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Wildfire exclusion over the past century or more has resulted in extensive fuel accumulations throughout much of the West that combined with recent climatic patterns have increased the frequency of relatively uncommon, large, high-severity wildfires. Forest restoration treatments intended to alter landscape-level fire disturbance patterns can be difficult to implement due to issues of scalability and cost. The utilization of biomass material generated during harvest can help offset restoration treatment cost. Currently, biomass supplies about two percent of all of energy consumed in the U.S. but is expected to grow to three percent of the national energy consumption demand by 2030. Estimating the potential level of biomass resources available from treatments would ensure expansions of the current wood products infrastructure are appropriately scaled to match the available resource. I completed a biomass assessment of feedstock generated from fuels reduction and forest health thinning in eastern Oregon to quantify the available biomass feedstock supply.

Additionally, the assessment quantifies benefits provided by such treatments through a reduction of landscape-level wildland fire hazard. Biomass feedstock supplies ranged from 131,495 bdt/year to 453,421 bdt/year in the Blue Mountain subregion and from 201,326 bdt/year to 697,344 bdt/year in the southern Oregon subregion. I modeled several management scenarios that varied in silvicultural approach and harvest level compared to a status quo scenario. Implementing the most aggressive treatment scenario across the total treatable landscape demonstrated a 10.8% decrease in landscape characterized as high fire hazard in the Blue Mountain subregion and a 6.5% decrease in the southern Oregon subregion. Utilization of the available biomass resource in eastern Oregon can provide a sustainable energy source into the future while also helping to responsibly manage our national forests.

Sustainable Biomass Supply from Fuel Reduction Treatments: A Biomass Assessment of Federally Owned Land in Eastern Oregon

by

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Kevin C. Vogler, Author

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Wildfire

Wildfire exclusion

Wildfire exclusion over the past century or more has resulted in a major backlog of unburned fuels in many western U.S. forests. As a result, and in combination with more recent climatic patterns, relatively uncommon, large high-severity wildfires are increasing in frequency (Hessburg, Agee, & Franklin, 2005). This is especially true in dry ponderosa pine (*Pinus ponderosa*) and mixed conifer forests of eastern Oregon, where frequent disturbance from low-severity fire had allowed for the development of a forest structure and species composition that sustained its condition through both space and time by facilitating similar disturbance patterns (Agee, 2003; Heyerdahl, Brubaker, & Agee, 2001).

Historically, wildfire was a frequent disturbance throughout ponderosa pine and mixed conifer forests in eastern Oregon. Studies analyzing fire scar records show that ponderosa pine forest types experienced mean fire return intervals (MFRI) of 4 to 36 years (Bork, 1984; Hall, 1980; Olson, 2000; Soeriaatmadja, 1966; Weaver, 1959) and mixed conifer forest types experienced mean fire return intervals of 3 to 71 years (Heyerdahl et al., 2001; McNeil, 1980; Morrison & Swanson, 1990; Perry et al., 2011; Weaver, 1959). Historical ranges of MFRI are due to variations in topographic location, fuel conditions and seasonal weather patterns. Historical ignition sources were a combination of positive lightning strikes and intentional Native American burning. These frequent disturbance patterns have been significantly altered over the past century as a result of a reduction in human ignitions, grazing and aggressive fire suppression.

The cessation of wildfire disturbance from the landscape was a gradual process beginning in the late 1800s that became more pronounced over time. Early impacts on historical disturbance regimes began with European settlement of the western United States. These early settlers began a pattern of fragmentation of wildfire’s habitat through the creation of fire breaks. They reduced the presence of grasslands through livestock grazing, converted grasslands to agriculture and irrigation systems, developed road networks and completely removed fuels with urban development (Dellasala, Williams, Williams, & Franklin, 2004). In addition to fragmenting wildfire's habitat, early settlers implemented a policy of ending anthropogenic ignitions through the removal of Native Americans from the landscape.

The first record of organized fire suppression originated in 1884 with the US Army patrolling the newly created National Parks (Agee, 1974). Fire suppression received a new sense of urgency after the great fires of 1910 burned through the majority of the West, leaving the newly created US Forest Service (USFS) to fear that it would not have any forests left to manage (Dombeck, Williams, & Wood, 2004). This fire suppression mentality was first codified into policy with the passage of the Clark-McNary Act of 1924 that tied federal appropriations to states first adopting fire suppression (Stephens & Ruth, 2005). Fire suppression policy was further expanded in 1935 with the USFS adoption of suppressing all fires by 10 A.M. the following morning. This policy became a reality following World War II with the increased availability of firefighters, heavy construction equipment, smoke jumpers, and aerial tankers (Dombeck et al., 2004).

The fire suppression policies and land use practices of the 1900s have proven to be un-sustainable in the long term. The cessation of frequent wildfire disturbance, which had historically pruned and cleaned western forests by removing fuel accumulations and fire intolerant species, has resulted in the general homogenization and densification of dry forest types. Without disturbance from wildfires, fire intolerant species regenerated vigorously in the understory, lowering crown base heights and creating ladder fuels to the crown layer which had increased in density. This can also be viewed as the development of a “fire deficit” (Marlon et al., 2012). These changes resulted in the effective fuel densification and homogenization of entire landscapes, which has led to the larger and uncharacteristically severe wildfires that are occurring today as the fire debt is paid back (Hessburg & Agee, 2003; Kennedy & Wimberly, 2009).

Implications of uncharacteristic high-severity fire

Fire severity is the magnitude of effect that a fire has on the environment. It is influenced by different patterns of fire line intensity, fire duration, and the amount of live and dead fuels present (Van Wagtendonk, 2006). In a forestry context, fire severity is often used to refer to the percentage of basal area that was killed by wildfire. Low-severity fire is typically characterized by 0-20%, mixed-severity by 20-70% and high-severity as greater than 70% basal area mortality. In dry forests historically characterized as mixed-severity fire regimes, mortality levels tended to be at the lower end of the 20-70% range (Hessburg et al., 2005).

While certain forest types were historically managed under a particular severity regime (e.g., low or high), there were always other fire severity levels present at some spatial scale due to variations in fuels, weather and topography. Past land management practices, including fire suppression, have led to observed increases in the relative amount of high-severity fire on the landscape and the size of large fires that are burning at that effect (Hessburg et al., 2005; Kennedy & Wimberly, 2009; Miller, Safford, Crimmins, & Thode, 2009).

An increased percent of the landscape impacted by uncharacteristic high-severity wildfire introduces a range of ecological and social problems. Dry forest types are characterized by slow growth and poor germination rates and the loss of large patches of forest cover due to high-severity wildfires jeopardizes the age structure and overall sustainability of these systems. In addition, many forests in eastern Oregon lack large tracts of older forest structure due to prior logging practices. An increased rate of loss of the remaining older forest structure due to wildfires threatens species such as the northern spotted owl that are reliant on that structure type. Healey et al., (2008) found that the current rate of loss of old-growth structure that has taken place since the 1992 Northwest Forest Plan is higher as a result of current wildfires than the combined loss from wildfire and the logging of old-growth in the two decades prior to the plan.

In addition to the ecological pressures that increased high-severity fire puts on dry forests, it also creates numerous problems for an increasing number of humans living in the wildland urban interface (WUI) and the resources on which they rely. Humans cannot coexist in an environment with high-severity fire without conflict. The current trend of exponentially growing suppression costs (Calkin, Gebert, Jones, & Neilson, 2005) alongside an increasing loss of property and human life highlight the challenges humans face while trying to cohabitate with high-severity fire.

Fire suppression and wildland-urban interface

The wildland urban interface is defined as the area where houses meet or intermingle with undeveloped wildland vegetation (Radeloff et al., 2005). A combination of the increasing level of high-severity fire and the number of developments in the WUI has led to an increase in the frequency of problem wildfires that demonstrate how these two realities cannot coexist. High-severity fire in the WUI ultimately leads to a higher risk of loss of property, loss of human life, poor air quality and associated health impacts, degradation of water quality, and enormous expenditures on wildfire suppression in an attempt to counter these consequences.

Rapid moving high severity wildfires resulted in the loss of over 27,000 structures between 2000 and 2009, including over 13,000 primary residential homes (Botts et al., 2013). Structural loss from wildfires often occurs as a result of high severity crown fires that burn with rates of spread several times faster than surface fires and cause spotting that can occur over long distances. Spotting and increased radiant heat from crown fires make structures more difficult to defend than surface fires and can produce significant ember rain that results in the ignition and loss of structures (Cohen, 2000).

An increase in the frequency and size of high-severity wildfires and how they threaten the WUI increases the exposure of wildland firefighters to life-threatening fire conditions while trying to protect homes. Wildland firefighters are generally not trained in home protection nor are they trained to risk life and limb to protect property. However, it cannot be dismissed that when fighting fire in an area where the values at risk are high, it impacts the human decision making process. During 2013, thirty seven wildland firefighters were killed on the job, marking the highest year for wildland firefighter fatalities since 1910 (“National Interagency Fire Center,” 2014b). Examining the number of firefighter fatalities over the last 70 years reveals an alarming trend of increasing wildland firefighter deaths despite advances in communication, organizational structure, training, technology and physical fitness requirements (Figure 1.1). This upward trend is likely due to the discontinuity of the increasing habitation in WUI and level of high-severity fire.

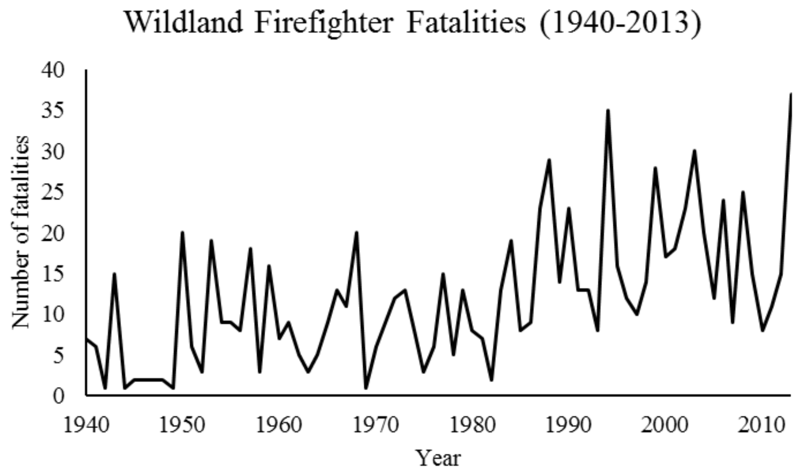

Figure 1.1 Wildland firefighter fatalities in the United States since 1940, developed from (National Interagency Fire Center, 2013)

The general public also faces increased exposure as the amount of high-severity fire increases across the landscape. The massive smoke plumes generated from wildfires have numerous detrimental impacts on neighboring communities. Smoke causes damage to buildings, impacts tourism revenue, limits visibility increasing likelihood of automotive accidents, and causes health problems especially in children, the elderly and those with cardiopulmonary disease (Sandberg, Ottmar, Peterson, & Core, 2002).

In addition to problems created by smoke, wildfires have the potential to cause significant damage to municipal watersheds. High-severity wildfire by its very definition impacts the majority of the vegetation on a site. The loss of vegetation cover can have costly consequences when it takes place in a watershed that is relied on as a municipal water source. Sedimentation levels vary based on geography, weather and soil type, and exports gradually return to pre burn levels as vegetation reestablishes. However, the large pulses of sedimentation following a high-severity fire can have short term negative consequences for fish, water quality in both color and taste, and ability to detect dangerous diseases in municipal drinking sources. The risks associated with different contaminants range from aesthetics to potential toxicity or carcinogenicity with prolonged exposure to elevated concentrations (H. G. Smith, Sheridan, Lane, Nyman, & Haydon, 2011). According to 2004 estimates, the 2002 Hayman Fire has caused over 40 million dollars of damage to Denver watersheds and reservoirs (Lynch, 2004)

In an effort to protect the wildland urban interface from property damage, smoke impacts, loss of habitat and a reduction in water quality, management of wildfires near the WUI has become more costly. Wildfire suppression costs have grown exponentially alongside the increase in high-severity fire size and frequency. The ever-growing cost of fire suppression feeds a negative feedback loop as we delay wildfire to a later date when that fire debt is repaid with even greater severity due to the increased fuel loads. In addition, the majority of expenditures are highly inefficient and ineffective due to the reliance of suppression efforts on favorable weather conditions (Finney, Grenfell, & McHugh, 2009). The annual cost of wildfire suppression within the U.S. from 1985 to 2012 has increased consistently over the last three decades (Figure 1.2). Wildfire suppression costs, in addition to the other issues stemming from cohabitation of humans and high-severity fire in the wildland urban interface will likely intensify with global climate change.

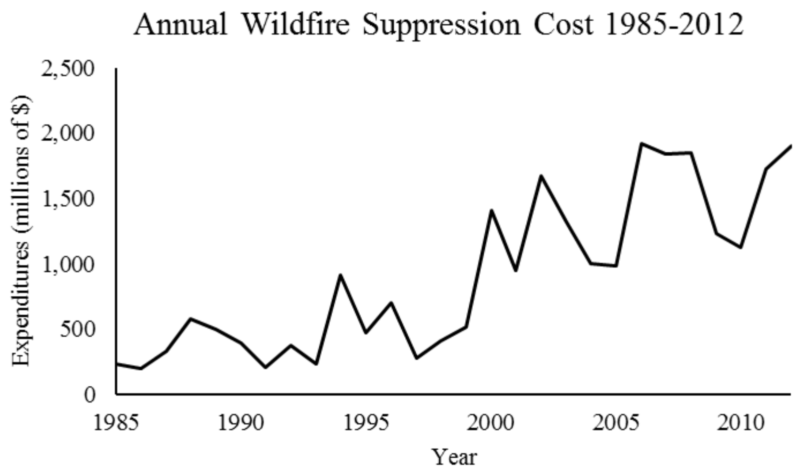

Figure 1.2 Annual cost of wildfire suppression within the U.S. from 1985 to 2012, developed from (National Interagency Fire Center, 2014a)

Role of climate change

Global climate change will likely exacerbate issues caused by problem wildfires. Current models predict that the Pacific Northwest will likely get substantially warmer and drier over the next 100 years (Mote & Salathe Jr, 2010). Climate change is also leading to earlier snowmelt that allows for fuels to dry out and become available to burn earlier in the season (Westerling, Hidalgo, Cayan, & Swetnam, 2006). As the average yearly temperature warms and snow melt takes place earlier in the season, the fire season will increase in length due to additional fuel availability. A longer fire season increases the likelihood that an ignition will take place during severe fire weather conditions, and thus a likely increase in the frequency of large, high-severity, problematic wildfires.

Climate change will also likely increase the frequency of above-average hot and dry years. Analysis of fire scars and historical weather data shows that the most severe wildfire years are directly correlated to years with above normal temperatures in both the spring and summer (Heyerdahl et al., 2008; Heyerdahl, Brubaker, & Agee, 2002). These observed findings have been corroborated using modeling-based approaches, where larger fires are predicted to occur as weather patterns change (Littell et al., 2010; Rogers et al., 2011).

The largest forestland holder in the United States is the USDA Forest Service (USFS). The agency has a broad multi-objective mission with goals that currently focus on: protecting endangered species and old-growth forests, production of renewable timber resources and the protection of forests, aesthetic qualities and recreational opportunities. In order to balance these goals with their ever-increasing expenditures on wildland fire suppression, the USFS must take a proactive role in managing the way that wildfire interacts with the landscape. One way USFS land managers can address these issues is through the use of strategically placed forest restoration or fuels treatments that can alter landscape level fire behavior as well as change stand level fire severity impacts.

Fuels treatments and forest restoration

Forest restoration treatments are one tool in the silvicultural tool box that can be used to alter landscape-level fire disturbance patterns so that fire impacts can be utilized to meet the goals and objectives of a forest. Forest restoration has the objective of establishing stand composition, structure and function thought to have been historically resilient to regular fire (and other) disturbances. Such treatments typically involve thinning selectively to alter current atypical species composition and stand structure in order to change immediate fire behavior and move the stand on a different future developmental trajectory. The specific form and goals of particular restoration treatments vary, and would be part of site-specific silvicultural prescriptions. However, a common theme in restoration treatments is re-establishment of natural fire disturbance patterns following mechanical treatment. Forest restoration should be thought of as a drawbridge rather than a moat, facilitating the reintroduction of fire so that future disturbances occur at severity levels more indicative of historical disturbance regimes (Ingalsbee, 2005).

While fuels treatments have been shown to be able to reduce wildfire size (Arno & Fiedler, 2005; Cochrane et al., 2012) and severity (Prichard & Kennedy, 2012), they are only effective if they include some treatment that removes surface fuels (Agee & Skinner, 2005). Surface fuels can be treated through prescribed burning or a mechanical treatment that either alters and or removes the fuel load. In addition to reducing surface fuel loads, effective fuels treatments must convert more than thirty percent of the landscape to a slower spread rate fuel type for impacts to be discernible at the landscape scale (Finney, 2003).

Large-scale fuels treatments are necessary to effectively alter landscape-level fire disturbance patterns but difficult given the current high cost of treatment implementation and social resistance to mechanical harvesting. In order for fuels treatments to be effective, they must raise the canopy base height and remove surface fuel accumulations. Treatments accomplishing these goals rely on the processing and transportation of large quantities of small, low-value materials. Fuels treatment harvesting costs range between $35 to over $1000 per acre (Rummer et al., 2005). The use of prescribed fire to treat surface fuels typically costs between $55 and $330 per acre in the West depending on site complexity (Cleaves, Martinez, & Haines, 2000). If fuel needs to be piled prior to burning due to smoke or hazard restrictions, costs can jump to between $300 and $900 dollars per acre (Becker, Larson, & Lowell, 2009). As fuels treatments are scaled to appropriate sizes to ensure meaningful impacts on altering landscape scale wildfire severity, these costs of treatment can become prohibitive.

Therefore, in order to sustainably implement fuels treatments at an appropriate scale, fuels treatment costs must be reduced and/or offset by the treatment itself. This can be accomplished by altering the treatment silviculture to yield more valuable material at lower cost, and by offsetting the costs of subsequently treating surface fuels by utilization of that material in developing biomass markets (Fried, Barbour, Fight, Christensen, & Pinjuv, 2008; Hartsough et al., 2008).

NARA and the biomass industry

Biomass

Biomass has a broad definition depending on the context in which it is presented. In a general sense, biomass refers to any organic non-fossil material of biological origin that constitutes a renewable energy source (“US EIA,” n.d.). In a forestry context biomass refers to all parts of a tree not currently utilized in traditional saw wood and pulpwood markets. For this project it refers specifically to all branch wood, bark, and tree tops that are less than four and half inches in diameter (Keyser & Dixon, 2013). It should be noted that the 4.5-inch diameter limit used in this project represents a snapshot in time; the “true” definition of what would constitute the biomass supply would change with access to pulpwood processing facilities and current demand specifications.

The appeal of further developing the current biomass infrastructure is in its potential to stimulate a market demand for this material that would offset the cost of restoration treatments (Evans & Finkral, 2009; Nicholls, Monserud, & Dykstra, 2008). Restoration costs would be offset both by the deferred cost of treating this material through other means (e.g., pile burning) and by its sale as a commodity to developing biomass markets.

Biomass material can be converted into usable energy through thermal and biological conversion pathways (Bridgwater, 2006; McKendry, 2002). It can be used in thermal bioenergy systems where densified wood pellets, wood chips, or firewood are combusted in high-efficiency boilers to generate heat used in institutional and commercial buildings as well as residential homes (Nicholls, Monserud, & Dykstra, 2009). That heat can also be used to propel turbines in the production of electricity. These systems are often built as an addition to or in combination with a traditional wood products processing facility so that the excess heat generated can be used in the drying of wood (Nicholls et al., 2008). Wood biomass can be used as a single feedstock source in the generation of electricity or in combination with other widely used energy products such as coal. Finally, there are developing technologies that use biomass feedstock in the production of liquid fuels such as syngas, ethanol, and isobutanol through biological conversion (White, 2010).

The utilization of biomass material currently makes up about two percent of the annual energy consumption in the United States and 27% of the total renewable energy consumed. Based on current levels and trends of growth in the United States, the Department of Energy predicts the biomass industry will grow to three percent of the national energy consumption demand by 2030 (White, 2010).

While an expansion of the biomass industry has great potential for offsetting forest restoration treatment costs, there are many challenges that potential expansion of the industry faces. These include the high infrastructure costs, high processing and transportation costs, competition from the fossil fuel and natural gas industries, difficulty securing long-term power purchase agreements, social acceptability issues, concerns of the ecological sustainability of additional extraction, and the uncertainty of feedstock supply into the future (Becker et al., 2011; Sundstrom, Nielsen-Pincus, Moseley, & McCaffery, 2012).

Northwest Advanced Renewables Alliance

In order to address these challenges and facilitate the creation of a liquid fuel biomass industry in the Pacific Northwest, the Northwest Advanced Renewables Alliance (NARA) was established in 2011 with 40 million dollars in grant funding from the United States Department of Agriculture ("National Institute for Food and Agriculture Newsroom," 2011). NARA is a partnership between Washington State University, Montana State University, Oregon State University, Pennsylvania State University, Salish Kootenai College, University of Idaho, University of Montana, University of Washington, the USFS, Gevo, Catchlight Energy, Weyerhaeuser and other partners. NARA is currently working to develop the technology and planning infrastructure that can address the barriers biomass utilization faces in order to make an ecologically, socially, and economically sustainable biomass industry in the Pacific Northwest a reality.

Biomass and restoration silviculture

My project within the NARA context investigated the role biomass from fuel reduction projects on federal land can play in a future biomass utilization industry, and how the utilization of this material can be quantified in its impact on reducing stand-level fire hazard. Specifically, I addressed the key questions of:

1) Whether fuel reduction treatments can provide a sufficient and sustainable biomass feedstock supply given the extent of the resource in eastern Oregon and the Pacific Northwest;

2) What scale of infrastructure and economies could be supported by the implementation of typical silvicultural approaches across a range of stand types present in eastern Oregon and the Pacific Northwest; and

3) What benefit from fire hazard reduction can biomass utilization have, which may provide the critical social support needed to effectively implement a biomass infrastructure on federal lands.

Eastern Oregon was selected to perform a case study within the larger NARA region. In order to assess biomass availability within this region, I modeled current and predicted future harvest levels of sampled inventory data and calculating the amount of biomass residuals generated. Previously, numerous biomass studies have been completed across varying levels of complexity and from scales ranging from small local feedstock supply studies (Schmidt, 2012) up to nationwide assessments (Downing et al., 2011; Perlack et al., 2005) and a wide range in between (Hampton, Sesnie, Bailey, & Snider, 2011; Rummer et al., 2005). This effort extends previously completed work in the region that integrated fire hazard analysis into biomass assessments, such as BioSum (Fried et al., 2005) and Fuel Treatment Evaluator (Skog et al., 2006), by its increased geographic extent, use of newly developed fire modeling tools (Ager, Vaillant, & McMahan, 2013) and its sensitivity analysis of silvicultural prescriptions.

Research questions

- How sensitive are regional model outputs of biomass feedstock availability and fire hazard to prescription form and thinning intensity?
- How does current management levels on federal land in eastern Oregon compare to management need as defined by departure from historical condition?
- How does fire hazard and biomass supply change over time under different assumptions of management intensity and silvicultural prescription?
- What scale of biomass infrastructure could be supported by fuel reduction thinning on federal land in the Eastern Oregon subregion?

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Chapter 2: Prescription development and model sensitivity analysis

Abstract

Large fuel accumulations across the landscape combined with recent climatic patterns have increased the frequency of relatively uncommon, large, high-severity wildfires. Forest restoration treatments that aim to alter the increasing trend in frequency of uncharacteristically high-severity wildfire events become cost prohibitive when implemented at meaningful scales. However, there is potential to offset these costs by altering the treatment silviculture to yield more valuable material at lower cost, and by offsetting the costs of subsequently treating surface fuels by utilization of that material in developing biomass markets.

Currently, biomass supplies two percent of all of energy consumed in the U.S. and is expected to grow to three percent of the national energy consumption demand by 2030. One often cited barrier to the expansion of the biomass industry is the uncertainty regarding the long term availability of feedstock supply. Numerous biomass feedstock supply assessments have been previously completed at a range of spatial scales and complexity levels. A sensitivity analysis was completed to understand the degree to which these assessments are sensitive to silviculture prescription form and thinning intensity. Biomass yields were found to respond linearly over all forest types to an increase in management intensity. This finding

improves the reliability of generated biomass feedstock supply estimates, given that they are based on average prescription basal area targets and thinning form.

Introduction

Fire hazard

Fire hazard is the potential fire behavior for a fuel type regardless of the fuel type's weather-influenced fuel moisture content and actual weather conditions. Assessment of fire hazard is based on physical fuel characteristics such as fuel arrangement, fuel load, condition of herbaceous vegetation, and presence of ladder fuels (Hardy, 2005). Fire hazard is commonly characterized as potential flame length or by the torching and crowning indices at assigned weather conditions.

Flame length is the average distance from the base of the flame to its highest point. The equation for how to calculate flame length can be seen below (Byram, 1959).

$$F_L = .237 * HWR^{.46}$$

Where:

F_L= Flame length (m)

H= Fuel combustion heat yield (kJ/kg)

W= Weight of fuel consumed per unit area (kg/m^2)

R= Rate of spread (m/sec)

The weight of fuel consumed and the rate of fire spread are a function of the fuel moisture content and the adjusted wind speed. These values are held constant when calculating fire hazard but there is currently no defined standard for how to set these values when conducting a fire hazard assessment, making comparisons between studies difficult (Cruz & Alexander, 2010).

The total weight of fuel consumed by a fire is the sum of all available surface and crown fuels. Crown fuels are only available to burn when the critical flame length level is reached, resulting in torching. The equation for the critical flame length needed to initiate torching can be seen below (Scott & Reinhardt, 2001).

$$F_{L_{initiation}} = .237 * \left(\frac{CBH * (460 + 25.9 * FMC)}{100}\right)^{.69}$$

Where:

$F_{Linitiation}$ = Flame length required for the transition into passive torching (m)

CBH = Crown base height (m)

FMC = Foliar moisture content (%)

If the surface flame length exceeds the critical flame length and torching occurs, then the total flame length would be calculated based on the combined consumption of surface and crown fuels. Thus critical flame length can also be defined as the wind speed required to initiate torching. This method for calculating total flame length is used in numerous fire modeling tools: BehavePlus (Andrews, 2007), NEXUS (Scott & Reinhardt, 2001), FlamMap (Finney, 2006), FARSITE (Finney, 2004), Fire and Fuels Extension to the Forest Vegetation Simulator (Reinhardt & Crookston, 2003).

The critical wind speed needed to initiate torching is also known as the torching index (TI), another commonly used metric to define fire hazard. TI is highly dependent on the CBH of a given stand. As CBH increases, either as a result of stand development or active management, a higher windspeed is required in order for torching to occur (Scott & Reinhardt, 2001).

In addition to the potential for passive torching of individual tree canopies, which can be quantified using the torching index, active crown fire potential can be quantified using the crowning index (CI). The CI is the critical wind speed required for the movement of fire from one tree's crown to adjacent crown fuels and is highly dependent on the crown bulk density of a stand (Scott & Reinhardt, 2001).

The assessment of potential fire hazard through the use of flame length, torching index, or crowning index can be a useful tool in landscape-level planning. Understanding potential fire behavior allows land managers to develop more effective fire suppression plans as well as understand and plan for the future developmental trajectory of a forest following disturbance from wildfire. Fire hazard metrics can be used to provide a prediction of potential fire severity. A stand that has a high potential flame length will likely incur high levels of tree mortality in the event of a wildfire (Reinhardt, Keane, & Brown, 1998).

Flame length was used as the fire hazard metric for this modeling project and was calculated over time using the Fire and Fuels Extension (FVS/FFE) to the Forest Vegetation Simulator (FVS). FVS/FFE is a submodel that links outputs from the stand growth model FVS with calculations of fuels dynamics and potential fire behavior. FVS/FFE has been widely used in studies that have calculated fire hazard (Ager, Finney, Kerns, & Maffei, 2007; Finney et al., 2008; Johnson, Kennedy, & Peterson, 2011). While FVS/FFE has been widely used and represents the best available science in fire hazard modeling it has been criticized for under predicting crown fire behavior and its lack of sufficient field validation (Honig & Fulé, 2012; Stephens et al., 2009).

Modeling fire risk over time

Fire hazard is the potential for a given fire intensity level given stand condition, it is not the likelihood of a fire event occurring. In order for the potential fire behavior to be realized, an ignition must have taken place within or near the boundaries of the stand. The likelihood of a stand burning is defined as fire risk. The most frequently used metric to calculate fire risk is burn probability (Scott, Thompson, & Calkin, 2013). Burn probability can be calculated using any modeling program (e.g. FlamMap) that can saturate a landscape with ignitions over multiple iterations and model the subsequent fire growth over a defined number of burn periods. The percentage of times that each parcel within a study area burns over all simulated runs is used to calculate burn probability (Finney, 2006).

The calculation of burn probability was not feasible with this project due the intensive data requirements of FlamMap and the large-scale of this work. Currently, the USFS Western Wildland Environmental Threat Assessment Center is developing a modeling tool that would link FVS/FFE data outputs with FlamMap allowing for the calculation of burn probability over very large landscapes (Ager, 2014). The integration of this tool into future analysis would further improve our understanding of the implications of management decisions on fire potential. For this project, I instead focused on stand level fire hazard and the ability of simulated treatments to alter the percentage of the landscape characterized by high hazard.

Silvicultural prescriptions

A century or more of forest management practices, grazing, and fire suppression have led to a general homogenization and densification of dry forest types in the Pacific Northwest (see chapter 1). The result has been an increase in the frequency and severity of large wildfire events (Hessburg & Agee, 2003). In order to reverse this trend and protect resources of concern, forest restoration treatments are being regularly implemented on USDA Forest Service lands. The intent of these treatments is to alter the current species composition and stand structure in order to influence the stand's future developmental trajectory. The specific type and goals of a particular restoration treatment vary and would be based on site-specific silvicultural prescriptions. However, a common theme of restoration treatments is a need to alter a stand in order to allow for the reestablishment of natural fire disturbance patterns within the larger landscape.

Fuels treatments aim to improve stand-level resiliency, defined as the capability of maintaining substantial live basal area after being burned by a wildfire sufficient to carry the stand and larger forest into the future and provide basic ecosystem services (Agee & Skinner, 2005). The relative resiliency of a stand can be measured using modeled fire hazard metrics. Agee & Skinner (2005) outlined the structural characteristics of a forest stand that has high resiliency to wildfire disturbance (Table 2.1).

Table 2.1: Principles of fire resistance for dry forests from (Agee & Skinner, 2005)

Principle	Effect	Advantage	Concerns
Reduce surface fuels	Reduces potential flame length	Control easier; less torching	Surface disturbance less with fire than other techniques
Increase height to live crown	Requires longer flame length to begin torching	Less torching	Opens understory; may allow surface wind to increase
Decrease crown density	Makes tree-to-tree crown fire less probable	Reduces corn fire potential	Surface win may increase and surface fuels may be drier
Keep big trees of resistant species	Less mortality for same fire intensity	Generally restores historic structure	Less economical; map keep trees at risk of insect attack

Improving resiliency to wildfire requires manipulating stand structure so as to reduce potential flame length and torching/crowning hazard that would lead to undesirable levels of mortality of large trees.

The horizontal and vertical structure of an established stand of trees can be altered to improve its resistance and resiliency to wildfire through the use of herbicides, prescribed fire, or mechanical thinning (Agee & Skinner, 2005). Herbicides can be used as a tool to decrease overstory and understory crown vegetation density (CBD) as well as height to live crown in the long term (CBH), but will result in a marked increase in dead surface fuel loadings. The increase in surface fuels, the financial cost of implementing herbicide treatments by hand, and social concerns over widespread use do not make herbicides a particularly viable tool for improving widespread stand resiliency to wildfire.

The use of prescribed fire has been shown to be an effective method for reducing surface fuel levels (Van Wagtendonk, 1996). Prescribed fire has also been shown to be somewhat effective in increasing canopy base height and reducing ladder fuels by scorching the lower crown of a stand; however, it is not an effective tool for reducing canopy bulk density as fire intense enough to do so will likely exceed desired severity and operational control thresholds (Miller & Urban, 2000; Schwilk et al., 2009). Therefore, in order to effectively alter crown base height, crown bulk density and improve stand resilience, mechanical fuels treatments should be implemented. Mechanical treatments that address both of these goals can come in two general approaches: 1) a light restoration treatment characterized by thinning from below and 2) a heavy restoration treatment characterized by thinning across diameter classes.

A thinning from below (TFB) treatment means that trees are removed from the understory starting with the smallest size class and moving into successively larger size classes until a residual basal area target is reached. Thinning from below is the choice method to reduce ladder fuels (particularly from unusual densities of shade-tolerant, fire-sensitive understory saplings) and preferentially removes the smallest trees, typically resulting in a well-spaced residual stand. Thinning from below improves vigor of residual trees by decreasing competition and improving resource availability, reducing the risk to residual trees from insect and disease, and maintains and promotes structural elements of larger trees within the stand. However the benefits of any reduction in wildfire hazard due to ladder fuels are temporary as crown bulk density and surface fuels remain high and trees will inevitably reestablish in the understory, thus maintaining the hazard of crown fire if it is initiated. In addition, the low market value of material harvested often means the cost of treatment is not covered by the sale of logs removed.

A thinning across diameter (TAD) class treatment refers to removing trees from a range of sizes. This allows for the ability to create within-stand diversity among tree sizes and residual spacing. The implementation of a thinning across diameter classes could include individual tree selection, group selection or variable retention harvests (Franklin & Johnson, 2012). TAD has the potential to have long lasting impacts on the reduction of wildfire hazard by significantly altering stand structure. It also has greater potential to pay for the cost of treatment by the removal of some larger trees. However, TAD may reduce habitat value for species such as the northern spotted owl that require denser stands for nesting. In addition, if not implemented and maintained correctly, TAD may result in a pulse of new regeneration that would increase wildfire hazard over time.

Treatment implementation

In 1993 the Interior Columbia Basin Ecosystem Management Project (ICBEMP) was chartered as a joint effort between the US Department of Agriculture, USFS, Department of Interior, and the BLM in order to develop scientifically-based ecosystem management strategies for lands managed by the BLM and USFS in the interior Columbia river basin (Haynes, Quigley, Clifford, & Gravenmier, 2001). The goal was to develop a comprehensive management plan for eastern forests similar in scope and scale as the Northwest Forest Plan that covered western forests in Oregon and Washington. While this process was underway, a temporary amendment to the regional forest plan was put in place until a more scientifically-based plan could be written. This temporary amendment (“Eastside Screens”) called the interim management direction establishing riparian, ecosystem and wildlife standards for timber sales is still in place today due to logistical and political challenges preventing implementation of subsequently developed forest management plans.

Currently in eastern Oregon, all harvesting is limited to trees under 21 inches diameter breast height (DBH) as a result of the “Eastside Screens” without a categorical exclusion (USDA Forest Service, 1995). The intent of this rule was to protect the remaining older forest structure in eastern Oregon. However, as previously mentioned, the rate of loss of older forest structure has increased since the passage of this ruling due to impacts from high-severity wildfire (Healey et al., 2008).

Due to the unforeseen implications of the ruling and disturbances from fire, the goals and objectives of this policy have not been effective. The broad reach of the policy provides unnecessary constraints on local land managers and limits their ability to implement sound silvicultural practices where they are appropriate. There is potential for this ruling to be revisited with the 2012 forest planning rule that directs national forests to revisit their forest plans with an ecological forestry theme (USDA, 2012).

In order to investigate the impact that the removal of this policy would have on both stand-level fire hazard and on biomass feedstock supply a heavy restoration thinning across diameter classes was modeled both with and without a 21 inch DBH limit. This resulted in four different silvicultural treatment scenarios that were modeled (Figure 2.1):

1. No action
2. Light restoration treatment - thin from below with a 21-inch DBH limit
3. Heavy restoration treatment – thin across diameter classes with a 21 inch DBH limit
4. Heavy restoration treatment – thin across diameter classes with a no DBH limit

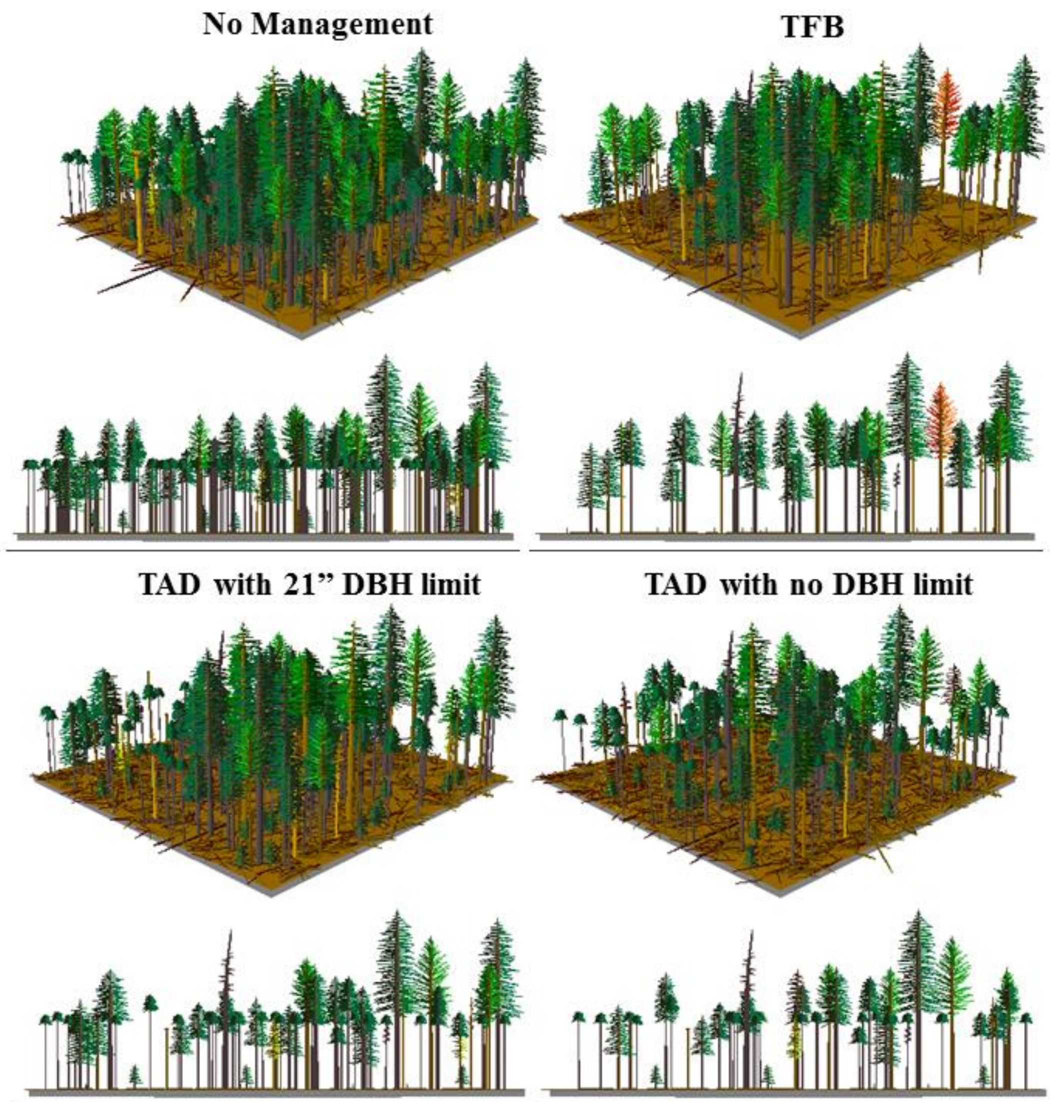


Figure 2.1. Range of stand structures created by different silviculture prescription forms using stand visualizations of a mixed-conifer stand located in the Malheur National Forest with 579 TPA and 171 ft^2 BA prior to treatment.

A range of silvicultural prescription forms (e.g. TFB, TAD) have been used in other previously completed biomass assessments as well as wide range residual basal area targets (Downing et al., 2011; Fried et al., 2005). In order to investigate how sensitive FVS modeled biomass and fire hazard outputs are to prescription form and residual basal area, I performed a model sensitivity analysis.

Research Questions

- How sensitive are regional model outputs of feedstock availability to prescription form and thinning intensity?
- How sensitive is modeled fire hazard to different forms and intensities of restoration thinning treatments?

Methods

Study Area

This analysis covers all non-reserved forested USFS lands in eastern Oregon. The study area is divided into two subregions: the Blue Mountains and southern Oregon. The Blue Mountain subregion includes the Ochoco, Malheur, Umatilla and Wallowa-Whitman National Forests. The southern Oregon subregion includes the Deschutes and Fremont-Winema National Forests. These groups were assigned because of the relative proximity of the forested areas within the two regions and due to forest productivity differences that result in the two subregions being processed separately within the FVS model. A map of forest ownership within the study area can be seen in Figure 2.14.

All USFS land that is currently classified as either wilderness or roadless was excluded from this analysis. In addition, all lands that are classified as non-forested (<10% canopy cover) were also excluded. This resulted in a study area of approximately 9.4 million acres. The six national forests that make up the study region represent a very diverse landscape. Elevations over the study area range from 262 to 5948 feet. The study area covers a wide range of forest types from productive hemlock forests to dry ponderosa pine and juniper woodlands (Figure 2.15).

Model Description

FIA stand level data

The model was populated with forest inventory data from the USFS Forest Inventory and Analysis (FIA) data library. The FIA program was established by congressional mandate in the McSweeney-McNary Forest Research Act of 1928 and the Forest and Rangeland Renewable Resources Planning Act of 1974. FIA provides gridded forest inventory plots across the entire United States with information on the current extent, condition, volume, growth, and depletion of timber on the nation's forest land (Smith, 2002). The study area included 1301 FIA plots that were not classified as non-forested or reserved.

Each plot represents approximately 6000 acres with individual plot expansion factors ranging from 5087 to 9030 acres. FIA data points used in this analysis are well distributed throughout the study area (Figure 2.16). I downloaded data on November 6, 2012 and sorted to include plots sampled between 2001 and 2011. The median year 2006 was selected to represent the sampling date of all plots in order to improve data processing efficiency. In addition, all plots that were listed as having an inventory year prior to 2001 or were listed as 9999 where not used because they were collected using different sampling protocols. The expansion factors used in this analysis represent the elimination of those sampling plots.

The FIA data plots were converted to a FVS compatible format using the FIA2FVS conversion software. FIA2FVS converts the tree list data within the FIA database into a new Microsoft Office Access database that includes the StandInit and TreeInit tables required for running FVS.

All FIA plots were modeled at the plot level and not the condition class level due to the current limitations of the FIA2FVS conversion software. This generalization inevitably introduced inaccuracies on plots where different condition classes represent vastly different stand structures. For example, if one condition class has 200 ft^2 basal area (BA) and another has 0 ft^2 of BA, under the current method a stand would be modeled that has 100 ft^2 BA. Multiple condition classes are present in 167 of the 1301 study plots. The level at which this bias influences the final results is not known. Further work would greatly benefit from the development of a procedure to convert FIA plot condition classes into a FVS readable format so that the data can be analyzed at the condition level with newly calculated expansion factors.

Mixed Conifer Reclassification

Mixed conifer forests are found in the transition between dry ponderosa pine (*Pinus ponderosa*) woodlands and moist grand fir (*Abies grandis*) forest types. A combination of steep ecological gradients and historical mixed-severity fire regimes allowed for the development of this structurally and compositionally diverse forest type (Franklin & Dyrness, 1973). Currently, the FIA data set does not classify mixed conifer as a forest type outside of California due to its adherence to the Society of American Foresters (SAF) forest type codes.

Mixed conifer forest types are characterized by differences as compared to pure ponderosa pine stands or wetter true fir and other forest types dominated by high-severity fire regimes in terms of structure, species composition and disturbance patterns (Merschel, Spies, & Heyerdahl, 2014). In order to analyze mixed conifer stands separately from pure ponderosa pine (PP) or Douglas-fir (DF) forest types, plots were reclassified from PP or DF into a new mixed conifer forest type. The rule used to reclassify plots can be seen below in table 2.2.

Table 2.2: Mixed conifer forest type reclassification rule

Forest Type	FIA code	Screen 1	Screen 2
Douglas-fir	201	$>$ 30% of BA $\neq$ DF	PP BA $\neq 0$
white fir	261	$>$ 30% of BA $\neq$ WF	PP BA $\neq 0$
grand fir	267	$>$ 30% of BA $\neq$ GF	PP BA $\neq 0$
ponderosa pine	221	$>$ 30% BA $\neq$ PP	-
sugar pine	224	-	-
incense-cedar	222	-	-
Jeffrey pine	225	-	-
western larch	321	-	-

Silvicultural Prescription Development

Silvicultural prescriptions must be developed to take into account site-specific conditions. However, due to the scale of this study, developing individual stand-level silvicultural prescriptions was not feasible. The silvicultural prescriptions used in this project were developed based on an exhaustive literature review of stand reconstruction studies and a survey of 14 local USFS silviculturists, NEPA planners and forest managers (Table 2.3). Following the original development of these prescriptions, they were presented to USFS land managers at the 2012 5th International Fire Ecology and Management Congress (Portland, OR), 2013 National Advanced Silvicultural Program Workshop (Corvallis, OR), 2014 Central Oregon Fire Science Symposium (Bend, OR) and the 2014 Large Wildland Fires Conference (Missoula, MT) in order to solicit feedback. The basal area targets that were used in this project were taken as the approximant mean value of the range of typical regional basal area thinning targets for each listed forest type.

Table 2.3: Developed silvicultural prescriptions for the Blue Mountain and southern Oregon subregions

Blue Mountains Variant (BM)				**Southern Oregon Variant (SO)**			
Forest Type Group	Included FIA Forest Types (FORTYCD)	TAD to (ft^2 BA)	TFB to (ft^2 BA)	Forest Type Group	Included FIA Forest Types (FORTYCD)	TAD to (ft^2 BA)	TFB to (ft^2 BA)
Douglas-fir	201	50	70	Douglas-fir	201	90	110
ponderosa pine	221	35	55	ponderosa pine	221	50	70
mixed conifer	321	60	80	mixed conifer	222, 224, 321	60	80
lodgepole pine	281	60	75	lodgepole pine	281	60	70
mesic high severity fire regimes	261, 265, 266, 267, 268, 270	100	120	mesic high severity fire regimes	202, 261, 262, 263, 264, 265, 266, 267, 268, 270	100	120
juniper	369	*No Treatment*		juniper	184, 369	*No Treatment*	
other	367, 368, 703, 704, 901, 962, 974, 975	*No Treatment*		other	241, 367, 368, 901, 922, 923, 943, 962, 974, 975	*No Treatment*	

Model Sensitivity Analysis

The ArcFuels toolbar (Vaillant, Ager, Anderson, & Miller, 2011) within ArcGIS was used to facilitate a sensitivity analysis of the developed model. ArcFuels allows for the iteration and batch running of the FVS model as well as the Fire and Fuels Extension (FFE). The ArcFuels "FVS Treatment analysis" tool was used with the "Substitute Value" function to iterate FVS to simulate a harvest on each plot with a residual basal area of 50 ft^2 BA/ac above and below the developed target prescription. This process was repeated for each forest type using a thinning prescription of 1) Thin from below with a 21 inch DBH limit, 2) Thin across diameter classes with a 21 inch DBH limit, and 3) Thin across diameter classes with no DBH limit. Results were analyzed for modeled fire hazard and biomass production for each prescription over the residual basal area range.

Biomass

FVS reports all material generated during a modeled harvest in cubic feet (CF). In order to convert these values to bone dry tons (2000 lbs of material at 0% moisture content), CF was converted to dry weight value using the oven dry weight of species-specific wood weight and average bark volume and weight. Average oven dry weight ranged between 21.8 lb/cf for grand fir and 28.1 lb/cf for Douglas-fir. Average bark volume as a percentage of wood volume ranged from 8.9% for lodgepole pine to 25.6% for ponderosa pine (Miles & Smith, 2009). In addition, it was assumed that 30% of all biomass material would be retained in the woods due to operational constraints and concerns over maintaining long-term site productivity (Forest Guild, 2013). The total bone dry tons of biomass generated per acre was calculated using the following formula:

$$Biomass = \frac{((RTCuFt - RMCuFt) * \left(Wt_{wood} * W_{pct} + Wt_{bark} * B_{pct}\right))}{2000\ lbs}$$

Where:

Biomass = Weight of branches, unmerchantable tops and associated bark (bdt)

RTCuFt = Total volume of wood removed during thinning (ft^3)

RMCuFt = Total merchantable wood volume removed during thinning. Merchantable wood volume is defined as all material above a 1' stump up to a 4.5" top (ft^3)

Wt_{wood} = Average oven dry weight of wood species (lbs per ft^3)

W_{pct}= Average wood volume as % of total volume

Wt_{bark} = Average oven dry weight of bark species (lbs per ft^3)

B_{pct} = Average bark volume as % of total volume

Results

The mixed conifer reclassification procedure resulted in 286 plots in the Blue Mountains and 152 plots within the southern Oregon subregion being reclassified as mixed conifer forest type. The reclassified plots made up 33% of the total 1301 plots within the study area.

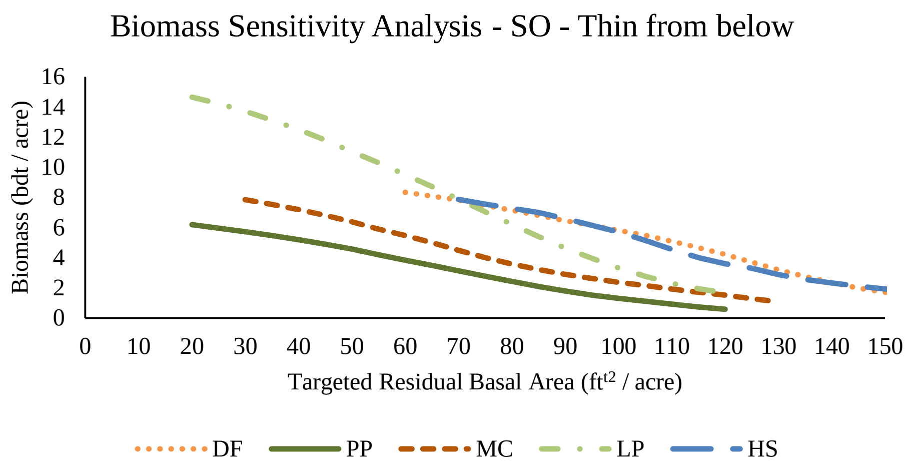
The average biomass generated per acre in the southern Oregon subregion ranged from a low of 3.12 bdt/acre for ponderosa pine with a TFB prescription to a high of 7.88 bdt/acre for lodgepole pine with a TFB prescription (Figure 2.2). In the Blue

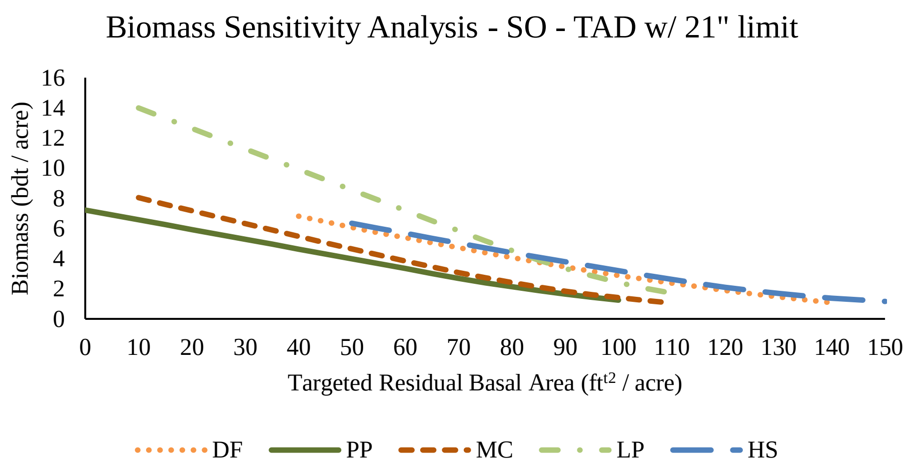
Mountain subregion the average biomass generated per acre ranged from a low of 1.53 bdt/acre for mixed conifer with a TAD 21L prescription (Figure 2.6) to a high of high of 5.71 bdt/ acre for lodgepole pine thin TFB prescription (Figure 2.5).

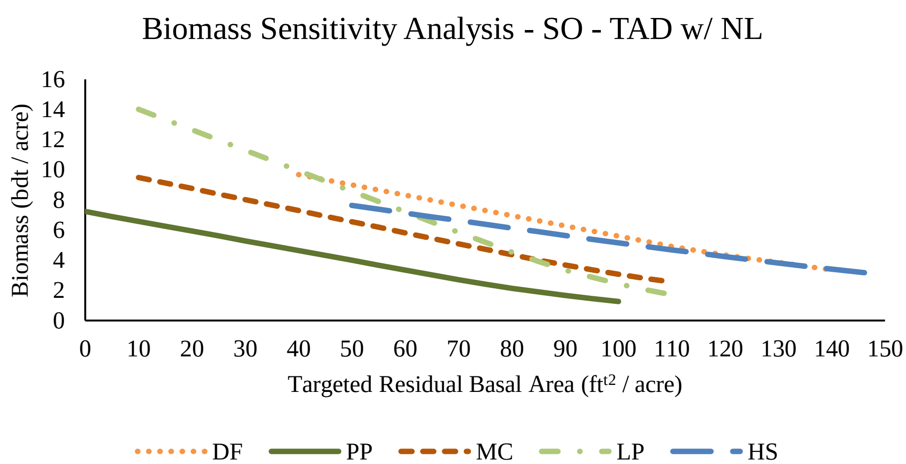
All forest types showed a steady linear increase in the amount of biomass that would be generated per acre as the residual basal area decreased. Lodgepole pine showed the highest levels of biomass generation especially at lower residual basal area levels. The average biomass generated per acre was higher for all forest types in the southern Oregon subregion than in the Blue Mountain subregion (Figures 2.2-2.10).

The total potential flame length increased linearly as the residual basal area increased. In the mesic high-severity forest type where the highest residual basal areas were modeled, potential flame length appears to reach an asymptote likely due to the physiologic height limit of the modeled trees. The ponderosa pine forest types showed very little response in potential flame length over the range of residual basal areas. In the Blue Mountain variant, the potential flame length increased in the ponderosa pine forest type as the residual BA decreased from 40 ft^2/ac to 0 ft^2/ac (Figures 2.11-2.13).

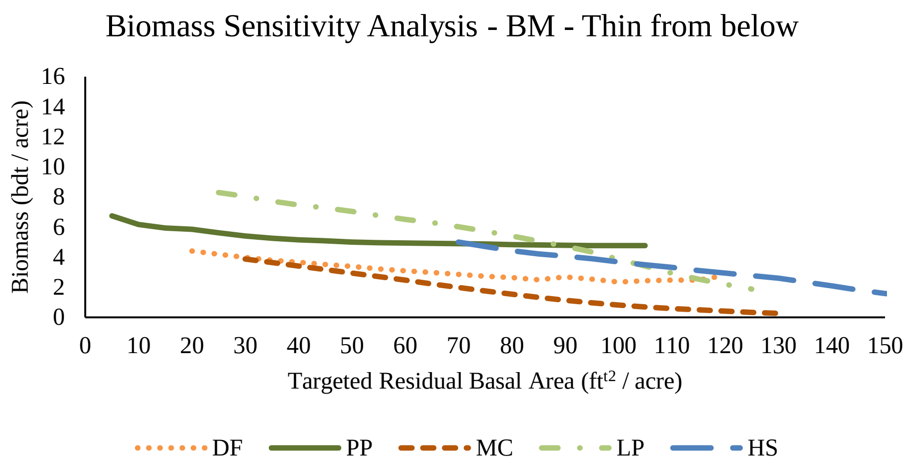
The average potential flame length within the southern Oregon subregion ranged from a low of 4.2 ft for ponderosa pine with a TAD 21L prescription (Figure 2.9) to a high of 36.8 ft for Douglas-fir with a TFB prescription (Figure 2.8). The average potential flame length within the Blue Mountain subregion ranged from a low of 4.7 ft for ponderosa pine with a TFB prescription (Figure 2.11) to a high of 20.0 ft for lodgepole pine with a TAD 21L prescription (Figure 2.12).

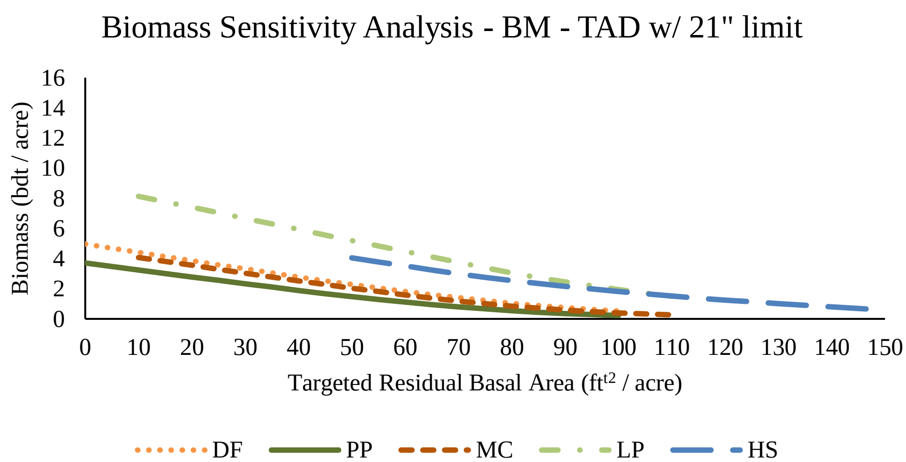


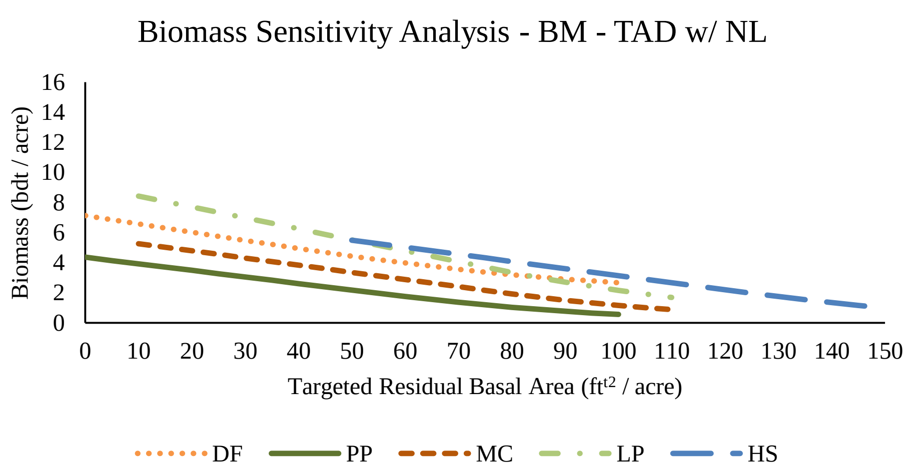




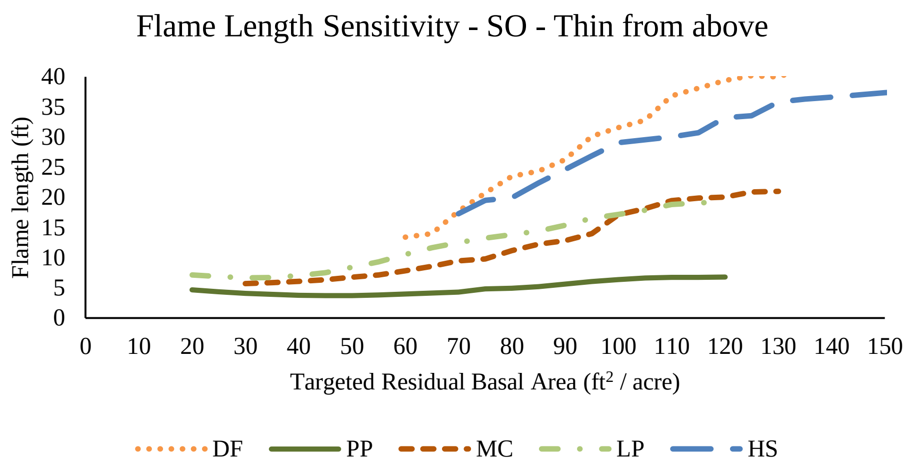
Figures 2.2-2.4. Biomass generated from harvesting to various residual basal area targets within the southern Oregon subregion

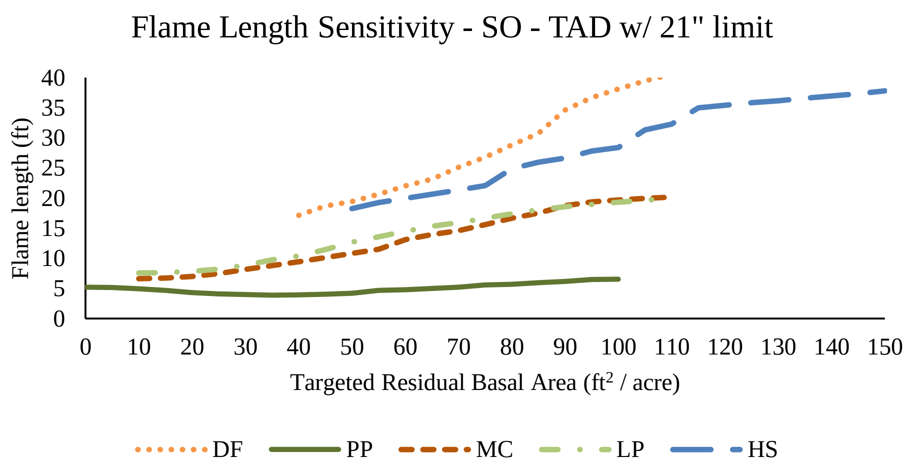


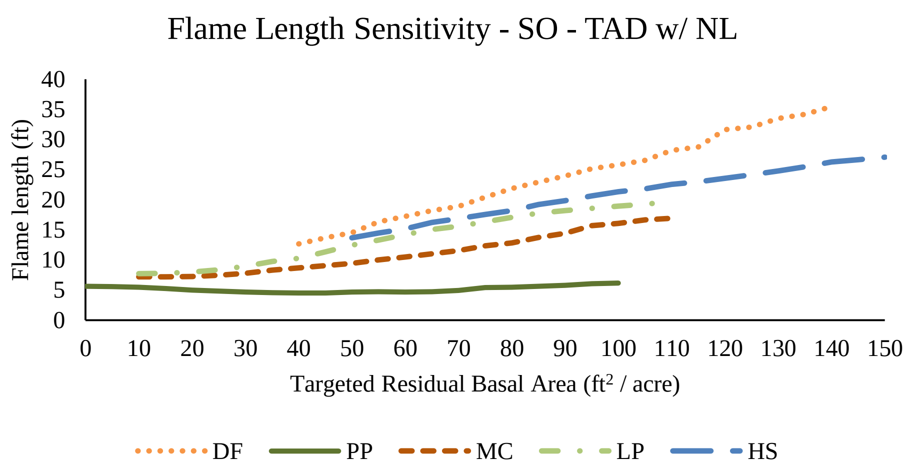




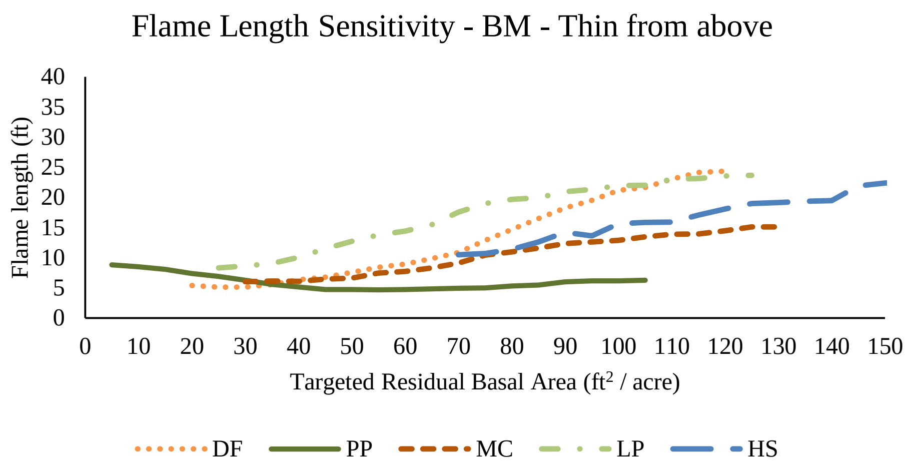
Figures 2.5-2.7. Biomass generated from harvesting to various residual basal area targets within the Blue Mountain subregion

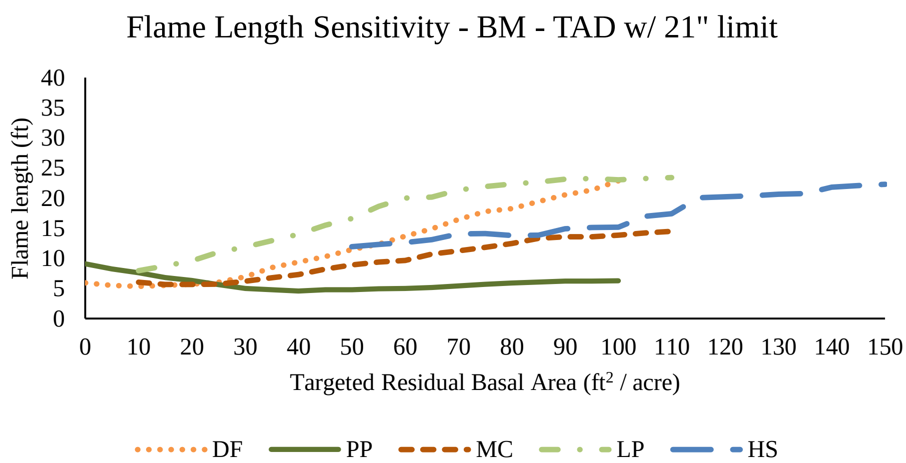


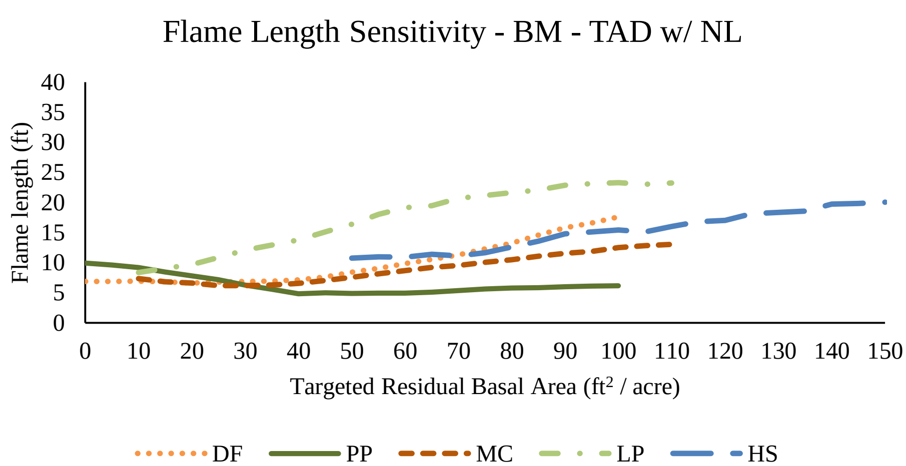




Figures 2.8-2.10. Total potential flame length following a thinning treatment to a range of residual basal area targets within the southern Oregon subregion







Figures 2.11-2.13. Total potential flame length following a thinning treatment to a range of residual basal area targets within the Blue Mountain subregion

Discussion

Mixed conifer reclassification

Modeled ponderosa pine plots showed a strong positive response in the amount of biomass generated over the range of decreasing residual basal area but showed very little response in regards to potential total flame length. This is likely due to the way plots were reclassified into the mixed conifer forest type. Ponderosa pine plots that were in a degraded condition characterized by infilling of shade intolerant species and which would receive a benefit in a reduction of fire hazard with a thinning treatment, had been reclassified as mixed conifer as a result of the level of non-ponderosa pine basal area present. Only ponderosa pine plots in a low departed condition remained, which would not receive a significant benefit in fire hazard reduction from a thinning treatment. In the Blue Mountain subregion the ponderosa pine forest type showed an increase in potential flame length at residual basal areas below 40ft^2/ac as result of how the surface fuel model is calculated within that FVS/FFE variant.

Model sensitivity to biomass feedstock supply

The observed linear increase in biomass over all forest types and prescription groups shows that the model is not particularly sensitive to thinning intensity in regards to feedstock supply. As thinning intensity increases and prescription form removes larger trees, the relative amount of biomass proportionally increases. This finding improves the reliability of generated biomass feedstock supply estimates, given that they are based on average prescription basal area targets and thinning form.

If desired management stocking density was changed across the landscape to a higher or lower level; modeled biomass feedstock estimates supply would respond proportionally to the change.

Overall, biomass yields were lower than expected, especially in model runs where residual basal area was modeled at 0 ft^2/ac (clear cut). This is likely due to the method in which the data were summarized (average yield per acre per forest type within each subregion). The presence of poorly stocked stands that would produce low levels of biomass at each residual basal area target likely lowered the predicted total biomass availability. In addition, the targeted residual basal area was often not reached due to the maximum diameter cut limit resulting in lower than expected biomass yields.

It should also be reiterated that all plots were summarized at the plot level and not at the condition level. The presence of multiple condition classes within a plot would alter the amount of biomass feedstock material that would be predicted to be generated within an area. The degree to which this may or may not bias biomass feedstock levels is not known.

Model sensitivity to wildfire hazard assessment

Similarly to biomass feedstock levels, potential flame length responded linearly to residual basal area, with an increase in total potential flame length as residual basal area increased. This result is also influenced by how the data were summarized. When analyzing an individual stand this trend would likely not be found. When an individual stand is thinned beyond the CBH and CBD threshold required for the initiation of torching, there would be marked decrease in potential total flame length.

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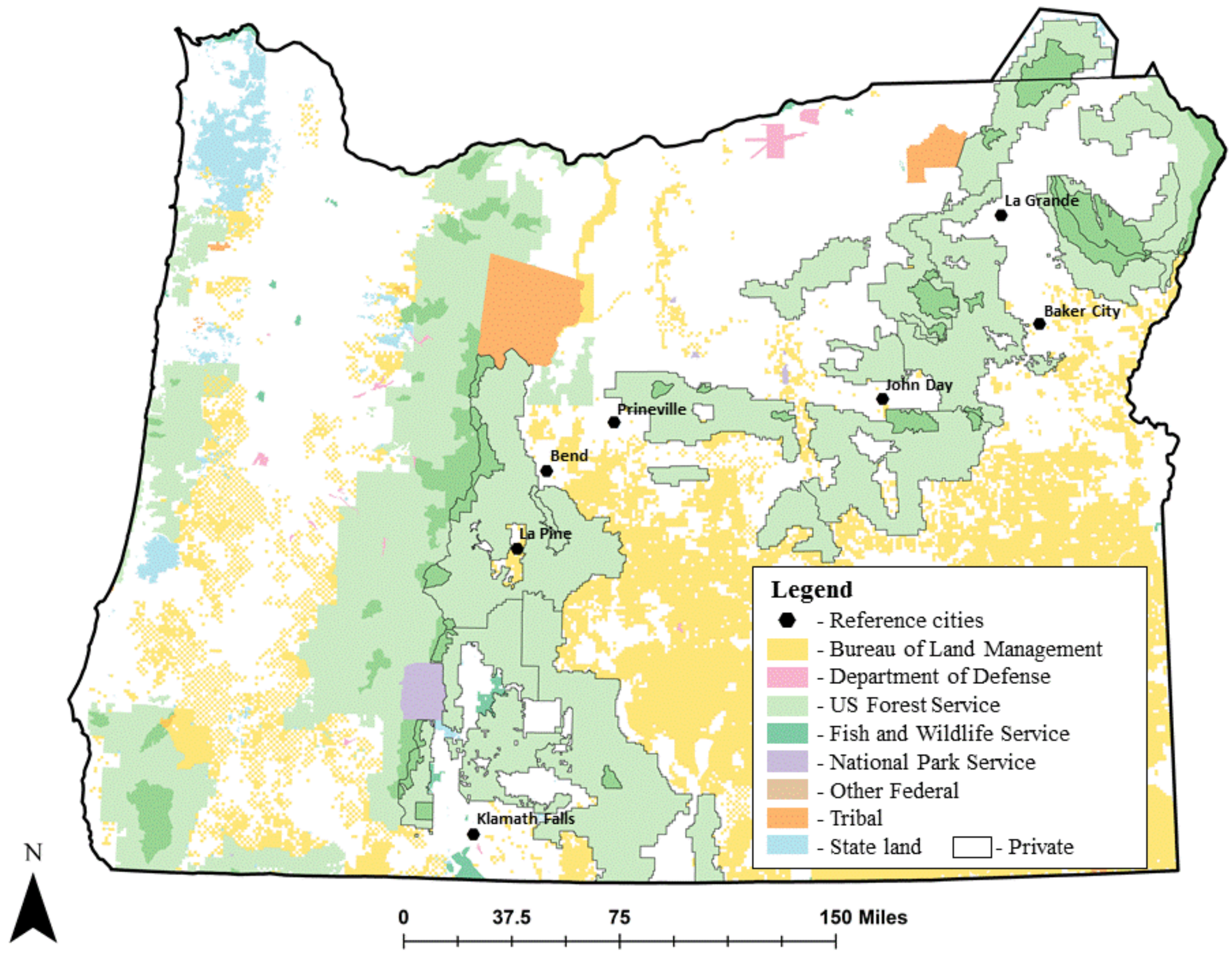

Figure 2.14. Map of administrative boundaries within the study area

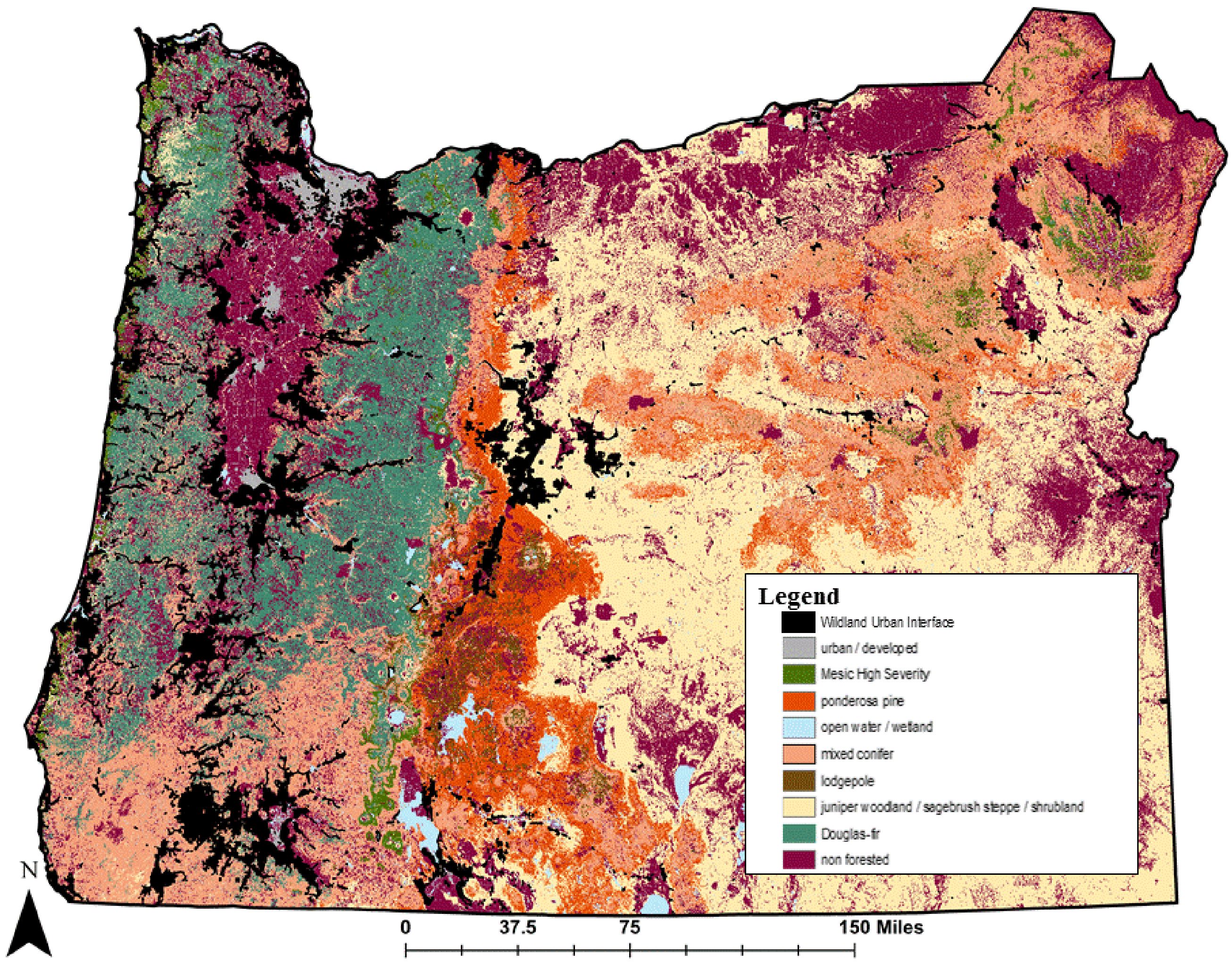

Figure 2.15. Map of potential forest type and location of the Wildland Urban Interface within the study area

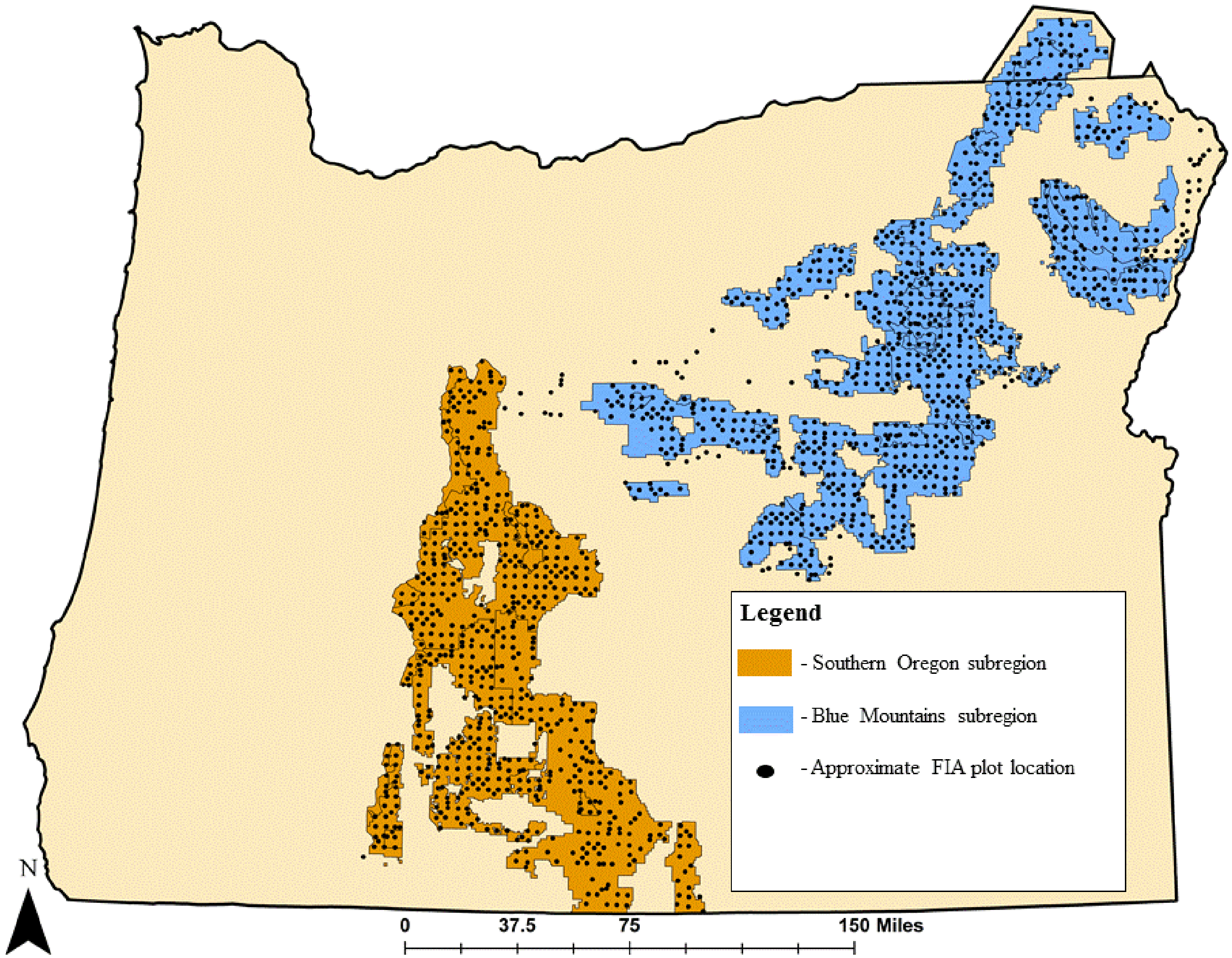

Figure 2.16. Map of the location of the two subregions within the study area and the approximate location of all modeled FIA plots

Chapter 3: Assessing biomass feedstock availability and the ability of restoration treatments to improve stand-level resilience

Abstract

Forest restoration treatments intended to alter landscape-level fire disturbance patterns can be difficult to implement due to issues of scalability and cost. The utilization of biomass material generated during harvest can help offset restoration treatment cost. Estimating the potential level of biomass resources available from treatments would ensure expansions of the current wood products infrastructure are appropriately scaled to match the available resource. A biomass assessment of feedstock generated from fuels reduction and forest health thinning in eastern Oregon was completed to quantify the potentially available biomass feedstock supply. Additionally, the assessment quantifies benefits provided by the treatments through the reduction of landscape-level wildland fire hazard. Biomass feedstock supplies ranged from 131,495 bdt/year to 453,421 bdt/year in the Blue Mountain subregion and from 201,326 bdt/year to 697,344 bdt/year in the southern Oregon subregion. Several management scenarios varying in silvicultural approach and harvest level were modeled and compared to a status quo scenario. Implementing the most aggressive scenario across the total treatable landscape demonstrated a 10.8% decrease in landscape characterized as high fire hazard in the Blue Mountain subregion and a 6.5% decrease in the southern Oregon subregion.

Introduction

Wildfire exclusion over the past century or more has resulted in a major backlog of unburned fuels in many western U.S. forests. Large fuel accumulations combined with recent climatic patterns have increased the frequency of relatively uncommon, large, high-severity wildfires (Hessburg et al., 2005). In order to alter the increasing trend in frequency of uncharacteristically high-severity wildfire events, and the multitude of ecological and social problems that they create, the USFS must implement appropriately-scaled forest restoration treatments across the landscape.

Both the necessary scale and rate of implementation for fuel reduction treatment projects are currently far below what would be necessary to make a meaningful difference across the landscape (North, Collins, & Stephens, 2012). However, over the past 15 years the USFS has worked to develop legislative policies and funding mechanisms that will make appropriately-scaled fuels and restoration treatments a reality in the future (Table 3.1).

Table 3.1: Legislation and funding mechanisms enabling future implementation of appropriately-scaled fuels and forest restoration treatments

Year	Name of Legislation	Impact	Citation
1999	Omnibus Appropriations Act (P.L. 105-277)	Granted the USFS the authority to develop stewardship contracts allowing for greater project flexibility and the authority to create multi-year contracts based on "best value"	(Moseley & Davis, 2010)
2000	Community Forest Restoration Act	Established the Collaborative Forest Restoration Program (CFRP) by providing 5 million dollars annually to fund fuels reduction treatments in New Mexico. Currently to date it has funded 175 projects on over 30K acres	(Prante, Thacher, McCollum, & Berrens, 2007)
2003	Healthy Forest Restoration Act	Streamlined the NEPA process for all fuels reduction projects and mandated the prioritization of treatments within the WUI	(O'Laughlin, 2005)
2009	Omnibus Public Land Management Act	Established the Collaborative Forest Landscape Restoration Program (CFLRP) by providing 40 million annually to fund fuels projects that are over 50K acres in size	(Schultz, Jedd, & Beam, 2012)
2010		Four Forest Restoration Initiative (4FRI) was selected for funding under the CFLRP program. The project in northern Arizona is the largest USFS restoration project to date and plans to restore 600K acres of ponderosa pine forests over the next 20 years	(Schultz et al., 2012)

Despite these policies, restoration treatment costs remain a significant barrier to the implementation of treatments at meaningful scales. Forest restoration harvesting costs range between $35 to over $1000 per acre (Rummer et al., 2005). The use of prescribed fire to treat surface fuels typically costs between $55 and $330 per acre in the West depending on site complexity (Cleaves et al., 2000). If pilling fuel prior to burning is necessary due to smoke or hazard restrictions, costs can jump to between $300 and $900 dollars per acre (Becker, Larson, & Lowell, 2009). As fuels treatments are scaled to appropriate sizes to ensure meaningful alterations of landscape-scale wildfire severity, treatment costs can become prohibitive.

One way that treatment costs can be lowered is through the utilization of woody biomass material generated during harvest in existing and developing biomass markets. Currently, biomass supplies two percent of all of energy consumed in the U.S. and is expected to grow to three percent of the national energy consumption demand by 2030 (White, 2010). Increased utilization of biomass has the potential to decrease costs of restoration treatments both by deferring cost of treating this material through other means (e.g., pile burning) and by sale as a commodity to developing biomass markets.

One often cited barrier to the expansion of the biomass industry is the uncertainty regarding the long-term availability of feedstock supply (Becker et al., 2011). A critical step in planning large forest restoration treatments such as the Four Forest Restoration Initiative (4FRI) is an assessment of the forest resources that could potentially be made available through the implementation of those treatments.

Understanding the long-term availability of wood and biomass supply would enable the planning of any potential expansion of the current wood products infrastructure to appropriately match the scale of the available resource. The first step in the development of a forest resource products assessment is developing an understanding of the amount of acreage that is currently in a departed condition and which would benefit from a forest restoration treatment.

Characterizing restoration need

Forests are characterized as departed from historic conditions if they exhibit a change to one (or more) of the following ecological components: vegetation characteristics (species composition, structural stages, stand age, canopy closure, and mosaic pattern); fuel composition; fire frequency, severity, and pattern; and other associated disturbances (e.g. insect and disease mortality, grazing, and drought) (Ryan & Opperman, 2013). The LANDFIRE Fire Regime Condition Class (FRCC) model is frequently used to quantify departure from historic condition (Hampton et al., 2011; McNeil Technologies, 2003).

FRCC is a classification of the degree of departure from the historical natural fire regime. FRCC compares current conditions to the modeled historic range of ecological variability and quantifies the degree of departure. Uncharacteristic conditions that represent departure from the historic range of variability include presence of invasive species (e.g., weeds, insects, and diseases), “high graded” forest composition and structure (e.g., large trees removed in a frequent surface fire regime), or repeated annual grazing that maintains grassy fuels across relatively large areas at levels that will not carry a surface fire (Hann, Strohm, Omi, & Joyce, 2003). FRCC currently characterizes 11.8% of the entire NARA region (OR, WA, MT and ID) as moderately departed and 1.8% as highly departed (Ryan & Opperman, 2013). Given the large scale of lands currently in a departed condition, methods must be developed in order to prioritize treatment areas within the larger landscape.

Treatment prioritization

When considering the widespread need for restoration and fuels reduction, treatment decisions must be made within the context of the spatial location of forested stands and their proximity to values of interest. Not every departed stand is a high priority candidate for treatment. Moist and high elevation forest types contain a significant amount of biomass and have high potential flame lengths, thus high fire hazard. Yet these forest types are unavailable to burn under most conditions due to high moisture content and therefore pose very low fire risk (Agee & Skinner, 2005).

Since the implementation of fuels treatments is often costly, and the USFS has limited resources for implementation, the location of treatments should be prioritized to provide the greatest benefit to identified values of concern. Ager et al. (2013) provides a theoretical framework for approaching fuels treatment prioritization, based on values at risk and landscape level goals (Figure 3.1).

	Spatial Strategies for Fuel Management					
	Restoration of low severity fire regime	**Broad landscape protection**	**Localized protection**	**Protection of dispersed values**	**Restoration of mixed severity fire regime**	**Strategic containment**
Spatial pattern of values	High density, dispersed	Low density, dispersed	Variable density, clumpy	Clumpy	Any	Low or none
Landscape goal	Low hazard fire containers	Disrupt spread, facilitate containment	Localized defensible fuel breaks	Dispersed defensible fuel breaks	Restoration of dispersed natural fire barriers	Contain large fires at defensible locations
Performance measure	Area burned by prescribed and natural fire	Reduction in landscape burn probability	Local reduction in exposure near values at risk	Reduced exposure to fire	Landscape reduction in hazard and burn probability	Area burned by natural fire
Treatment goal	Reduce fire severity	Reduce fire spread rate	Facilitate suppression	Facilitate suppression	Reduce fire spread rate	Facilitate suppression
Example map						

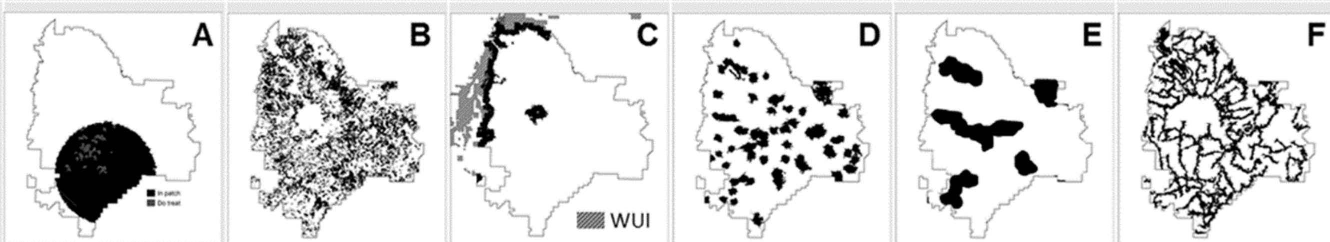

Figure 3.1. Theoretical framework for how to approach fuels treatment prioritization from (Ager et al., 2013)

For this modeling project, I developed a treatment prioritization scheme that prioritized treatments reducing fire hazard to the wildland urban interface as mandated by the Healthy Forest Restoration Act (O'Laughlin, 2005) as well as those located across the landscape that maintained older forest structure following disturbance from wildfire (Ager et al., 2013). This prioritization scheme was incorporated in a developed biomass assessment model that investigated the role of biomass from fuel reduction projects on federal land in a future biomass utilization industry, and how the utilization of this material can be quantified by its impact on reducing stand-level fire hazard. Specifically, the model was used to address the following research questions:

1) Whether fuel reduction treatments can provide a sufficient and sustainable biomass feedstock supply given the extent of the resource in eastern Oregon and the Pacific Northwest;

2) What scale of infrastructure and economies could be supported by the implementation of typical silvicultural approaches across a range of stand types present in eastern Oregon and the Pacific Northwest; and

3) What benefit from fire hazard reduction can biomass utilization have, which may provide the critical social support needed to effectively implement a biomass infrastructure on federal lands.

Methods

Model Description

Model Overview

I developed a model to produce estimates of regional biomass feedstock supply and assess relative fire hazard. Using protocols from prior modeling efforts (Ager et al., 2013; Fried et al., 2005; McNeil Technologies, 2003; Skog et al., 2006), a model framework was developed (Figure 3.2).

1.) Input Data

- FIA Plot level data used
- Stratified into:
  - BM – Ochoco, Malheur, Umatilla, Willowa-Whitman
  - SO – Deschutes, Fremont-Winema
- DF and PP labeled forest types reclassified into mixed conifer based on percentage of total BA

2.) Silvicultural Prescription Scenarios

Four prescription scenarios were modeled:
1) Grow Only
2) Rx 1 – Thin from below (TFB) to BA target
3) Rx 2 – Thin across diameter classes with a 21" DBH limit (TAD21) to BA target
4) Rx 3 – Thin across diameter classes with no diameter limit (TADNL) to BA target

3.)Setting Harvest Intensity Level

Three management intensity levels were modeled:
1) Current harvest levels
2) ½ full restoration in 25 Years ≈ 2x increase in harvest levels
3) Full restoration in 25 Years ≈ 4x increase in harvest levels

4.) Plot Prioritization

The Landscape Treatment Designer (LTD) was used to prioritize treatment areas based on equal weighting of:
1. Treatment effectiveness in reducing mortality of trees > 10" diameter
2. Distance to the WUI (Radeloff et al., 2005)

5.) Growth and Yield

- The Treatment Analysis Tool within the ArcFuels Toolbar was used to iterate FVS in order to model harvest on every plot at each time step
- All runs were compiled and queried to select plot management year based on LTD prioritization and management intensity level.

6.) Data Products

- Total of 10 model scenarios
- Physically available biomass (bone dry tons) and fire hazard (flame length) data was compiled for each time of the 10 modeled scenarios

Figure 3.2. Overview of model framework used to develop regional estimates of physically available biomass feedstock supply and landscape level wildfire hazard.

Input data

Forest inventory data from the USFS Forest Inventory and Analysis (FIA) data library were downloaded on November 6, 2012 and sorted to isolate non-reserved forested plots within the study area. The FIA2FVS tool was used to convert the 1301 non-reserved, forested FIA plots located within the study into a FVS-compatible format. The sampling year was set to the median value of 2006 and applicable ponderosa pine and Douglas-fir plots were re-classified to mixed conifer forest type.

Silvicultural prescription scenarios

A series of silvicultural prescriptions were developed based on an exhaustive literature review of stand reconstruction studies and a survey of 14 local USFS silviculturists, National Environmental Policy Act (NEPA) planners and forest managers. Following the original development of these prescriptions, they were presented to USFS land managers at the 2012 5th International Fire Ecology and Management Congress (Portland, OR), 2013 National Advanced Silvicultural Program Workshop (Corvallis, OR), 2014 Central Oregon Fire Science Symposium (Bend, OR) and the 2014 Large Wildland Fires Conference (Missoula, MT) in order to solicit feedback. Prescriptions included a no-management alternative, thinning from below and a thinning across diameter classes to residual basal areas that ranged from 50 ft^2/ac to 120 ft^2/ac depending on forest type (Table 2.3).

Setting harvest intensity levels

Three potential future harvest intensity levels were modeled:

1) Current harvest levels representative of status quo where 0.7% of the treatable landscape is harvested each year

2) Moderate restoration where ½ of all departed lands are restored to historical stand structures within 25 years. This represents an approximate twofold increase in harvest levels or the treatment of 1.3% of the treatable landscape per year.

3) Heavy restoration where all departed lands are restored to historical stand structures in 25 years. This represents an approximate fourfold increase in harvest levels or the treatment of 2.6% of the treatable landscape per year.

Current harvest level estimates were developed from analyzing the Forest Service Activity Tracking System (FACTS) database. FACTS is a reporting management system that tracts all management that occurs on USFS lands. Data was collected from 2008 to 2012 for all national forests within the study area. The database was sorted to remove the presence of multiple management activities occurring within the same project area and summarized for average number of acres treated annually either mechanically or with prescribed fire. It is possible that some duplicate management entries were inadvertently missed resulting in an over prediction of current management intensity.

Estimations of restoration need were developed from the Fire Regime Condition Class (FRCC) data product. The LANDFIRE "Existing Vegetation Cover" raster was processed to create a non-forested mask layer. The "Reclassify" tool within ArcGIS was used to set all pixels defined as forested (>10% Canopy Cover) to a value of 1 and all other pixels to a value of 0. A non-reserved USFS lands raster mask was generated by joining a non-reserved USFS lands shapefile layer with an Oregon State boundary shapefile. This layer was then converted into a raster and reclassified so that pixels representing non-reserved USFS lands received a value of 1 and all other pixels received a value of 0.

The two generated mask layers were combined with the FRCC raster layer using the "Raster Calculator" tool to create a new raster layer that represented vegetation departure for non-reserved, forested, USFS lands. The total amount of departed lands that met these conditions were summarized at the national forest level using the "Zonal Statistics" tool.

Plot selection prioritization

Plot prioritization was developed with the Landscape Treatment Designer (LTD) tool. Prioritization was based on an equal weighting of distance to the wildland urban interface (WUI) and the effectiveness of a restoration treatments to maintain large diameter trees following disturbance by wildfire

Distance to the WUI was calculated by taking the Euclidian distance from the approximate location of each FIA plot to the nearest WUI boundary (Radeloff et al.,

2005) using the “Nearest Neighbor” analysis tool within ArcGIS. Distances were grouped into 10 categorical bins in order to scale weighting evenly with treatment effectiveness.

Treatment effectiveness was defined as the ability of a treatment to improve a stands capability of maintaining substantial live basal area after being burned by a wildfire (Agee & Skinner, 2005). In order to determine relative treatment effectiveness, each FIA plot was first grown forward to 2013 and a wildfire was simulated using FVS/FFE under approximate 95th percentile fire weather conditions (Table 3.2).

Table 3.2. Weather parameters used in modeling wildfire impacts on both current stand structure and on stands that have received a restoration treatment.

Variable	Value
Tempurature (°F)	90
20 ft wind speed (mph)	20
Fuel Moisture (%)	
1-h fuel (0-0.25")	8
10-h fuel (0.25"-1")	8
100-h fuel (1-3")	10
1000-h fuel (>3")	15
Duff	50
Live	110

The number of trees, in 10 inch size classes, killed as a result of the wildfire were summarized from the FVS_Mortality table at the plot level.

Next, each plot was remodeled with a thinning treatment taking place in 2011, a biomass harvest/ removal in 2012 and a disturbance by wildfire in 2013. The number of trees in each ten inch size class per plot killed as a result of the wildfire were summarized. The difference between the level of mortality of large trees as a result of the modeled wildfire and the level of mortality of large trees following thinning and wildfire disturbance was summarized to determine the number of trees maintained as a result of the thinning treatment. This was used to generate a categorical 1-10 score of treatment effectiveness where larger trees received a higher weighting in the calculation of the final treatment effectiveness score.

The LTD program was run to sort each plot based on a priority that placed equal weighting of the developed categorical treatment effectiveness variable and the distance to WUI variable for all plots that had at least a 2 foot potential flame length. The prioritization ranking given to each plot within the two subregions was used to determine the year that each plot would receive treatment under the 10 simulated model scenarios.

Generating biomass yields and modeling fire hazard

The ArcFuels toolbar within ArcGIS was used to iterate FVS in order to model a harvest on every plot during each time step. The “Treatment Analysis” tool was used with the “Substitute Value” function to increment harvest year within the FVS KCP management file so that FVS would simulate a harvest and the growth in the subsequent years for each time step in the 25-year study window. This process was repeated for each forest type in the two subregions. Simulations were run on a 64-bit Windows 7 operating system with an Intel® Core™ i7-2600 CPU @ 3.40 GHz processor with 8.00 GB of RAM and took approximately 17 hours to complete per model scenario per subregion.

A link table was generated characterizing the year a treatment would take place for each plot based on its priority ranking and desired harvest level. This table was joined with a compiled results Access table and queried with SQL to develop biomass yields and fire hazard estimates for all managed and unmanaged plots over each time period for each of the 10 modeled scenarios and two subregions.

Results

Characterizing restoration need

Departure from historic condition (FRCC) ranged from 492,171 departed acres (VCC 1 and 2) on the Ochoco National Forest to 1,866,405 acres on the Fremont-Winema National Forest. A total of 80% of the non-reserved, forested, Blue Mountain subregion was characterized as departed, and 88% of the southern Oregon subregion was so characterized. Currently the USFS in the Blue mountain subregion is treating an average of 37,962 acres annually with mechanical harvest or an equivalent to 1.2% of the total departed acres. Within the southern Oregon subregion 26,237 acres are treated annually with mechanical treatments or an equivalent of 0.9 % of the total departed acreage (Figure 3.4).

Model validation

The model was run using a thinning from below prescription under *status quo* harvest levels (TFB_R1) and compared against reported cut and sold harvest reports from 2008 to 2012 for all national forests in the two subregions. The model estimated an average of 109,407 MBF harvested per year between 2008 and 2012 within the Blue Mountain subregion. The Ochoco, Malheur, Umatilla and Wallowa-Whitman National

Forests within the Blue Mountain subregion reported an average of 88,198 MBF harvested per year over this time period or 19.4% less than modeled estimates. The model estimated an average of 96,667 MBF harvested per year between 2008 and 2012 within the southern Oregon subregion. The Deschutes and Fremont-Winema National Forests in the southern Oregon subregion reported an average of 105,012 MBF harvested per year over this time period or 8.6% more than modeled estimates.

Biomass feedstock supply estimates

Average annual biomass feedstock supply in the Blue Mountain subregion for the 25-year study period ranged from 131,495 bdt/year with a thin from below prescription under current harvest levels to 453,421 bdt/year with a thin across diameter classes with no diameter limit prescription under fourfold increased harvest levels (Figure 3.6). Average annual biomass feedstock supply in the southern Oregon subregion ranged from 201,325 bdt/year with a thin from below prescription under current harvest levels to 697,344 bdt/year with a thin across diameter classes with no diameter limit prescription under fourfold increased harvest levels (Figure 3.5). Biomass estimates generated using a TAD2lL prescription averaged 10.1% higher compared to those generated using a TFB prescription and estimated generated using a TADNL prescription averaged 35.6% higher than those generated with a TFB prescription within the Blue Mountain subregion. Biomass estimates generated using a TAD2lL prescription averaged 13.6% higher compared to those generated using a TFB prescription and estimated generated using a

TADNL prescription averaged 20.7% higher than those generated with a TFB prescription within the southern Oregon subregion.

Potential fire hazard

Average total flame length for the entire treatable landscape within the Blue Mountain subregion at the end of the 25-year study window ranged from 22.8 ft with a thin from below prescription at current harvest levels to 15.8 ft with a thin across diameter class with no diameter limit prescription at a fourfold increase in harvest levels. These values were 11.0% and 38.3% lower respectively than the average 25.6 ft potential flame length under the no-management scenario. Average total flame length for the entire treatable landscape within the southern Oregon subregion at the end of the 25-year study window ranged from 21.4 ft with a thin from below prescription at current harvest levels to 14.5 ft with a thin across diameter classes with no diameter limit prescription at a fourfold increase in harvest levels. These values were 13.7% and 41.5% lower respectively than the average 24.8 ft potential flame length under the no-management scenario (Figure 3.7).

The percentage of the landscape characterized as high fire hazard (> 11ft) increased from 33.38% to 41.69% under the no-management scenario within the Blue mountain subregion and increased from 39.0% to 40.66% within the southern Oregon subregion. Under the most intensive management scenario (TADNL_R3) there is a 12.1% decrease in the porportion of the landscape burning at flame lengths greater than 11 ft in the BM subregion and a 10.3% decrease in the southern Oregon subregion compared to the grow only scenario. The most intensive management scenario resulted in a 10.8% decrease in the propotion of the landscape charecterized as high hazard compared to the status quo scenarion (TFB_R1) in the blue mountain subregion and an 6.5% decrease in the southern Oregon subregion.

The highest concentration of stands charecterized at high fire hazard are located at upper elevations where they pose low fire risk due to high relative moisture content. However the charecterization of over 20% of mixed conifer and ponderosa pine under most managament scenarios as high fire hazard demonstrates the management need (Figures 3.8-3.11). The degree to which the implimentation of these treatments would alter landscape-level fire severity paterns is not known due to the non-spatial nature of the fire modeling tools used.

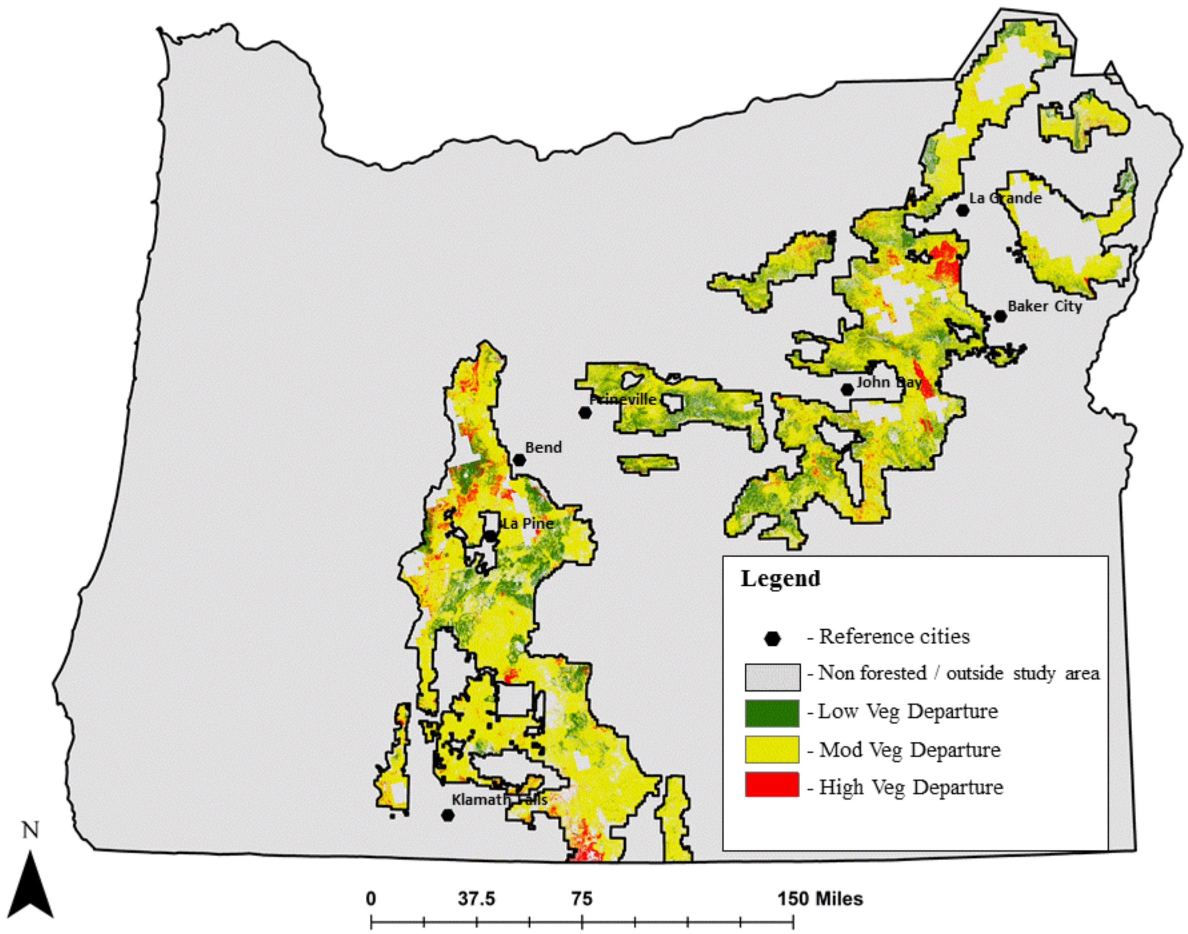

Figure 3.3. Map of FRCC modeled departure from historical condition for all forested non-reserved USFS lands in eastern Oregon. Within the study area 5% of the landscape is characterized as highly departed and 79% is characterized as moderately departed.

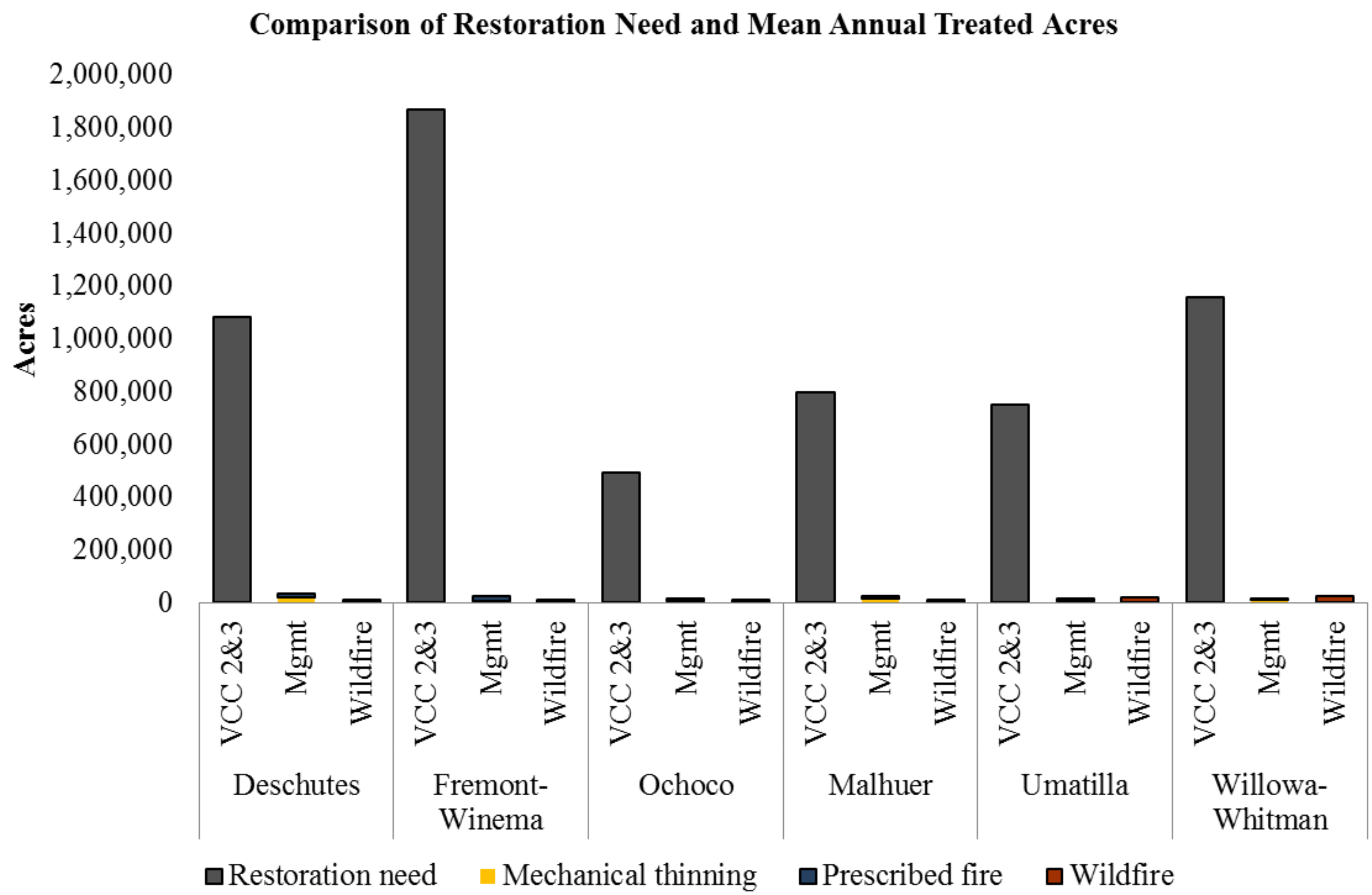

Figure 3.4. Comparison of restoration need relative to current levels of treatment (mechanical thinning and prescribed fire) and average acres burned by wildfire for each national forest in eastern Oregon.

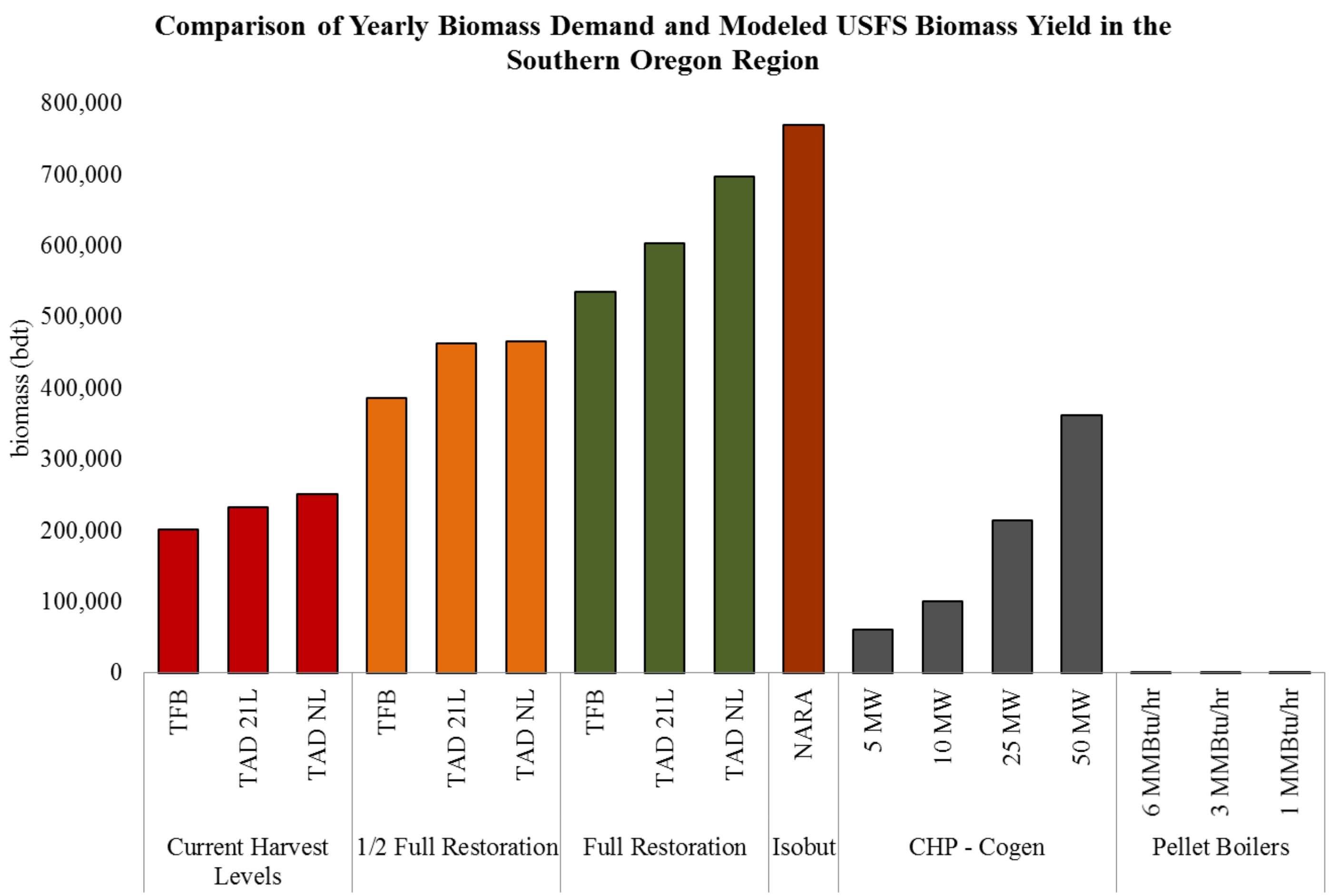

Figure 3.5. Comparison of modeled feedstock supply over a range of silvicultural prescriptions and harvest intensity levels and biomass feedstock demand of different scales of biomass infrastructure within the southern Oregon subregion.

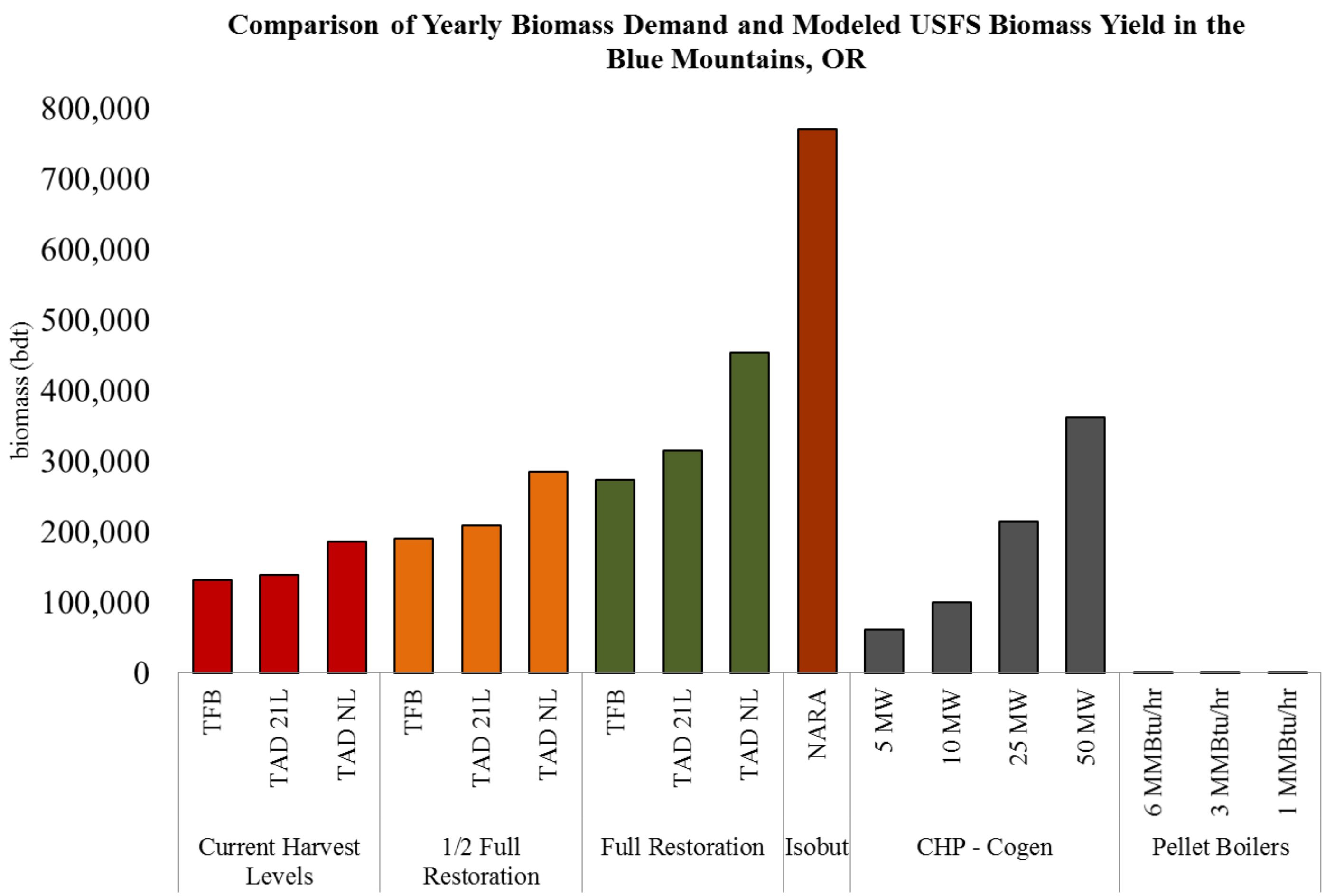

Figure 3.6. Comparison of modeled feedstock supply over a range of silvicultural prescriptions and harvest intensity levels and biomass feedstock demand of different scales of biomass infrastructure within the Blue Mountain subregion.

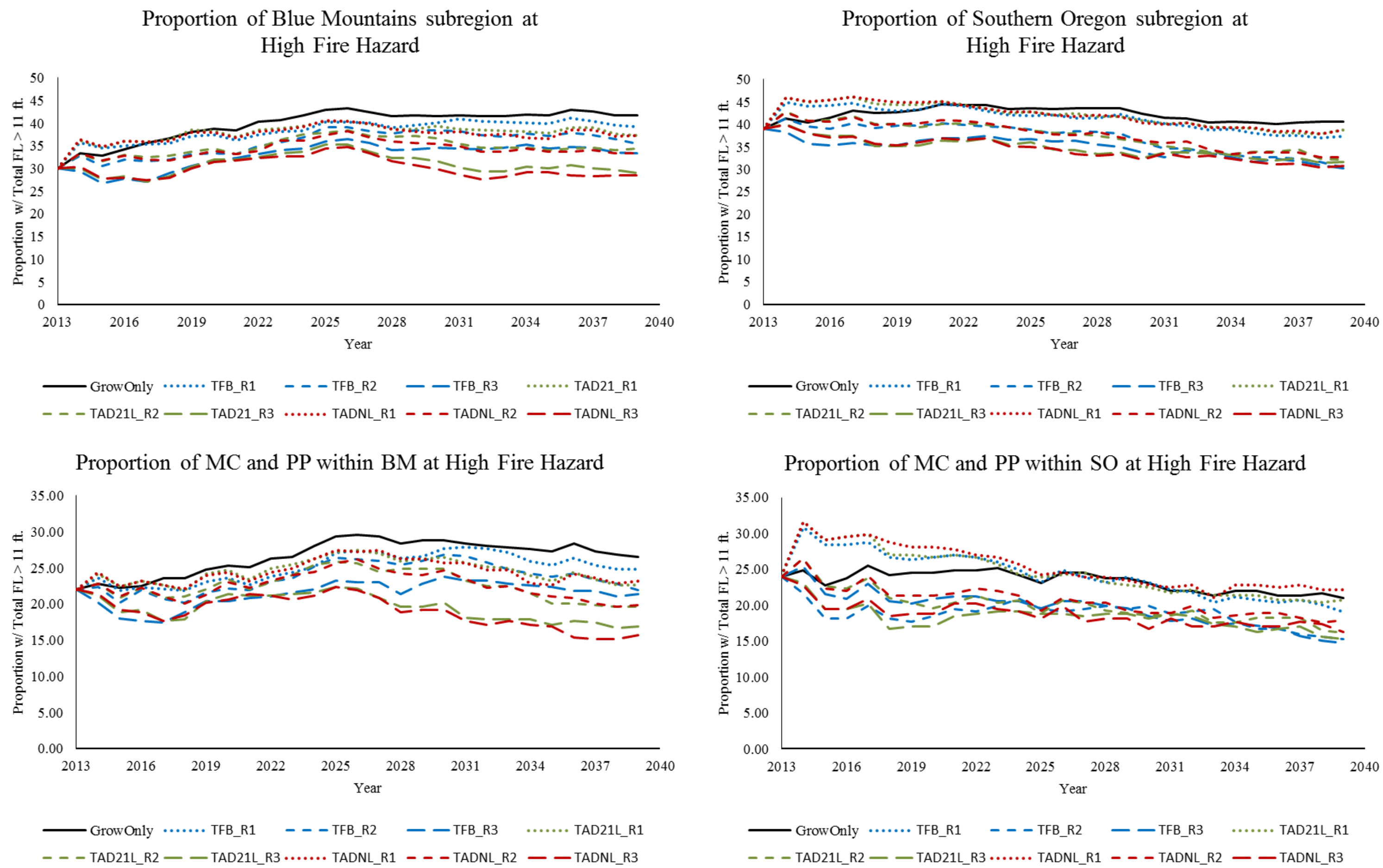

Figure 3.7. Proportion of the treatable area within the Blue Mountain and southern Oregon subregions with potential flame lengths greater than 11 ft. Under the most intensive management scenario (TADNL_R3) there is a 12.1% decrease in the porportion of the landscape burning at flame lengths greater than 11 ft in the BM subregion and a 10.3% decrease in the southern Oregon subregion compared to the grow only scenario.

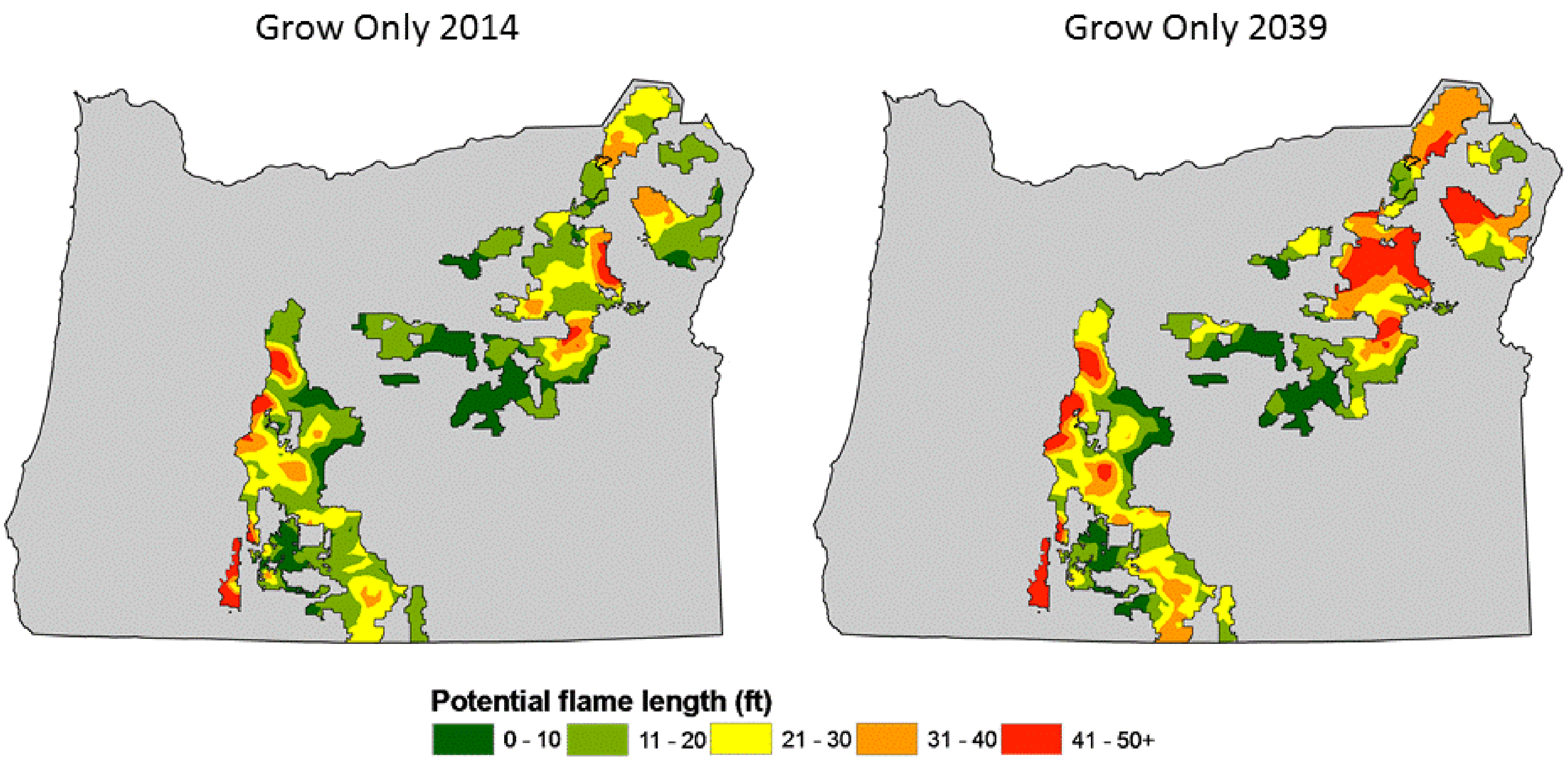

Figure 3.8. Map of the spatial pattern of potential flame length after 25 years of no active management. The percentage of the total landscape characterized as having potential flame length greater than 11 ft increased from 34.5% to 39.7% from 2014 to 2039.

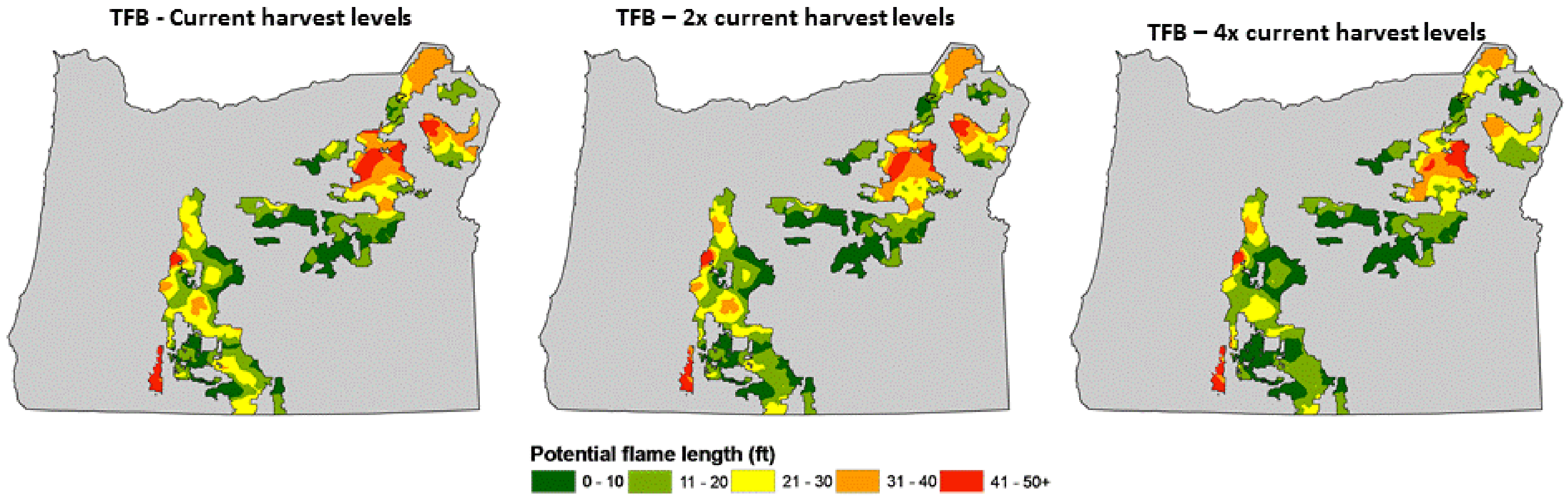

Figure 3.9. Map of the spatial pattern of potential flame length after 25 years of management with a thinning from below prescription under various harvest intensities. The percentage of the landscape characterized as having potential flame length greater than 11 ft decreased from 37.6% to 32.2% as harvest levels increased from current levels to 4x current levels.

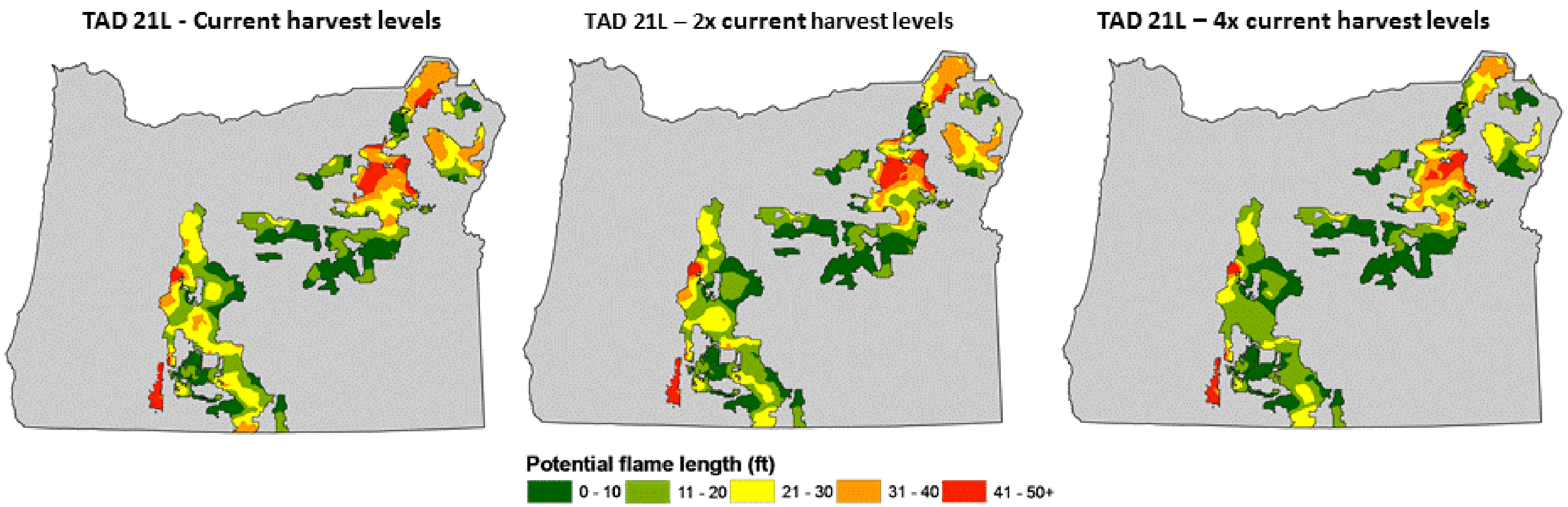

Figure 3.10. Map of the spatial pattern of potential flame length after 25 years of management with a thinning across diameter classes with a 21" diameter limit prescription under various harvest intensities. The percentage of the landscape characterized as having a potential flame length greater than 11 ft decreased from 38.0% to 32.2% as harvest levels increased from current levels to 4x current levels.

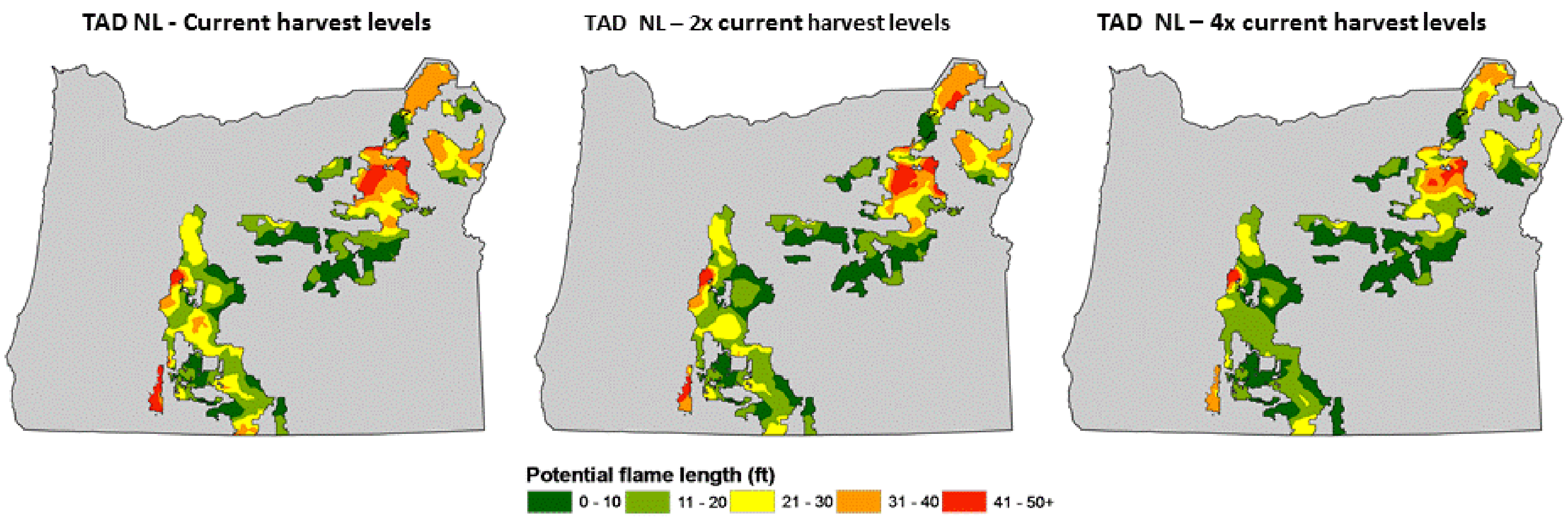

Figure 3.11. Map of the spatial pattern of potential flame length after 25 years of management with a thinning across diameter classes with a no diameter limit prescription under various harvest intensities. The percentage of the landscape characterized as having a potential flame length greater than 11 ft decreased from 38.0% to 29.5% as harvest levels increased from current levels to 4x current levels.

Discussion

Characterizing restoration need

The FRCC model characterizes a very large proportion of the landscape as currently in a departed condition. Similar rates of departure have been noted in other simulation studies comparing current conditions to historical range of variability (Keane, Hessburg, Landres, & Swanson, 2009; Nonaka & Spies, 2005; Swetnam & Brown, 2010). The USFS is currently treating less than 1% a year of the over six million acres characterized as being in a departed condition in the study area. The discrepancy between the scale of current management levels on USFS lands and the scale of the fuels problem is highlighted by the increasing trend of uncharacteristic high-severity wildfire events (Hessburg et al., 2005). In order to alter this trend, and the multitude of ecological and social problems subsequently created, the USFS must implement appropriately-scaled forest restoration treatments across the landscape.

Model validation

The model provided accurate estimates of wood supply in the southern Oregon subregion. However, the Blue Mountain subregion modeled estimates were substantially higher than reported harvest volumes. This discrepancy could be a result of how the national forests in the Blue Mountains report harvest volumes (e.g., only from commercial timber sales) or differences in treatment prioritization as compared to current methods for model priority. Despite discrepancies between modeled and reported wood volume, estimates of biomass supply were very similar to those generated in the McNeil 2003 “Biomass Resource Assessment and Utilization Options for Three Counties in Eastern Oregon” report (McNeil Technologies, 2003). McNeil (2003) analyzed aerial photographs to determine the amount of overstocked stands on the national forests in the Blue Mountains. Estimates of overstocked acres were used to develop harvest targets. Harvest volumes from those acres were generated by simulating thinning treatments with the FVS model on CSV sample plots. The McNeil analysis resulted in an estimated biomass availability 6% higher than those generated using the TFB_R1 scenario in this model.

Additional model validation would benefit from comparisons of feedstock supply estimates to estimates generated using the NARA economics team’s market demand model as well as comparisons to other current harvested volume reports. Further comparisons would provide additional feedback into the validity of the developed modeling approach.

Biomass feedstock supply

There was a wide range of biomass that was estimated to be available over the 10 modeled scenarios. Estimates represent the amount of biomass physically available and not the amount that would be economically available. Physically available biomass supply is constrained by the economic feasibility of accessing that material. Costs associated with biomass harvesting, collecting, and transportation have been frequently cited as significant barriers to biomass utilization (Aguilar & Garrett, 2009;

Dennis R. Becker et al., 2009; D. L. Nicholls et al., 2008). While only a percentage of physically available biomass would be cost effective to remove, the economic realities of removing biomass are ever changing as ongoing operational research develops more efficient ways to process and transport biomass material.

These estimates of physically available biomass feedstock supply provide a decision window into the range of potentially available feedstock supply levels. None of the model scenarios in the Blue Mountains or the southern Oregon subregions produced enough biomass feedstock supply estimated to support the yearly demand of the proposed NARA isobutanol facility (Figure 3.5-3.6). The high capital infrastructure cost of building an isobutanol facility requires that it be quite large in order cover those costs. Therefore determining an appropriate location for a facility is very difficult due to its high biomass feedstock supply demands as well as its reliance on a large water supply and accessibility to adequate transportation networks. Currently the NARA project is investigating the feasibility of locating an isobutanol facility in the more productive forests of Oregon and Washington’s coastal mountain range.

The range of biomass availability estimated in the model shows that there is a sufficient biomass resource in both the Blue Mountain and southern Oregon subregions to support additional biomass infrastructure. Further expansion of the current biomass infrastructure with development of cogeneration power plants, thermal bioenergy systems, or a combination of the two would benefit from further study investigating harvest treatment and transportation costs to determine delivered feedstock supply at various price points.

Reliance on wood supply from USFS lands can potentially be risky given the highly politicized nature of federal land management. However, if stake holders are included in the process early and development of stewardship contracts through a collaborative process occurs, meaningful management on federal lands can be successful (Franklin & Johnson, 2012; Moseley & Davis, 2010). An example of a success story is the Blue Mountain Partners collaborative group that help facilitate the awarding of a ten-year stewardship contract on the Malheur National Forest to Iron Triangle LLC in September 2013. The stewardship contract will treat between 180,000 and 500,000 acres over 10 years while sustaining the previously defunct Malheur lumber company in John Day, Oregon.

Potential fire hazard

We cannot prevent high-severity wildfire from occurring in the future, even under the most active fuel management scenarios. We can however alter the relative amount of the landscape likely to burn at high severity through the implementation of thoughtful, appropriately-scaled fuels treatments (Ager et al., 2013). Model results show that we can be successful in altering stand-level fire hazard characterized by either average total flame length or the percentage of the landscape with the potential to burn at high severity through the implementation of restoration treatments (Figures 3.7 & A7-A26).

Model results show a marked decrease in the level of the landscape that has the potential to burn at high severity but decreases were not proportional to increased treatment levels (Figure 3.7). This phenomenon is believed to be based on three factors:

1) My model was not specifically parameterized to reduce the presence of high severity wildfire. The treatment prioritization scheme developed mimics the current USFS harvest patterns in order to develop accurate estimations of potentially available biomass supply. If the model was instead parameterized to provide the greatest reduction of fire hazard across the landscape, by prioritizing the treatment of stands that would incur the greatest reduction in potential flame length, a more significant decrease in fire hazard would likely be shown.

2) The model generalized potential flame length as the highest potential flame length within a stand and not the average or most representative flame length. Therefore, the model reports the flame length from any passive torching within a stand as the potential flame length for that stand. There is undoubtedly variances across a given stand where mixed severity fire effects would be present. While a large percentage of the landscape remains at high fire hazard, the implementation of treatments would have altered the level of high severity effects across the stand under all but the most severe wildfire conditions.

3) Finally, the model is spatially independent. Each stand is treated individually without any consideration of neighboring stands and surrounding vegetation. Fire is a

dynamic, spatially-dependent disturbance agent that is highly influenced by changes in fuels, weather and topography at a range of scales. The degree to which treatment of an individual stand would impact the level of the landscape that is at risk of burning at high severity cannot be determined using these modeling tools.

This modeling exercise in addition to other field-based studies demonstrates that we can reduce wildfire severity through the implementation of fuel reduction treatments (Arno & Fiedler, 2005; Cochrane et al., 2012; Prichard & Kennedy, 2012). The optimal level and frequency of wildfire severity to sustainably manage for the range of values of concern is not known. Historically, it is estimated that the level of wildfire burning each year was ten times the current level (Agee, 2003). Developing a better understanding of whether this increased level or another level of fire frequency and severity is optimal would allow for better planning of fuels treatments. In this context fuels treatments would be utilized as a drawbridge, facilitating the reintroduction of wildfire through a shift from fire suppression to fire maintenance utilizing fire's impacts to manage for values of concern (Ingalsbee, 2005; North et al., 2012)

In addition, it is unknown to what degree fuels treatments can alter landscape-level wildfire patterns. Future research needs to address what level of treatment (percentage of landscape per year) is required in order to reach desired wildfire frequency and severity levels and how long it would take before treatments at that level would result in a discernable change to observed wildfire patterns. Finally, it is unknown how an increased level of treatment can be quantified in its ability to prevent loss to values of concern as well as how it will influence future expenditures on wildfire suppression.

Management implications

The utilization of biomass material can aid in the expansion of fuels treatments to appropriate scales. However, biomass utilization is not a silver bullet that will single handedly revolutionize fuels management. Nevertheless, it can and should play a role in a larger spectrum of management and policy changes aimed at improving our ability to sustainably coexist in wildfire's natural habitat.

Understanding the potential level of biomass resources available from treatments would ensure expansions of the current wood products infrastructure are appropriately scaled to match the available resource. In addition, studies such as this one can help provide the critical social support needed to effectively implement a biomass infrastructure on federal lands by quantifying the benefit from fire hazard reduction.

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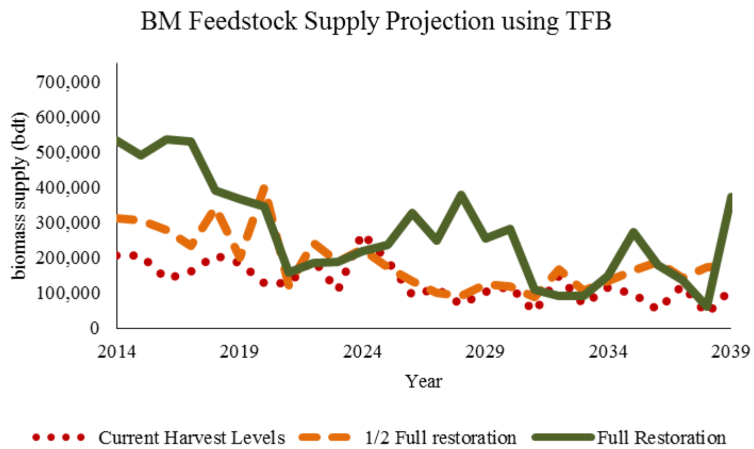
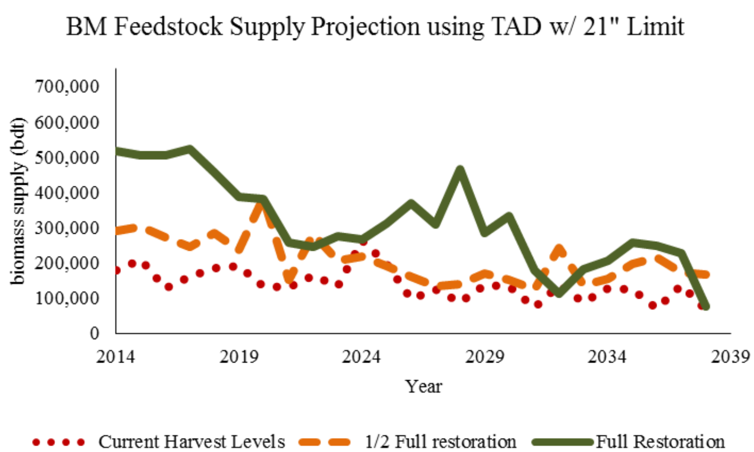
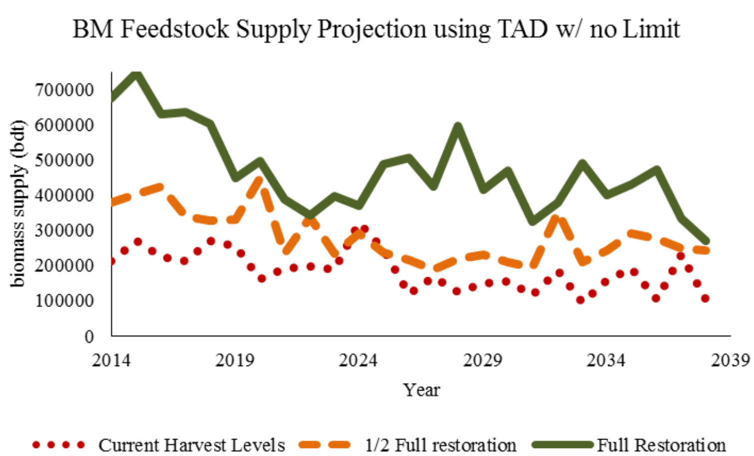
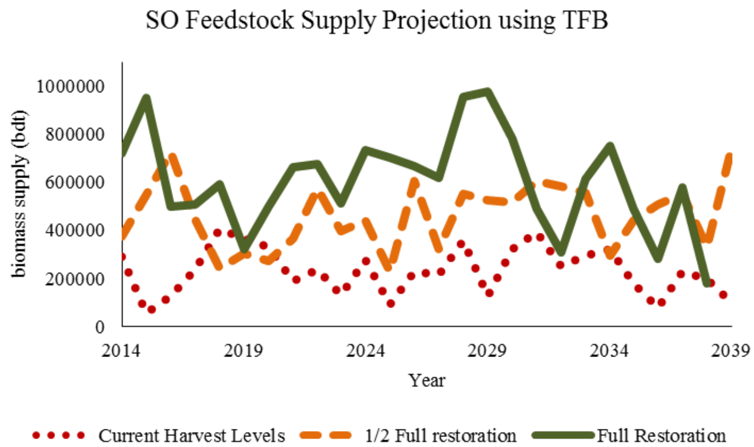
Appendices

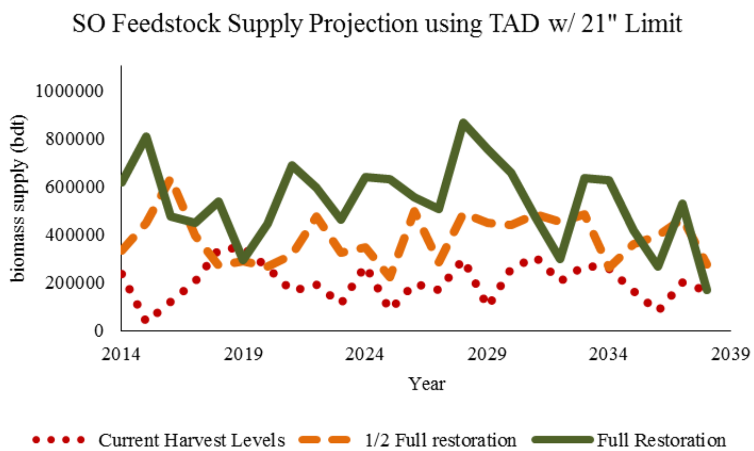


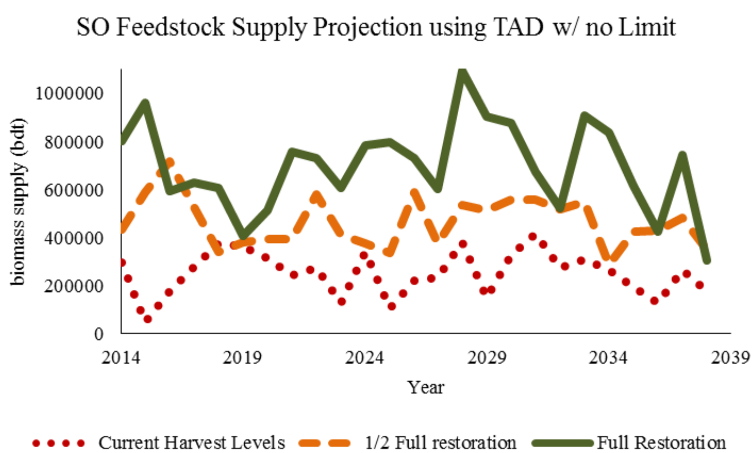




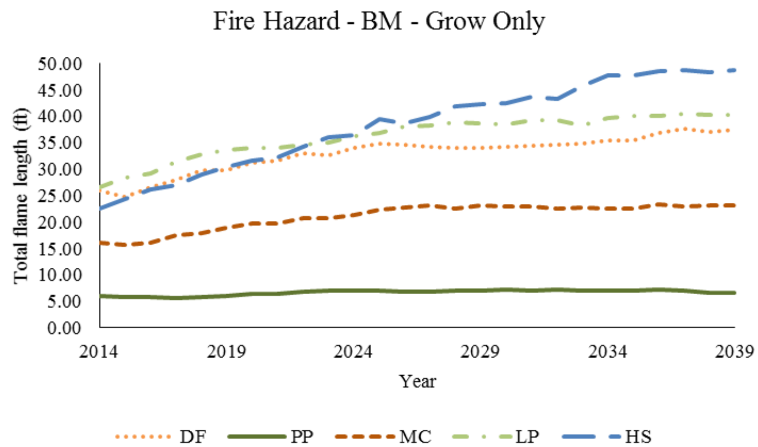
Figures A1-A3. Modeled annual feedstock availability for the Blue Mountain subregion

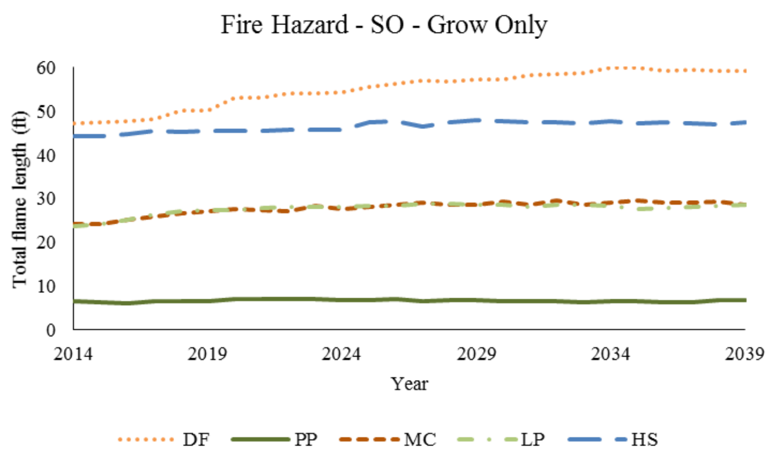




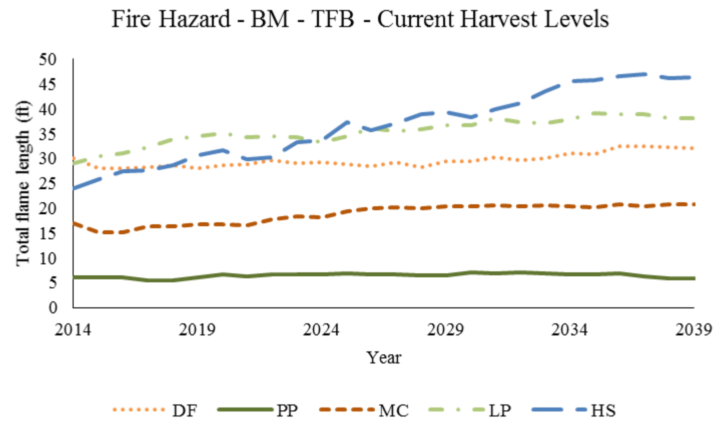


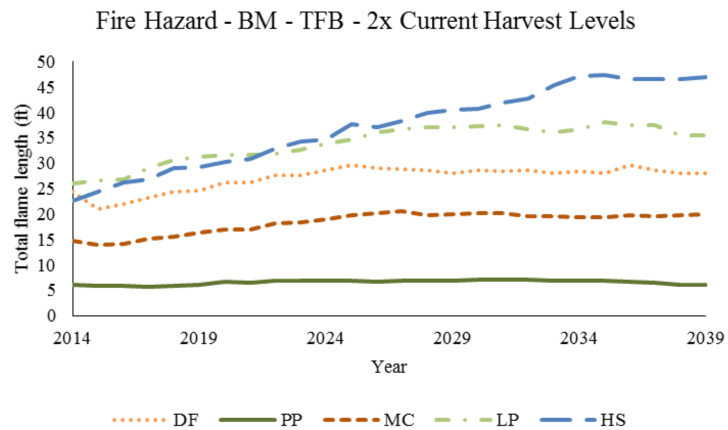
Figures A4-A6. Modeled annual feedstock availability for the southern Oregon subregion

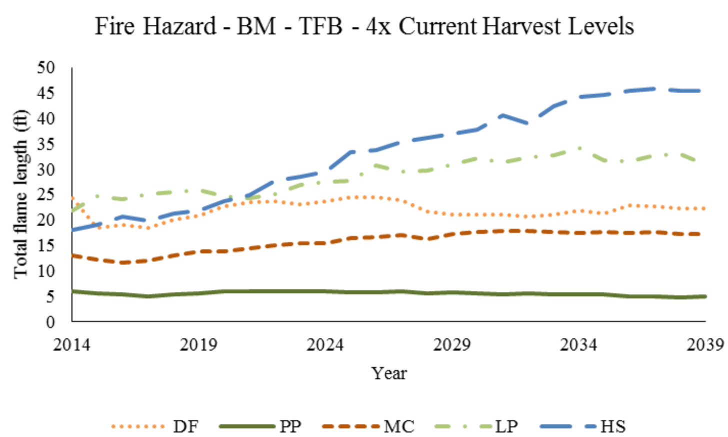




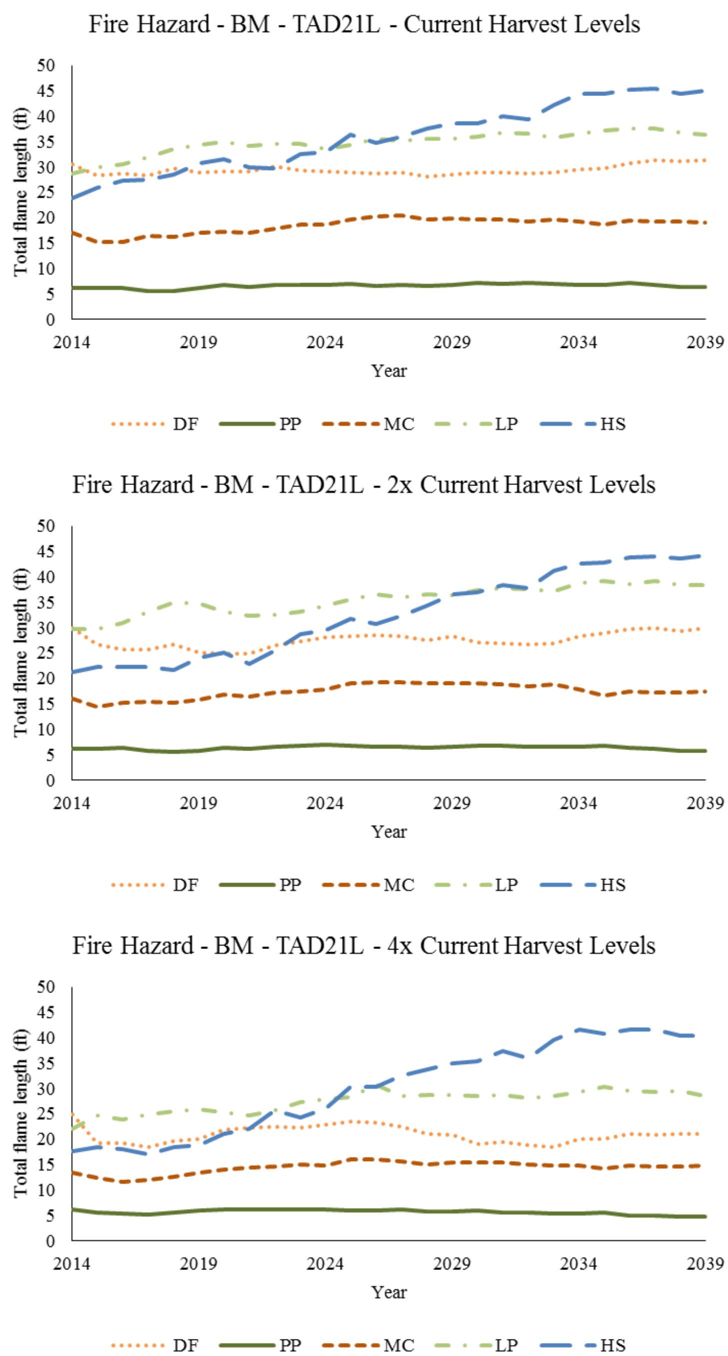
Figures A7-A8. Average total flame length for Blue Mountains and southern Oregon subregions for 25 years with no active management



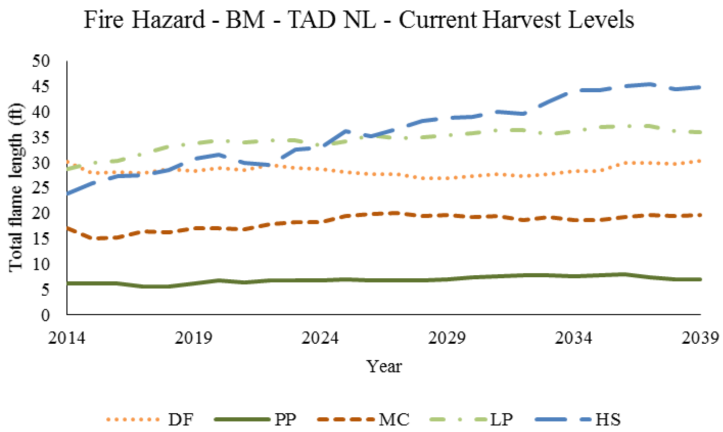


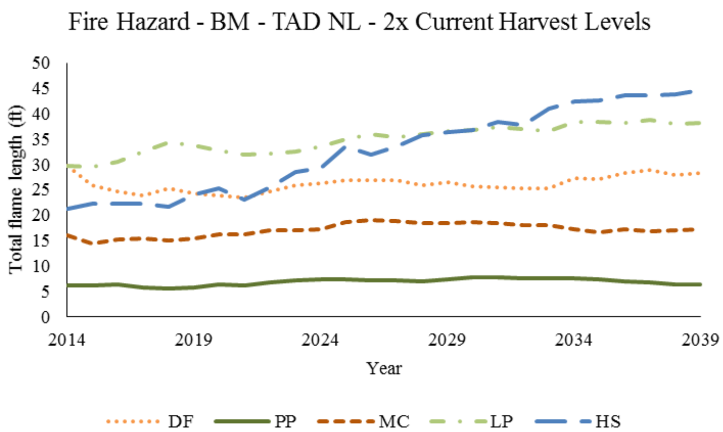


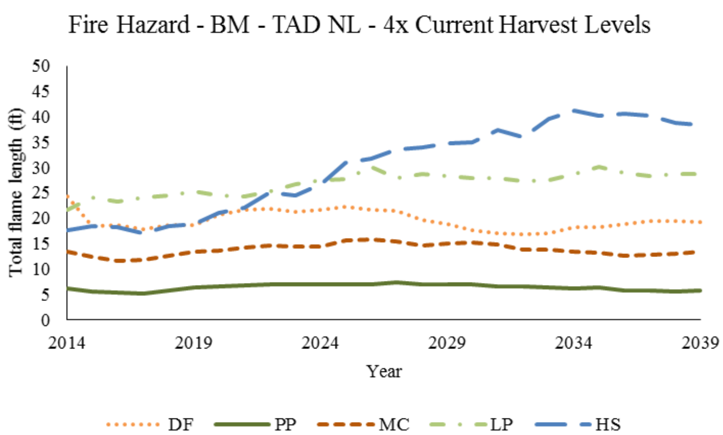
Figures A9-A11. Potential total flame length over 25 years of management with a thinning from below prescription under various harvest intensities within the Blue Mountain subregion.



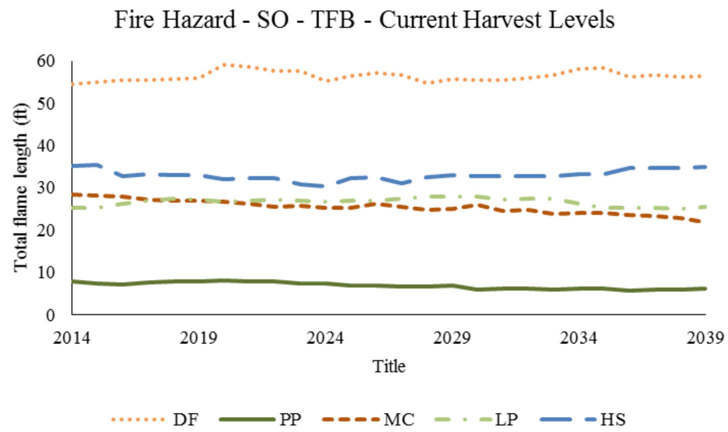
Figures A12-A14. Potential total flame length over 25 years of management with a thinning across diameter classes with a 21" diameter limit prescription under various harvest intensities within the Blue Mountains subregion.

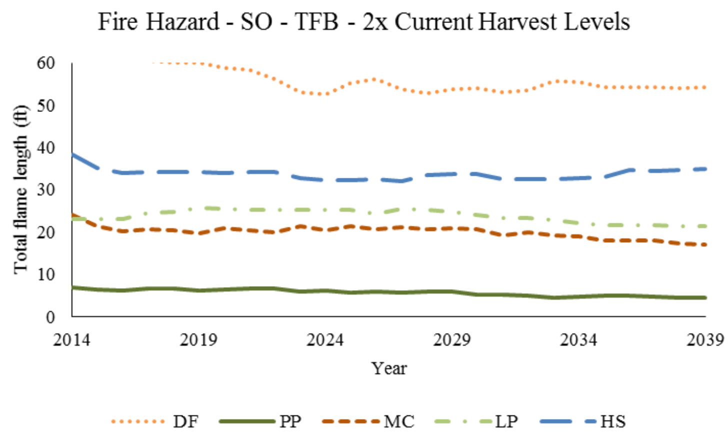


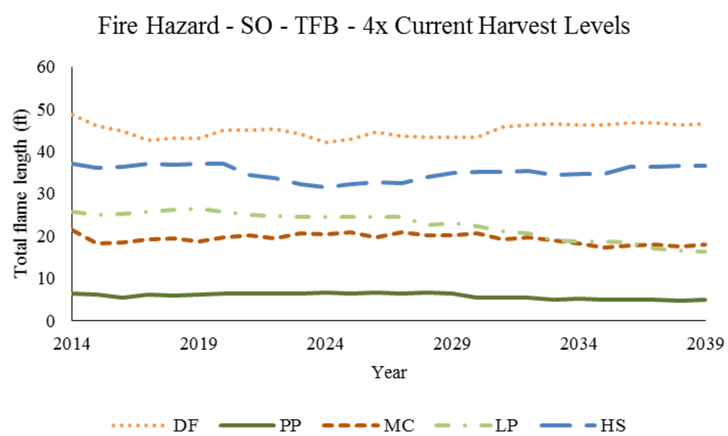




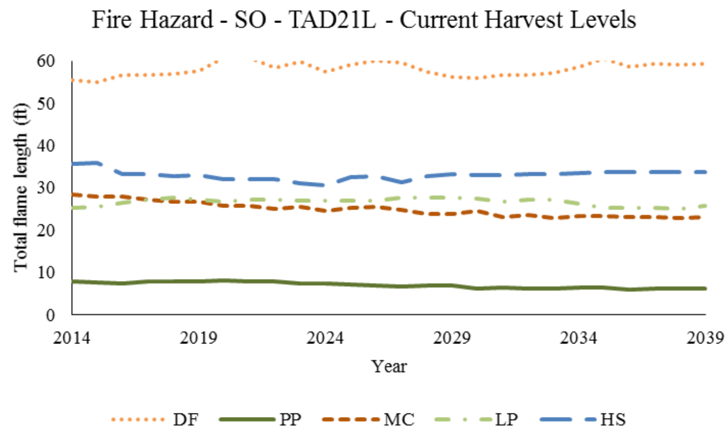
Figures A15-A17 Potential total flame length over 25 years of management with a thinning across diameter classes with no diameter limit prescription under various harvest intensities within the Blue Mountains subregion.

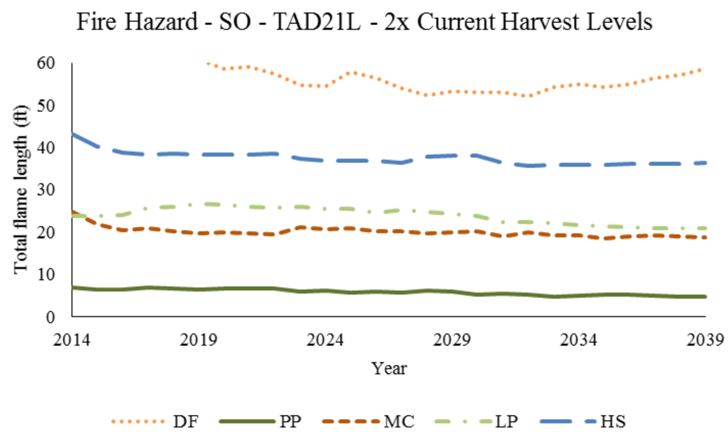


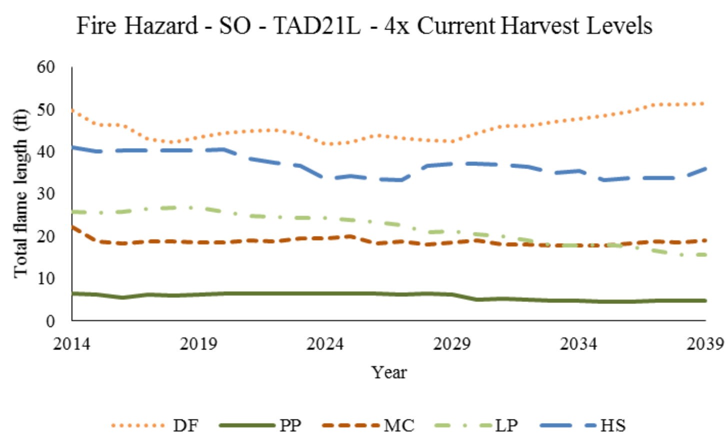




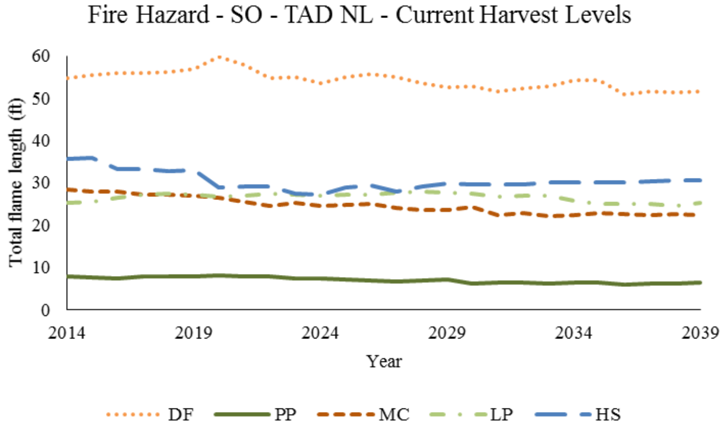
Figures A18-A20. Potential total flame length over 25 years of management with a thinning from below prescription under various harvest intensities within the southern Oregon subregion

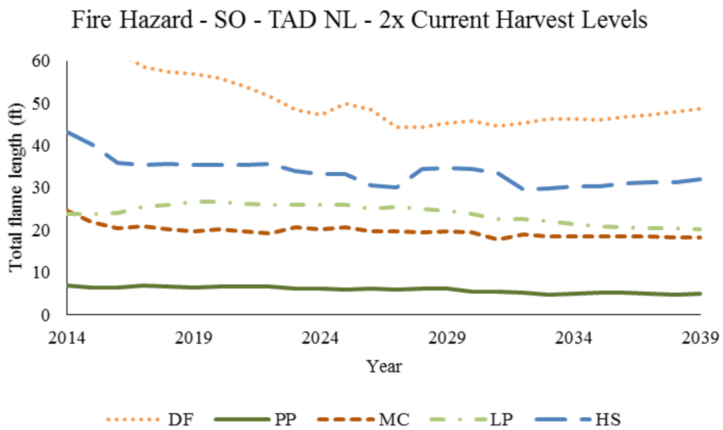


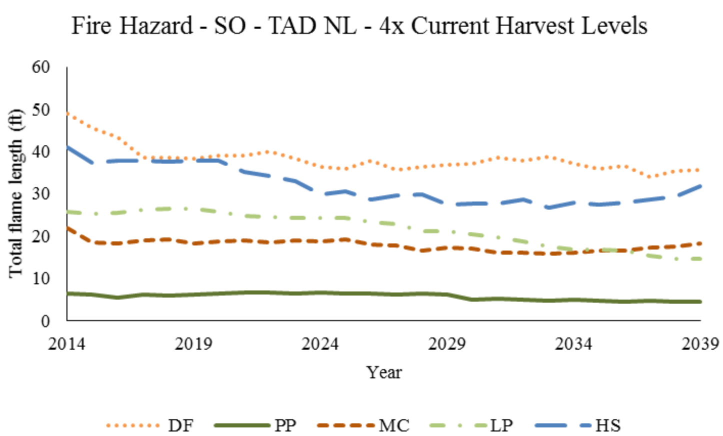




Figures A21-A23. Potential total flame length over 25 years of management with a thinning across diameter classes with a 21” diameter limit prescription under various harvest intensities within the southern Oregon subregion







Figures A24-A26. Potential total flame length over 25 years of management with a thinning across diameter classes with a no diameter limit prescription under various harvest intensities within the southern Oregon subregion.