further complicated by a lack of sufficient resources to adequately protect the mosaic of different land ownerships that make up these remote rangelands, the state of Idaho in 2012 took note from similar actions in nearby states and created a pathway for local residents to aid in fire suppression activities alongside federal firefighting crews with their authorization of the creation of Rangeland Fire Protection Associations (RFPAs) (Stasiewicz and Paveglio, 2017). While RFPAs have existed in the neighboring state of Oregon since the 1960's, local residents in across the border in Idaho had no such legal resource until this action (Stasiewicz and Paveglio, 2017).

In Idaho, currently there are two ways that local residents can aid in fire protection activities on private and public unprotected lands; Fire Protection Districts (FPDs) and RFPAs. The primary focus of FPDs is the protection of structures and they can also offer some wildland fire protection in certain cases (IDL, 2015). But, what are RFPAs and how can they help ensure more comprehensive management implementation across these remote rangelands? RFPAs are non-profit organizations that create an avenue for local residents to work and coordinate with land management agencies and aid in wildfire detection, prevention and or suppression efforts on remote areas of public and private lands with little to no governmental suppression capacity (Abrams et al., 2017; Idaho Forestry Act, 2013; IDL, 2015; Stasiewicz and Paveglio, 2017; Stasiewicz and Paveglio, 2018). They sprang from the efforts of a group of private Idaho ranchers in December of 2010 who wanted to have a better avenue for protecting themselves, their lands and livelihoods from the increasing threat posed by wildfires (IDL, 2015). Through a collaborative effort between themselves, the then governor of Idaho Butch Otter, the BLM and the Idaho Department of Lands (IDL) an avenue for the creation of RFPAs was established (IDL, 2015). The three main issues intended to be addressed through the creation of these associations were at the time and still remain today to be: (1) the alignment of local, state and federal concerns about more frequent and larger scale wildfire events on rangelands, (2) conservation of sagebrush ecosystems and sage grouse habitat threatened by wildfire for the benefit of all parties and (3) repeated loss of forage and access to public grazing allotments due to wildfire (IDL, 2015; Stasiewicz and Paveglio, 2018; USDI, 2015).

Rangeland Fire Protection Associations (RFPAs) of Idaho

For more information pertaining to specific RFPAs please visit:
https://www.idl.idaho.gov/fire-management/rangeland-fire-protection-associations/

Organization Name	Area (acres) Protected	Current Membership
Mountain Home RFPA	674,326 ac	40
Owyhee RFPA	1,370,873 ac	51
Saylor Creek RFPA	2,222,000 ac	68
Three Creek RFPA	1,120,000 ac	51
Black Canyon RFPA	185,000 ac	19
Shoshone Basin RFPA	488,000 ac	19
Notch Butte RFPA	341,000 ac	28
Camas Creek RFPA	1,494,000 ac	20
Henry's Creek RFPA	914,696 ac	19

Table 8. Rangeland Fire Protection Associations of Idaho. *Table Derived From:* Idaho Department of Lands (2021)

Currently, there are 9 established RFPAs throughout southern Idaho that together help manage over 2 million acres of public and private land (Idaho Department of Lands, 2021). To introduce these associations a list was created and can be seen in Table 8 broadly detailing each and a map showing the boundaries of their management zones is illustrated in Figure 25. As has been stated previously, the RFPA that is the focus of this project will be the Owyhee RFPA located in southwest Idaho south of Boise and bordering Oregon.

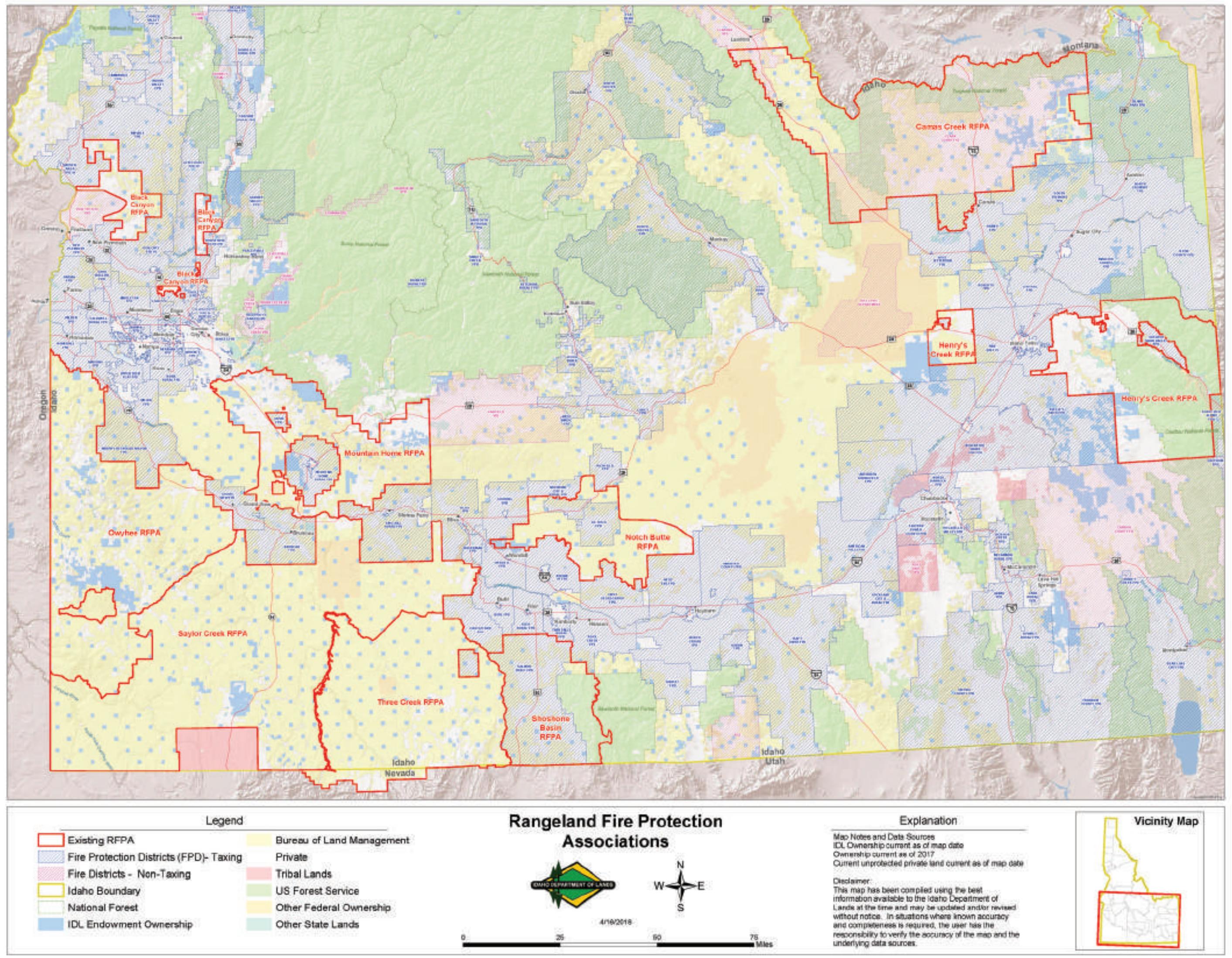


Figure 25. Map of Current Rangeland Fire Protection Associations in Idaho. *Figure Credit:* Idaho Department of Lands (2017)

How are RFPAs Formed?

In order to form an RFPA, local residents must petition the director of IDL and show completion of four preliminary steps: (1) acquire nonprofit status, (2) acquire liability insurance, (3) establish a board of directors to serve as the governing structure for the association and (4) demonstrate the ability to fund their own startup costs or enter into an agreement with the Idaho state legislature to cover the costs (Idaho Forestry Act, 2013). After establishment, the director of IDL will conduct a review annually of the adequacy of the RFPA's governing and management structure, adequacy of their liability insurance and training status of all association personnel (Idaho Forestry Act, 2013). In terms of providing funding for their liability insurance and procurement of the necessary personal protective equipment (PPE) as well as radios for communication with other management agencies, each RFPA must internally determine how to distribute costs throughout their members (Idaho Forestry Act, 2013). Additionally, in order for members of these associations to legally be allowed to participate in wildland fire detection, prevention or suppression on publicly owned lands they must first complete an initial 40-hour wildland firefighter training program and thereafter, on an annual basis, must attend recertification meetings (BLM, 2016; Idaho Forestry Act, 2013).

These minimum measures are intended to ensure that the civilian volunteers of the RFPAs assume their own liability in the face of fighting often dangerous wildland fires and to ensure that they can effectively communicate and coordinate in real time with other managing agencies during performance of their firefighting duties (Stasiewicz and Paveglio, 2018). Additionally, it is common practice for RFPAs to work with local, state and federal fire management agencies to determine their protection districts, also known as "mutual aid areas" (Stasiewicz and Paveglio, 2018). These areas and the associated guidelines dictating the responsibilities of all parties involved in firefighting activities during the performance of their firefighting duties are typically determined through the establishment of mutual aid agreements (MAAs) with state and federal fire management entities and through memorandums of understanding (MOUs) between the RFPAs and more local fire management entities (Stasiewicz and Paveglio, 2018).

Once an RFPA is established and agreements are made between the collaborating fire management entities, members who have completed the necessary training and attained the necessary PPE are allowed to assist in detection, prevention and suppression activities on publicly owned lands (Stasiewicz and Paveglio, 2018). This additional aid provided by RFPA members is often pivotal to the success of fire management operations in the remote rangelands of southern Idaho as, more often than not, state and federal agencies do not have adequate resources readily available to contend with fires when they do occur in these remote areas, but RFPA members being those who live and work within the landscape on a daily basis often do (Abrams et al., 2017; IDL, 2015; IDL, 2017; Stasiewicz and Paveglio, 2017; Stasiewicz and Paveglio, 2018). Through acquisitions of equipment from neighboring local, state or federal fire management entities in addition to the equipment already owned and operated for personal use (tractors, dozers, discing equipment and water tanks), trained RFPA members are uniquely positioned to often not only be the first line of defense when these remote wildland fires occur, but also to detect and prevent fires from occurring in the first place and in some cases they can even be the only personnel available at all (Abrams et al., 2017; Stasiewicz and Paveglio, 2017; Stasiewicz and Paveglio, 2018).

This has obvious implications in terms of the efficacy of fire management goals in these remote sagebrush steppe rangelands. To that end, through the execution of this project a robust and easily accessible heuristic for land managers within the Owyhee RFPA to use in their determination of site specific suites of best management practices was developed. The goal of which was to better integrate the knowledge, skills, manpower and equipment of this RFPA into the overall federal fire management strategies for these rangelands. It is the hope of this project that the methods and outcomes produced can be subsequently utilized throughout the region to create more comprehensive, cohesive, collaborative and adaptive management strategies for long-term fuels reduction and rangeland restoration throughout the Great Basin as a whole.

Overview of Landscape Architecture in Land Planning Applications

The Field of Geodesign

As has been shown through the preceding sections, the need for robust, adaptive, multi-layered systems of protection for communities and the environments they live in and depend on for their livelihoods, recreational opportunities and overall continued existence on the landscape is growing ever greater in today's world of rapidly changing human and natural systems. To that end, the role of practitioners in the field of landscape architecture is becoming increasingly integral to the process of long-term land planning as well as to the design of more adaptive and robust communities for the future. Through collaboration with researchers, planners, administrators, as well as the "people of the place" landscape architects are adept at bridging the gap between managers and stakeholders and transforming the wants and needs of communities into on-the-ground applications that create avenues for resilient and sustainable future growth. Projects incorporating these collaborations of design professionals, geographic scientists, information technologists and the people of the place form the basis for this field within the overarching umbrella of landscape architecture that has been termed "geodesign" (Steinitz, 2012).

What is geodesign and how do landscape architects fit into the process? For an overview of this exciting and evolving field we turn to one of the foremost progenitors of the field as it is today, Carl Steinitz. Through the creation of his scenario based geodesign framework Steinitz created an avenue for researchers, managers and stakeholders to collaboratively answer the question, "How do we get from the present state of this geographical study area to the best possible future?". In order to answer this question Steinitz's geodesign framework, at its core, seeks to answer seven ancillary questions using an iterative process: (1) How should the study area be described? (2) How does the study area operate? (3) Is the current study area working well? (4) (5) How might the study area be altered? (6) What differences might the changes cause? (7) How should the study area be changed?" (Steinitz, 2012, p.25). This is achieved through a collaborative and iterative process between the stakeholder advisory group or "SAG" (a group comprised of residents of the study area each contributing a different perspective and base of knowledge including experience with habitat management, fisheries science, recreation, local policy including tribal and water rights, farming, and land management practices) and the geodesign team (which, among other research professionals, incorporates individuals from the field of landscape architecture) in which each question is answered threefold, once in every iteration. This process includes associated models, which are abstracted illustrations of perceived reality, including representation models, process models, evaluation models, change models, impact models, and decision models the parameters of which will have been developed collaboratively by the SAG and geodesign team (Steinitz, 2012, p. 25). The first and second iterations of the process strive to define and then refine the definition of the study area and the methodology that will be used for analysis and the third iteration emphasizes gathering quantitative and qualitative data from the SAG and geodesign team to arrive at a preliminary research product or set of modeled scenarios for alternative futures (Steinitz, 2012, p. 87). Products deemed compelling by the geodesign team then go to the SAG for final approval and any unacceptable products are sent back through the frameworks process for revision or scale modification. Once the research product has been given final approval by the SAG, its findings are then to be implemented into management actions going forward ranging from site-scale design interventions to landscape-scale public policy (Steinitz, 2012, p. 88). This process can be seen in illustrated form in Figure 26.

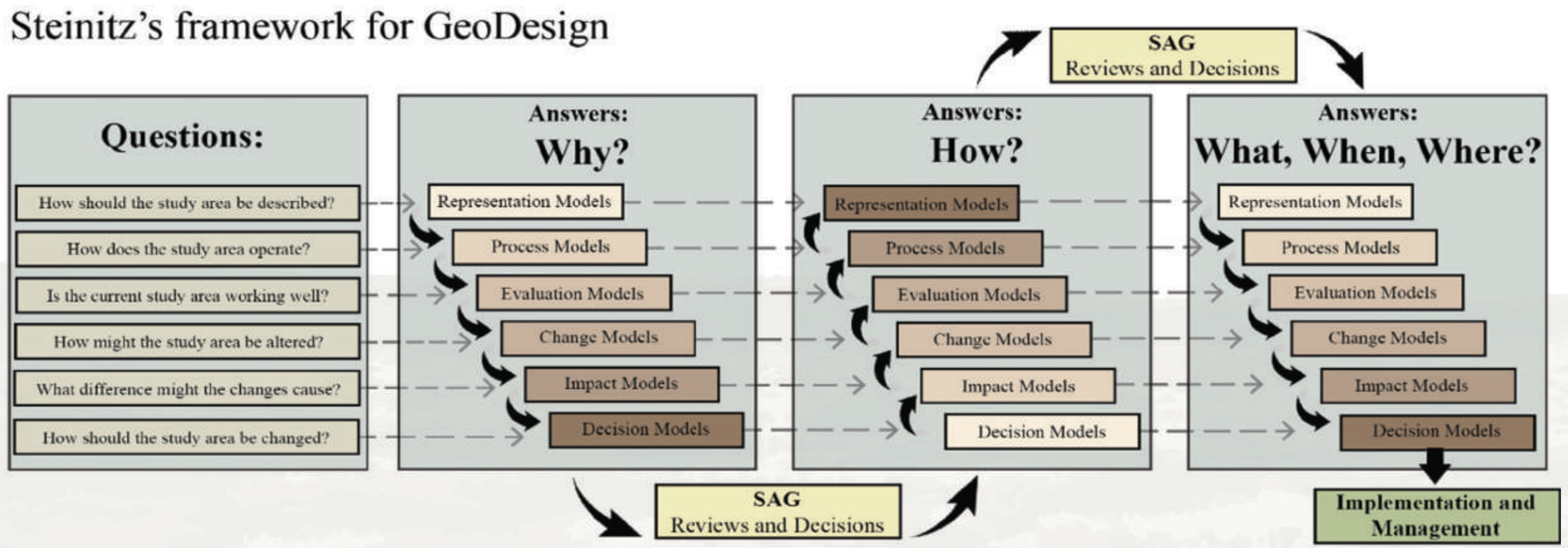


Figure 26. Steinitz's Framework for Geodesign. *Figure Adapted From*: Steinitz (2012)

Another innovator of geodesign, Allan Shearer, whose work has aided in making scenario development for the geodesign process more robust defines scenarios as follows: "Scenarios are understood to be predictive judgements which describe what could happen, not predictions that describe what will happen, or even what is likely to happen. Scenarios are fictional, meaning they are unverifiable but plausible, accounts which represent a process of change over some duration. Scenarios describe situations, actions, and consequences that are contingently related. Finally, scenarios organize information within explicitly defined frameworks" (Shearer, 2005).

Typically, these scenarios are conveyed to those outside the research team as scenario narratives. These scenario narratives are, "qualitative descriptions that, through a storyline process, describe either the end state of the desired scenario or the propagations of change necessary to achieve the desired end state" (Mahmoud et al., 2009). Presenting scenarios in this manner makes their complex natures more discernable and so is a means to facilitate deeper and more meaningful discussions between the SAG and research team, which allows the research team to then build the modeling frameworks to better suit the needs of the people of the place (Mahmoud et al., 2009; Shearer, 2005; Steinitz, 2012).

For the geodesign process, a scenario-based approach helps produce more robust predictions about the alternative futures a study area might experience. This is the case as they allow for both the relation and comprehension of isolated pieces of information within a single framework and a structured approach by which to consider individual factors across different frameworks. The questions that must be answered when creating each scenario – who, what, when, where and why - ensures that each is depicted and analyzed through ad many differing perspectives as possible, thereby limiting the occurrence of unforeseen consequences and in many cases serving as a catalyst for considering novel or even artificial scenarios. Thus, they serve as a vehicle to better enlighten, enrich and promote more discussions between and amongst the SAG and the research team, leading to better solutions that are more tailored to the people of the place and their needs, wants, beliefs and goals (Shearer, 2005).

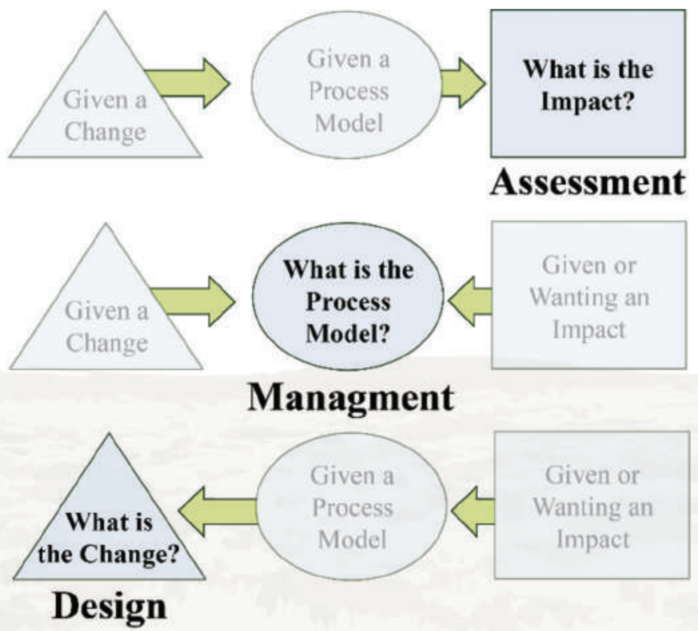


Figure 27. The Three Applications of Models. *Figure Adapted From*: Steinitz (2012)

The main purpose of a scenario within the framework of geodesign is to act as a variable or set of variables for a model or set of models; a model being an abstraction of the real world, as seen by the researchers, that can ultimately be mathematically tested to obtain statistics about the possible alternative futures of a given study area; as shown in Figure 27 (Steinitz, 2012, p. 7). The products of these models, termed alternative futures, are what have been determined to be the most likely outcomes given the specific scenarios input into the model and as such, reflect the changes that could happen to the study area at a spatiotemporal scale; through the physical world bounded within the study area and through the advance of time in that study area (Shearer, 2005; Steinitz, 2012). Typically, within the field of geodesign it is the job of landscape architects to facilitate informed communication and collaboration between researchers, administrators and the people of the place through the creation of visual representations of these geospatial scenarios and alternative futures as well as by way of offering their expertise on the creation of resilient land planning and design applications within the developed scenarios.

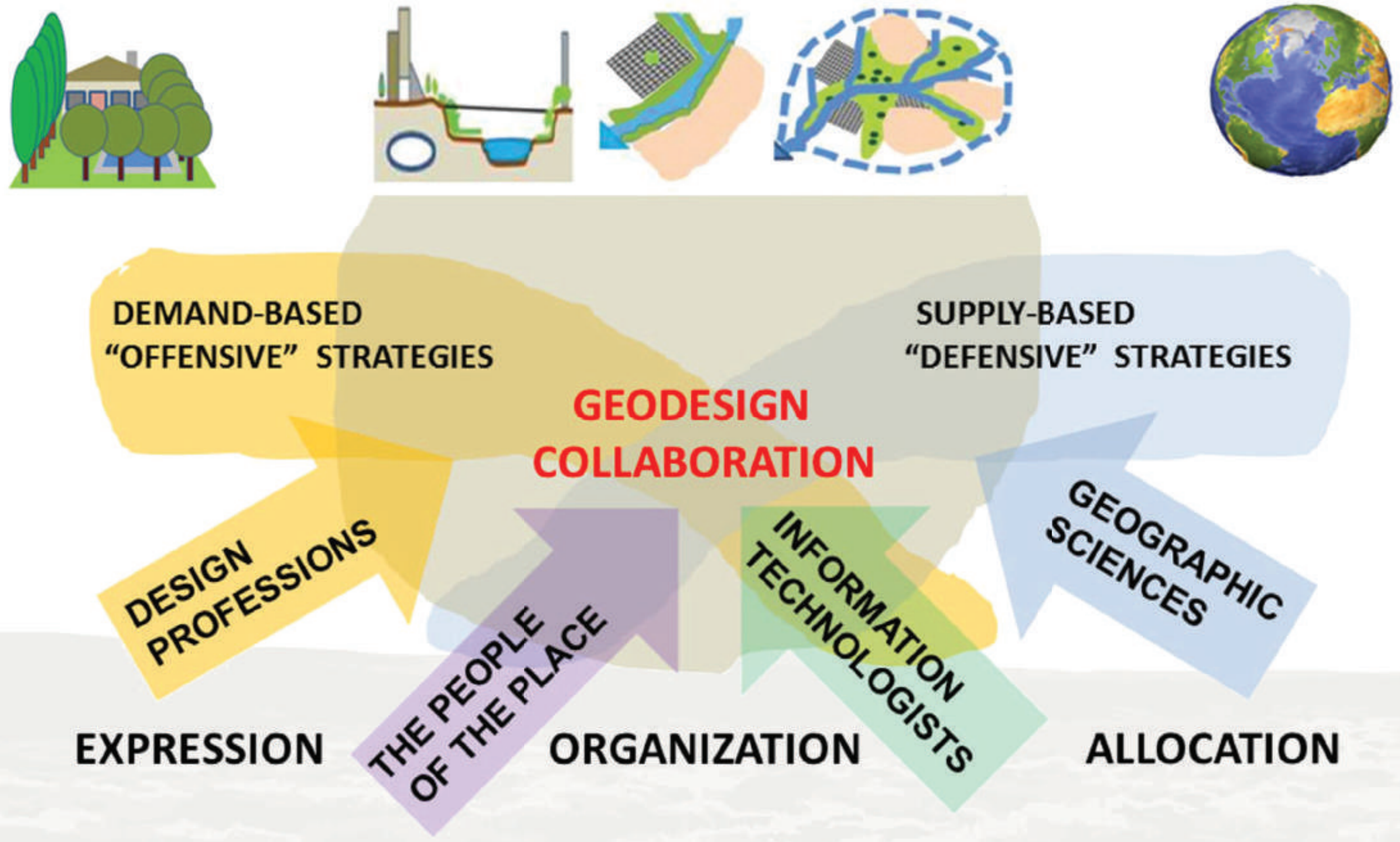


Figure 28. The Differing Scales of Collaboration Inherent in the Field of Geodesign. *Figure Adapted From*: Steinitz (2012)

Relevance of the Project to Landscape Architecture

With respect to this project and its relevance and specific integration into the field of landscape architecture, the writings of Deming and Swaffield in their book, "Landscape Architecture Research: Inquiry, Strategy, Design" will serve as the foundation for its justification and explanation. From their writings it is clear that this project falls under their categorizations of "positivist natural sciences – modeling" as well as "pragmatism through place studies and project evaluation". See Table 9 for the foundations for knowledge claims developed by Deming and Swaffield (2011).

Foundations for Knowledge Claims

A heuristic classification of knowledge claims within the dicipline of landscape architecture.

Assumptions About Knowledge and the World	The Purpose of Knowing	Examples of Theoretical Perspective	Examples within Landscape Architecture	Typical Research Strategies	Typical Research Methods	Predominant Modes of Representation
Objectivism	Instrumental/ Predictive What, Where & How?	(Post) Positivist Natural Sciences	Landscape Perception Stuides Landscape Ecology	Descriptive Survey Modeling Experimentation & Quasi-experiments	Measurement and Mapping Questionaire Surveys Statistical Analysis Alternative Futures	Mathematical Symbols with Written Interpretation
(Social) Construction	Interpretive Who, When & Why?	Pragmatism Hermeneutics Symbolic Interaction Phenomenology	Design Process Place Studies Community Studies Historical Studies Project Evaluations	Classification Ethnography Discourse Analysis Iconography Historiography Evaluation & Diagnosis	Close Observation Interviews and Focus Groups Documentary Analysis Life Histories Post Occupancy Evaluation	Written Narrative with Illustrative Diagrams and Photographs
Subjectivism	Critical *What are the consequences? How might things be done differently?*	Critical Inquiry Post-structuralism Feminist	'Expressivist' Theory 'Critical Visual Studies' Design Scenarios	Action Research Projective Design Logical Systems & Argumentation	Deconstruction Reflection Creative Intervention	Diverse Media: -Written -Graphic -Aural -Performance

Table 9. Foundations for Knowledge Claims in the Field of Landscape Architecture. *Table Derived From*: Deming and Swaffield (2011)

Genes by Environment: Modeling, Mechanisms and Mapping (GEM3)

Overview of the GEM3 Project

This project exists within the framework of the Idaho-based National Science Foundation (NSF) Established Program to Stimulate Competitive Research (EPSCoR) Genes by Environment: Modeling, Mechanisms, and Mapping (GEM3) project: OIA-1757324. The GEM3 project seeks to understand how changes in the environment affect local species and their habitats; specifically redband trout and sagebrush. This research combines both researchers with strengths in bioinformatics, complex modeling, ecology, fisheries science, genomics, geospatial science, remote sensing, and social-ecological science (SES) as well as an abundance of local knowledge garnered from SAGs to contribute to the national challenge of understanding the "Rules of Life: predicting phenotypes from what we know about the genome and environment." See the graphics below for illustrations of the participating institutions and colleges within the project. To determine the best path forward, the GEM3 project has employed the use of geodesign based on the robust methodology developed by Carl Steinitz (2012), as outlined above, to model alternative futures for Owyhee and Teton County in southern Idaho. Their models are intended to simulate various alternative futures depending on separate, but related, variables encompassing historical, economic, cultural, social, ecological, and constructed systems through time and space throughout the regions.

Project Goals, Objectives and Relevance to GEM3

This project serves to augment the outcomes of the overarching GEM3 project through the creation of a suite of best management practices intended to better integrate the local knowledge, skills, manpower and equipment of RFPAs into the overall fire management strategies of the chosen study area under the assumptions of both the "Destroying Boise's Playground" and "Business as Usual" scenarios developed through collaboration between the GEM3 geodesign team and their SAG. Where the "Business as Usual" scenario assumes that all current and existing trends of landscape growth and change will for the foreseeable future continue at the same overall rates as have been historically occurring, and where the "Destroying Boise's Playground" scenario of future change assumes that little to no enforcement of existing regulations, inadequacy of those regulations and lack of funding and revenue coupled with an increased inundation of the area by recreators who are not respectful or are ignorant of the rules, risks and regulations of the area coalesce to produce exponential population growth in the Treasure Valley as well as increased detrimental pathways of recreational use of the natural resources of the Owyhee area. Both scenarios of future change have obvious and differing implications in terms of the efficacy of fire management goals in these remote sagebrush steppe rangelands.

To that end, it was the final goal of this project to create more comprehensive, cohesive, collaborative and adaptive management strategies via the creation of an easily accessible online geospatial HUB application containing scenario-specific suites of robust and resilient BMPs for long-term fuels reduction and rangeland restoration under these stakeholder-derived scenarios. The intended objective of this HUB application is the facilitation of a more comprehensive and regionally implementable management strategy that can be used as an integrative framework for local land managers to aid federal managers in the management of fire in these areas of complex mosaics of landscape ownership and those similar to them. The utility of this is that a HUB application that is easily accessible out in the field containing scenario-specific blanket management strategies such as the one produced by this project can be implemented under the same or similar parameters across a large geographic range and thus will help ensure the efficacy of management efforts is not hindered by counter-productive and even detrimental management strategies of others in the same areas. This, it is hoped, will lead to a more cohesive and effective overall management strategy for wildfire in the rangelands of the northwestern U.S. that begets a reduction in the prevalence and intensity of large ecosystem-altering fires in the future resulting in the better protection of existing, and the creation of new, healthy sustainable sagebrush steppe ecosystems for the benefit of the native fish and wildlife that rely on them as well as for current and future generations of recreators and land users.

Methodology

Introduction to Methodology

Due to its, "strength of drawing on both qualitative and quantitative research" and the nature of what this project has attempted to accomplish a convergent parallel mixed methods approach that utilizes both quantitative and qualitative data collection and analysis was chosen as the methodological pathway (Creswell, 2009). The mixed methods approach of this project began with hindcasting of various past and current trends as well as forecasting of plausible future trends of the study site and its surrounding area. It then moved on to creation of risk and protection zones on the landscape, which were used to delineate priority zones for management actions and techniques. Next, geospatial layers depicting where mechanical management techniques, chemical application and targeted grazing operations could realistically occur on the landscape were created and combined with the previously created priority zones. This led to outputs illustrating where the differing suite of management actions could be applied as well as the relative priority of each with respect to where it could possibly be implemented on the landscape at a site-specific scale. In terms of the final outputs, these geospatial datasets were compiled into an online HUB application (https://experience.arcgis.com/experience/9116e77e758d440898874679b56630b9/page/Home/) for ease of use by local land managers. Within this HUB each technique has had temporality added to when it is best applied, in addition to heuristic pathways for use by local land managers in their determination of which other management techniques are best used in concert with or in exclusion of it depending on the selected site's specific management needs. The following paragraphs of this methodology section outlines these methods in greater detail, the products of these methods will be examined in the results section and the creation of the HUB, and its heuristic pathways are further outlined in the discussion section.

Through these methods, this project illustrates a robust heuristic for use by land managers in determination of BMPs for the Owyhee RFPA under the assumptions of two stakeholder-driven scenarios developed as part of the scenario development process during the NSF funded Idaho EPSCoR GEM3 project; grant number OIA-1757324. Over the course of multiple workshops between researchers and the SAG beginning in the Fall of 2018 and continuing through Fall of 2022 four scenarios of plausible future change were decided upon: (1) Business as Usual, (2) Destroying Boise's Playground, (3) Ecological Conservation and (4) Managed Recreation. Of these, the chosen scenarios of the project to run this methodology for were the Destroying Boise's Playground scenario and the Business as Usual scenario. The two overarching questions this project sought to answer through the methodology and its output of a robust heuristic for determining BMPs for the Owyhee RFPA were; (1) If the chosen scenarios of future landscape change developed by the SAG come to pass, what areas of the landscape would be most heavily affected by fire? and (2) What could be done to mitigate that risk as well as restore rangelands under the assumptions of each scenario?

Methodology Process Diagram

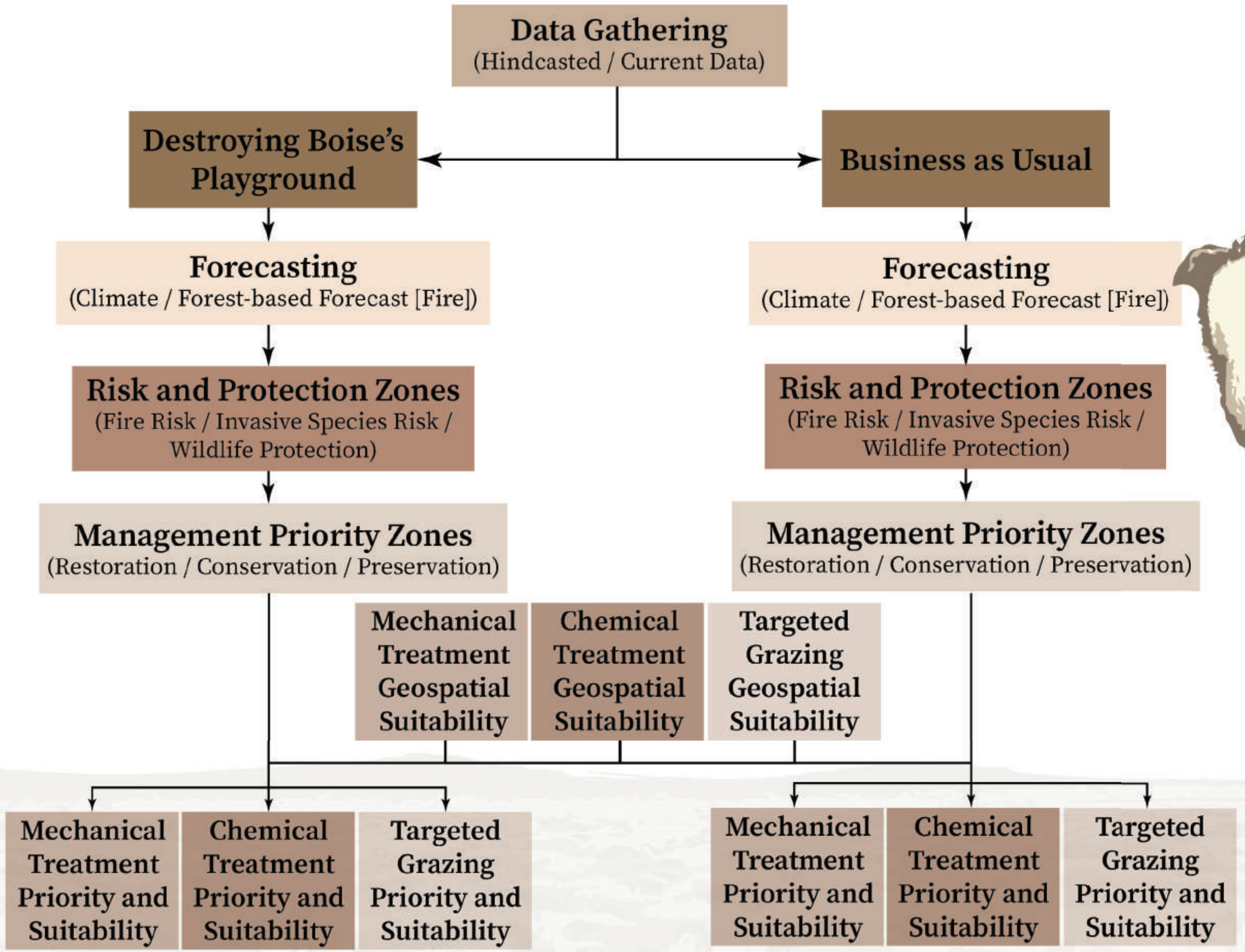


Figure 29. Methodology Process Diagram.

Destroying Boise's Playground Scenario

Under the Destroying Boise's Playground Scenario, the Owyhee area is expected to experience a massive boom in population growth brought on by immigration to the area by people fleeing other large urban centers around the country in search of a relatively more rural-esuqe lifestyle. This increase in population with people unfamiliar to the area and its culture is expected to increase conflicts between user groups of the natural resources due to differing values of the landscape among newcomers and longtime residents; as well as increase the stressors on the local environment through increased use, some of which is assumed to be in conflict with existing regulations regarding off-road trail use and trailblazing. This influx of new recreators and land users are also expected to stretch the services of the area in all sectors (law enforcement, hospitality, recreation, education and infrastructure) well beyond capacity, further exacerbating any detriments to the landscape they might incur. This, along with the changes in climate predicted under the Representative Concentration Pathway (RCP) value of 8.5, a greenhouse gas concentration trajectory adopted by the Intergovernmental Panel on Climate Change (IPCC), would lead to an increase in the rate of infiltration of invasive species into the already degraded ecosystems further increasing fire occurrence and accelerating habitat loss.

Figure 30. Destroying Boise's Playground Scenario Narrative Illustrative Graphic

Business as Usual Scenario

The other scenario chosen to perform the methodology of this project for, the Business as Usual scenario, is best thought of as a constant or representative of current trends against which it is useful to compare the differences assumed under other scenarios of plausible changes that might occur to those trend trajectories over time. With that, under this scenario, it is assumed that population growth in the area will remain at current levels determined by the 2020 census (US Census Bureau, 2022); 0.336% in Owyhee County annually, 2.6% in Ada County annually and 2.2% in Canyon County annually. As with the Destroying Boise's Playground scenario, changes in climate are expected to continue current trajectories indicated by RCP 8.5 and the World Climate Research Programme's "Coupled Model Intercomparison Project 5" (CMIP5) projections. It is also assumed that invasion rates by exotic annual grasses will remain constant at an increase in land cover of 0.5% annually, sagebrush reduction in land cover will remain constant at a loss of 0.5% annually throughout the study site, land development will increase at a rate of 0.5% annually, and trail use will also increase at a rate of 0.5% annually.

Figure 31. Business as Usual Scenario Narrative Illustrative Graphic

Hindcasting

To begin this methodology, a thorough investigation of historical trends that the study site has exhibited over the past few centuries was undertaken. Much of this research into the scientific literature as well as the available geospatial, cultural and social data has been outlined in more detail throughout the preceding sections. However, overall, the findings of this project indicate that the Owyhee area, which is characterized by high desert plant and animal communities that live in a landscape dominated by deep canyons, plateaus, and tall mountain ranges has, over the past few centuries, seen massive changes to its overall ecosystem processes and makeup: see Figure 30 for a contextual illustration of the historic effects fire has had on the landscape within the study site.

This shift has been brought on, both directly and indirectly, by changes in land use and management strategies in addition to rapid and drastic climatic changes. Changes found to be exhibited on the landscape through this investigation include, but are not limited to, changes in fire regimes, invasion of non-native as well as native species into novel habitats, reduction of sagebrush steppe ecosystems and their accompanying dependent species, the use of rangelands for forage for increasing amounts of large ungulates, as well as large increases to the human population of the surrounding area which has contributed to increased recreational use and has subsequently led to an intensification of stressors to the environment of the Owyhee area (Baker et al., 2011; Chambers et al., 2014; Fesenmyer & Dauwalter, 2014; Griffin, 2002; Kitchen, 2016; Knick et al., 2011; Miller et al., 2011; Miller et al., 2014; Miller and Rose, 1999; North et al., 2015; Williamson et al., 2019; Woods et al., 2013).

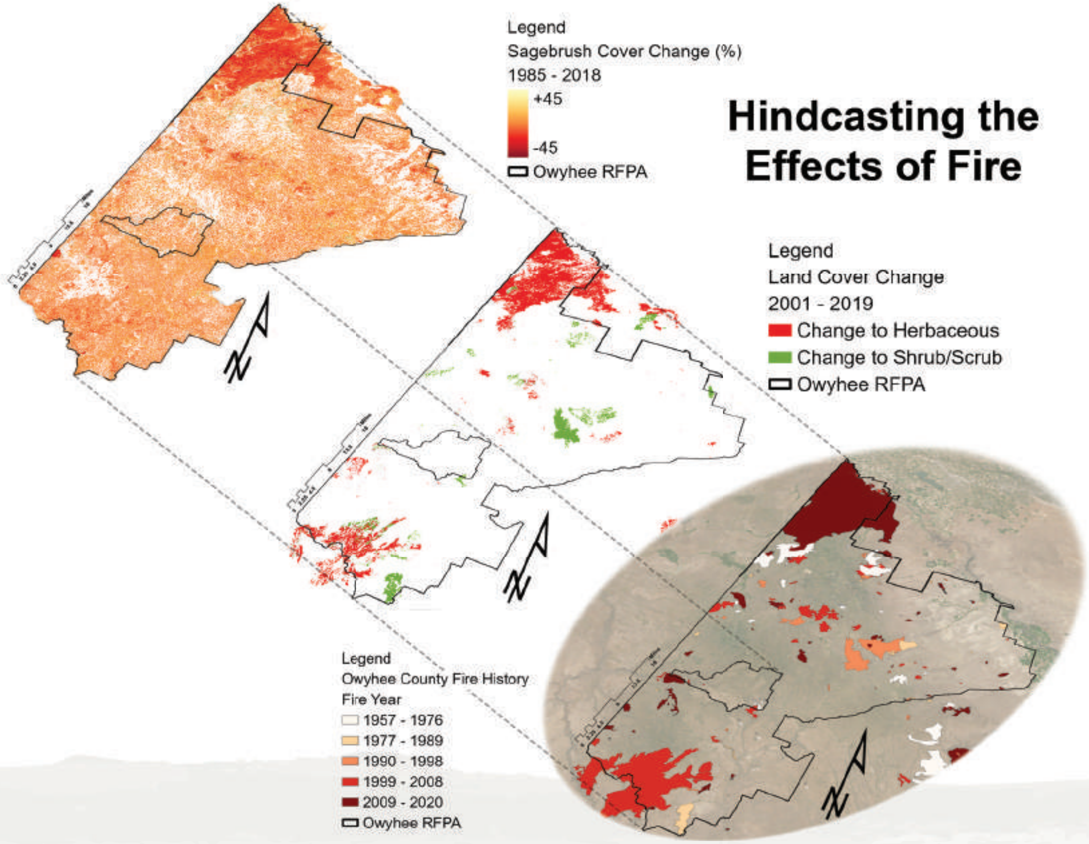


Figure 32. Hindcasting the Effects of Fire within the Owyhee RFPA.

Future Forecasting

Climate

In accordance with the assumptions of future change decided upon by the SAG, the climate change forecasts used for the purposes of this project were the World Climate Research Programme's CMIP5 projections as well as those illustrated under the assumptions of RCP 8.5. These future climate projections were attained through the Climate Toolbox web application developed by the University of California – Merced and came as two separate layers, each depicting 30 years of projected (2010-2030 and 2040-2069) changes using the methodology imposed by CMIP5 with an expected RCP 8.5 value of future carbon emissions. Once gathered, these layers were joined together and used as the basis for assumptions of plausible future climate change trajectories in all pertinent applications for this project.

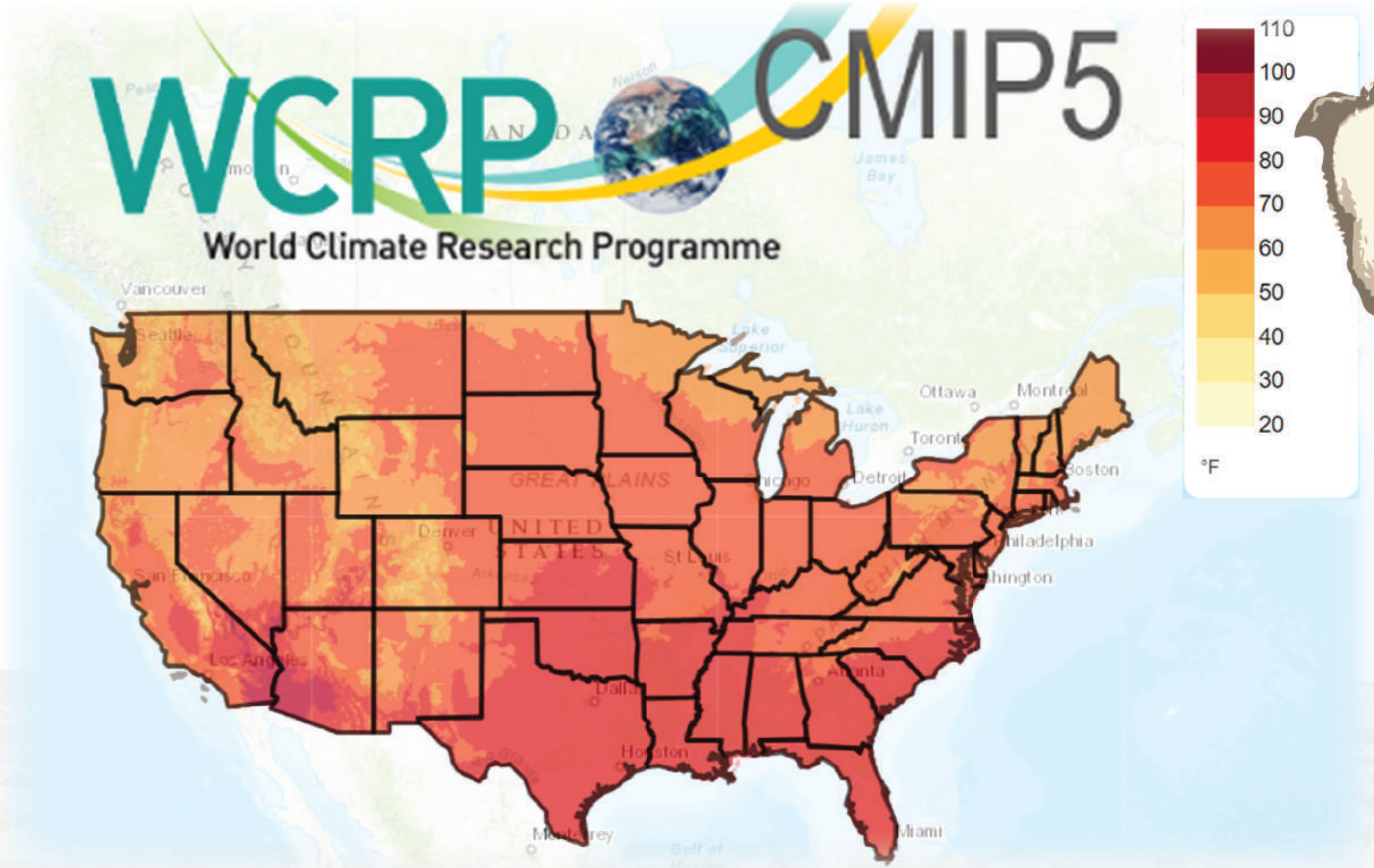


Figure 33. Projected Average Future Summer Temperatures (2010-2039) for the Contiguous US Under the Assumptions of CMIP5 with RCP 8.5. *Derived From*: University of California Merced's "Climate Toolbox" application.

Leo Breiman's Forest-based Forecast

Once all the relevant research was completed and the necessary accompanying data sets were mined and transformed to fit the needs and scope of the project, the first step in the process, in terms of running the methodology, was to perform Forest-based Forecasts of future fire occurrence under the assumptions of each chosen scenario. Forest-based Forecast is a tool within ESRI's ArcGIS Pro 2.9.2 application which, "uses forest-based regression to forecast future time slices of a space-time cube [and] generates predictions using an adaptation of Leo Breiman's random forest algorithm, which is a supervised machine learning method" (Breiman, 2001; ESRI, 2021). This tool uses a space time cube of the input data, shown in Figure 34, in this case constructed from data on all fires that occurred within the study area beginning in 1957 and continuing through 2020, which essentially layers each consecutive year of data on top of the previous creating a dataset the spans the x, y and z axes. The tool takes this dataset and uses it to construct decision tree "forests" that are then used to predict the next proceeding time steps consecutively. The validity of how well these forest predictions "fit" each time series is measured by the "Forecast root mean square error" or RMSE, "which is equal to the square root of the average squared difference between the forest model and the values of the time series" (Breiman, 2001; ESRI, 2021). The equation for which can be seen below in Figure 34, "where T is the number of time steps, ct is the value of the forest model, and rt is the raw value of the time series at time t" (Breiman, 2001; ESRI, 2021).

The determination of how well the outputs of this forecast model can forecast future values of each time series is then made via the tool running these outputs through the validation model: shown in Figure 35, "where T is the number of time steps, m is the number of time steps withheld for validation, ct is the value forecasted from the first T-m time steps, and rt is the raw value of the time series withheld for validation at time t. It is constructed by excluding some of the final time steps of each time series and fitting the forest model to the data that was not excluded. This forest model is then used to forecast the values of the data that were withheld, and the forecasted values are compared to the raw values that were hidden" (Breiman, 2001; ESRI, 2021).

$$\text{Forecast RMSE} = \sqrt{\frac{\sum_{t=1}^{T}(c_t - r_t)^2}{T}}$$

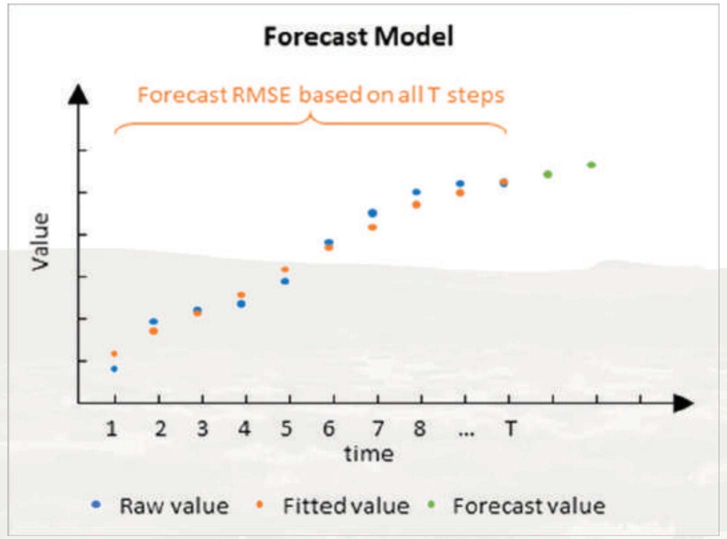


Figure 34. Leo Breiman's Forecast RMSE Equation and Graphic. *Derived From*: ESRI (2021)

$$\text{Validation RMSE} = \sqrt{\frac{\sum_{t=T-m+1}^{T}(c_t - r_t)^2}{m}}$$

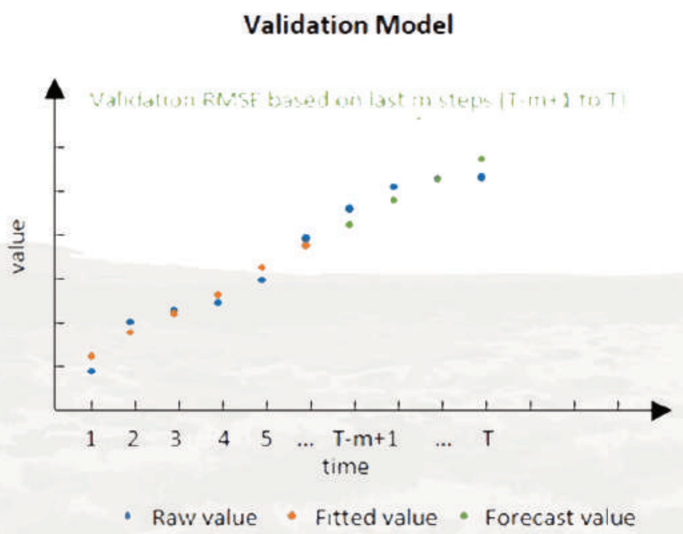


Figure 35. Leo Breiman's Forecast RMSE Validation Model Equation and Graphic. *Derived From*: ESRI (2021)

Risk and Protection Zones

The next step was to create layers depicting areas expected to experience increased fire risk, increased risk of infiltration by invasive species and areas of currently prime or near-prime habitat in need of special emphasis for protection strategies going forward under the assumptions of both scenarios. The processes for the creation of these three layers were the same between both scenarios, but the input data differed according to the specific scenario's parameters.

Layers for illustrating areas on the landscape of varying possible future risk of large surprise fires, which were termed "Fire Risk Zones", were constructed for each scenario using weighted raster overlays within ESRI's ArcGIS Pro 2.9.2 application using the outputs from the Forest-based Forecasts for the particular scenario as well as datasets displaying soil temperature and moisture regimes, invasive annual grass cover, piñon-juniper encroachment, the aforementioned CMIP5 with RCP value of 8.5 future climate projections for spring and summer precipitation averages as well as summer temperature averages.

The layers termed "Invasive Species Risk Zones" that were used to show what areas of the study site are expected to have a higher risk of infiltration by invasive species, mainly cheatgrass as well as piñon-juniper expansion, were then created for both scenarios using the same process. However, as with the Fire Risk Zones, differing inputs based on the assumptions of each scenario were used for each layer. This was also completed using a weighted raster overlay in ESRI's ArcGIS Pro 2.9.2. The inputs for these analyses were the Forest-based Forecast outputs for the respective scenario the Invasive Species Risk Zone was being created for, in addition to datasets for soil temperature and moisture regimes, invasive annual grass cover, piñon-juniper encroachment, the previous twenty years of site burn history, and CMIP5 with an RCP value of 8.5 future climate projections of winter precipitation.

Finally, the layer termed "Wildlife Protection Zones" that show areas of currently prime or near-prime habitat in need of special emphasis for management strategies geared towards ongoing protection were created. As this layer only depicts current conditions that exist on the landscape, this layer was only created once and was used to delineate Wildlife Protection Zones under the assumptions of both scenarios and was also created using weighted raster overlays using ESRI's ArcGIS Pro 2.9.2. The datasets that contributed to this output layer were those representing soil temperature and moisture regimes, invasive annual grass cover, piñon-juniper woodland expansion, waterbodies and streams, sagebrush cover, areas outlined by the USDA as Sage-grouse Priority Areas for Conservation (PACs), as well as the previous twenty years of burn history within the site.

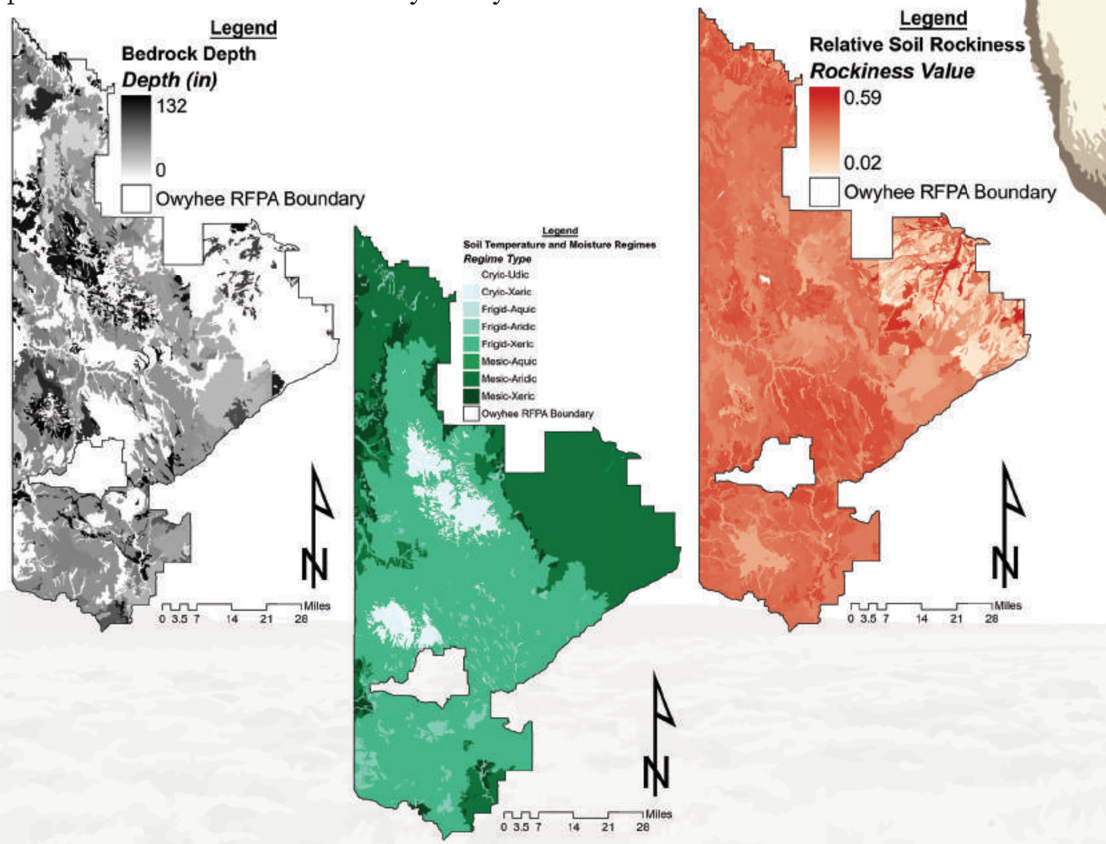


Figure 36. Representation of Some of the Inputs that Were Used in the Creation of Risk and Protection Zones.

Management Priority Zones

Once the Fire Risk Zones, Invasive Species Risk Zones and Wildlife Protection Zones for each scenario were created the next step in the process was to combine them, per scenario. As with the creation of the risk and protection zones, this was done in ESRI's ArcGIS Pro 2.9.2 using the "raster calculator" tool to produce a weighted raster overlay result. For both scenarios the output was a single raster layer for each. These raster layers were then symbolized to display their data in the form of three distinct categories by "natural jenks"; a process described in ESRI's ArcGIS Pro 2.9.2 application as one where, "numerical values of ranked data are examined to account for non-uniform distributions, giving an unequal class width with varying frequency of observations per class" (ESRI, 2022). For these newly symbolized raster layers, the three output categories were termed Restoration Zones, Conservation Zones and Preservation Zones. For the purposes of this project, Restoration Zones are the highest priority for management action and require substantial management actions to return to "healthy states" and mitigate future fire risk and further rangeland degradation, Conservation Zones are of moderate priority for management actions and as such will require a moderate intensity of management actions to return to healthy states, and finally Preservation Zones are those with the lowest priority for management actions as they already contain healthy and resilient ecosystems. For both scenarios, these were subsequently broken up into their own separate raster layers to be used as clipping geometries for the proceeding steps in the methodology.

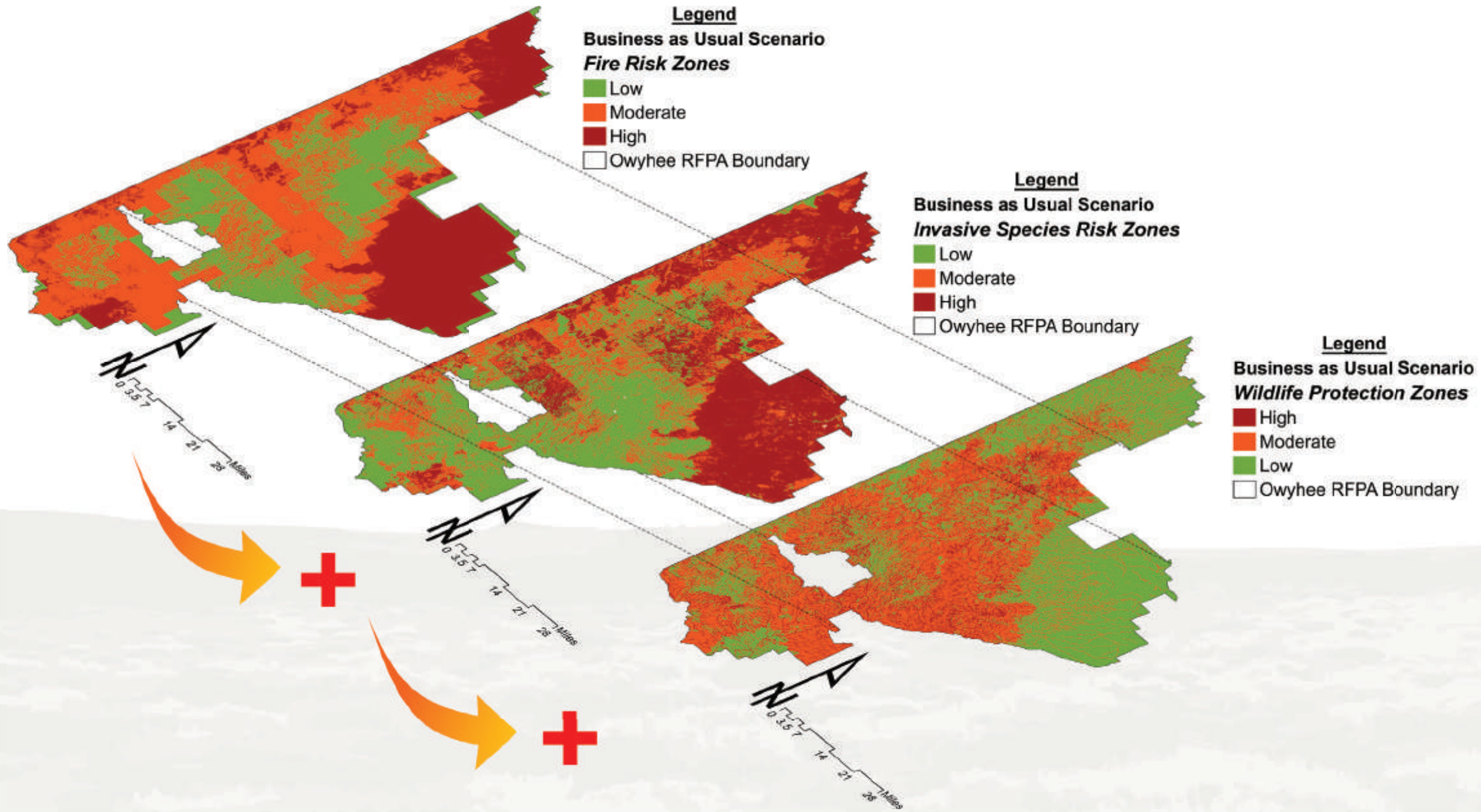


Figure 37. Representation of Inputs that Used in the Creation of Management Priority Zones.

Mechanical Treatment Methods

With the creation of the Management Priority Zones completed, the process of making geospatial layers delineating the actual treatment methods could proceed. The first of which were the mechanical treatment methods. As stated previously mechanical treatments are those that involve, "the use of vehicles such as wheeled tractors, crawler-type tractors, specially designed vehicles with attached implements designed to cut, uproot, or chop existing vegetation" (BLM, 2021). The BLM further groups mechanical treatments into three subgroups according to the delineations defined by Monsen et al. (2004), which are: (1) seedbed preparation equipment, (2) seeding equipment and (3) special use equipment (BLM, 2020). For the purposes of this project, these three subgroups were broken up into six distinct categories: (1) Plowing and Disking equipment, (2) Chaining and Dragging equipment, (3) Broadcast Seeding equipment, (4) Drill Seeding equipment, (5) Other Seeding Equipment and (6) Chopper/Dozer equipment.

A thorough investigation into existing scientific literature, the BLM approved standard operating procedures guide produced by Monsen et al. (2004), as well as manufacturer specific manuals and guides regarding use and effectiveness of each category of mechanical treatment was undergone. This allowed for the production of a management suitability index (MSI) that was used in the creation of each mechanical treatment raster layer. This comprehensive table can be found in Appendix 5, but a simplified version can be found below in Table 10.

These base layers were created with the ArcGIS Pro application's "raster calculator" tool to produce separate weighted raster overlays for each treatment category and illustrated the areas on the landscape comprising each mechanical treatment's plausible applicability. As these output raster layers were intended to illustrate only what areas of the landscape could plausibly accommodate the application of each treatment category they were able to be used as base layers for mechanical treatment applicability under the assumptions of both chosen scenarios. However, as a final step to separate the mechanical treatment results per scenario, each treatment suitability layer was broken up using the Management Priority Zones for each scenario as clipping geometries. The result of these clips were two sets of raster layers with 30x30m cells for each of the mechanical treatment categories depicting, geospatially, both their applicability and their application priority on the landscape.

Shortened Mechanical Treatment MSIs

Generalized MSIs used in the creation of treatment specific geospatial suitability layers for each overarching type of mechanical treatment.

Equipment Type	Slope	Bedrock Depth	Soil Rockiness	Sagebrush Cover	Tree Canopy
Plowing and Disking	<30%	18"+	Low-Med	<26%	<10%
Chaining and Dragging	<45%	18"+	Any	<26%	<35%
Chopping and Dozing	<50%	Any	Any	<26%	Any
Drill Seeding	<18%	15"+	Low	<26%	<10%
Broadcast Seeding	Any	Any	Any	<65%	Any
Other Seeding Equipment	<45%	15"+	Low-Med	<26%	<35%

Table 10. Shortened MSI Table Used in the Creation of Mechanical Treatment Suitability Layers

Chemical Treatment Methods

The next treatment method analyzed in this project was for chemical application, both aerially and ground-based. From the list of approved chemicals for use on BLM lands, three have been shown in the literature to be useful in reducing cheatgrass cover; Rimsulfuron, Imazapic and Glyphosate. As such, these were chosen to be used as the chemical treatments for this project. In a similar manner to the creation of the mechanical treatment suitability layers, the BLM approved standard operating procedures, EPA product labels specific to each chemical as well as relevant scientific literature on use and effectiveness were all used as guidelines in the creation of geospatial suitability layers. Other than their suggested mixture quantities, all three approved chemicals had the same exclusionary requirements for use. Therefore, only two geospatial suitability raster layers were created for all three chemicals under the assumptions of both scenarios; one for aerial application suitability and one for suitability for application from the ground using mechanical means.

The process for creating suitability layers was comprised of the same steps for both areas suitable for aerial application as well as for ground application by mechanical means; only the inputs differed between the two. The first steps of the processes involved clipping and buffering waterbodies and streams within the within the site boundary to match the differing exclusionary areas per the MSI created for each application type; aerial or ground-based. Next, the 2019 National Land Cover Dataset (NLCD) was clipped to the site boundary and subsequently, per the requirements set down by the MSIs, reclassified to show only cropland, developed land and riparian areas. In addition to the buffered streams and waterbodies were used as exclusionary clipping geometries in the following steps.

For the creation of the raster layer depicting areas suitable for aerial application, the base layer for Broadcast Seeding mechanical treatments was used as a proxy. This layer was then clipped to show the inverse of the exclusionary layers created in the previous steps; the output of which illustrated areas of the landscape suitable for aerial chemical application.

Conversely, for the creation of the raster layer delineating areas suitable for ground-based application of chemicals via mechanical treatment methods, the base layer for Chaining and Dragging mechanical treatments was used as a proxy. As with the aerial application suitability raster layer, this mechanical treatment base layer was clipped to show the inverse of the exclusionary layers created in the previous steps and produced an output illustrating areas on the landscape suitable for chemical application via ground-based methods.

In order to align these two suitability rasters with the chosen scenarios of the project the final step involving transformations to the data layers were made to these outputs. Both were separately clipped using the geometries of the Management Priority Zones of the two scenarios; "Destroying Boise's Playground" and "Business as Usual". This gave an output of four individual rasters; two showing areas of suitability and priority for aerial chemical application under the assumptions of each scenario and two showing areas of suitability and priority for ground-based chemical treatment via mechanical methods under the assumptions of each scenario.

Targeted Grazing Application

The last of the treatment methods analyzed by the project was the application of Targeted Grazing techniques. For creation of the MSI for Targeted Grazing application, the BLM approved techniques outlined by Monsen et al. (2004) in addition to relevant scientific literature including Chapter 15 of Pasture and Grazing Management in the Northwest (Gerrish & Cheyney, 2010) and "The Green and Brown Guide" (Smith, Sheley, & Svejcar, 2012) were used as the foundational guidelines. In order to create the base suitability raster layer for this treatment technique, a series of calculations for determining stocking rates (i.e. the number of cattle, expressed as "head of cattle", needed on a particular plot of land per estimated the dry matter production rate of said plot of land) was undertaken. This first involved the exportation of the attribute table for the raster layer illustrating cheatgrass coverage amounts (by percent) in July of 2021 obtained from the Multi-Resolution Land Characteristics Consortium (MRLC) database to excel. Next calculations derived from Pasture and Grazing Management in the Northwest converting the coverage percentages into estimated dry matter production per day per acre were carried out, which then allowed for the calculation of stocking rates for eight-day grazing periods using an average steer weight of 600lbs.

The output calculation, which illustrated head of cattle per 30x30m raster pixel, was then returned to ESRI's ArcGIS Pro 2.9.2, joined with the initial cheatgrass cover raster layer, had the necessary exclusionary areas indicated previously from the relevant literature redacted from it and was finally symbolized to depict this new dataset. The result was a raster suitability layer showing geospatially the estimated head of cattle needed per 30x30m cell of the raster. Finally, this layer was clipped using the geometries of the Management Priority Layers for each scenario; giving two rasters illustrating stocking rate suitability as well as priority across the landscape under the assumptions of both scenarios.

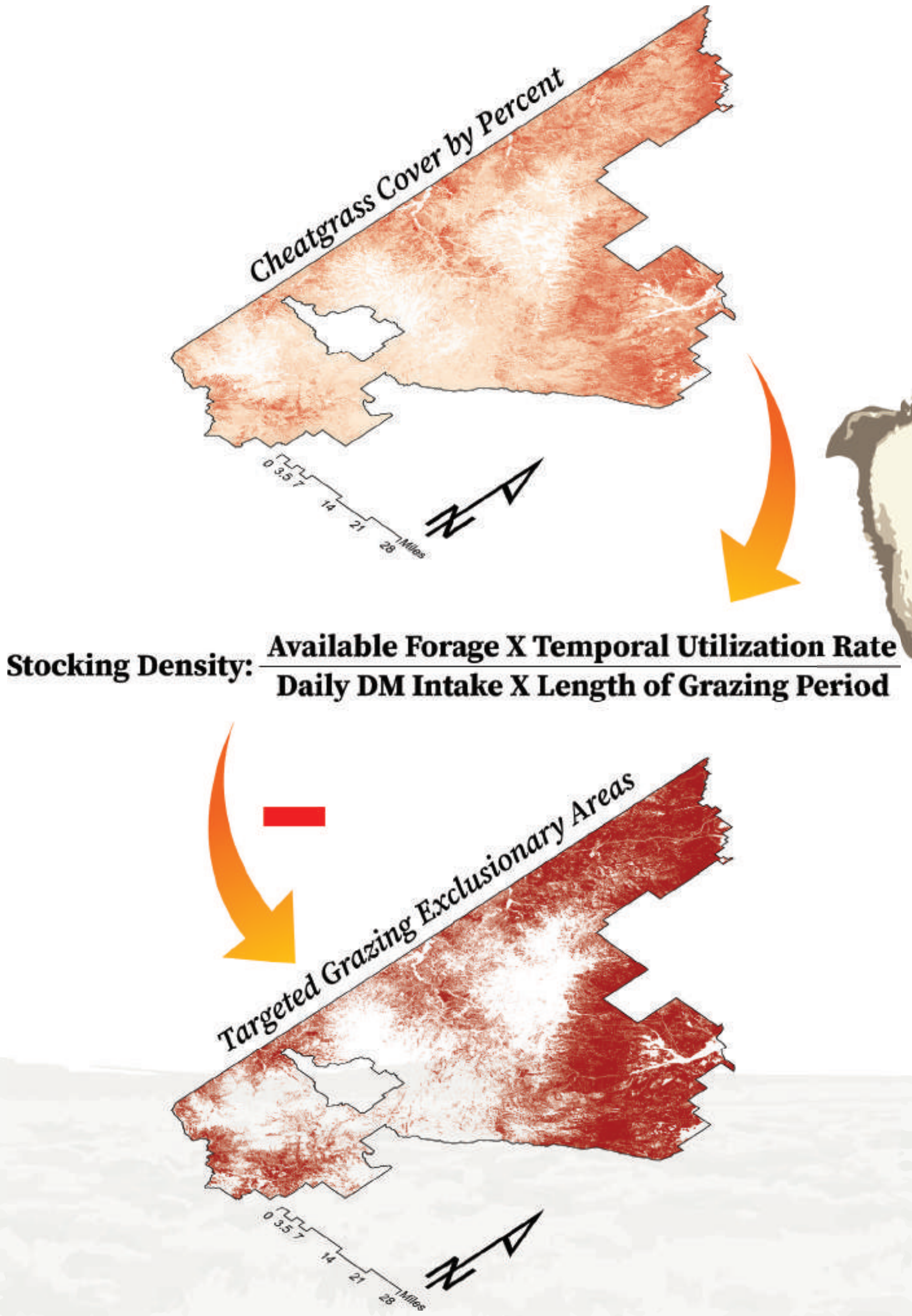


Figure 38. Representation of Methods Used in Creation of Targeted Grazing Treatment Suitability Layers.

Results

Leo Breiman's Forest-based Forecasts

Business as Usual

The results of the forest-based forecast for the Owyhee RFPA under the stakeholder-derived assumptions of future landscape change for the Business as Usual Scenario can be seen in Figure 37. It shows that the forecasted fire risk for the majority of the lands encompassed by the RFPA, 1,359,628.07 of the total 1,370,873 acres to be exact, would be relatively low. Furthermore, it shows how the remaining 10,692.53 acres are located in the northern portion of the site and were forecasted to fall under a moderate risk category. There were no areas forecasted to have a high risk of fire under the assumptions of this scenario.

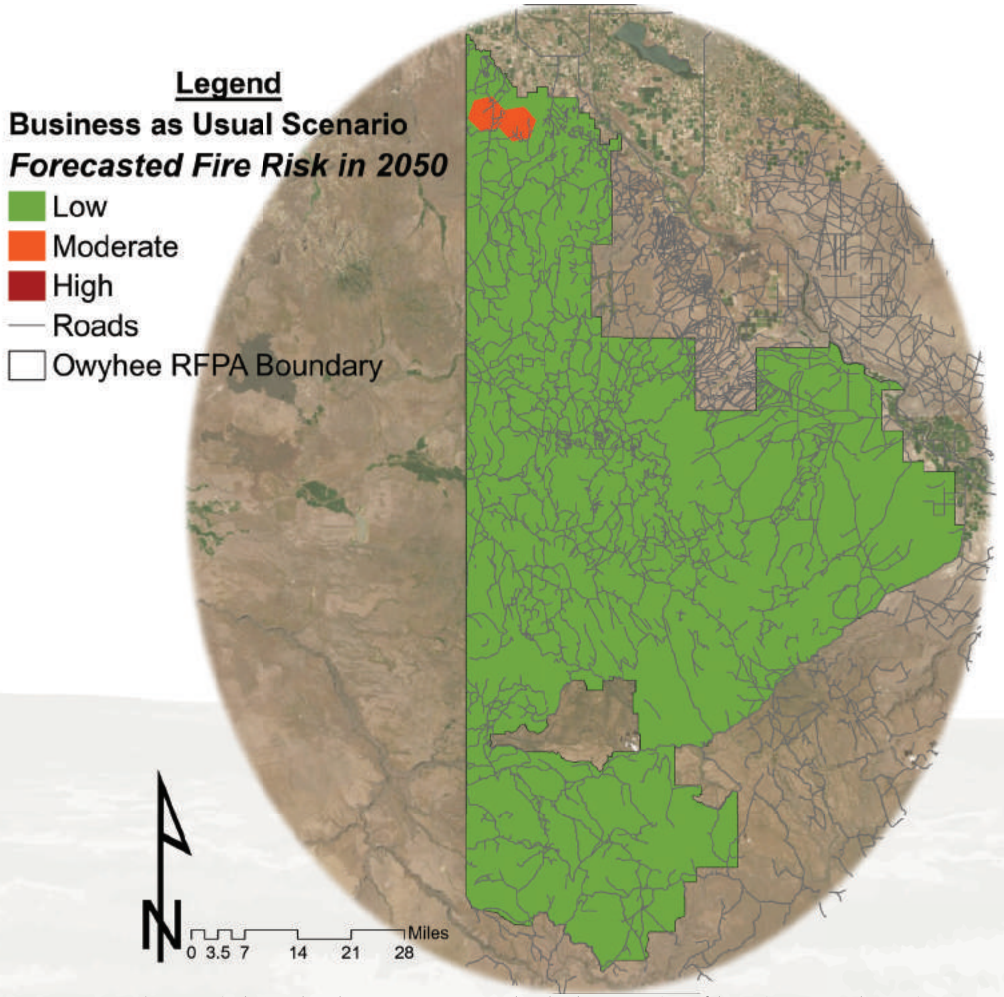


Figure 39. Final Forest-based Forecast Output Created Under the Assumptions of the Business as Usual Scenario.

Destroying Boise's Playground

Conversely, the results of the forest-based forecast for the Owyhee RFPA under the stakeholder-derived assumptions of future landscape change for the Destroying Boise's Playground Scenario can be seen in Figure 38. As can be seen areas in the north of the site were forecasted to have a higher risk of fires in 2050 than the same areas under the Business as Usual scenario. This suggests that these lands would warrant a higher degree of management actions than under the previously shown scenario. This result forecasts that in 2050 of the 1,370,873 acres making up the Owyhee RFPA, 1,224,638.76 acres would fall under a low risk of fire occurrence, 140,395.24 acres would have a moderate risk and 5,356.61 acres would be at a high risk of fire occurrence.

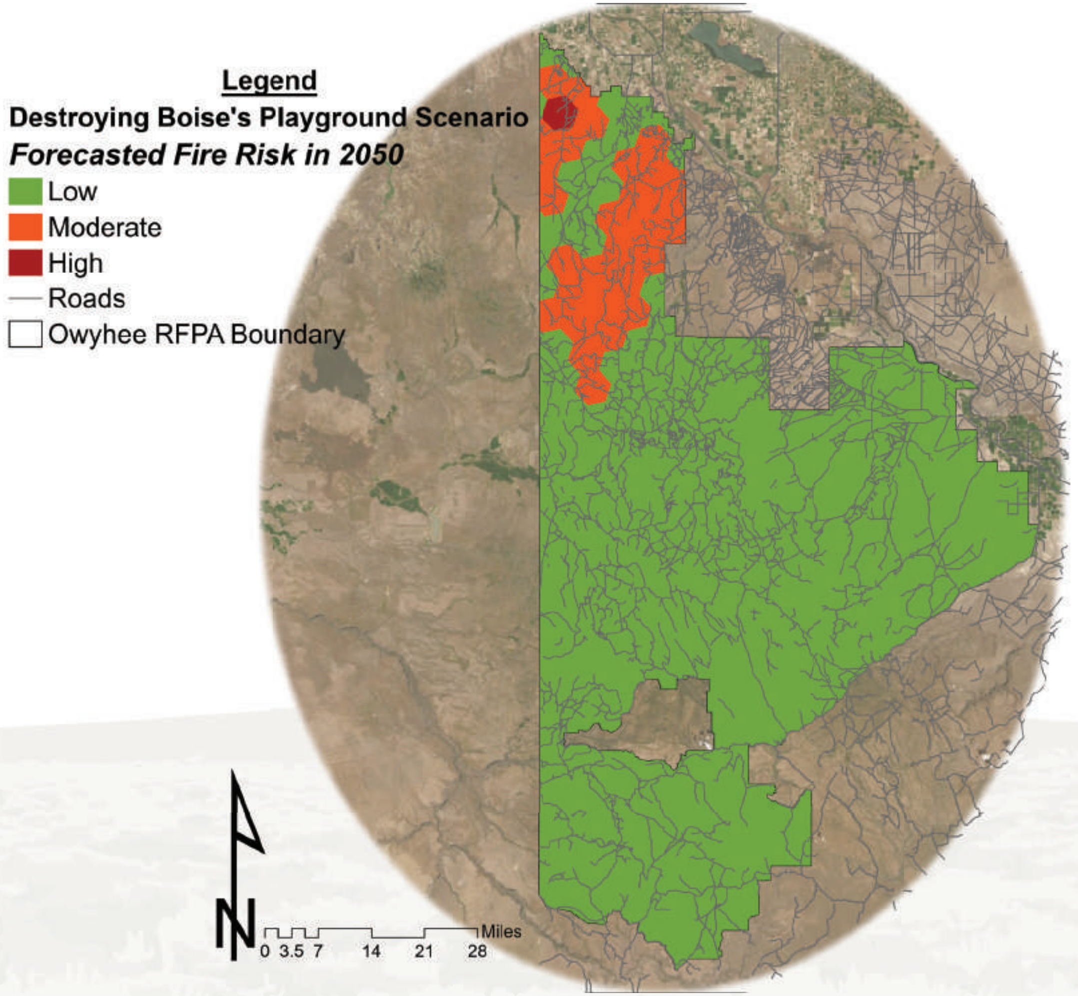


Figure 40. Final Forest-based Forecast Output Created Under the Assumptions of the Destroying Boise's Playground Scenario.

Risk and Protection Zones

Business as Usual

As was outlined above in more detail, the next steps in the process involved combining the results of the forest-based forecasts along with other data discussed earlier, including land covers, forecasted recreational use, forecasted future temperature and precipitation, as well as soil temperature and moisture regimes, to name a few, to create layers depicting areas at higher risk for fire, for invasion by invasive species as well as those for areas with healthy ecosystems in need of specific protection in the future under the assumptions specific to each scenario. The results obtained for the Business as Usual scenario can be seen in Figures 39, 40 and 41.

Evident in these figures is the fact that the areas at highest risk for future fire occurrence as well as for invasion by invasive species are mainly clustered in the northern and eastern portions of the site. This lines up with the results shown for the Wildlife Protection Zones, where the areas containing currently healthy ecosystems in need of specific protection efforts going forward can be seen to be mainly comprised of the lands at low and moderate risk for future fire occurrence and invasion by invasive species.

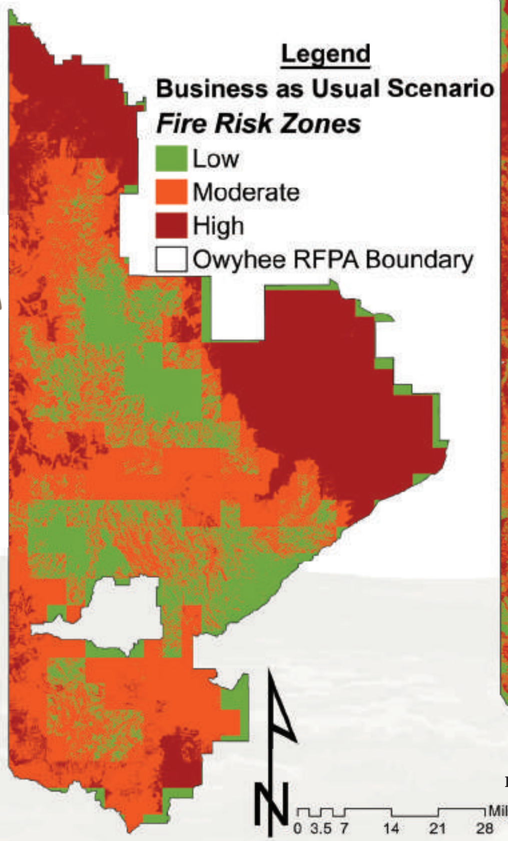


Figure 41. Final Fire Risk Zones Output Created Under the Assumptions of the Business as Usual Scenario.

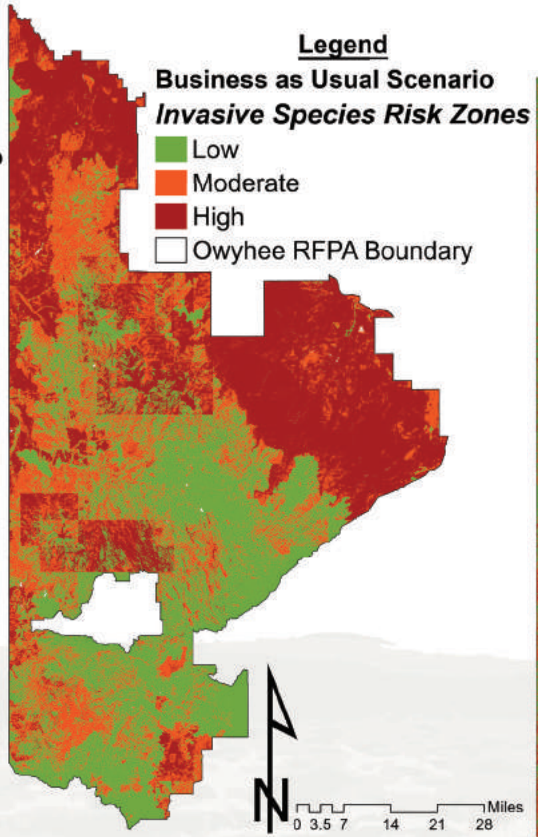


Figure 42. Final Invasive Species Risk Zones Output Created Under the Assumptions of the Business as Usual Scenario.

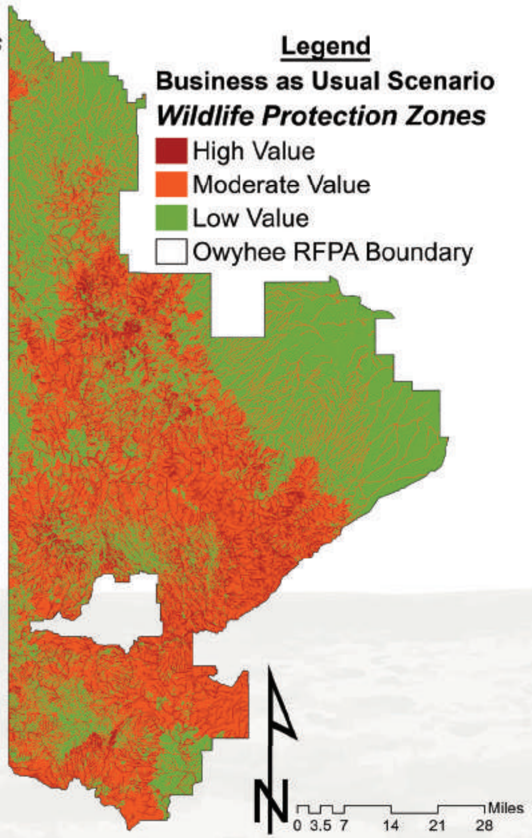


Figure 43. Final Wildlife Protection Zones Output Created Under the Assumptions of the Business as Usual Scenario.

Destroying Boise's Playground

Figures 42, 43 and 44 shown below illustrate the final results for Fire Risk Zones, Invasive Species Risk Zones and Wildlife Protection Zones under the assumptions of the Destroying Boise's Playground scenario. Most of the difference between the zones under this scenario and the other can be seen in the north of the site, where under this scenario, the areas likely to experience a higher risk of future fire occurrence and to be more susceptible to invasive species is larger than in the Business as Usual Scenario. This can be attributed to differences in assumptions between the two scenarios. For instance, the explosive population growth commensurate with a drastic increase in recreational use, both lawful and unlawful, that is expected to occur under the Destroying Boise's Playground scenario, but not under the Business as Usual Scenario, can be assumed to be a main contributing factor to these displayed increases. As was stated in the methods section of this paper, the wildlife protection zones remained the same between the two scenarios. This is because they are intended to show areas currently in need of long term protection for the future and as such, are based current and historic data as opposed to forecasted future data.

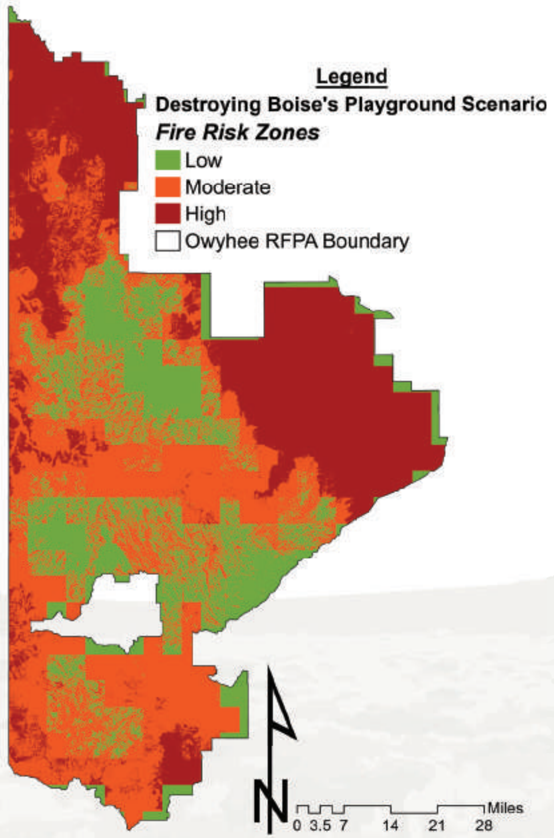


Figure 44. Final Fire Risk Zones Output Created Under the Assumptions of the Destroying Boise's Playground Scenario.

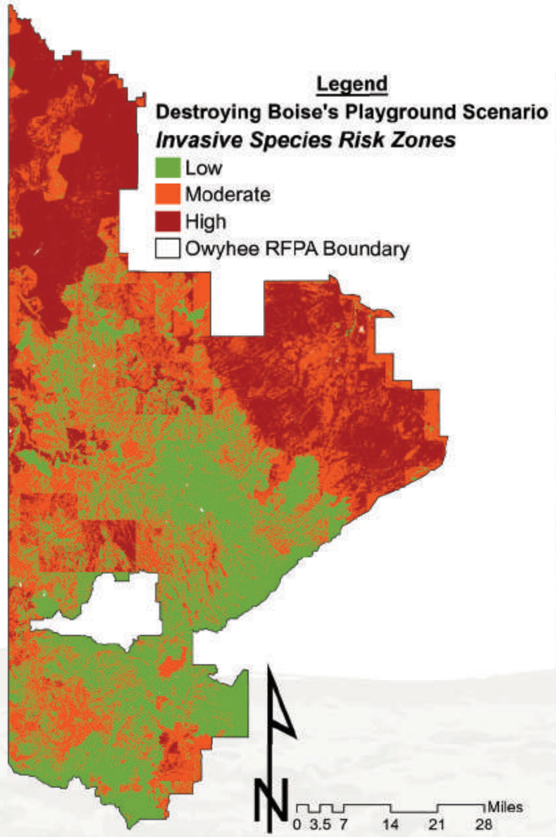


Figure 45. Final Invasive Species Risk Zones Output Created Under the Assumptions of the Destroying Boise's Playground Scenario.

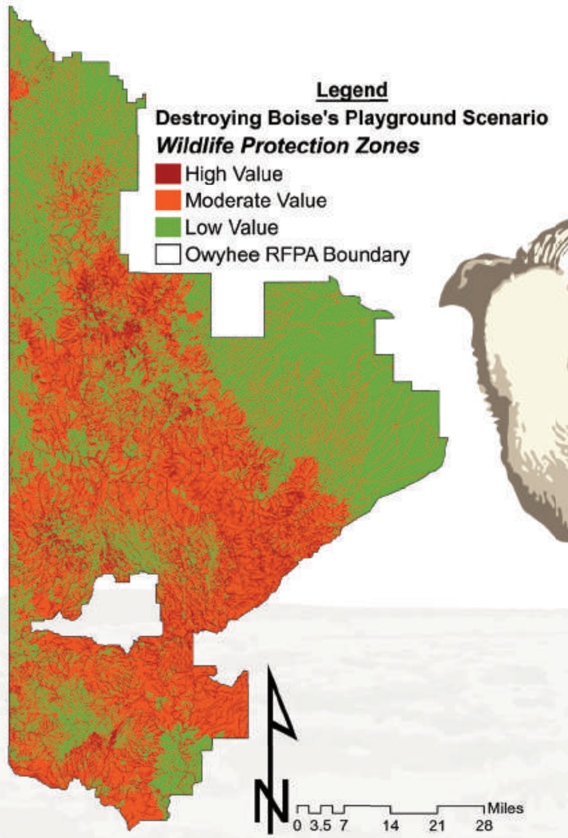


Figure 46. Final Wildlife Protection Zones Output Created Under the Assumptions of the Destroying Boise's Playground Scenario.

Management Priority Zones

Business as Usual

Next among the outputs produced were the Management Priority Zones for both scenarios. Again, these were created through combination of the risk and protection zones unique to each scenario. Those produced for the Business as Usual scenario can be seen in Figures 45, 46, 47 and 48. They show the Restoration Zones are mainly located in the north and east of the site and the management intensity required to return ecosystems to “healthy states” diminishes as one looks more centrally as well as to the south-eastern portion of the site where most of the areas under the Preservation Zone are located.

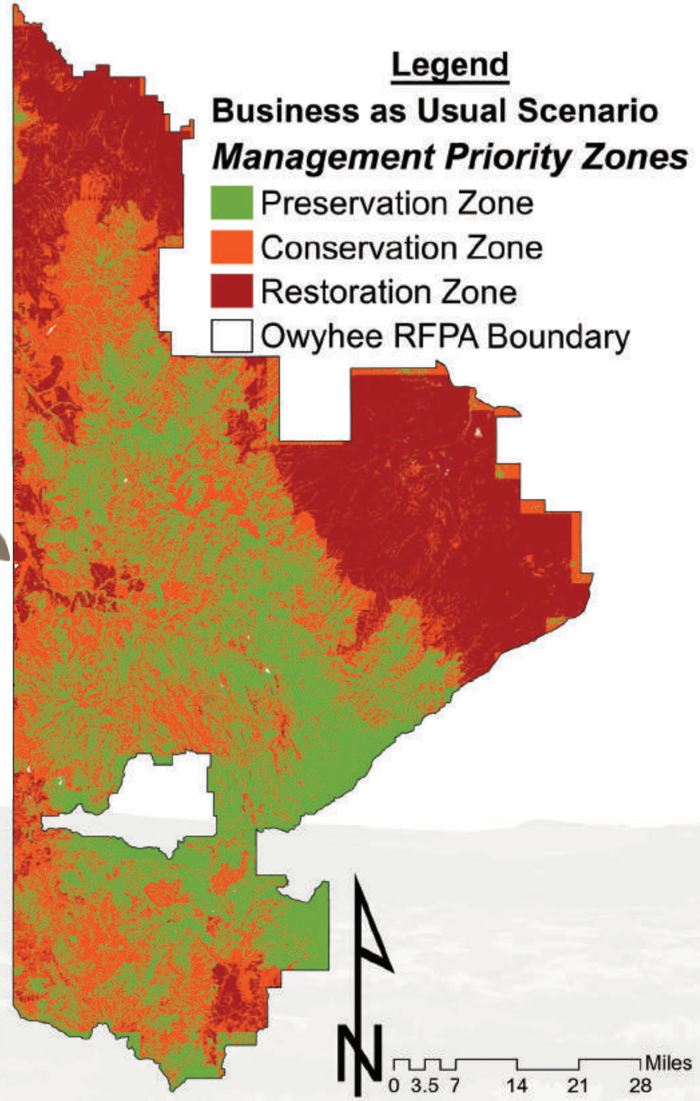


Figure 47. Final Management Priority Zones Output Created Under the Assumptions of the Business as Usual Scenario.

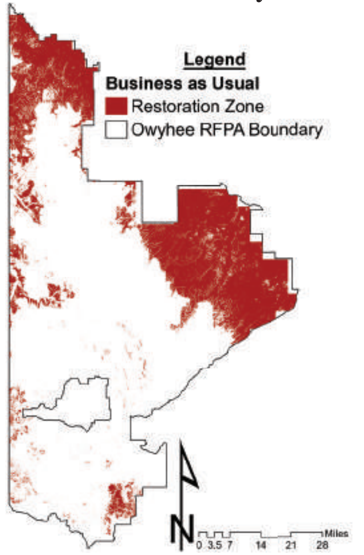


Figure 48. Final Restoration Zone Output Under the Assumptions of the Business as Usual Scenario.

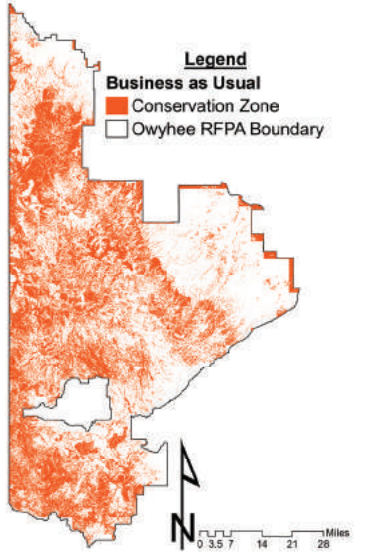


Figure 49. Final Conservation Zone Output Under the Assumptions of the Business as Usual Scenario.

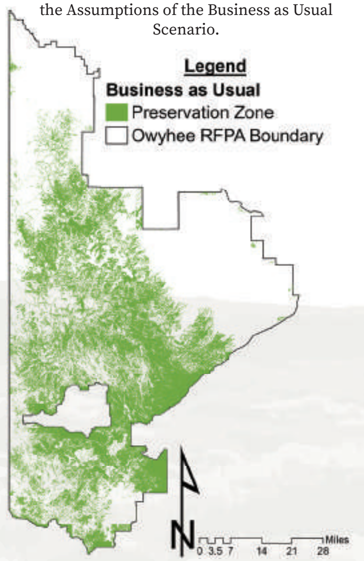


Figure 50. Final Preservation Zone Output Under the Assumptions of the Business as Usual Scenario.

Destroying Boise’s Playground

Figures 49, 50, 51 and 52 below show the Management Priority Zones created under the assumptions of the Destroying Boise’s Playground scenario. Overall, these results are relatively similar between the scenarios in terms of general locations of each priority zone. However, under this scenario, the area encompassed by the Restoration Zone (lands in need of the most intensive management actions to return to healthy ecosystem states) is nearly 30,000 acres larger. This increase, which occurs mainly in the northern panhandle of the site, reflects both the input of the differing fire forecasts as well as the differing assumptions between the two scenarios discussed previously.

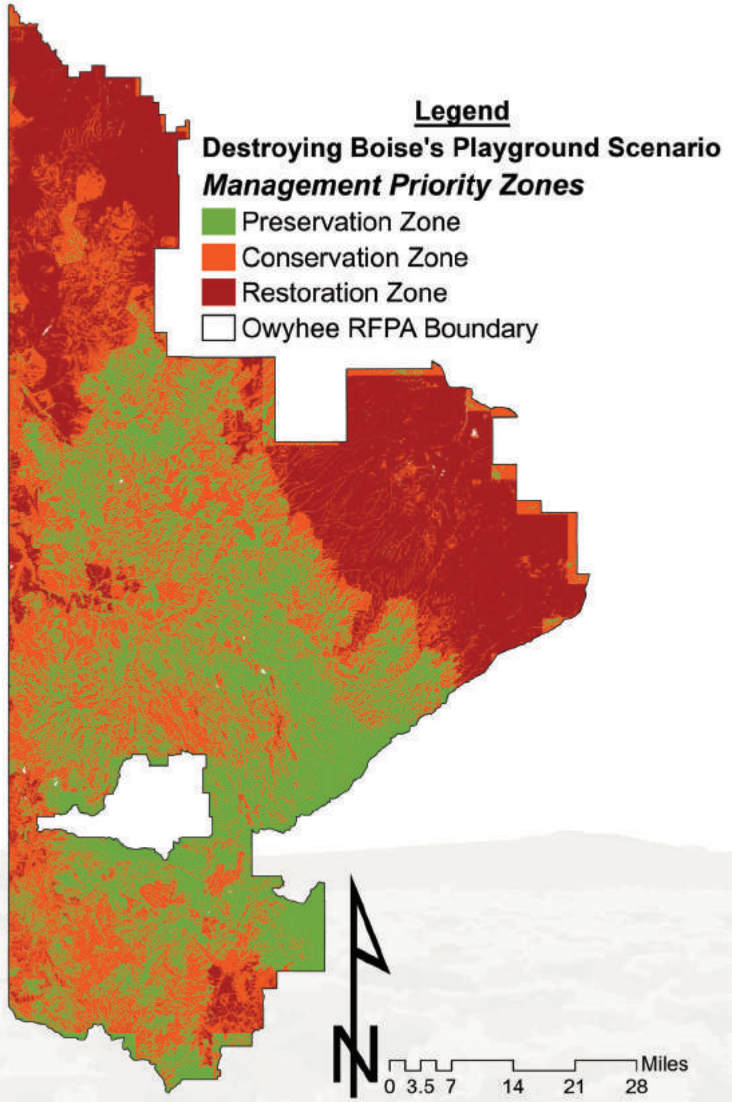


Figure 51. Final Management Priority Zones Output Created Under the Assumptions of the Destroying Boise’s Playground Scenario.

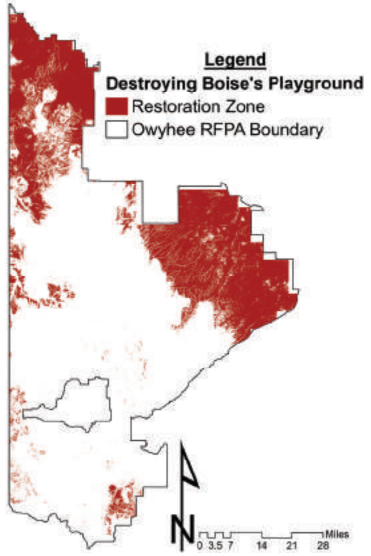


Figure 52. Final Restoration Zone Output Under the Assumptions of the Destroying Boise’s Playground Scenario.

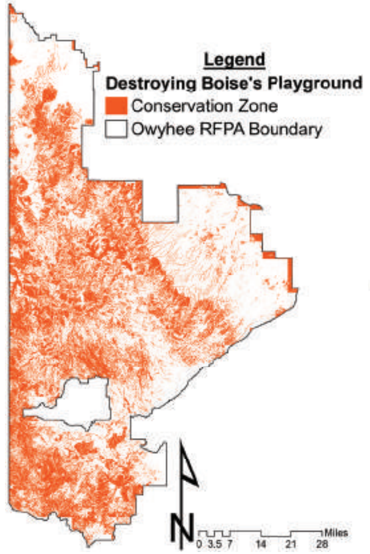


Figure 53. Final Conservation Zone Output Under the Assumptions of the Destroying Boise’s Playground Scenario.

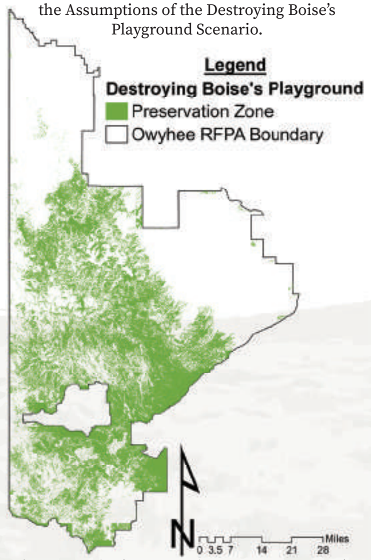


Figure 54. Final Preservation Zone Output Under the Assumptions of the Destroying Boise’s Playground Scenario.

Mechanical Treatment Method Priority and Suitability

Business as Usual

The first treatment methods analyzed after the creation of the Management Priority Zones were the Mechanical Treatments. As outlined previously, those chosen for analyzation by this project were Plowing and Disking, Chaining and Dragging, Chopper-Dozer application, Drillseeding, Broadcast seeding as well as a catch-all layer for Other types of seeding equipment. These outputs, which were broken up by management action priority based on the site specific needs of the landscape using the Management Priority Zones for each scenario as clipping geometries, illustrate where each can plausibly be implemented due to the physical limitations of the equipment as well as those imposed by the landscape itself. The results for each under the assumptions of the Business as Usual scenario can be seen in Figures 53, 54, 55, 56, 57 and 58.

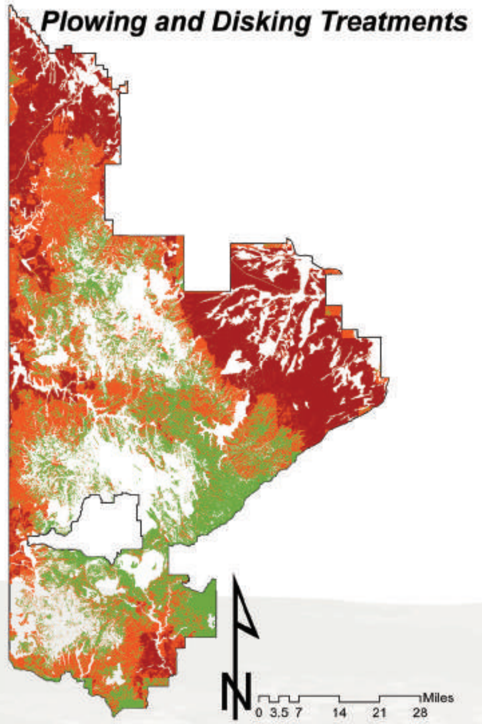


Figure 55. Final Plowing and Disking Treatment Priority and Suitability Output Created Under the Assumptions of the Business as Usual Scenario.

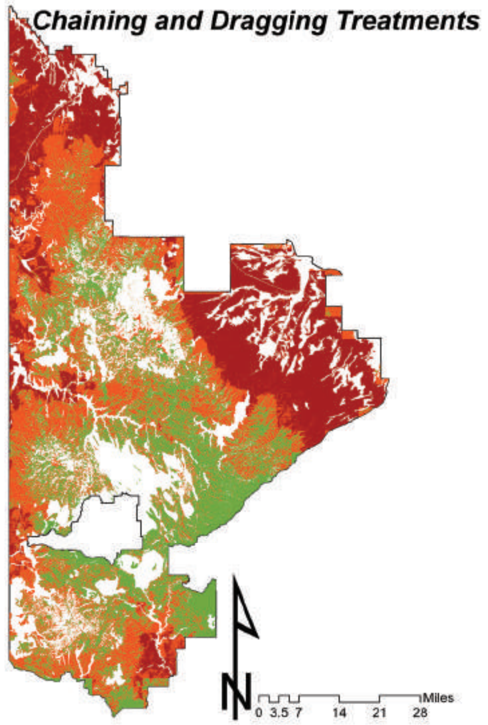


Figure 56. Final Chaining and Dragging Treatment Priority and Suitability Output Created Under the Assumptions of the Business as Usual Scenario.

Legend

Business as Usual Scenario

- Preservation Zone
- Conservation Zone
- Restoration Zone
- Owyhee RFPA Boundary

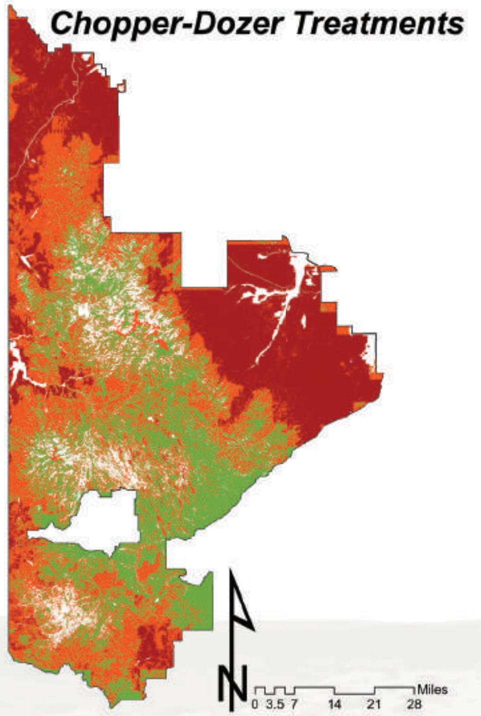


Figure 57. Final Chopper-Dozer Treatment Priority and Suitability Output Created Under the Assumptions of the Business as Usual Scenario.

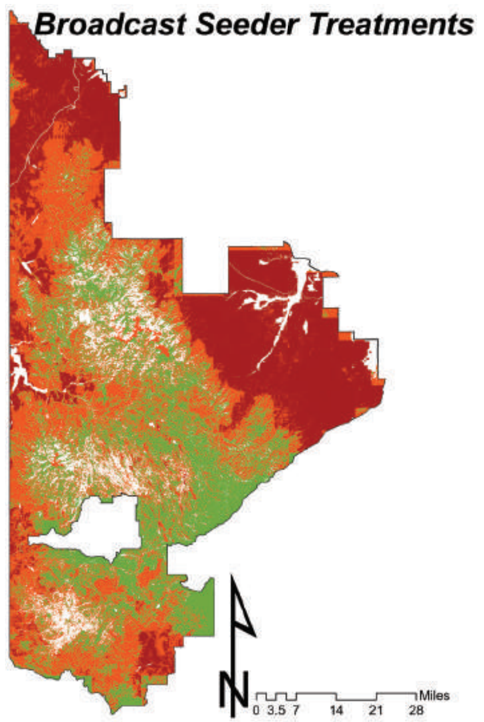


Figure 58. Final Broadcast Seeder Treatment Priority and Suitability Output Created Under the Assumptions of the Business as Usual Scenario.

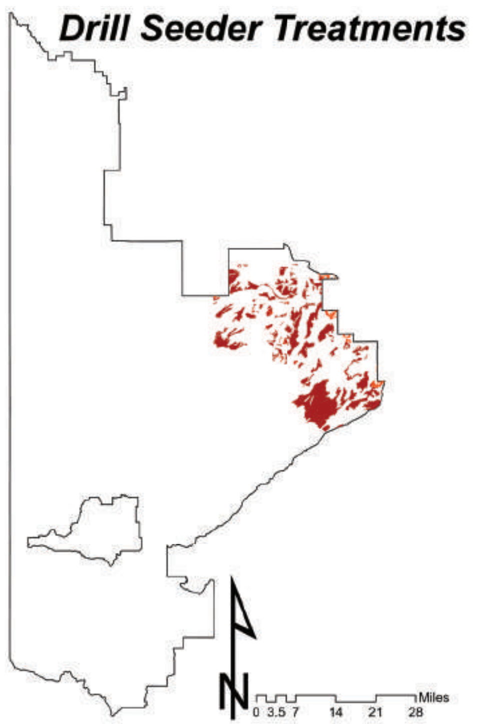


Figure 59. Final Drill Seeder Treatment Priority and Suitability Output Created Under the Assumptions of the Business as Usual Scenario.

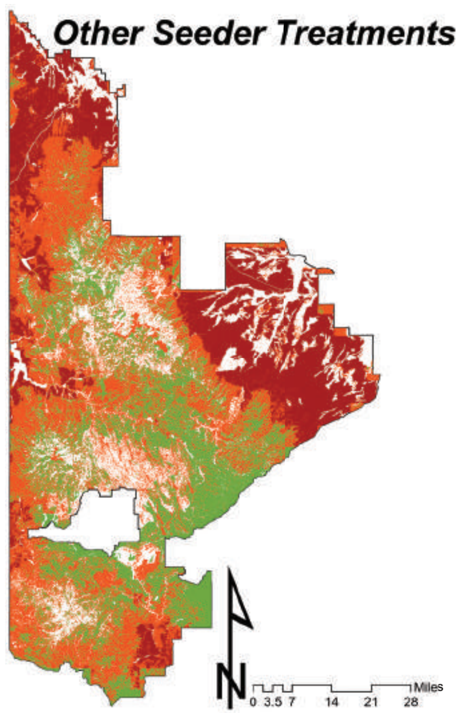


Figure 60. Final Other Seeder Treatment Priority and Suitability Output Created Under the Assumptions of the Business as Usual Scenario.

Disk Plow

Destroying Boise's Playground

Figures 59, 60, 61, 62, 63 and 64 show the mechanical treatment outputs obtained under the assumptions of the Destroying Boise's Playground scenario. As with those for the previous scenario, these are broken up by which encompassing Management Priority Zone they occur within. Additionally, it can be seen that, for the outputs of both scenarios, each management technique has a different overall area in which it can be plausibly applied and areas deemed unfeasible lack any color. This can be seen most prevalently in the Drill Seeder treatment areas for both as these large implements require flat, relatively rock-free soil to operate effectively. Conversely, in terms of the techniques able to be plausibly implemented on the widest scales throughout the landscape for both scenarios, Broadcast Seeding as well as Chopper-Dozer treatments are the two largest.

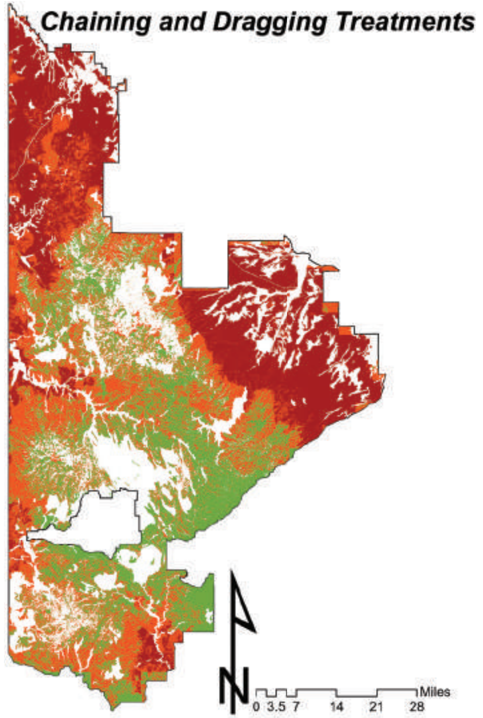


Figure 62. Final Chaining and Dragging Treatment Priority and Suitability Output Created Under the Assumptions of the Destroying Boise's Playground Scenario.

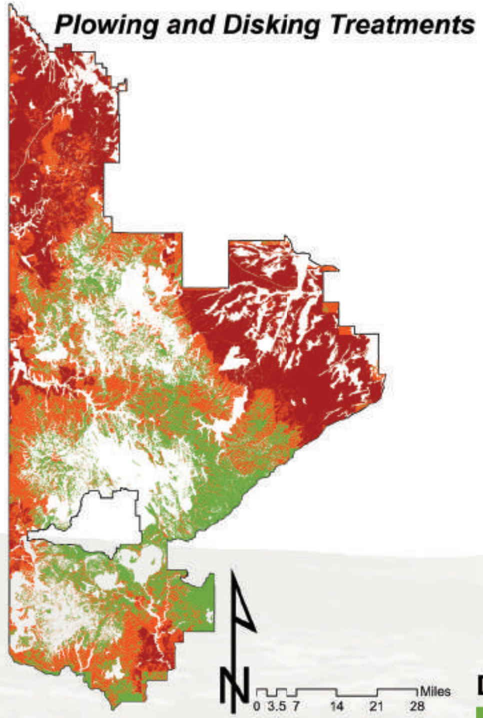


Figure 61. Final Plowing and Disking Treatment Priority and Suitability Output Created Under the Assumptions of the Destroying Boise's Playground Scenario.

Legend

Destroying Boise's Playground Scenario

- Preservation Zone
- Conservation Zone
- Restoration Zone
- Owyhee RFPA Boundary

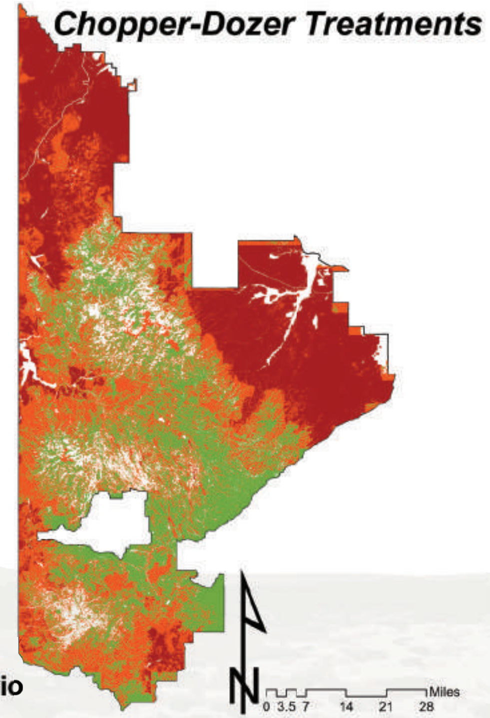


Figure 63. Final Chopper-Dozer Treatment Priority and Suitability Output Created Under the Assumptions of the Destroying Boise's Playground Scenario.

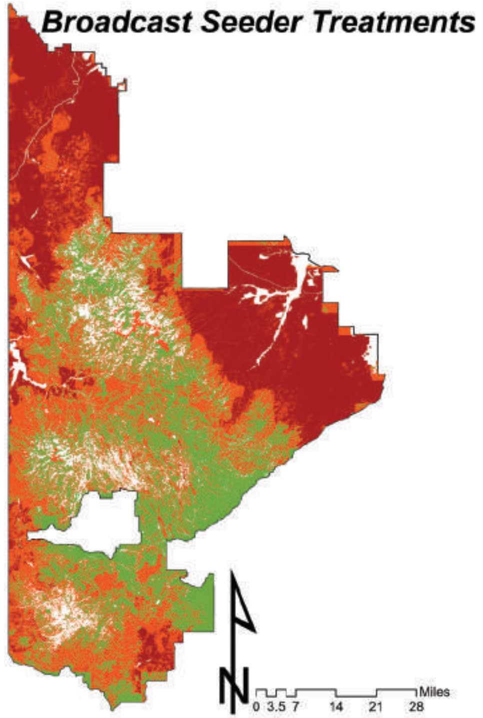


Figure 64. Final Broadcast Seeder Treatment Priority and Suitability Output Created Under the Assumptions of the Destroying Boise's Playground Scenario.

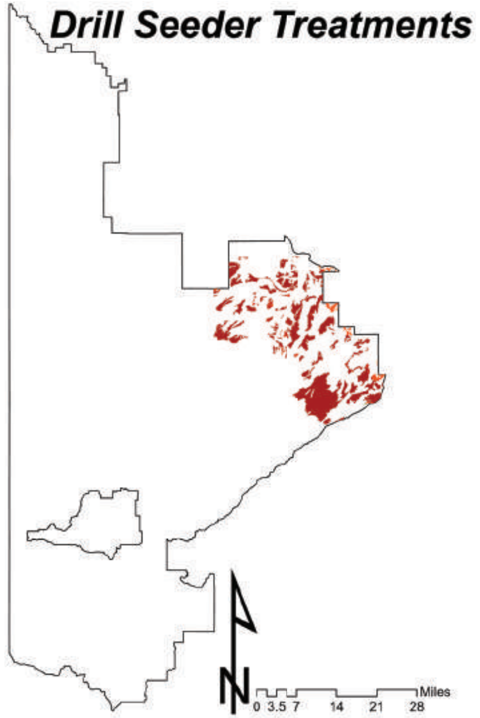


Figure 65. Final Drill Seeder Treatment Priority and Suitability Output Created Under the Assumptions of the Destroying Boise's Playground Scenario.

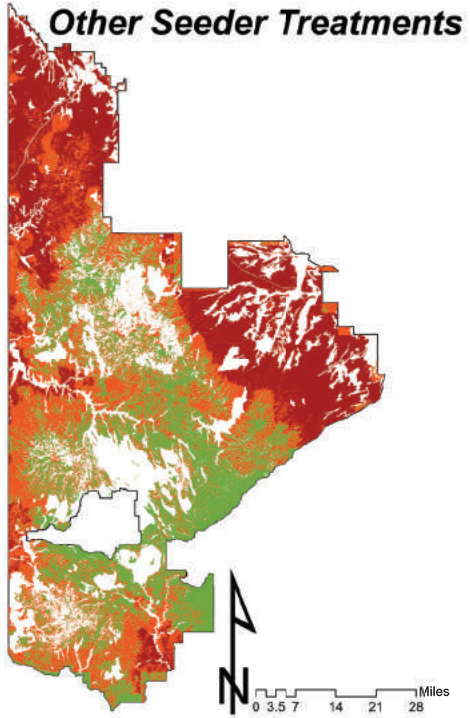


Figure 66. Final Other Seeder Treatment Priority and Suitability Output Created Under the Assumptions of the Destroying Boise's Playground Scenario.

Ely Chain

Chemical Application Priority and Suitability

Business as Usual

For areas able to be treated with the three BLM approved chemicals that have been shown to be effective at reducing cheatgrass (Rimsulfuron – 3.0 oz/ac, Imazapic – 4.0 oz/ac and Glyphosate – 12.0 oz/ac) the results were broken up by application method, aerial or ground-based using mechanical means, as well as by encompassing Management Priority Zone for each scenario. Furthermore, the base raster layer created for Broadcast Seeding mechanical treatments had the exclusionary areas indicated by previous analysis of relevant literature and use guides applied to it; allowing it to then be used as a proxy to show areas able to be treated aerially. Similarly, the base raster layer created for Chaining and Dragging mechanical treatments had ground-based chemical exclusionary areas applied to it, thus, allowing it to be used as a proxy for ground-based chemical treatments using mechanical means. The results of these transformations under the assumptions of the Business as Usual scenario are depicted in Figures 65 and 66.

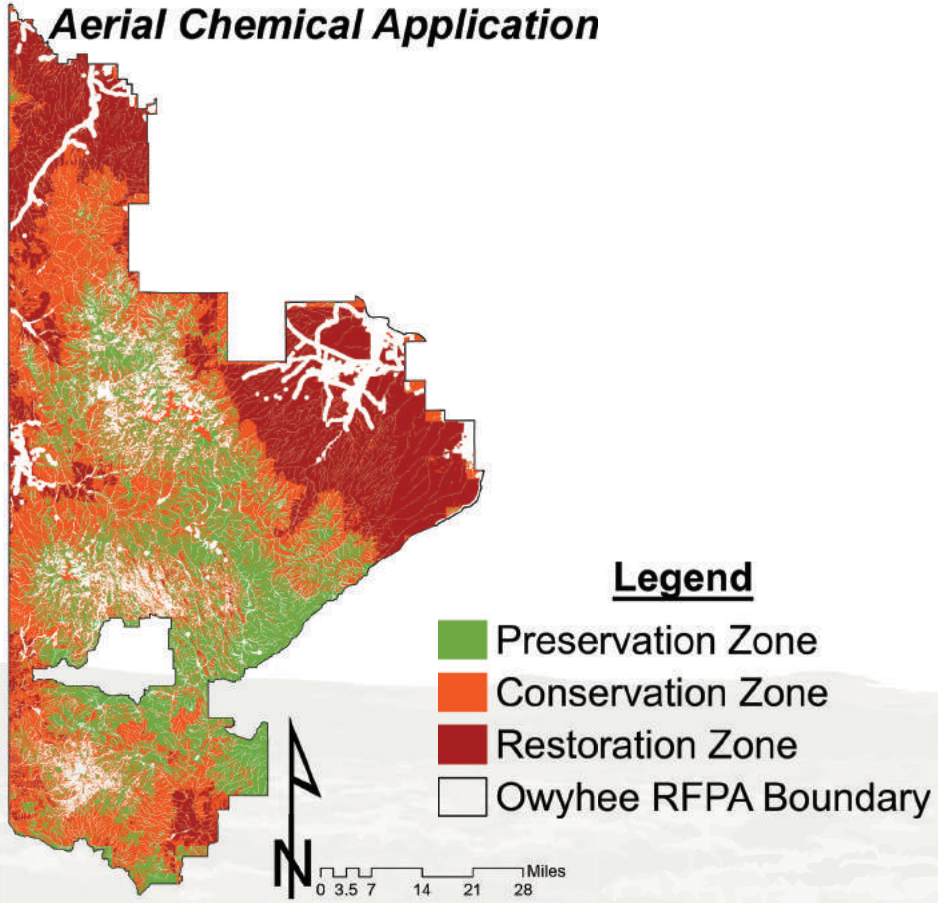


Figure 67. Final Aerial Chemical Application Priority and Suitability Output Created Under the Assumptions of the Business as Usual Scenario.

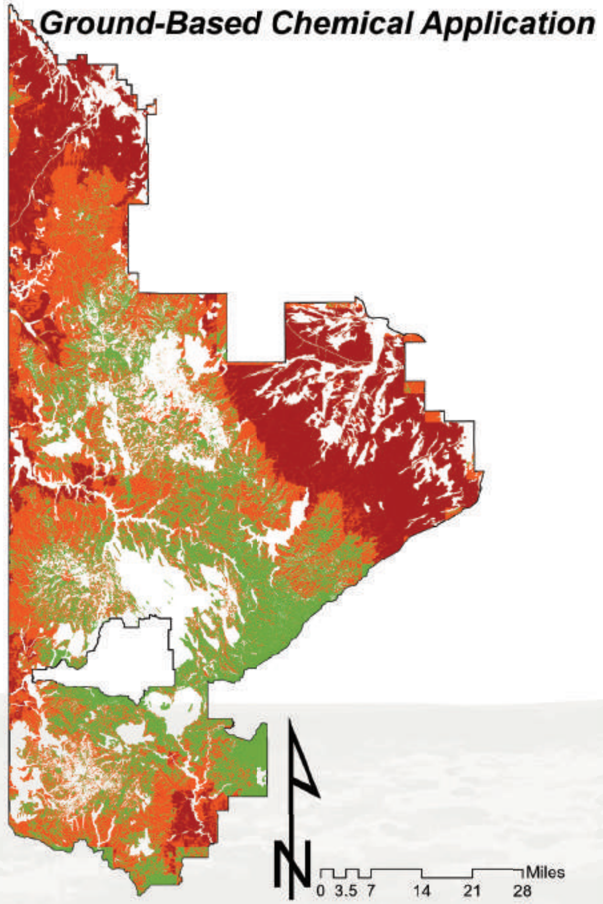


Figure 68. Final Ground-Based Chemical Application Priority and Suitability Output Created Under the Assumptions of the Business as Usual Scenario.

Destroying Boise's Playground

Being that the same base layers and exclusions to use were applied in both scenarios for aerial as well as ground-based chemical application using mechanical means, the outputs between the scenarios do not differ in overall applicable area. However, they do differ in terms of the differing extents inherent in the Management Priority Zones used as the clipping geometries used for each scenario. Figures 67 and 68 illustrate those differences that occurred under the assumptions of the Destroying Boise's Playground.

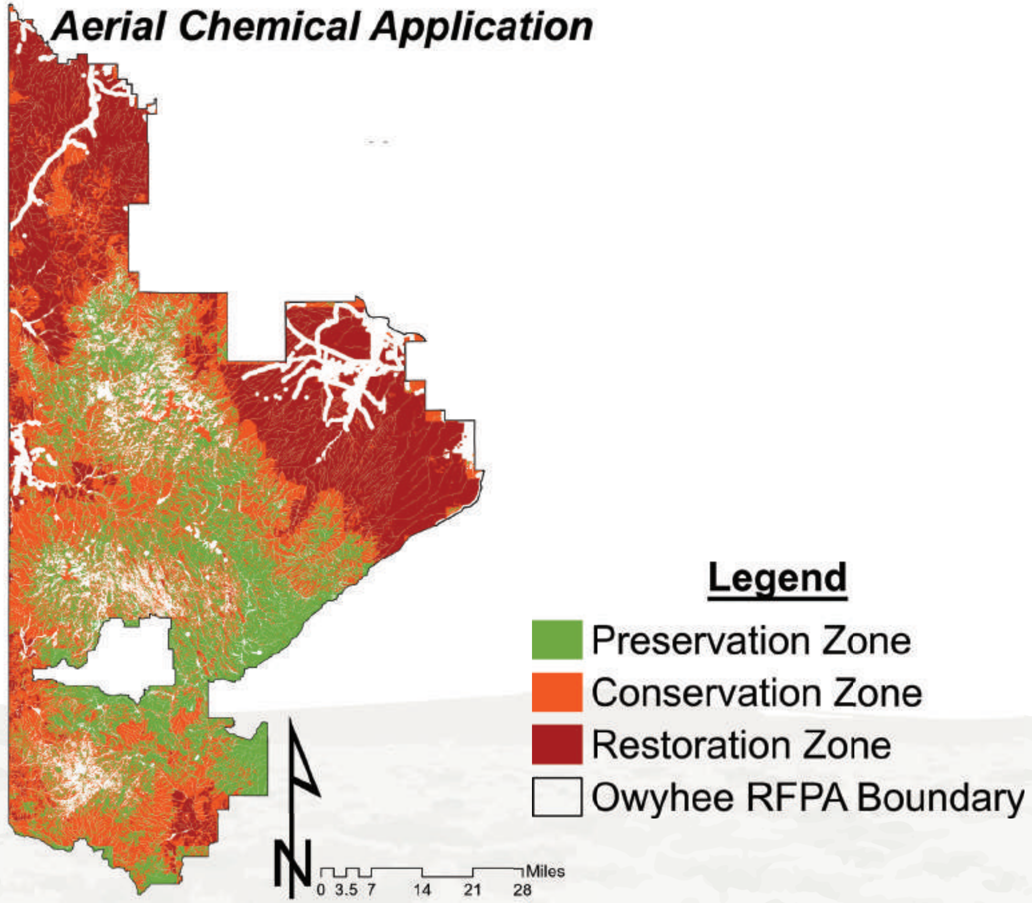


Figure 69. Final Aerial Chemical Application Priority and Suitability Output Created Under the Assumptions of the Destroying Boise's Playground Scenario.

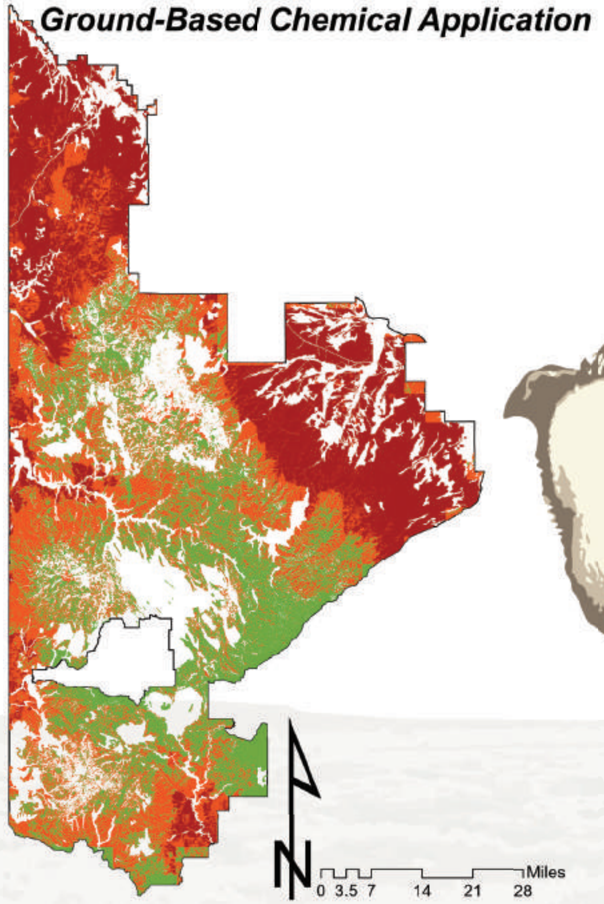


Figure 70. Final Ground-Based Chemical Application Priority and Suitability Output Created Under the Assumptions of the Destroying Boise's Playground Scenario.

Targeted Grazing Application Priority and Suitability

Business as Usual

The final treatment type analyzed for this project was Targeted Grazing application suitability across the landscape. The methods utilized to produce these layers have been outlined above; the output produced under the assumptions of the Business as Usual scenario can be seen in Figure 69. As stated previously, the results are shown in head of cattle needed per acre for an 8-day stocking period and have been classified by by the Management Priority Zones specific to each scenario.

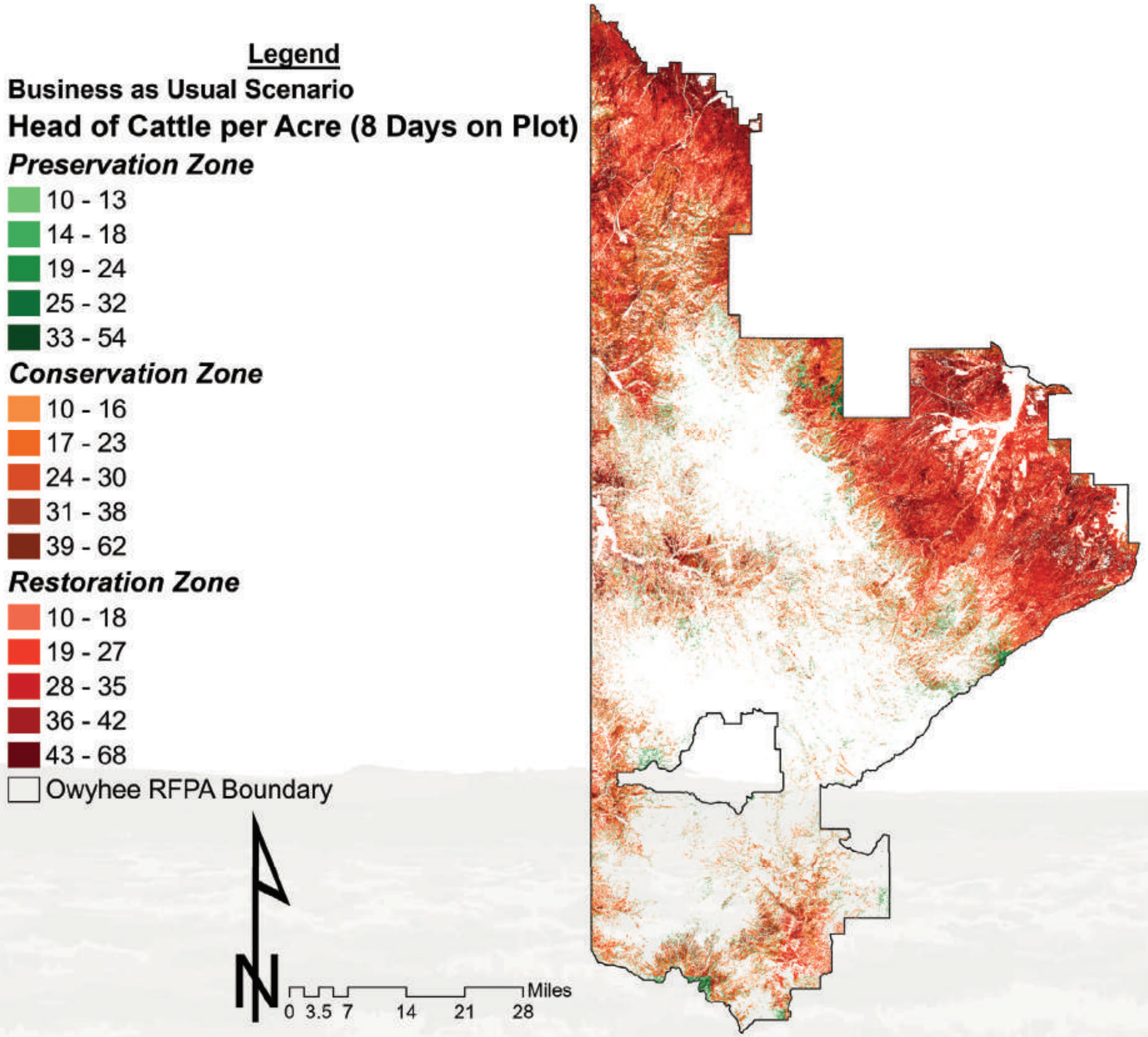


Figure 71. Final Targeted Grazing Application Priority and Suitability Output Created Under the Assumptions of the Business as Usual Scenario.

Destroying Boise's Playground

In a manner similar to previous treatment method analyzation techniques in this project, the base layer created for Targeted Grazing was used in the creation of the outputs for both scenarios. In this case, the reasoning for this was that these Targeted Grazing techniques were: (1) created using current data as opposed to forecasted future data (2) are intended to illustrate where on the landscape they could plausibly be applied according to requirements found through analyzation of the relevant literature and (3) being that they were created using only current data are intended to show where management actions would be most useful in the near future as opposed to 10, 20 or 50 years hence and would need to be updated yearly to continue to be effective. Additionally, as with previous treatment datasets produced through this project, the differences between the outputs of both scenarios occur as a result of the differing extents inherent in the Management Priority Zones used as the clipping geometries used for each scenario. The results for Targeted Grazing application under the assumptions of the Destroying Boise's Playground scenario can be seen in Figure 70.

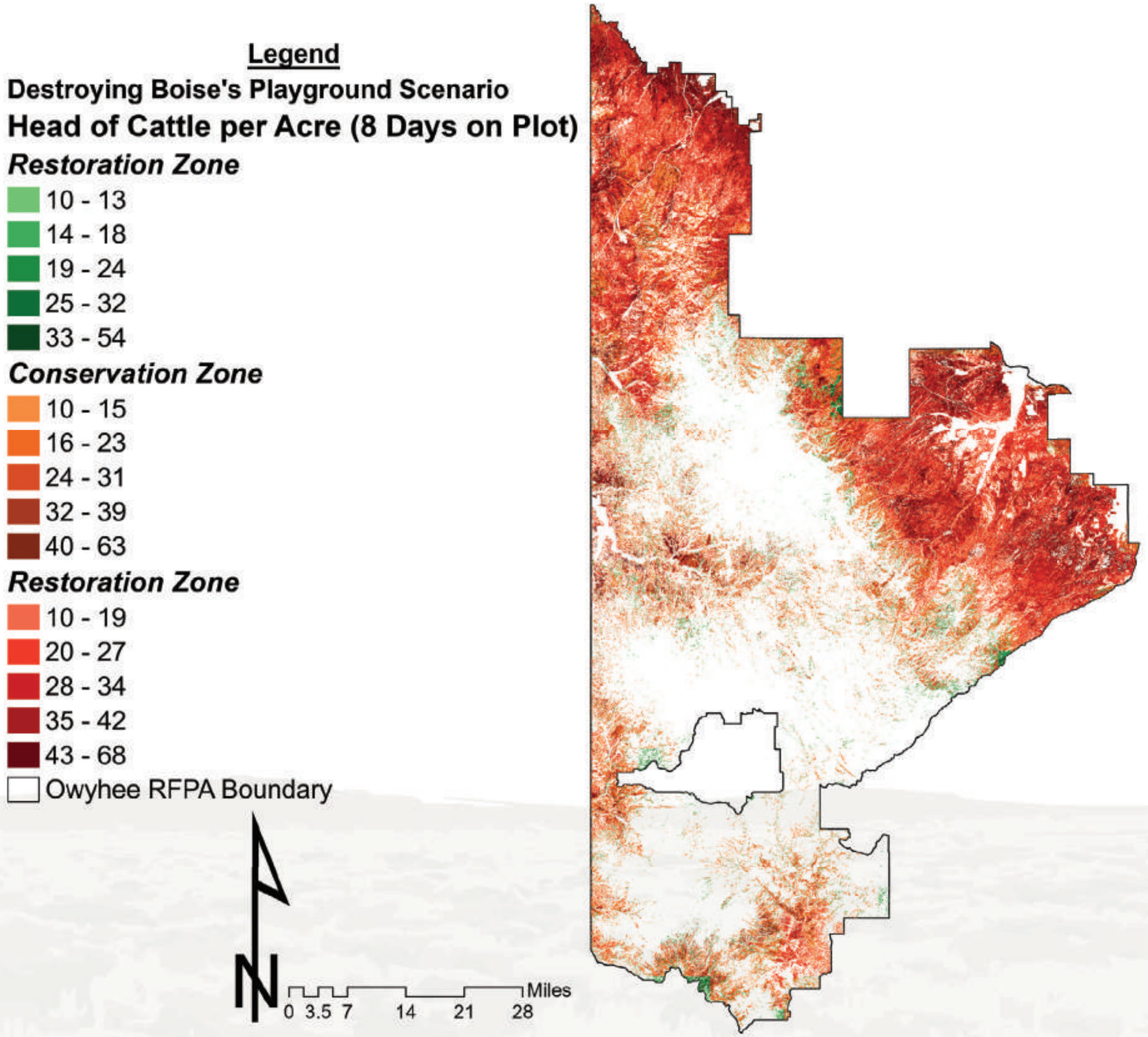


Figure 72. Final Targeted Grazing Application Priority and Suitability Output Created Under the Assumptions of the Destroying Boise's Playground Scenario.

Discussion

Conclusions

In this final chapter, the goals and objectives of this project will be reiterated. The results obtained through performance of the methodology will be discussed in more detail. The creation of as well as suggestions for use of the HUB application will be explained. Finally, it concludes with an analysis of this project's applicability and reproducibility in other similar areas, the lessons learned through completion of this project and possible next steps for those wishing to carry on this work.

Goals and Objectives

As was stated in section 1.8.1 the final goal of this project was stated as being the creation of more comprehensive, cohesive, collaborative and adaptive management strategies via the creation of an easily accessible online geospatial HUB application containing scenario-specific suites of robust and resilient BMPs for long-term fuels reduction and rangeland restoration under the two chosen stakeholder-derived scenarios; "Destroying Boise's Playground" and "Business as Usual". The intended objective of this HUB application is the facilitation of a more comprehensive and regionally implementable management strategy that can be used as an integrative framework for local land managers to aid federal managers in the management of fire in these areas of complex mosaics of landscape ownership and those similar to them.

The utility of a HUB application that is easily accessible to land managers while they are out in the field containing scenario-specific blanket management strategies such as those of this project is that it can then theoretically be widely implemented under the same or similar parameters across a large geographic range and thus ensuring the efficacy of management efforts is not hindered by counter-productive and even detrimental management strategies of others in the same areas. It is the intention of this project that this will lead to a more cohesive and effective overall management strategy for wildfire in the northwestern US that begets a reduction in the prevalence and intensity of large ecosystem-altering fires in the future resulting in the better protection of existing, and the creation of new, healthy sustainable ecosystems for current and future generations.

Discussion of Results

The results obtained through the performance of the methodology overall illustrate the large differences warranted in the management needs of the landscape that are projected to occur under the two stakeholder-derived scenarios of how the landscape could change in the future. For instance, under the Destroying Boise's Playground scenario, the forecasted overall trend of higher fire occurrence in the northern panhandle, with respect to the Business as Usual scenario, indicates a need for more intensive management actions in this area of the landscape. Both scenarios of future landscape change, however, will require intensive management throughout the eastern reaches of the site to help styme detrimental effects on the existing ecosystems as future projections of climate as well as soil temperature and moisture regimes suggest these areas will in the coming years maintain, if not improve, the conditions necessary for the propagation and infiltration of invasive species such as cheatgrass, which will in turn continue to create positive feedback loops with fire leading to further ecological degradation in these sites.

The layers produced illustrating the application and priorities for the different management treatments are all intended to be used as aids to land managers in their decision-making processes about management actions to take on lands under their purview as opposed to being concrete guidelines. Those who live and work on the land, and in many cases have done so for generations, are assumed to have a greater understanding of the site-specific needs, limitations to management actions and effective pathways of management on lands they manage than could possibly be attained through the geospatial processes undergone through this project alone. As such, this project only seeks to provide additional tools to as well as augment the knowhow of those land managers with the latest scientific knowledge in the hopes of easing their burden as well as by providing a framework to better integrate them into a more comprehensive and cohesive overall management strategy with the federal government in these vast, remote tracts of land.

HUB Application Description and Use Guide

As has been stated previously, in order to achieve the objective of better integration of the knowledge, skills, equipment and manpower of local rangeland working communities into the overall federal management plan for the region, a HUB application illustrating the geospatial outputs for all management treatment types under the assumptions of both scenarios of future landscape change was created using ESRIs online "Experience Builder" application. This HUB application entitled, "The Owyhee RFPA Management Strategy Guide" is formatted for and intended to be accessed via tablet by land mangers while they are out in the field actively managing the landscape to help them gain a greater picture of how the landscape might change within the spot they are located as well as what mitigation techniques are available to them depending on the exact location in which they are currently assessing. It can be accessed by following the URL: https://experience.arcgis.com/experience/9116e77e758d440898874679b56630b9. A visual representation of this hub application can be seen in Figure 71 and a textual guide for use will be outlines in the proceeding paragraphs of this section.

Once accessed, a series of interactive "cards" can be used to navigate through the application. On the beginning page, one will be greeted with a brief outline of the goal of the application itself as well as three interactive "cards" that, when activated, will take the user to subsequent pages detailing either the management actions as well as the relative priority areas for said management actions available to them for the two scenarios or to the background contributing data used to create the geospatial representations of management action applicability and priority that is contained in the data repository.

If one follows the path of either of the scenario "cards" they will be met with a web page that gives a brief narrative of the selected scenario with links to the three overarching management technique types below in the form of interactive cards: (1) Mechanical Treatments, (2) Chemical Application and (3) Targeted Grazing. These may then be followed for further breakdowns of the different categories, again in the form of interactive "cards", making up each management technique type as well as a suggestion of temporality in which they are intended to be applied throughout the year. On the face of each of these "cards" is a brief description of its respective management technique type and its uses on the landscape in terms of management goals obtained through the use of said technique. Finally, once the desired management technique has been identified and the user activates its respective card, they will then be taken to a separate web page containing a geospatial representation, or map, of where on the landscape said management technique can feasibly be applied that is further broken up through symbology, what management priority zone it occurs within across the landscape. Users may then either manually zoom in to their current area of interest or select an area of interest by selecting the grazing allotment or grazing plot to view it more closely.

Of the pathways through this HUB application for scenario-driven geospatial representations of management techniques, the only "card" that does not lead to an interactive map illustrating where the selected management technique could be feasibly applied can be found within the Targeted Grazing page for each scenario. This "card" entitled "The Green and Brown Guide" can instead be activated to lead the user to a downloadable PDF of a phenology worksheet intended to be filled out by the user to help them identify when to begin and when to end targeted grazing efforts on a site specific scale. This worksheet developed in 2012 by Smith, Sheley, & Svejcar is intended to aid managers in their "monitoring of the growth stage of plants to determine optimal grazing periods to stress invasive and undesired species while allowing desired perennial grasses to grow undisturbed."

Conversely, if the user follows the path created by the Data Repository card on the home page, they will be directed to a secondary page. This page is comprised of six additional cards; three for each scenario. Activating these cards will, much like those found in the management technique sections detailed previously, take the user to geospatial representations of their respective data. The data that can be found here are the Forest-based Forecast, Risk and Protection Zones and Final Management Priority Zones for each scenario respectively.

As has been stated repeatedly in previous sections, all datasets presented within this application are intended to serve more as helpful facilitators to land managers in their determinations of what management actions to take across lands under their purview as opposed to concrete guidelines to be followed and implemented without question. It is the view of this project that the current knowledge and skills of those who live and work on the landscape could be augmented with this HUB application and as such it is in no way intended to be viewed or utilized as a rigid framework to be imposed on those who already have an in depth knowledge, respect and love for the lands within the study site of the Owyhee RFPA.

Figure 73. Visual Representation of the HUB Application as Would be Seen by a User.

Applicability in Similar Sites

Being that the selected study site of this project, the Owyhee RFPA, comprises a small portion of the overarching Great Basin ecosystem of the United States it can be assumed that it has a relatively similar climate and ecological makeup to those other landscapes found throughout the region. Thus, it can also be assumed that the methodology presented in this study could be utilized throughout the majority of the Great Basin in a similar manner to produce analogous results and geospatial representations of management techniques in addition to identification of areas in need of more intensive management action as well as of those areas of currently “healthy” ecosystems in need of specific protection in the future. It is the hope of this project that this occurs and in doing so creates a more robust, comprehensive and integrated approach to rangeland restoration and fire mitigation efforts throughout the entirety of the Great Basin ecoregion.

Lessons Learned

Of the many lessons learned through the process of completing this project, the framework for geodesign developed by Carl Steinitz proved by far to be the most influential and consequential. To that end, in order to assure that the results of subsequent research efforts using the methodology presented in this project are robust and actually representative of the study areas of these possible future efforts, it is strongly suggested that the people of the place for the respective study areas be included in the process. Furthermore, their assumptions of how the landscape in which they live must be the driving force behind all scenarios of possible future landscape change trajectories. This, inherently, will lead to differences in data inputs, exclusionary requirements, climate forecasts, accepted management techniques and management priorities among other things. It is imperative that the researchers conducting said future study take these changes into account and act as facilitators to provide the people of the place with solutions that fit their needs, wants and desires as opposed to imposing their perceived ideal frameworks onto them. This will help engender a sense of ownership in the proposed management strategies and going forward will make them more robust, resilient and will increase the chances of them being implemented effectively and as described.

Limitations

In terms of limitations to analyses and the project overall, the biggest issue ran into by far were gaps in available data. Most importantly perhaps, were the gaps found in the SSURGO soils datasets used. Being that the selected study site was so remote and overall uninhabited, soil surveys often had gaps within them containing no data. Additionally, differing time scales among datasets created unique obstacles that had to be overcome when combining and analyzing them for use in forecasting possible future landscape change. Finally, as it did with the rest of the globe, the COVID-19 pandemic significantly hampered research efforts. This occurred in the form of cancellation of multiple planned trips to the study site itself as well as the cancellation of multiple stakeholder meetings that were scheduled to occur in person.

Next Steps

Now that this project has come to the end of its first iteration, there are certain steps that would be beneficial if performed to ensure that its outputs are as robust and resilient as possible. First and foremost, it is imperative that the created HUB application is given both to experts in the field and, more importantly, to members of the Owhyee RFPA for them to assess and give feedback on. Their questions, comments and concerns must then be implemented into the application and its accompanying datasets to ensure that the information found within it is easily accessible and is as accurate and useful as possible to land managers. With that, now that the COVID-19 pandemic seems to be winding down, it would be extremely useful to present the findings of this project to stakeholders in person and gather their feedback in an in-person setting.

As has been shown throughout this project, the need for adaptive, multi-layered systems of protection for communities and the environments they live in and depend on for their livelihoods, recreational opportunities and overall continued existence on the landscape is growing ever greater in today’s world of rapidly changing human and natural systems. To that end, it is the hope that the framework presented in this project for integrating the knowledge, skills, manpower and equipment of local rangeland working communities into the overarching federal management plans that exist in these remote areas will be implemented elsewhere throughout the Great Basin. Furthermore, it is hoped the outputs of this project will help lead to a more cohesive and effective overall management strategy for wildfire in the rangelands of the northwestern US that begets a reduction in the prevalence and intensity of large ecosystem-altering fires in the future resulting in the better protection of existing, and the creation of new, healthy sustainable sagebrush steppe ecosystems for the benefit of the native fish and wildlife that rely on them as well as for the benefit of current and future generations of recreators and land users.

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Appendices

Appendix 1:

Plans of Action Considered by the BLM in Formation of their 2020 PEIS

Plans of Action Considered by the BLM in Formation of their PEIS for Fuels Reduction and Rangeland Restoration in the Great Basin

Evaluated Alternatives

Alternative A - *"No Action Alternative"*	The No Action Alternative analyzed the implementation of individual fuels reduction and rangeland restoration projects with site-specific NEPA.
Alternative B - *"Selected Alternative"*	Alternative B, the Preferred Alternative in the Final PEIS, is the environmentally preferred alternative in this ROD. Alternative B will result in the largest potential treatment and emphasis areas combined with the availability of the full range of treatment methods. As a result, it will offer BLM the most flexibility in implementing fuels reduction and rangeland restoration treatments. While other alternatives may have fewer short-term adverse impacts by restricting certain tools such as chemical treatments, Alternative B will have the fewest long-term adverse impacts through the greatest reduction in potential threats. Over the long-term, Alternative B has the greatest potential for long-term beneficial impacts through lengthening fire return intervals, shifting fire regimes to more historical conditions, and reducing departure from desired vegetation states. Alternative B will be detailed throughout next few paragraphs.
Alternative C - *"Manual/ Mechanical Only"*	Alternative C analyzed the effects of using only manual and mechanical methods to address degraded vegetation states within the 26.8-million-acre potential treatment area. No chemical treatments, prescribed fire, targeted grazing, or nonnative plant material would be used. No sagebrush would be removed and no treatments would occur in Phase III Pinyon-Juniper or in areas of high resistance and resilience.
Alternative D - *"Limited Area"*	Alternative D analyzed the same treatment methods and flexibility described in Alternative B, but in a more limited geographic area. The potential treatment area consisted of the 5.6 million acres within the FIAT Planned Treatment Areas. The FIAT did not evaluate treatments in Phase III Pinyon-Juniper so it is unlikely that they would occur under this alternative. The FIAT emphasis area was the same as the potential treatment area in Alternative D.

Alternatives Considered but Eliminated from Analysis

Fuels Reduction Only	Given the increasing trend in the number and size of wildfires in the Great Basin, an alternative focused on fuels reduction treatments to achieve desired conditions was considered. This alternative was dismissed after assessing treatment objectives and determining that desired outcome for the vegetation states within the analysis area was more likely achievable through both fuels reduction and restoration treatments.
Use of Wild Horses and Burros to Reduce Vegetation	During scoping, commenters suggested the use of wild horses and burros to manage vegetation, noting that, since wild horses eat cheatgrass, they could remove invasive annual grasses. This alternative was dismissed because it would not meet the purpose and need in its entirety and would be inconsistent with policy (BLM Handbook H-4700-1). Wild horses and burros may not be restored outside of existing herd management areas (HMAs) or in HMAs that are at or above appropriate management levels (AMLs); therefore, this alternative would be restricted only to HMAs below minimum AMLs. Furthermore, herding wild horses and burros would be necessary to meet the purpose and need. This would be contrary to the Wild Free-Roaming Horses and Burros Act of 1971, as amended.
Use of Excess Wild Horses and Burros (Through Transfer of Ownership) to Mitigate or Prevent Wildfire	Transferring excess horses from government ownership to private, state, or county ownership is out of the scope of this project. Horses managed by a grazing operator could be considered for targeted grazing under the alternatives analyzed in this document; however, it is unlikely that the BLM could realistically transfer ownership of excess wild horses and burros to enough willing and capable partners to reduce fuel loading (See Section 2(b) of PL 92-195). Under such a scenario, privately managed horses or burros would need to be completely removed from the treatment area once the treatment is concluded. As a result, this alternative was eliminated from detailed analysis.
Reduction in Livestock Grazing	Several commenters on the Draft PEIS suggested reductions in livestock grazing to better address one of the causes of rangeland degradation and disturbance. This alternative was dismissed because it is not within the scope of this PEIS. Reducing livestock grazing would not necessarily meet the purpose and need (Section 1.2), which states "The purpose of the project is to enhance the long-term function, viability, resistance and resilience of sagebrush communities through vegetation treatments to protect, conserve, and restore sagebrush communities in the project area." The Draft PEIS does include Design Feature 15 (see Appendix D), which requires providing adequate rest from livestock grazing after restoration projects. Livestock grazing management is comprehensively regulated by 43 CFR Part 4100 and includes a variety of considerations in addition to vegetation management to determine stocking levels for a particular allotment. BLM elected to focus on those actions that could be authorized through a DNA or tiered NEPA in this PEIS rather than expand its focus to include all potential avenues to treat vegetation. Activities proposed to facilitate rangeland restoration are intended to complement existing direction mandated in other programs. As such, this analysis does not directly address livestock. BLM anticipates that field offices will manage its programs to address sources of rangeland degradation while planning restoration projects to ensure desired conditions are achieved.

Appendix 2:

Common Seedbed Preparation Mechanical Treatments Found in Monsen et al. (2004)

Common Seedbed Preparation Mechanical Treatments

Mechanical treatment involves the use of vehicles designed to cut, uproot, or chop existing vegetation. The selection of a particular mechanical method is based upon characteristics of the vegetation, seedbed preparation and re-vegetation needs, topography, terrain and soil characteristics

Equipment	Description	Primary Area of Use	Limitations
Disk Plow	Consists of a single gang of a few to several disks on a frame supported by wheels. Each disk is slanted at an angle to the vertical, with a separate bearing and frame attachment.	Deep plowing of rock-free and debris-free soil. Controls deep rooted plants.	Restricted to fairly rock-free and large debris-free sites. Slow speed. Large amount of power required to operate.
Brushland Plow	A specially designed rangeland disk. The brushland plow consists of seven pairs of opposite, opposing disks attached to spring-loaded arms that are connected to a heavy duty frame supported by three wheels. Each pair of disks is independently suspended	Shallow plowing on smooth, rough, rocky and uneven terrain. Controls grasses, forbs, and nonsprouting shrubs.	Will not control sprouting shrubs. Difficult to transport. Operational speed is slow.
Off-set Disk	Two rows of gangs of disks are set at an angle to each other. Angles are adjustable. Disks cut in two different directions, turning soil and vegetation both ways. Disks can be smooth or cutout.	First gang of disks turn soil and vegetation. second gang turns soil and vegetation in opposite directions. Vegetation is cut up and broken. Controls most grasses, forbs and small non-sprouting shrubs. Works well on dry, heavy and moderately rocky soils.	Cannot be operated in soil with large rocks and on slopes over 30 percent. Fairly slow operational speed.
Smooth Anchor Chain	Anchor chain weighing 40 to 160 lb per link, 90 to 350 ft long, with swivels on either end and sometimes in the middle.	Moderate soil scarification. Uproots and breaks off trees and shrubs and releases understory vegetation. Covers seed. Cost per acre to operate is moderate. Can be operated on uneven rocky terrain. Ideal for removing trees, releasing understory shrubs, grasses and forbs and covering seed.	Will not control sprouting shrubs. A less than acceptable job of killing nonsprouting shrubs and trees. Will ride over young, flexible trees.
Ely-anchor Chain	Anchor chain weighing 40 to 160 lb per link, 90 to 350 ft long, with steel bars or railroad rails welded cross ways to chain links. Swivels are attached at either end and throughout.	Uproots and breaks off trees and shrubs. Releases understory vegetation. Percent kill of shrubs and trees is higher than with a smooth chain. Does an excellent job of scarifying soil surfaces and covering seed. Can be operated on rough, rocky terrain. Cost to operate is moderate.	Has tendency to hook and drag trees and shrubs to the middle of the chain. this lifts the chain off the ground, resulting in poor soil scarification. Can uproot and kill some understory vegeatiation.
Dixie Sager	Anchor chain weighing 40 to 160 lb per link, 90 to 350 ft long, with railroad rail welded to each side of each link horizontal to the link. Crown of rail welded next to link. Swivels are attached at either end and throughout.	Uproots and breaks off trees and shrubs. Releases understory vegetation. Does an excellent job of uprooting and killing big sagebrush, scattering smaller piñon and juniper, and scarifying the soil. Covers seed. Can be operated on rough rocy terrain. Cost of operation is moderate.	Does not work well in full piñon-juniper stands. Trees are hooked by the railroad rail and are dragged along. This lifts the chain off the ground and results in poor sagebrush kill and soil scarification.
Cables	Cable 1.5 to 2 inches thick, 100 to 550 ft long, with swivels at both ends and throughout.	Will uproot larger trees, slightly scarify soil surface and cover seed. Can be used on rocky, uneven terrain. Cost of operation is low. Ideal for removing scattered large trees and releasing understory shrubs.	Percent kill of trees is lower than with smooth, Ely, or Dixie-sager anchor chains. Soil is poorly scarified.
Pipe Harrow	Spiked pipes trailed behind a spreader bar. Pipes are attached to spreader bar by swivels at equal intervals along bar.	Scarifies soil surface, removes small brittle shrubs, covers seed. Ideal for interseeding desirable species into sparse vegetation stands. Works well on rocky land and uneven terrain. Cost of operation is low. Seeding can occur concurrently.	Does not control plants other than brittle shrubs. Soil scarification is limited on compacted soil.
Land Imprinter	Cylinder or drums with various configurations, sizes and shapes of angle iron welded to the drum surface. Seed dispensers may be attached to frame-tow bar combination.	Operation on rough, rocky and brush covered terrain on most soil types. Creates small depressions. Seeds are deposited into depressions in a firm seedbed. Cost of operation is moderate.	Does not work well in dense shrubs or grass communities or on compacted and rocky soil.
Root Plow	Straight or V-shaped blade attached to shanks. Shanks are attached to a trailing draft or arm or tow-bar, dozer blade or dozer frame.	Used to undercut undesirable grasses, fobs, shrubs and small trees in soils free of large rocks. Works well in dry soils.	Not adapted to shallow, rocky, steep or wet areas. Kill of sprouting and rhizomatous species may be low. Cost of operation can be high.
Disk-Chain	An anchor chain, with cutout disks connected to every other link. Varying lengths of disk-chains are connected to either end of a double roller bar, forming an "A" with the apex forward and the roller bar back. Roller bars vary from 24 to 46 ft (7.3 to 14 m) wide. A spreader bar is connected from the center of the roller bar to the apex. The length of the spreader bar determines the angle of the chains and disks. Chains are connected to each other; the roller bar is connected by swivels. Only one tractor is required to operate a disk-chain. Seeding and disking can occur simultaneously. Broadcast seeders can be connected to the roller bar on a trailing trailer. Seed boxes have been placed over the roller bars.	The disk-chain is designed for use on smooth, rough, uneven, and rocky terrain in all vegetative types ranging from grass communities to large shrubs and sparse stands of small trees. The disk-chain is an ideal piece of equipment for large sites, strips, and localized site seeding in sparse trees and shrub stands. The disk-chain does an excellent job in reducing the density of cheatgrass and perennial species.	Care must be taken in extending the spreader bars too far. If the angle between the spreader bars and the chain exceeds 30 percent, excessive wear to the components will result.

Appendix 3:

Common Seeding Equipment for Mechanical Treatments Found in Monsen et al. (2004)

Common Seeding Equipment for Mechanical Treatments

For more in-depth descriptions of the equipment types detailed below see Monsen et al., 2004.

Equipment	Description	Primary Area of Use
Drills	They are large heavy pieces of equipment typically pulled behind tractors, dozers or other large machines. Drills dispense and place various types of seed in the most ideal situations for germination and establishment.	Depends on type of drill, but most are suited for rough, rocky terrain where dense litter has not accumulated.
Ground Broadcasting	This is a method for uniformly broadcasting seed from handheld or vehicular mounted seeders. Seed is generally distributed by means of a rotary wheel. Ground broadcasters can be operated manually by a tractor's track or by hydraulic, gasoline, or electric motors. They can be mounted on trucks, trailers, or tractors and other prime movers, and attached to various types of seedbed preparation equipment.	Broadcast seeders are used to seed areas that are inappropriate for drill seeding, such as rocky or rough terrain, rocky soils, areas with large amount of debris, and small, irregularly shaped areas. Broadcast seeders can be used alone or in conjunction with seedbed preparation equipment. Broadcast seeding coupled with anchor chaining, disk-chaining, pipe harrowing, land imprinting, drilling, scalping, harrows, or other seed coverage treatments is often preferred over drill seeding. Costs are generally much lower than for drilling. Variable planting depths are achieved by broadcasting which often favors mixed species plantings. Sagebrush, rabbitbrush, forage kochia, and a number of other species do best with surface seeding on a disturbed surface. Broadcast seeders have been designed to facilitate surface seeding. With proper equipment, multiple species mixtures with differing seeding requirements can be seeded simultaneously.
Aerial Broadcasting	Aerial broadcasting is achieved through use of fixed-wing aircraft as well as helecoptors and is usually the most economical method for seeding large acreages. Typically, aerial broadcasting requires between 33 and 50 percent more seed than drilling, but its ability to uniformly distribute seed over short time periods throughout areas that would be otherwise inaccessable make it a useful tool to be employed in a variety of conditions.	Aerial boradcasting is used on sites with large areas that must be planted in small windows of time as well as on sites where terrain, access or enviornmental qualities make the use of other means of seeding impractical or impossible. Helicopters are usually selected over fixed-wing aircraft if irregular-shaped sites and variable terrain are seeded and when air strips are unavailable. Helicopter seeding is recommended for planting high elevation sites, streambanks, and roadways where fixed-wing planes do not operate as safely or satisfactorily.
Seed Dribblers	Seed dribblers deposit selected seed onto crawler tractor tracks. The seed is carried forward, dropped onto the soil, and pressed into a firmed seedbed. Tractor-pulled seed dribblers deposit seed directly into prepared seedbeds.	Dribblers are ideal for planting species that require firm seedbeds or whose seed is in short supply or extremely costly. Generally, seedling establishment of shrubs and forbs is greater when seeded through a dribbler than when broadcast or drilled. Species that require minimal coverage, like rabbitbrushes, sagebrushes, asters, and forage kochia establish much better when dribbled than when drilled. Dribblers are generally used in conjunction with other operations like chaining, cabling, and pushing trees and shrubs.
Brillion Seeders	The Brillion seeder is pulled behind large equipment and consists of a two compartment seed box mounted above and between two standard cultipackers. Each cultipacker consists of closely spaced, V-shaped, grooved steel wheels. The grooves of the two cultipackers are offset. The first cultipacker smooths and firms the seedbed and makes small furrows. The fluted seed metering device broadcasts the seed between the cultipackers onto the created furrows. The second cultipacker, which is offset, covers the seed in the original furrows and creates new ones. The two compartments in the seed box allow for seeding two types or mixes of seed.	The Brillion seeder is used to seed smooth areas. It creates an excellent firm seedbed and can seed at quite precise rates.
Surface Seeders	Surface seeders have been developed to accommodate species that require surface, or near surface seeding. Surface seeders are pulled behind large equipment and consist of a seed box that drops the seed onto a line of tires that gently push the seed into the soil surface.	Some species that require surface seeding on disturbed soil include the sagebrushes, rabbitbrushes, asters, and forage kochia. Surface seeders provide the means for depositing seed onto the surface of disturbed soil. Use is restricted to areas where a tractor can operate.
Interseeders	Another type of implement that is pulled behind larger equipment is an interseeder. Interseeders are designed to seed desirable species into existing vegetation with minimal disturbance. Interseeders consist of a one- or two-way scalper or furrow opener and a heavy-duty seeder. Seeders are driven by rotation of a press wheel. Seed is metered out by a fluted shaft or a spoked wheel with cups attached on the spoke ends. Scalp or furrow depth can be regulated with a depth regulator wheel or hydraulics of the tractor. Seed is covered by the press wheel or drag chain.	The use of interseeders is restricted to soils that are fairly free of rock, roots, and stumps, and to terrain on which the tractor can safely operate. Grasses, forbs, and shrubs can be seeded through interseeders with or without previous seedbed preparation. Interseeders are used to establish desirable species in cheatgrass and other annual communities, monotypic grass stands (fig. 32A,B), perennial communities, burned areas, and disturbed sites. On these sites, establishment of seeded species can be superior to broadcast and drill seeding.
Hydro Seeders	Hydroseeders are designed to apply seed, fertilizer, soil amendments, and fiber mulch to the soil surface in a hydraulic spray. Hydroseeders consist of a truck or trailer, tank, pump, discharge nozzle, and engine. The tank is equipped with various types of agitators to assure uniform mixing. The pump sprays the mixture up to 200 ft (61 m). Interchangeable nozzles provide for various spray patterns and quantity of delivery. Nozzles are designed to rotate horizontally and vertically.	Hydroseeders are generally used to seed steep slopes or very rocky areas. There are a number of disadvantages to hydroseeding. They include: (1) seed is not placed in the soil, (2) seed and seedlings can dry out, (3) some seedlings cannot grow through the mulch, (4) seed can be damaged by agitators and pumps, (5) precocious germination can occur as a result of moisture in the mulch, (6) seeding may be done during unfavorable seeding periods, (7) expense, and (8) large water requirements.

Appendix 4:

Common Special Use Equipment for Mechanical Treatments Found in Monsen et al. (2004)

Common Special Use Equipment for Mechanical Treatments

For more in-depth descriptions of the equipment types detailed below see Monsen et al., 2004.

Equipment	Description	Primary Area of Use
Transplanter	Transplanters are tractor-drawn implements that scalp the soil surface and open a furrow. Bareroot stock, wildings, cuttings, or container-grown plants are placed in the furrow and soil are packed around the plant roots	Transplanting can be economically utilized on critical big game, upland gamebird, and livestock ranges; disturbed sites; sites with high erosion potential. It is also widely used in high aesthetic value recreational areas, windbreaks, shelterbelts, and riparian sites. For best results, transplanting should occur in the early spring when soil moisture content is high and chances for spring storms are greatest. Fall transplantings are less successful, primarily due to frost heaving and drying. Transplanters are restricted to soil at least 18 inches (45.5 cm) deep that is free of large rocks, roots, and stumps.
Roller Chopper	Roller choppers consist of a steel, 5 ft by 12 ft (1.5 m x 3.7 m) diameter drum with 12 grader blades evenly spaced and welded vertically around the outside of the drum and is pulled behind large equipment. Intake and drain plugs are installed to allow the drum to be filled with 800 to 900 gallons (3,000 to 3,400 L) of water. Steel frames, tongue, and hitch are attached to both ends of the drum.	Roller choppers are used to (1) push over, uproot, and chop up trees and shrubs with the main trunk at ground level less than 6 inches (15.3 cm) diameter, (2) create seedbeds, (3) cover seed, (4) create water catchment basins, and (5) to stimulate shrubs by pruning to 12 inches (30 cm) above ground level. When piñon and juniper have invaded grasslands, shrublands or chained areas, the roller chopper has been used successfully to remove them.
Dozers and Blades	Dozers and blades typically are used in one of 5 different configurations: (1) **Standard** - a straight concave blade solidly mounted to a crawler or rubber tired tractor (2) **Three-way Dozer** - a multi-purpose dozer blade that is adjustable for height, tilt, angle, and pitch (3) **Brush/Forest Rake** - consists of a special blade with vertical teeth generally with replaceable tips, or a vertical toothed implement that is attached to a standard or three-way blade (4) **Hula Dozer** - a standard dozer blade with hydraulic side tilt and pitch that is often equipped with four removable digger teeth spaced along the blade (5) **Shearing/Clearing** - a straight or V-shaped solid blade with straight or sharpened cutting edges along the bottom	Blades are used to uproot, cut off, move, pile, and windrow trees and shrubs; build or clean roads, fences, and fire lines; construct trenches, basins, and terraces; move and pile rocks and debris; prepare seedbeds and planting sites; and grade and carry out general excavation.
Trenchers	Trenchers consist of one or two large disks are mounted on a crossbar or shank. Disks rotate hydraulically to allow for operation in two directions. Disks and crossbars are hydraulically controlled and will adjust to the contour of the site and depth and width of the designed trench. Broadcast and dribbler seeders can be attached to these trenchers, allowing for seeding to take place concurrently.	Trenchers are used to construct trenches, scalps, depressions, and furrows for the purpose of intercepting runoff, collecting snow and precipitation, preventing erosion, removing competing vegetation and seed, creating a seedbed, and promoting plant establishment and growth.
Fireplows	Fireplows consist of a V-shaped lister share with large disks located on each side of the share (plow). Where needed, a coulter can be attached in front of the lister share. A moldboard wing may be attached behind either disk allowing for the trench berm to be moved away from the trench edge. Browse seeders or thimble seeders can be connected to the fireplow, allowing for seeding to occur simultaneously	Fireplows are used to construct trenches, scalps, depressions, and furrows for the purpose of intercepting runoff, collecting snow and precipitation, preventing erosion, removing competing vegetation and seed, creating a seedbed, and promoting plant establishment and growth.
Gougers	Gougers consist of three to five half-circle blades attached to solid arms that are spring loaded. The blades are raised and lowered automatically, scooping out depressions in a cyclic manner. Seed is broadcast into the depression from a seed box mounted above the blades and arms.	Gougers are used to construct trenches, scalps, depressions, and furrows for the purpose of intercepting runoff, collecting snow and precipitation, preventing erosion, removing competing vegetation and seed, creating a seedbed, and promoting plant establishment and growth.
Fire Ignitors	There are 3 different catagories of fire ignitors: (1) **Aerial** - these are connected or suspended from helicoptors. The two most widley used of which are the flying drip torch (helitorch) and ping-pong injectors (2) **Drip Torches** - can be backpack, handheld, vehicle and trailer mounted and consist of a fuel tank, wand, stem or boom to direct the flame and a fuel ignitor (3) **Flame Throwers** - depending on size, these can either be hand operated or vehicle mounted. They are comprised of pressurized tanks, a hose and nozzle.	Ignitors are dispersed aerially, from ground rigs or by hand to ignite fires in fire management, slash clean up, and range improvement.
Herbicide Sprayers	Liquid herbicides are most commonly applied on rangelands by broadcast spraying. Application is by ground rigs, fixed-wing aircrafts, helicopters, and hand sprayers	Application of herbicide by ground rigs has several advantages over aerial application: small acreages can be sprayed, no landing strip is required (fixed-wing only), there is less drift, application is not restricted by fog or wind, equipment is generally less expensive, and applicators are safer. Aerial application does have some advantages over ground rigs: application rate (acres per hour) is greater and large areas can be sprayed during short periods of time when conditions are ideal. For this reason, aircraft are commonly used to spray large acreages. Aerial application is also well adapted to spraying wet, rough, steep, and rocky terrain. Cost of application is less, vegetation and soil are not disturbed, and dense, tall brush stands can be treated more effectively.
Steep-slope Scarifier and Seeder	The machine consists of a tubular constructed frame with: (1) front- and rear-mounted reversible spring-loaded scarifier tines, (2) soil drags, (3) four spring-loaded press wheels, and (4) two electrically powered rotary seeders or spreaders. The seeder is bolted to the end of the crane by a knuckle joint, and can be turned in any direction or angle. The machine can be operated to run horizontally across a slope, or up or down a roadcut or fill surface. Seed and fertilizer are dispensed separately through the two spreaders.	The seeder was initially developed to seed steep roadcuts and fill surfaces where conventional equipment is not able to operate. Steep, inaccessible sites are normally broadcast seeded without any seed coverage, and poor plant establishment usually occurs. The steep-slope scarifier seeder is not only able to operate on uneven terrain, but seeds are planted in the soil. The steep-slope seeder is not capable of reducing existing competition, but can be used to seed areas without damage to existing plants. When mounted on a gradall or crane, the machine has limited reach, and can only be operated within the reach of the crane.

Appendix 5:

Mechanical Treatment MSIs

Mechanical Treatment MSIs

MSIs used in the creation of treatment specific geospatial suitability layers for each type of mechanical treatment. Information Derived from: Monsen et al. (2004), US Army Corps of Enigineers Operation Manuals and Manufaturer Specific Operational Use Guides and Manuals

Equipment Type	Slope	Bedrock Depth	Soil Rockiness	Small Shrub Presence OK?	Medium Shrub Presence OK?	Large Shrub Presence OK?	Small Tree Presence OK?	Large Tree Presence OK?
Disk Plow	<30%	18"+	Low	Y	N	N	Y	N
Brushland Plow	<30%	15"+	Any	Y	Y	Y	Y	N
Off-set Disk	<30%	18"+	Medium	Y	Y	N	Y	N
Smooth Anchor Chain	<50%	10"+	Any	Y	Y	Y	Y	Y
Ely-Anchor Chain	<50%	15"+	Any	Y	Y	Y	Y	Y
Dixie Sager	<50%	15"+	Any	Y	Y	Y	Y	Y
Cables	<50%	5"+	Any	Y	Y	Y	Y	Y
Pipe Harrow	<30%	10"+	Any	Y	Y	Y	Y	Y
Land Imprinter	<45%	10"+	Medium	Y		N	N	N
Root Plow	<20%	18"+	Low	Y	Y	Y	Y	N
Disk-Chain	<30%	18"+	Medium	Y	Y	Y	Y	N
Rangeland Drill	<18%	5"+	Low	Y	Y	N	N	N
Traux Drill	<18%	5"+	Low	Y	N	N	N	N

Equipment Type	Tree Density	Clearance	Seed Type	Seeding Depth	Adjustable?	Target Flora							
						Grass	Forbs	Non-sprouting Shrubs	Sprouting Shrubs	Small Shrubs	Large Shrubs	Small Trees	Large Trees
Disk Plow	<10%	N/A	N/A	N/A	N/A	Y	Y	N	N	Y	N	N	N
Brushland Plow	<10%	N/A	N/A	N/A	N/A	Y	Y	Y	N	Y	Y	N	N
Off-set Disk	<10%	N/A	N/A	N/A	N/A	Y	Y	Y	N	Y	N	N	N
Smooth Anchor Chain	<35%	N/A	N/A	N/A	N/A	N	N	Y	N	N	Y	Y	Y
Ely-Anchor Chain	<35%	N/A	N/A	N/A	N/A	N	N	Y	N	Y	Y	Y	Y
Dixie Sager	<25%	N/A	N/A	N/A	N/A	N	N	Y	N	Y	Y	Y	Y
Cables	<25%	N/A	N/A	N/A	N/A	N	N	Y	N	N	Y	Y	Y
Pipe Harrow	<15%	N/A	N/A	N/A	N/A	N	N	Y	N	Y	N	N	N
Land Imprinter	<15%	N/A	N/A	N/A	N/A	N	N	Y	N	Y	N	N	N
Root Plow	<25%	N/A	N/A	N/A	N/A	Y	Y	Y	Y	Y	Y	Y	N
Disk-Chain	<25%	N/A	N/A	N/A	N/A	Y	Y	Y	Y	Y	Y	Y	N
Rangeland Drill	<10%	High	Any	0.25"-2"	N	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Traux Drill	<10%	Moderate	Any	0.25"-2"	Y	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Appendix 5 Continued:

Mechanical Treatment MSIs

Mechanical Treatment MSIs

MSIs used in the creation of treatment specific geospatial suitability layers for each type of mechanical treatment. Information Derived from: Monsen et al. (2004), US Army Corps of Enigineers Operation Manuals and Manufaturer Specific Operational Use Guides and Manuals

														Target Flora							
Equipment Type	Slope	Bedrock Depth	Soil Rockiness	Small Shrub Presence OK?	Medium Shrub Presence OK?	Large Shrub Presence OK?	Small Tree Presence OK?	Large Tree Presence OK?	Tree Density	Clearance	Seed Type	Seeding Depth	Adjustable?	Grass	Forbs	Non-sprouting Shrubs	Sprouting Shrubs	Small Shrubs	Large Shrubs	Small Trees	Large Trees
Ground-Based Seed Broadcasters	<45%	N/A	Any	Y	Y	Y	Y	Y	Any	N/A	Any	Surface	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Aerial Seed Broadcasters	N/A	N/A	Any	Y	Y	Y	Y	Y	Any	N/A	Any	Surface	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Seed Dribblers	<30%	5”+	Any	Y	Y	Y	Y	Y	<35%	N/A	Any	0”-2”	N	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Brillion Seeders	<30%	5”+	Low	N	N	N	N	N	<5%	Low	Any	Any	N	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Surface Seeders	<50%	5”+	Any	Y	Y	N	Y	N	<25%	Low	Any	Any	Y	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Interseeders	<50%	10”+	Low	Y	N	N	Y	Y	<35%	N/A	Any	Any	N	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hydroseeders	<60%	10”+	Any	Y	Y	Y	Y	Y	<35%	N/A	Any	Any	N	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Transplanters	<30%	18”+	Low	Y	N	N	N	N	<5%	N/A	N/A	18”+	N	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Roller Chopper	<45%	Any	Medium	Y	Y	Y	Y	N	Any	N/A	N/A	N/A	N/A	N	N	Y	N	Y	Y	Y	N
Trenchers	<50%	Any	Low-Med	Y	Y	Y	Y	N	<50%	N/A	N/A	N/A	N/A	N	N	N	N	N	N	N	N
Fire Plows	<50%	Any	Any	Y	Y	Y	Y	N	<50%	N/A	N/A	N/A	N/A	N	N	N	N	N	N	N	N
Gougers	<50%	Any	Any	Y	Y	Y	Y	N	Any	N/A	N/A	N/A	N/A	N	N	N	N	N	N	N	N
Dozers / Blades	<50%	Any	Any	Y	Y	Y	Y	Y	Any	N/A	N/A	N/A	N/A	Y	Y	Y	Y	Y	Y	Y	Y