AN ABSTRACT OF THE DISSERTATION OF

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Title: Managing for Landscape Resilience in the Frequent-Fire Forests of Central Oregon

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Wildfire in dry, frequent-fire forests is a pressing issue for natural resource managers, communities and politicians in the western United States. Area affected by wildfire has climbed steadily over the last twenty years and is expected to increase in the future. Recognition of the importance of both social and biophysical influences on wildfire management has led to calls for integrated social-ecological research and new methods for studying ecosystems that incorporate both social and biophysical science. This project integrates social and biophysical research methods to address research questions related to wildfire, forest dynamics, and management of national forestlands in Oregon's Central Cascades. Qualitative content analysis is paired with landscape modeling to answer research questions related to managing frequent-fire forests for landscape resilience. Collectively, both approaches present a more complete understanding of challenges and opportunities related to managing for landscape resilience than could either approach on its own. One common thread identified in both approaches is the importance of bringing more fire onto the landscape, either through the use of prescribed fire or carefully managed wildfire. Both interview respondents and modeling results demonstrate the importance of using managed fire to reduce the risk of high-severity wildfire. Another compelling result of the analysis stemmed from modeling simulations which showed current levels of management to lead to the same amount of high-severity fire as a no management scenario. Finally, the modeling results demonstrated that not every acre has to be managed to reduce wildfire risk across a larger landscape. Landscape-scale management plans are thus critical to the development of effective management strategies, and forest plans may fulfill this role. Forest Service budgeting based on forest plans could lead to more efficient, effective, and responsive public administration of federal lands.

Managing for Landscape Resilience in the Frequent-Fire Forests of Central Oregon

by

Emily K. Platt

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

Emily K. Platt, Author

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Alan Ager provided information on historic weather inputs and processing for Chapter 3.

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Chapter 1

Introduction: Integrated Social-Ecological Research in Central Oregon

Wildfire in dry, frequent-fire forests is a pressing issue for natural resource managers, communities and politicians in the western United States. Area affected by wildfire has climbed steadily over the last twenty years and is expected to increase in the future due to climate change (Brown et al. 2004). The influence of wildfire on forestlands and communities can be dramatic and significantly alter both ecological values, such as the amount of old and young forest, and social values such as the view from popular hiking trails or timber production. Recognition of the importance of both social and biophysical influences on ecosystem dynamics (Hobbs 2007, Choi et al. 2008, Kay 1993, Dombeck et al. 2004) has led to calls for integrated social-ecological research (Collins et al. 2011) and new methods for studying ecosystems that incorporate both social and biophysical science (Liu et al. 2007, Ostrom 2009). This project integrates social and biophysical research methods to address research questions related to wildfire, forest dynamics, and management of national forestlands in Oregon's Central Cascades.

Chapter 1 provides an overview of key concepts developed throughout the dissertation. Chapter 2 focuses on Forest Service administrative systems and the alignment of organizational structures and processes with Agency goals and objectives. Chapter 3 outlines the development and evaluation of an integrated social-ecological landscape model using the Envision modeling platform. Chapter 4 focuses on simulation scenarios used to explore landscape resilience under six different management scenarios.

Social and Political Drivers of National Forest Management

Restoration has become a management priority for western federal lands with congressional and administrative policies increasingly directing the Forest Service to focus on restoration management. Congressional direction on restoration management has come through several recent laws. In 2009 Congress passed a law creating the Collaborative Forest Landscape Restoration Program (CFLRP) which encourages 'the collaborative, science-based ecosystem restoration of priority forest landscapes' (16 U.S.C. 7303). Like other congressional policies, the CFLRP links restoration to wildfire risk reduction and the reduction of wildfire management costs by re-establishing natural fire regimes and reducing the risk of uncharacteristic wildfire (e.g. Healthy Forest Restoration Act of 2003, FLAME Act of 2009). Twenty-four landscape projects have been funded by the CFLRP to date (Table 1.1). In a report directed by Congress, the Wildland Fire Leadership Council (2010) likewise recognized the link between wildland fire management and restoration. The report states that 'restoring and maintaining resilient communities and landscapes is one of the primary factors that presents both challenges and opportunities for addressing wildland fire problems' (WFLC 2010). The National Cohesive Wildland Fire Management Strategy, also mandated by the FLAME Act, calls for restoration and maintenance of landscapes (National Strategy 2014). Wildfire management is integrally linked to the concept of restoring federal lands in the West, in part because of the mounting and unsustainable cost of wildfire suppression (Dombeck et al. 2004), now at over 2 billion annually in the United States (Stephens et al. 2013).

Table 1.1. Collaborative Forest Landscape Restoration Program projects funded (FY 2010-2012)

State	Number of CFLR projects	Total CFLR Funding ($)
Arizona	1	2,000,000
Arkansas	2	1,301,000
California	3	2,164,000
Colorado	2	1,446,000
Florida	1	1,171,000
Idaho	3	3,774,000
Mississippi	1	2,710,000
Missouri	1	617,000
Montana	1	1,029,000
New Mexico	2	792,000
North Carolina	1	605,000
Oklahoma	1	342,000
Oregon	3	6,500,000
Washington	2	2,598,000

The Forest Service has responded through formal and informal processes. The Forest Service calls for restoration in its most recent strategic plan as well as in recently revised regulations that guide the development of management plans for each of the nation's 155 national forests and 20 national grasslands. One strategic plan goal is to 'ensure national forests and private working lands are conserved, restored, and made more resilient to climate change, while enhancing water resources' (USDA n.d.). More formally, the regulations that guide the development of national forest management plans (forest plans) require management to 'maintain or restore the ecological integrity of terrestrial and aquatic ecosystems and watersheds' (NFSLMP 2012). Ecological integrity is defined as 'the quality or condition of an ecosystem when its dominant ecological characteristics occur within the natural range of variation and can withstand and recover from most perturbations imposed by natural environmental dynamics or human influence'. Forest plans must also consider dominant ecological processes, disturbance regimes, and stressors including wildland fire and climate change. Forest plans must specifically address wildland fire, opportunities to restore fire adapted ecosystems, and opportunities for landscape scale restoration (NFSLMP 2012). Secretary of Agriculture Tom Vilsack demonstrated the Agency's commitment to restoration in a speech declaring restoration of watershed and forest health to be the primary management objective of the USDA Forest Service (Vilsack 2010).

Public support for active forest restoration is also increasing across the west. Collaborative forest management has resulted in new partnerships between diverse stakeholders and land managers (Charnley and Poe 2007). Oregon was at the heart of the contentious debate over old-growth forest logging and conservation (Durbin 1996), and despite this – or perhaps because of it – over ¾ of Oregonians now support active forest management (Abrams 2005). Collaborative forest management may increase eroded trust in land management agencies (e.g. Franklin and Johnson 2012) and support institutional flexibility, cited by ecologists as important to the Agency's ability to respond to climate change (Millar et al. 2007, Liu et al. 2007) as well as local landscape dynamics and ecological variability (Stine et al. 2014, Kennedy and Wimberly 2009).

Administrative theory suggests different approaches for analyzing the role of governance in addressing challenges related to wildfire and restoration management. The role of hierarchy, politics, interest groups, non-governmental partnerships, and new public management are still heatedly debated among public administration theorists and political scientists (Kettl 2000), and no single way of theoretically addressing public governance issues is accepted (Kettle 2000). The relation of public administration governance issues and national forest management are explored in more depth in Chapter 2.

The political and social focus on restoration has highlighted outstanding ecological questions as well.

Ecological Drivers of National Forest Management

Our knowledge of forest systems and fire behavior has increased dramatically over the past few decades, and researchers and managers alike largely agree that past management practices have had unintended consequences on today's forests (Spies and Turner 1999, Hessburg et al. 1999, Agee 1993, Merschel 2012, Hagmann et al. 2013). Current dry forest landscapes have been homogenized and often fragmented (Hessburg 2003). Old fire resistant trees have been lost, understory diversity has been reduced, and high stand densities on dry sites have increased susceptibility to drought and insect outbreaks (Perry et al. 2011). Fuel continuity has increased in dry pine forests (Covington 2003). The cumulative changes to fuel beds and structure in these frequent-fire forests has led to an increased probability of high-severity fires and insect outbreaks (Stine et al. 2014, Hessburg et al. 2005, Covington 2003). Wildfire suppression is an often-cited cause of these forest conditions (Weaver 1959, McNeil 1975, Hemstrom 2001, Coops et al. 2012, Knapp et al. 2012). Yet wildfire is a natural, and unavoidable, process in many western forest ecosystems (e.g. Agee 1993, Weaver 1959, Bork 1984) making suppression an impractical and ecologically maladapted management approach (Hessburg et al. 2005, Mutch 2013, Arno and Fiedler 2005). While low intensity fires under moderate weather conditions can be suppressed, wildfires under the most extreme weather conditions largely cannot (Stephens et al. 2014, Platt unpublished data, FTCWRC 2012). The current suppression strategy therefore results in the suppression of only 98% of all wildfires while the 2% that cannot be contained result in the vast majority of area burned. This high level of suppression has led to less low- and mixed-severity fire and conditions conducive to more high-severity fire (Stine et al. 2014, Miller and Safford 2012, Hessburg and Agee 2003). Moreover, fire historically added heterogeneity to the landscape that could limit the size of future fires by creating landscape patches more likely to burn at low or mixed severity (Odion et al. 2004, Agee 1998). Reintroduction of fire into frequent-fire forests (Noss et al. 2006, Reinhardt et al. 2008, Wohlgemuth et al. 2006) and restoration of resilient forest structures and patterns are suggested as important solutions to reducing the risk of large high-severity wildfires on federal lands in the West (Millar et al. 2007, Hessburg et al. 2007, Stine et al. 2014).

Current forest policies are based in restoration ecology, which is still a young field where debate about the most basic of all restoration premises – restoration goals – is common (e.g. Miller and Hobbs 2007). Perspectives differ on what restoration means and how it should be approached. The Society for Ecological Restoration (SER) defines restoration as the process of assisting the recovery of an ecosystem that been damaged, degraded or destroyed (see www.ser.org). While this definition is helpful, key questions remain unanswered such as what are appropriate goals for restoration projects and how can restoration targets be set for dynamic ecosystems? Management based on natural disturbance regimes has been suggested as a way to maintain biodiversity (Spies and Turner 1999, North et al. 2009) and reduce the potential for high-severity fire in areas with historical low- and mixed-severity fire regimes. This approach addresses several challenges inherent in setting restoration goals.

First, research has shown ecosystems to be dynamic (Shugart 1984), with multiple potential ecological realizations and deterministic succession as the exception rather than the rule (Whisenant 1999). 'Natural states' are thus elusive and always changing (Jackson and Hobbs 2009). This relatively new paradigm for conceptualizing ecosystems (Wu and Loucks 1995) views historical conditions as a series of realized points along one of many possible paths, a dynamic and contingent ecosystem (Cadenasso et al. 2006), rather than a predictable, self-regulating, and closed system where human influence and disturbance can be ignored (Wu and Loucks 1995, Spies and Turner 1999). Spies and Turner (1999) define the new paradigm as embracing ecosystems as dynamic with multiple possible successional pathways and endpoints, recognizing the strong influence of both disturbance and human influence on ecosystem dynamics. Management modeled on historical disturbance patterns may better incorporate the fundamental influence of disturbance regimes on ecosystem structure, function and processes.

Second, disturbance-based management incorporates knowledge of historical landscapes and processes without locking managers into unsustainable or unrealistic management regimes. Historic range of variability (HRV) is often used by researchers, land managers, and policy makers as a measure of how much a given area has changed from a historical state (e.g. Wimberly et al. 2000, Nonaka and Spies 2005, NFSLMP 2012). The development of the HRV concept complemented the view of ecosystems as dynamic and enabled managers to move away from the idea of restoring landscapes to a single historical reference condition. Yet HRV has two key limitations. A historical timeframe must be selected to define the historical range of natural conditions, and the timeframe chosen is merely a single realization of a dynamic and contingent ecosystem. Also, aiming to restore historical conditions assumes that key environmental variables of the historical period were similar to those that exist today. For example, the mean temperature and the seasonal temperature fluctuations should be comparable to those experienced today. However the pre-settlement period, often selected as the reference timeframe, generally falls within the Little Ice Age (~1400-1900) where the climate conditions were much different than they are today (Millar and Brubaker 2006, Whitlock 1992). Climate change will continue to alter environmental conditions (Blate et al. 2009, Mote et al. 2003), increasing the potential for historical forest states to be misaligned with current environmental conditions. A rise in temperature is expected to lead to drying of the soil column and increased tree stress, decreased productivity at the lower tree line, increased productivity at the upper tree line, and a longer fire season that could increase both fire frequency and severity (Mote et al. 2003). In recognition, restoration ecologists recommend shifting away from the static and increasingly unrealistic view of ecosystems as particular assemblages in particular places toward a more dynamic and flexible approach that considers a range of strategies for dealing with uncertainty about future conditions (Hobbs et al. 2009, Falk 2006, Choi et al. 2008). Disturbance based management adds flexibility to the HRV concept by acknowledging the importance of changing environmental conditions while still incorporating knowledge of historical ecosystem dynamics and response to disturbance in order to anticipate ecosystem response today.

While restoration of historical conditions may in some cases minimize risk and be an adequate restoration objective (Jackson and Hobbs 2009), a singular focus on restoring historical conditions does not assure managers of the same ecosystem response today that occurred historically. Not only have environmental conditions changed, but often key structural ecosystem attributes have been altered. For example, researchers in central Oregon's pumice plain have found structural changes in lodgepole pine forests that make current forests less likely to burn at mixed severity than historically because of the decline of a shrub component which carried fire in the past (Heyerdahl et al. 2013). The shrub layer historically regenerated after fire and fire exclusion has led to a decadent shrub layer not likely to carry fire into the canopy (Heyerdahl et al. 2013). Today a high-severity fire driven by strong winds is more likely (Heyerdahl et al. 2013). In addition, new interactions between species are likely to occur, and novel species assemblages can be expected (Jackson and Overpeck 2000, Millar and Brubaker 2006). Recruitment seems to be especially sensitive to climate, and different species may reproduce successfully today than one hundred or three hundred or five hundred years ago when today's forests were seeds and saplings (Millar and Woolfenden 1999). For example, cooler and wetter conditions may have contributed to the wave of grand fir establishment, along with grazing and fire suppression, in the late 1800s and early 1900s in central Oregon (Merschel et al. 2014).

Where there is a misalignment between environmental conditions and forest conditions, an increasing level of management input will be needed to maintain forest conditions and could create forests ill-adapted to current conditions and more susceptible to undesirable changes (Stine et al. 2014, Millar et al. 2007). Focusing on maintaining or recovering natural processes (e.g. productivity, carbon sequestration, fire) may be more realistic than trying to maintain particular states or species assemblages.

Third, disturbance based management is directly related to resilience, an increasingly popular focus for natural resource managers and researchers (Harris et al. 2006, Palmer et al. 2006, North et al. 2009, Magness et al. 2011, Bagchi et al. 2012, Franklin and Johnson 2012, Churchill et al. 2013). Despite the recent appeal of resilience, it can be a fuzzy and ill-defined concept and is not always desirable (e.g. in the case of resilient non-native plant species). Most often, resilience is described as the capacity of an ecosystem to recover from stress or a disturbance. Suding and Hobbs (2008) define ecological resilience as the amount of change a system can undergo and retain the same structure, function and feedbacks though it is unclear how much change may be consistent with this view of resilience. Holling (1973) suggests resilience should be thought of as the persistence of relationships within a system and the ability of the systems to absorb changes of state variables, driving variables, and parameters and still persist. In all cases, if the resilience of a system is exceeded, it is pushed to another state. The new state may be quite resilient itself, and pushing the system back to its former state could require extensive inputs.

Building on Holling (1973) and Suding and Hobbs's (2008) definitions, I define metrics of landscape resilience to fire. These metrics are based on the hypothesis that stand scale resistance to fire is associated with landscape scale resilience to fire. Resistance is the ability of a tree to withstand burning without mortal damage or a stand to withstand wildfire with limited mortality. Stand-scale metrics of resistance to fire include:

1. Large and giant trees. Large and giant trees (> 20" dbh) are generally more resistant to fire than smaller trees (Agee 1993).
2. Surface fuel model. Surface fuels are directly linked to flame length and thus fire severity (van Wagtendonk 2006, Scott and Burgan 2005).
3. Canopy cover. Canopy connectivity is directly associated with active crown fire (van Wagtendonk 2006).
4. Cover type. Some vegetation cover types are more resistant to fire than others due to life-history traits of component species and adaptations to fire (Agee 1993).

At the landscape scale, resistant stand characteristics would be expected to lead to:

1. Relatively low levels of high-severity fire. The amount of high-severity fire should be considered as a continuum rather than a threshold. The key is likely whether the amount of high-severity fire creates a positive feedback that would tend to destabilize the system. The amount of high-severity fire required to create such a positive feedback is likely to vary based on landscape and vegetation characteristics.
2. Stability of vegetation classes over time. Stability of vegetation classes over time can be used as a proxy for the persistence of relationships within a system (Holling 1973). Disturbance and vegetation succession are key drivers of landscape change (Spies and Turner 1999). Stability in the amount of particular successional stages in a landscape may then be used to indicate continuity of the relationship between disturbance and vegetation succession at the landscape scale. Stability is not meant to imply a single set amount but rather a level around which the landscape fluctuates and returns (Holling 1973).

These landscape scale metrics of resilience will be applied in Chapter 4.

Disturbance Framework

Disturbance can be used as a framework that integrates resilience, historical ecosystem knowledge, and the new paradigm of dynamic ecosystems. A conceptual framework is developed below to facilitate understanding of the role of disturbance in shaping landscapes. The framework focuses on frequent-fire forests and disturbances in these landscapes including wildfire, management, insect disturbances, and successional change. Anticipated climate changes such as a longer fire season, more drought, earlier snow melt, and increased forest mortality from insect outbreaks (Brown et al. 2004, Mote et al. 2003, Vose et al. 2012) are also considered.

Environment and climate define the range of possible vegetation types found across a landscape. Environmental influences include relatively stable landscape attributes such as soil type and topography. Climatic influences include precipitation, temperature and seasonal patterns of each. Vegetation type is a function of climate and environment as well as internal biotic interactions and the interaction of vegetation type with disturbance (Spies and Turner 1999). In frequent-fire forests in the Pacific Northwest, successional trajectories are shaped in large part by disturbance extent and severity (Stine et al. 2014). In the disturbance framework (Figure 1.1), vegetation refers to the amount and distribution of different classes of vegetation cover types, sizes, levels of canopy cover and layering, and amounts of surface fuel. Directly influenced by interactions with vegetation (Stine et al. 2014), disturbance is also shaped by environment and climate, often mediated by vegetation. Disturbance includes the severity, extent and timing of disturbance and incorporates biotic, abiotic and management disturbance.

The disturbance framework is intended for consideration at the landscape scale. The definition of landscape used by Stine et al. (2014) is used here wherein local landscapes are generally one to several subwatersheds and regional landscapes are the all the local landscapes that comprise an ecological subregion, e.g. a set of landscapes. Disturbance and resilience can only be reasonably conceptualized at the regional landscape scale because disturbances at the regional landscape scale can significantly affect patterns at the more local scale (Stine et al. 2014). For example, a wildfire might burn a local landscape entirely at high-severity but the regional landscape may retain heterogeneity and a suite of forests with different age classes, mortality levels, etc. Considering resilience at a scale smaller than the size of these fires could lead to an assessment of disturbance patterns and resilience that doesn't adequately reflect landscape processes. Likewise, while microclimate differences may be influential in affecting stand and meso-scale resilience (e.g. south-facing ridges), climate change is expected to alter aspects of climate across much broader landscapes. Considering resilience to climate change at too small of a scale would not adequately account for landscape context of stands or subwatersheds, or the potential for adaptation across or within shifting climate zones. Considering disturbance and ecological resilience at the landscape scale aligns analysis with the scale of disturbances such as wildfire.

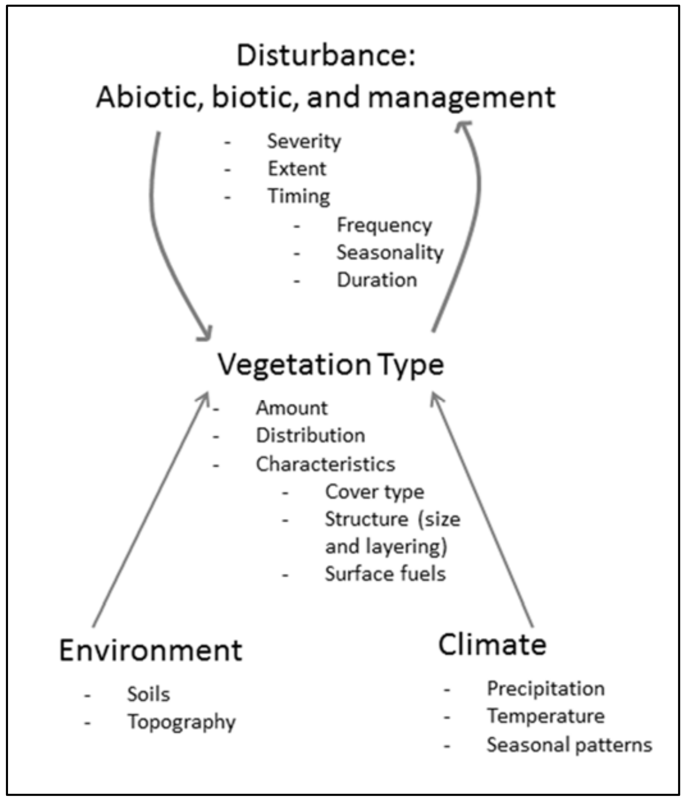

Figure 1.1. The disturbance framework is intended to facilitate understanding of the role of disturbances like wildfire in large regional landscapes.

The disturbance framework highlights the feedback between vegetation characteristics and disturbance. Landscape management must not only address disturbance processes at the scale at which the disturbances occur (Stine et al. 2014) but also the vegetation processes that form the foundation of ecosystem response to disturbance (Spies and Turner 1999). Managing disturbance without consideration of vegetation processes would discount the importance of key establishment phases and biotic competition that may alter the desired ecosystem response to disturbance (Spies and Turner 1999). The disturbance framework invites researchers and managers to develop and test hypotheses about the interactions or feedbacks between disturbance (management or natural) and vegetation communities and the strength of these interactions. The disturbance framework also invites testing of the relative importance of disturbance or vegetation characteristics in shaping landscape dynamics. Testing which part of a system is most responsive to management or natural disturbance under what conditions could provide information useful for both conservation and active management purposes.

Disturbance Framework Application

The framework is applied in an example of a frequent-fire forest type in central Oregon below. Dry mixed conifer forests in central Oregon are 2-3 times as dense as historical forests in the same areas in the 1800s, when the climate was cooler and wetter (Merschel 2014, Hagmann et al. 2013, Millar and Woolfenden 1999). Moreover, fire suppression has led to a homogenous landscape rather than one in which patches of tens to hundreds to the thousands of acres (Spies et al. 2006, Agee 1998) have burned in the recent past. Using the disturbance framework, one might start by asking what kind of effect the vegetation changes will have on disturbance regime severity, extent or timing. In this case, research suggests such areas are conducive to high-severity fire because of the structure created by shade-tolerant trees, high surface fuel loads and interconnected, dense forest canopies (Hemstrom 2001, Hessburg 2005). Wildfire in 20^{th} century has been less frequent due to fire suppression (Stine et al. 2014, Miller and Safford 2012, Hessburg and Agee 2003), creating conditions for less frequent but larger and more severe wildfires. To assess the resilience of dry mixed conifer forest, one would need to know how the disturbance regime affects vegetation structure and how the resulting vegetation structure may in turn affect the disturbance regime. If high-severity fire begets more high-severity fire, as suggested by Odion et al. (2004) and Spies et al. (2006), a positive feedback loop may exist that could destabilize the system. If, however, high-severity fire creates a negative feedback, perhaps by reducing surface fuels and thus potential fire severity, high-severity fire could act as a stabilizing influence. The feedback created by fire could vary temporally as well. High-severity fire removes most living biomass from a site and sets the stage for early seral vegetation communities including grasses, shrubs, and young trees. While many tree species in frequent-fire forests have adapted properties to resist the effects of fire, some properties – such as thick bark – take time to develop and aren't yet present in young stands (Agee 1993) making young trees generally more vulnerable to high-severity fire. The frequency of high-severity fire thus might be one key to landscape feedbacks in dry mixed conifer forests.

If high-severity fire does create a positive feedback leading to more high-severity fire and this type of fire regime is not desired, can the vegetation characteristics be altered enough to affect the severity or extent of wildfire at the landscape scale? If so, how much management activity might be required and how should it be distributed on the landscape? What types of activities would be most effective? Is there public support and social license to implement management activities? The disturbance framework creates a context in which to consider these types of questions and frame hypotheses about how interactions between vegetation and disturbance shape landscapes over time.

Summary

Movement toward restoration- and resilience-based land management highlights the need for research on a series of related topics. This dissertation will focus on three:

1) Are the administrative systems of the Forest Service aligned with current management goals and objectives on the Deschutes National Forest?
    a) Does the administrative system have enough flexibility to address local management opportunities and challenges?
    b) From the perspective of federal land managers, are the "right" kinds of activities being implemented to achieve management goals and objectives?
    c) Are federal land managers able to achieve their management goals and objectives?
2) How do various management scenarios affect the resilience of forests in central Oregon?
    a) How is landscape resilience affected by wildfire under a no active management scenario?
    b) How does management modeled on historical disturbance regimes affect resilience of forests in central Oregon?
    c) How does size of treatment units, the amount of treatment, and treatment objectives affect resilience of forests in central Oregon?

3) Are current Forest Service administrative systems conducive to managing for resilient forests in central Oregon?

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Chapter 2: Managing for Landscape Resilience to Wildfire: Is US Forest Service Administration Effective?

Introduction

Fire, insects and other interrelated disturbance agents have long played integral roles in shaping forest patterns in central Oregon. Fire has become an increasingly important agent of change as conditions for large, intense wildfires become more common (Brown et al. 2004, McKenzie et al. 2004, Mote et al. 2003). Fire seasons are predicted to increase in length across the western United States (Vose et al. 2012), increasing the chance of more and larger wildfires. Fire exclusion and management have promoted the development of contiguous fuel beds that create conditions for larger fires whereas historically fires were often limited by a lack of contiguous fuels and in many cases a naturally patchy forest pattern (Weaver 1959, Hessburg et al. 2005). In addition the severity of fires is thought to be increasing (Miller and Safford 2012, Vose et al. 2012). Regardless of the specific cause, land managers in these dynamic forests must be ready to quickly shift strategies because fires and other disturbances can rapidly and dramatically alter these forests and catalyze change in successional pathways.

Large fires (many tens of thousands of acres) change the mosaic of old and young forests on the landscape and shape future forest structure, composition, and habitat values. Ecosystem services that local communities rely on – such as recreation and clean water – are also threatened by large, high-severity wildfires. For example, in central Oregon a single wildfire, the B&B, led to the loss of over 80% of one district's spotted owl nest cores (Platt unpublished data). In addition, high-severity wildfires cause greater tree mortality and can have substantially greater impacts on soil productivity and other conditions important for ecological recovery of forest communities (McNabb and Swanson 1990, Harvey et al. 1994). While high-severity wildfires certainly played a natural role in western forests in the past, conditions for large, high-severity wildfires have greatly increased over the past 100 years (Miller and Safford 2012, Barrett et al. 1997, Hessburg and Agee 2003, Hagmann et al. 2013).

Fire has become an increasingly important political and social issue as well. As is often the case with natural resource issues, the most pressing aspects are largely social (Williams, Wood, and Dombeck 1997). Wildland fire management was only 21% of the Forest Service discretionary budget in 2000 and by 2008 it was at 43% (Calkin et al. 2011). It currently stands at about 50%, or over 2 billion annually (Stephens et al. 2013). In an era of declining federal budgets, the focus on fire inevitably limits resources available to other important management areas like recreation, timber, and conservation.

Perhaps the primary social issue related to wildland fire today is the wildland urban interface (WUI). The expansion of development at the edge of large forested areas dramatically affects natural resource management related to fire. The precipitous rise in the cost of wildland fire management in recent years has largely been driven by suppression efforts tied to protecting private property in the WUI (QFR 2009, USDA OIG 2006). In addition, the development of homes in the WUI pressures government officials to alter their broader land management strategies to accommodate new dwellings. In particular, in frequent-fire areas across the West, the federal government actively suppresses as much wildfire as possible despite knowledge that fire suppression invariably leads to larger, more severe fires in the future (Marlon 2012, North et al. 2012).

Likewise, the political climate that shapes forest management in central Oregon is constantly shifting. The Forest Service is the largest single forest manager in central Oregon, and their management goals are influenced by congressional mandates and administrative policies, programs, and initiatives. President Clinton, for instance, supported a shift toward ecosystem management as part of a deal to lift the ban on old growth logging (Grumbine 1994). President Bush launched the Healthy Forest Initiative to address forest issues related to wildfire (Dombeck et al. 2004). During the Obama Administration, Congress passed the Collaborative Forest Landscape Restoration Act to fund large, community-supported restoration projects. Again, the shifting policy landscape requires forest managers to be adept at shifting management activities to achieve new objectives. Yet there is a lack of research on governance issues related to managing fire-prone landscapes. The neglect of governance issues is not unique to fire management. This weakness has been found related to climate change adaptation and forest management as well (Wellstead et al. 2013, Agrawal et al. 2008) though governance factors may be essential to developing successful management strategies (Wellstead et al. 2013).

The inherently dynamic nature of fire-prone forests combined with change and uncertainty related to climate create a need for management that can adapt to shifting ecological conditions. Likewise, changing public opinion, growing scientific understanding, and political currents shape the management landscape for frequent-fire forests and create a changing management framework. This may not be particularly problematic for private landowners who can assess the health of their lands and their management goals and adjust their management strategy accordingly. If, however, a management strategy is more difficult to adjust once it is set in motion, as might be the case for federal lands, management strategies may or may not be well-suited to shifting ecological or social conditions. A need for flexible administrative systems that reflect dynamic ecosystems and accommodate diverse interests has been noted (Brown 2003, Doremus 2001). Indeed, Dombeck et al. (2004) call for agency innovation as one of four key requirements for successful fire management.

This study aims to help build a better understanding of how well Forest Service administrative systems support attainment of agency goals and objectives and adapt to changing ecological and management influences. Some studies suggest relatively stable management structures (e.g. organizational incentives, budget priorities) despite changing objectives (Butler and Goldstein 2010, Kennedy and Quigley 1998, USDA OIG 2006). Yet it is unclear if the stability of these organizational systems interferes with the agency's ability to accomplish its goals and objectives. To explore this issue, I analyzed the ability of forest managers to meet their management goals and objectives related to land management, wildfire, and restoration. In addition, I assessed managers' ability to adapt to changing social, political, and ecological conditions in a geographic area undergoing rapid ecological and social change: central Oregon. This research specifically addresses the following question: are the administrative systems of the Forest Service aligned with current management goals and objectives on the Deschutes National Forest? Alignment between administrative systems and management goals and objectives will be indicated by:

1. Deschutes National Forest achievement of land management goals.
2. Deschutes National Forest achievement of land management objectives.
3. Ability of district rangers to address unique ecological, social, or economic issues.

Conceptual Background

<u>Public Administration</u>

Early administrative theorists (Goodnow 1900) focused on the importance of a clear delineation between politics and administration. Efficiency was considered the measure of good governance. Later administrative theorists recognized the inextricable link between politics and administration

(Long 1949, Bender and Moe 1985, Tucker and Ostrom 2005) and noted that democratic governance may lead to administrative systems that are not particularly efficient (Frederickson 2003). However, movement away from the classical administrative theory focus on structure, efficiency and the role of politics has been scattered, and generally accepted theories of public administration are lacking (Kettl 2000).

Many administrative theorists have followed Simon's (1945) lead and focused on decision making as the key to understanding public administration, entailing a shift in focus from organizational structure toward human behavior (Kettl 2000). The decision making focus has remained strong in the field of public administration and Simon's concept of "satisficing" continues to be used in decision making analyses today (e.g. Wiebe 2000, Swain 2000). Satisficing refers to decision making that is "good enough" (Frederickson 2003), or as Padgett (1981) describes, the first decision that meets the varied criteria and rules that shape the decision making environment. Satisficing is closely linked to the concept of bounded rationality, which postulates that sub-optimal decisions are made because of a lack of complete information and a lack of information processing capacity. A very different theory of bounded rationality holds that choices are based on shared understanding, organizational identity, and accepted rules.

Institutional theorists utilize decision theory but have a broader focus that incorporates consideration of organizational structure, individual and group behavior in an institutional context, and the influence of professional and cultural norms (Frederickson 2003). Institutional theorists view public organizations as a collection of rules, roles, norms and expectations that constrain choice and behavior (Frederickson 2003). Institutional theorists have developed frameworks that collect and organize potentially important factors (Ostrom 2011) but have not yet developed theories with explanatory power (Frederickson 2003).

Administrative theorists have also begun to incorporate analysis of networks of relationships rather than simple organizational hierarchies in order to capture the increasingly important interactions between public, private and non-profits organizations (Frederickson 2003). Still others have turned back to the roots of administrative theory and focused on management systems once again divorced from politics and other external influences (Osborne and Gaebler 1992). While the research question at hand would certainly guide selection of the 'right' administrative theory, most administrative theory is incomplete and requires additional development (Frederickson 2003).

Several aspects of public administration have important implications for decisions made by the US Forest Service. First, the role of the executive branch and the legislative branch in shaping decisions made by street level administrators is central to the century-old debate about federal agency discretion and directly affects the ability of agency decision makers to adapt administrative systems to changing social and ecological realities. Political scientists and ecologists have argued for more agency discretion to help address federal management challenges (Thomas 1996, Mashaw 1995) and enable managers respond to changing ecological conditions (Spies et al. 2010), climatic influences (Mote et. al. 2003, Millar et al. 2007), and time-sensitive windows for effective ecological responses (Doyle and Drew 2008). Likewise, social ecologists find that emerging natural resource issues are best dealt with locally to avoid escalation into disruptive issues requiring congressional or judicial intervention (Priester and Kent 1997). While the call for flexible, nimble natural resource agencies echoes across scientific disciplines, others argue less discretion is more appropriate because Congress is more accountable to the public and should be responsible for inherently political decisions (Culhane 1981, Nie 2004). Likewise, leaving highly charged issues to be settled locally may create long-standing controversies that can erode public trust and exacerbate controversy (Dombeck et al. 2003). Yet some argue that congressional oversight amplifies pathological tendencies in public administration by creating pressure to cater to special interests and subvert public interests (West 1995). Regardless, Congress exercises significant executive oversight through Congressional hearings (West 1995) and exerts strong influence on Agency priorities through the budget process (Padgett 1981). Even when the majority in Congress is from the same political party as the president, administrative decision making is inherently subjected to competing influences (West 1995). While administrative theorists have long accepted that politics and administration are inextricably linked, it is not clear when or under what conditions effective and responsive (West 1995) governance is best achieved. Are there conditions under which legislative engagement in administrative processes is critical to achieving effective and responsive governance? Are there conditions under which administrative discretion is a better option?

Organization Theory

The Forest Service is a centralized, hierarchical organization. Traditional organizational theory assumes that executives at the top of an organizational hierarchy have the broadest perspective on policy issues and are thus best able to keep the agency's activities in tune with public interest (Rourke 1984). However, a revisionist perspective in organizational theory argues that responsiveness requires significant delegation to lower levels of administration where government is more attuned to the needs and interests of local communities (Rourke 1984). In this view, centralized power could widen the split between knowledge and power that is endemic in modern bureaucracy (Rourke 1984). Priester and Kent (1997) argue that the Forest Service was more effective in the past because it operated more effectively within local cultures, and as the agency became more centralized the links to local culture were disrupted. Links to local cultures are being re-created to some degree with the advent of collaborative groups focused on bringing together diverse interest to solve controversial natural resource dilemmas (Parkins 2008, Wondolleck and Yaffee 2000, Schuett et al. 2001).

In addition to the question of what level of delegation most effectively and responsively serves the public interest, bureaucracies are faced with the challenge of balancing fair and consistent processes with innovation and responsiveness to changing social and ecological conditions. On the one hand, rigid processes assure agency leaders of a high degree of conformity to agency perspectives, values, and policies (Kaufman 2006). Yet in a world in which ecological, social and political conditions are constantly in flux, policies and procedures must adapt, and rigid processes stifle the flexibility needed to conceive new ideas (Kaufman 2006, Kotter 1990, Jones 2001). Rigid policies and procedures may be effective until substantial change is needed (Kaufman 1981). Likewise, West (1985) reports that bureaucratic processes tend to narrow options early in the decision making process and close off new ideas that might surface later. Similarly, Kotter (1990) notes that rigid management processes tend to focus on short time frames, details, and eliminating risks rather than long-term strategies, big picture integration and calculated risk.

Herrfahrdt-Pahle and Pahl-Wostl (2012) propose a structure for thinking about institutional resilience and change. They suggest three types of change can be found in the literature: persistence, adaptation and transformation. Persistence can be thought of as the lowest level of change. Change occurs within the context of current norms and values. Underlying assumptions are not questioned.

The next level of change is adaptation, which Herrfahrdt-Pahle and Pahl-Wostl (2012) associate with double-loop learning. Double loop learning questions assumptions without questioning the underlying norms and values. Adaptation is important to ensure institutions don't get locked into a rigid command and control framework that is persistent and brittle, in which small disturbances can cause major disturbances or break-downs. Finally, if there is a deep mismatch between institutional function and the environment, a third type of change, transformation, may be necessary to create a fundamentally new institutional system. This third type of change involves a paradigm shift and learning process that includes questioning of values and norms.

My analysis assessed the influence of legislative and administrative rules and guidance on the ability of Deschutes National Forest managers to achieve land management goals and objectives. The influence of organizational structure on managers' ability to achieve goals and objectives was also considered.

Methods

<u>Study Area</u>

The study area is bounded on the west by the crest of the Cascade Range and on the east by juniper woodlands and Oregon's shrub-steppe. In the north, the project area includes the growing cities of Sisters (population 2,118) and Bend (population 79,109). South of Bend, a public-private landscape incorporates several small communities including La Pine (population 1,687) and Gilchrist (population 238). The focal lands in the study area are 650,000 hectares managed by the Deschutes National Forest (DNF) (Figure 2.1). The DNF is comprised of three ranger districts: Sisters (128,600 ha), Bend-Fork Rock

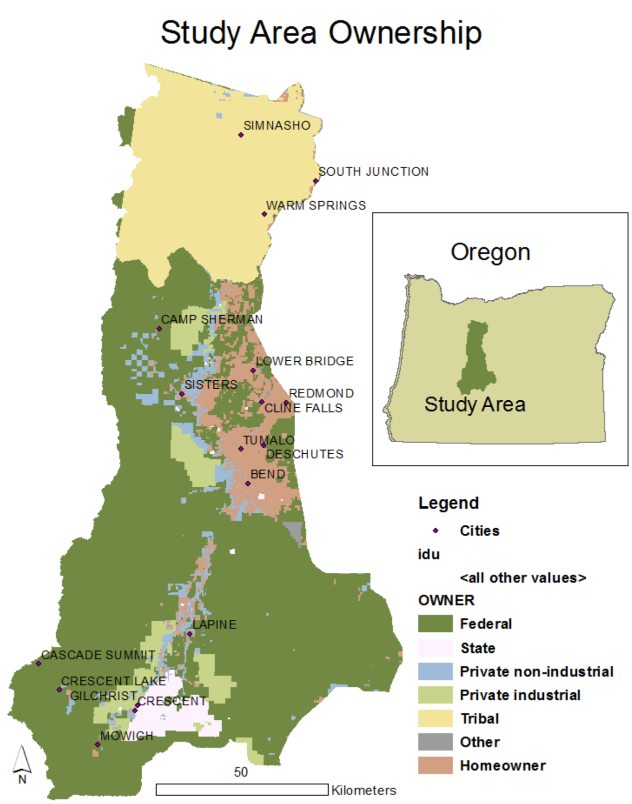

Figure 2.1. Study area ownership and geographical context.

(395,000 ha), and Crescent (124,700 ha). The three ranger districts report to forest headquarters. Forest headquarters reports to the Regional Office which reports to the Washington Office.

The varied climate and topography of the project area support a wide range of forest types including mountain hemlock, mixed conifer, lodgepole pine, ponderosa pine, and juniper. The natural fire history of the area varies with forest type and includes infrequent mixed- and high-severity fires in the western project area at higher elevations and frequent low-severity fires in the lower elevation, drier areas to the east (see Chapter 4).

Pre-1900, fires in the area generally included more mixed- and low-severity fire and less high-severity fire than currently occurs (Barrett et al. 1997). In addition, patch size in some forest types has increased over time (Agee 1999). These shifting spatial patterns have been linked to climate, timber harvest, fire suppression, road construction, and domestic livestock overgrazing (Hessburg et al. 1999, Vose et al. 2012). Climate change will likely continue to alter these patterns by increasing the magnitude or size of disturbance events like fire and insect outbreaks (Brown et al. 2004, Jump and Penuelas 2005).

Social conditions have changed as well. Central Oregon's population has climbed dramatically over the last two decades with Deschutes County growing 39.4% between 2000 and 2007 (US Census Bureau). Deschutes County is still Oregon's fastest growing county but slowed to a 5.2% growth rate between 2010 and 2013 (US Census Bureau) as the nation's economy slowed and Bend's booming building industry slowed. The area's relative newcomers often value recreation and Cascade views over commodity production (Sharp 2005). While distrust of the Forest Service was still high in the 1990s and early 2000s (Shindler and Toman 2003), over a decade of collaboration between the Forest Service and diverse public interests has begun to shift the tide. The Deschutes National Forest won funding for one of the nation's first Collaborative Forest Landscape Restoration (CFLR) projects, a federal program created by Congress in 2009 to "encourage the collaborative, science-based ecosystem restoration of priority forest landscapes." The strong working relationships between DNF leaders and community interests was a compelling factor in its selection as one of the nation's first ten CFLR projects.

<u>Qualitative Approach</u>

This research is grounded in qualitative analysis of thirty-two interviews of Forest Service staff at DNF headquarters and at each of the forest's three district field offices. Nine interviews of Forest Service staff at the regional and national offices also informed the analysis. Supplemental data sources used to test, deepen, and develop the analysis include activity data, GIS analysis, the DNF management plan, project planning documents, DNF budget data, and national Forest Service budget data. Qualitative analysis was selected for this exploratory research because of the inductive nature of much of the research and the inherently limited sample size (Bernard 1988) as interview respondents were required to be directly engaged in planning or implementing forest management activities on the DNF. Boeije (2010) describes the purpose of qualitative research as the description and understanding of social phenomena through flexible methods that use contact with the people involved to build understanding. Boeije (2010) further defines qualitative analysis as producing "rich, descriptive data that need to be interpreted through the identification and coding of themes and categories leading to findings that can contribute to theoretical knowledge and practical use."

<u>Data Gathering</u>

A guide for semi-structured interviews (Bernard 1988) was developed based on the research questions presented in the Introduction. The guide was used to gather specific information about current landscape conditions, management activities and their effects, management priorities, how priorities are determined, and opportunities and obstacles to meeting management goals and objectives on the DNF. Thirty-five interviews were recorded and transcribed. Six relied on notes taken during the interviews. Thirty-nine interviews were conducted in person and two were conducted by telephone. Respondents were purposively selected Forest Service staff directly involved in making decisions about land management activities in central Oregon. District rangers, silviculturists, fire specialists, wildlife biologists, ecologists, leadership at forest headquarters, and program managers at the regional and national offices of the Forest Service were interviewed between the winter of 2011 and the fall of 2012 (Table 2.1).

Table 2.1. Interview respondent specialties and positions

Position	Number interviewed
District ranger	5
Silviculturist/ forester	5
Fire specialist	5
Wildlife biologist	5
Ecologist	2
Planner or team leader	4
Budget specialist	3
Other headquarters staff	3
Regional or national administrator	9

Data Analysis

Following methods detailed in Richards (2005), I developed a unique hierarchical coding scheme to analyze the interview transcripts. Krippendorf (1980) noted that analytical constructs for institutional processes do not follow any easily generalizable format, and no existing coding scheme was identified that could be used to answer the research questions at hand. Interviews were coded manually, both to support understanding of the data and to identify important transcription errors (e.g. misunderstanding of key words such as fuel reduction, silviculture, and crown fire). In addition, significant differences have been found between computer coding and manual coding where concepts are relatively complex and inclusive (Linderman 2001), as is the case with some of the concepts studied in this analysis.

General code categories were initially broad and used to identify data in the transcripts generally relevant to the analysis. An interactive-hermeneutic approach to content analysis was used in which more selective categories for analysis were created during the process of reading the interview transcripts (Krippendorff 1980). For example, from the general coding category of institutional resilience, budget and planning subcategories were developed. Analysis was then directed by a growing understanding of the body of transcripts (Krippendorff 1980). Subcategories for both institutional and landscape resilience were developed based on an increased understanding of the data. Careful documentation of coding categories and an inter-coder reliability assessment was used to support reliability and validity of analysis (Kirk and Miller 1986). A 24.4% sample of the interviews was selected for the inter-coder reliability assessment. Code categories were deleted and code category descriptions were adjusted and added as needed to improve clarity and inter-coder reliability. Inter-coder reliability was 89.3%. See Appendix A for coding categories.

Coding was used to identify prevalent themes, assess the relationships between themes, and develop explanations for patterns found in the data (Krippendorf 1980, Richards 2005). Initial assumptions were tested with interview questions, content analysis of interview transcripts, an inter-coder reliability assessment, and supplemental data sources. The data were analyzed for themes that resonated across districts and type of respondent (e.g. ranger, biologist). Differences between districts and type of respondent were also considered as were linkages between institutional themes and landscape resilience themes. Consistent with grounded theory (Strauss 1987), analysis themes arose from the initial research questions as well as from the interview respondents. Explanations of patterns in the data were tested with interview data as well as data from other sources such as national laws and regulations, national and local planning documents, budget information, and activity data (Richards 2005). The number of times a theme was mentioned was tallied by district and for the overall set of interview transcripts. Stratification by program specialty (e.g. fire, wildlife) and district enabled analysis of differences in themes raised and their relative importance. Where multiple codes were located in the same place in an interview transcript, a natural linkage between coding themes was identified. The linkage data was explored in concert with transcript data that summarized how often themes were raised.

Results

Current Landscape Condition

The description of current forest conditions and the causes ascribed to those conditions as provided by respondents was coincident with current fire science (Hagmann et al. 2013, Hemstrom 2001, Hessburg et al. 2005). Respondents agree that conditions conducive to larger, more severe wildfire have increased on the DNF over the past 100 years and that high fire hazard forests dominate the landscape in a way inconsistent with historical conditions. In addition, respondents were in agreement that drought conditions and warmer summer temperatures increase the risk of high fire hazard conditions into the future. Not a single interviewee presented a description of current landscape conditions that conflicted with this overall view. Comments included descriptions such as, "Fire suppression policies have led to a lot of the conditions that we have now with a lot of dense understories, a lot of change in species composition and that sort of thing."

Management Goals and Objectives

Land management goals varied somewhat from district to district. Overall, however, there was a strong and consistent focus on 1) reducing wildfire risk in the wildland urban interface, 2) restoring frequent-fire ecosystems and forest resilience, and 3) providing recreation opportunities. On one district, in addition to the above goals, hydrologic restoration for fish was also a high priority. On a second district, providing spotted owl habitat over time was an additional high priority management goal. There was also variability in respondents' understanding of land management goals on a single district.

The Deschutes National Forest has activity targets associated with its land management activities, and I considered these targets to be management objectives. For instance, the DNF might have a target of reducing hazardous fuels on 10,000 acres of land each year. Objectives were more clearly defined and agreed upon than goals at both the forest and district levels.

Treatment Effect

While management priorities varied somewhat between districts, hazardous fuel reduction was a high priority objective on all three districts. Respondents were generally in agreement that fuels reduction work has been effective at reducing fire hazard on a local, site specific scale. Treating wildland-urban interface (WUI) areas has been a priority, and respondents generally agreed that forests near developed areas were in relatively good shape and had undergone real change from conditions ten years prior. Respondents reported beginning to consider the need to re-treat these areas in order to maintain the treatment benefit into the future though capacity is limited for such work. The spread of invasive weeds and discomfort with the habitat impact of mowing and grinding were raised as mild concerns in the context of the effect of fuel treatment work. Several respondents commented about the difficulty of knowing how effective treatments were until fire is put back on the landscape. Respondents were also in strong agreement that while fuel treatments are largely effective for the piece of ground they're on, the treatments need to occur at a larger scale. Respondents pointed out that such fuel treatments cover "just a skosh" of the landscape. A typical response was, "Some areas are very representative and exciting, but it's such a small percentage."

The remainder of the results focus on discussions with respondents about their goals, objectives and hopes for the landscape as well as obstacles or opportunities that have a strong influence on their ability to reach goals.

Budget Structure

The budget structure was the most-often cited obstacle to meeting management goals and objectives. Challenges related to the current budget structure were mentioned an average of 3.1 times in each interview on the DNF. The average ranged from 2 times per interview at the forest level up to 3.6 times per interview on one of the districts. To be clear, while capacity or general lack of adequate funding was mentioned, this concept area does not track those references and instead focuses on structural budget issues. Structural budget issues were raised by line officers, specialists and program managers. One program manager stated succinctly, "I just hate to keep saying it, but money drives what you do. So more than anything else, the budget drives the process." A line officer explained, "All budgets come with a narrative, a number and a target. That is a really important factor. You can paint that in a nice pretty picture, but at the end of the day that is a big part of what drives our priorities."

The Forest Service budget is divided into line items, and the line items can be seen as roughly equivalent to program areas, e.g. vegetation management is one line item, fuels reduction is one line item, wildlife is one line item. The Forest Service budget for fiscal year 2014 contained 83 line items. Each budget line item is linked to a measure or measures that track what has been accomplished for the given funds. For instance, the federal acreage of invasive species treated is tracked for the Forest Health Management line item, and the Land Management Planning line items tracks the number of land management plan amendments underway, the number of land management plan revisions or creations, and the number of land management assessments completed.

Respondents clarified that while the budget and targets are integrally linked, they are not linked in a 1-to-1 fashion. Facing decreasing budgets, districts may be expected to produce the same target, e.g. the same amount of board feet with less Forest Product dollars. A program manager closely involved in allocating budget funds stated, "I would have liked to see a better connection between dollars and targets, but that's just the way [its] drawn up." Forests and districts that meet their targets tend to be rewarded in the budget allocation process. A respondent explained, "The Deschutes is a high performing forest, so we get a lot of fuels allocation, for instance, because we are capable of treating a lot of acres."

Two factors related to the budget system were discussed by respondents as obstacles to meeting management goals and objectives. Because the budget is a key driver of management priorities, if line item funding and associated targets are not aligned with managers' professional judgment of need, a problematic misalignment exists. Two line items have been well-funded nationally and on the Deschutes National Forest in the recent past: Forest Products and Hazardous Fuels. These line items are associated with board foot production targets and acreage treated targets, making management activities that help meet these targets a priority. For instance, recreation management is a priority on the DNF and has increased in importance over the last decade along with the Bend area's dramatic population growth and concomitant increase in recreation visits. One specialist elaborates, "At some point the federal government is going to realize that we shouldn't be basing budget on board feet, we should be basing budget on visitation days or something to that effect … Recreation, it's like wildlife, we're pretty small because the budgets are pretty small."

The constraint created by targets isn't always a simple lack of funding for priority work. The timber target came up as a key constraint to meeting wildfire management objectives (hazardous fuel reduction) despite the hazardous fuel line item being better funded than timber on the DNF in recent years. One manager's comment was echoed by many others, "It makes me think of our stewardship projects in particular. There's a lot of acres with a little bit of volume. However treatments in those acres are no less important than they are in places that are high volume. It's just a different goal, different objective." A fire specialist explains, "So, historically the ranger … even though there may be a high fire danger area right here that really needs to get treated, if it doesn't have any valuable timber in it, or merchantable timber to pay to offset the cost of doing all the fuels stuff, then we can't … it's important, but our funding is limited and unfortunately we rely on volume, timber to dictate where we go. Hopefully we will be able to change that at some point." Likewise, fire specialists explained that it can be difficult to do maintenance treatments where fuel reduction work has already taken place because of budget line item constraints. That is, no volume can be produced in areas that just need maintenance treatments. Other researchers have similarly found that budget allocations are substantially at odds with Forest Service professional judgment (Cramer et al. 1993) and that the agency reward system is not aligned with the values of agency staff (Kennedy et al. 2005).

While the timber target was often cited as a constraint, specialists, line officers and program managers were not opposed to producing timber. In fact, many thought the timber program was critical to the forest's ability to meet proactive fire management and restoration objectives. That is, without timber-processing infrastructure, the DNF would not be able to accomplish its restoration goals. Respondents simply wanted timber production to be more of an outcome rather than a driving goal. "I would hope that our next round of planning gets out of … the whole timber target business." Line officers and specialists reported a preference for measuring outcomes related to management objectives such as landscapes restored and watersheds restored: a measure that's "more of a conglomerate". This mismatch between targets and management objectives led one line office to remark, "So I [am] always fighting for money, you know, saying I'm not going to produce that much timber target but the work we are doing is extremely supported and highly popular." Notably, the district where this comment was made was envied by respondents for being able to move more toward integrated management than the others. Targets were seen as more of a constraint by field staff – including district rangers and district specialists – than by staff at the forest level, potentially because field staff are more directly engaged in planning and implementing work on the ground and thus experience the unmet need more directly.

Specialists and line officers also regularly cited the political nature of the budget process as problematic. A specialist described, "I'm a little pessimistic because it [management] is so controlled by and run by contemporary political thinking rather than contemporary scientific thinking … It needs to be based more on these ecosystems, here's what they do, here's what they need … and it never gets there. And the main reason is because is because takes a vote of Congress." Respondents reported challenges in applying their professional expertise on the ground because of the latest political winds. Forest management inherently occurs over timeframes much longer than political seasons, and annual partisan bickering over budgets creates uncertainty that makes long-term management planning challenging.

Planning

Forest Management Plan

The forest management plan was raised as a key obstacle to meeting management objectives by 50% of respondents at the headquarters level and between 60 and 66.7% of respondents at the district level. The forest management plan was directly linked to landscape resilience concepts more often than any other institutional resilience theme (Figure 2.2). That is, when respondents were asked what kept them from reaching their goals for the landscape, issues related to the forest management plan came up more often than any other institutional/ administrative theme.

A common remark made by specialists and line officers alike is that the DNF management plan is old and dated. One typical comment was, "It is unfortunate that our planning, our existing planning, doesn't really do an awful lot except to provide us constraints. You know we know that a lot of the concepts at the time, which we thought were great, have changed ecologically." The Deschutes

National Forest management plan, published in 1990 after eight years in development, is based on social and biophysical science and principles 20-30 years old.

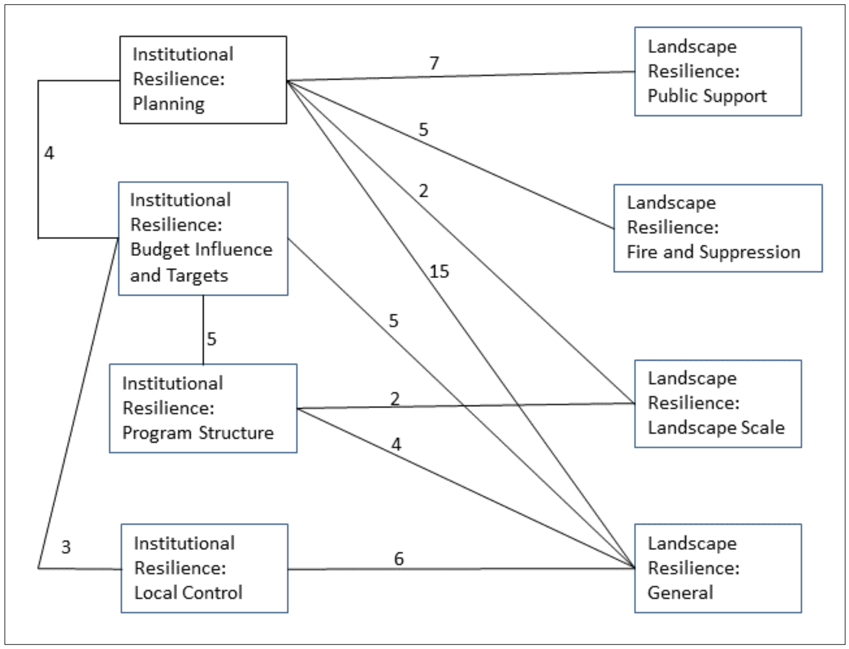

Figure 2.2. Linkages between institutional, or administrative, themes and landscape resilience themes show a strong connection between planning and landscape resilience.

Some of the plan-related obstacles mentioned by respondents were related to the use of prescribed fire. One respondent shares an example, "It [the management plan] limits the amount of underburning you can do per year to a certain percentage of that management area [Deer Habitat], which stretches across the whole forest, so we are planning a project here, they are planning one in ___, and they have something going on somewhere else. We are all like okay well has the 2% already been used up?" The 2-2.5% prescribed fire standard in the DNF management plan applies to this management area regardless of the forest type of historical fire return interval. Another specialist expanded on the need for integration of fire with other resource objectives, "There are a few pieces [of the management plan] where when we read through them and we have to implement them, you know we just kind of throw up our hands and just go okay well we are going to have to write off a certain number of acres in any one planning area for say thermal cover, or for hiding cover … we have such a dry environment here that we are really being asked to manage stands in an unsustainable way in some of them."

The outdated management plan affects other resource areas as well. Several specialists (wildlife biologist, forester, ecologist), lamented the plan rule that prohibits management in forest stands over 80 years of age because it limits managers ability to restore more natural successional and vegetation dynamics. Managing for successional forest dynamics has gained widespread scientific support since the DNF forest plan was published in 1990 (Franklin and Johnson 2012, Spies and Turner 1999, Stine et al. 2014).

Plan revision on the DNF is scheduled to begin in the next year or two under new regulations guiding development of national forest management plans (NFSLMP 2012). The new regulations enable an adaptive approach more amenable to the incorporation of new science and knowledge as it develops. In addition, the new regulations place a priority on early and regular public engagement in the plan revision process, which may provide an opportunity to ease public controversy around planning and support a more responsiveness planning process.

National Environmental Policy Act (NEPA)

Substantially fewer comments were made about the National Environmental Policy Act (NEPA) than about the forest management plan. Between 33 and 50% of respondents on the DNF mentioned NEPA as an obstacle to meeting management objectives. Some comments described the exorbitant amount of time spent analyzing an issue that was of concern to an individual or a very small minority of the public. Other typical comments included, "NEPA has become very expensive for us in this region … our documents have become so fat and so unreadable because we're, we're writing for the courts now. We're not writing for the public, which is the intent of the document, and … we end up writing and spending more time on that than the actual implementation." Similarly, other comments expressed frustration with the amount of NEPA it takes to do what appears on the surface to be a simple project. Finally, a another suite of NEPA comments suggested that the expense and complexity of current NEPA processes, coupled with limited capacity, leads NEPA planning teams to focus on relatively simple and straightforward acres because those acres can be more readily accomplished.

Program Structure and Integration

This theme captured comments about programs and staffing and how staff from different program areas and geographic areas interact. On one district program structure and integration was raised only once, and the comment reported a well-integrated staff with planning team dynamics that were extremely helpful in accomplishing management objectives. On another district, program integration and team dynamics was raised three times, again with one case being an extremely positive report of an integrated team that worked well together. Yet on the third district comments related to program structure and integration were raised seventeen times, and all cases focused on challenges and constraints related to accomplishing management objectives because of a lack of integration within teams or between resource areas.

The Forest Service has a long history that is integrally tied to the development of the professional forestry field in the United States. In its early days, the Forest Service consisted almost solely of foresters (Kaufman 2006). Today, the makeup of the Forest Service has changed dramatically to include people of color, women, and a range of specialists with expertise in plants, fish, recreation, engineering and other fields. The integration of new resource areas into the existing system can be challenging. One fire specialist explains, "Fuels management wise, I think we have been kind of the up and comers. We have probably had some of the most work to do to come to the table in that interdisciplinary setting in a more professional way." Another added, "We do have fire specialists on every team but I think the integration of fire as a profession and planning could be better done. I think part of that is historic baggage."

This feeling of being relatively new to project planning may explain why fire specialists follow rather than lead planning processes, despite the fact that hazardous fuels reduction has received comparable or higher levels of funding than timber on the DNF in recent years. One forester explained that once planning areas[1] are selected, "The individual treatment units are really driven a lot by the silvicultural planners … they're the ones I think really drive the treatments and fuels people to a lesser extent." Rather than an active bias toward silviculture, the arrangement may be a historic artifact of the agency's natural development, "Our history of management, as I understand it, has been very stand level … our silviculturists and our foresters have been … educated and told to manage at a stand level and that is what they have done. So we still tend to chink away stand by stand." The historic stand-by-stand management approach may make it hard to integrate new ways of thinking that require landscape-level management, as with fire management.

In central Oregon, the separation of resource areas is exacerbated by the Central Oregon Fire Management Service (COFMS). COFMS is a coordinating body for fighting wildfire in central

[1] Planning areas are relatively large geographic areas within which thinning or fuel reduction or other management activities take place.

Oregon and has been very successful at managing rapid suppression of fire starts. Yet COFMS is seen as quite separate from the rest of the agency, "They are almost their own agency." A program manager adds, "And so people in this office they don't know who's out there fighting fires. They don't know those people … I've been with the Forest Service for ____ years and I've never seen that model of operation before, where I was very used to, we all worked together."

In addition to their role as relative newcomers, fire specialists may confront planning team members that don't agree with or understand the role of fire in the project area. One planning team member describes, "You know sometimes we get in discussions when it gets down to the project level about what are you getting by doing that? Why do you want to do that? We are not in an urban interface. You know you cannot burn 10,000 acres, so why do you want to plan for it? Why is that important? What is the ecological benefit of fire? I know some people that work on our ID teams question that and I question it. But then there are a lot of folks who are interested in calling it restoration and restoring fire and having a natural fire regime." Fire is a disturbance agent that affects all other resource areas from silviculture and recreation to water resources and fisheries. A lack of agreement on overall objectives can thus be a real problem for fire specialists, "We manage a disturbance and you need to tell us what you expect that disturbance to do for you and we can try to achieve those objectives. But when you want us to help you achieve your specific resource objectives and they're completely competing across the board, that's never gonna happen. So what I would like is before we even go into an area, to have a common vision."

Respondents also talked about how program integration issues are changing. One fire specialist shared, "I think everybody's goals and where they're trying to head is starting to mesh a little bit more … it's starting to come along … we really try to get out on the ground … which definitely makes a difference. If you're just sitting in a room and talking about something you can talk about it forever." A silviculturist agreed, "When we started looking at the ________ area as an ID team, one of the things we did was, we did some internal teaching of each of the specialties … We took some time so that when it was the archaeologist or the recreation specialist or the wildlife biologist, we all had a good understanding of … the important things in our area of specialty … And so what it really facilitated … was problem solving … and instead of locking horns over [an issue] in the office, we'd go out to the field … And we'd walk around, we'd look at it, and we'd problem solve. And this included the Fish and Wildlife Service … it's the only time in my career that we had a group that gelled so well."

Managing for Landscape Resilience

This results section covers additional areas that respondents reported were important to managing for landscape resilience to disturbance. Unlike the themes above, these are not necessarily institutional issues but ecological imperatives that are closely linked to institutional themes.

Fire and Suppression

Line officers, specialists, and program managers all talked about the need to put more fire back on the landscape. Both prescribed fire and wildfire were mentioned in this context. Not surprisingly then, the current rate of fire suppression – 98% of all fire starts (USDA OIG 2006) – was seen as a real obstacle to achieving management goals and objectives. One fire specialist summarized the wildfire management strategy, "Usually when a fire happens we run out there and put it out." The high fire suppression rate means that natural fires that would otherwise reduce fuels don't occur. One program manager described the current suppression strategy as "transferring risk into the future." As a fire specialist explained, "The more you are successful at [suppressing] small fires, the worse the problem gets – eventually you'll get one under conditions that are untenable." Another adds, "I think the only way to create resiliency in a fire dependent ecosystem is to put fire back into the fire dependent ecosystem and I don't think we are even coming close … We're way behind par here. I just don't see us having resilience unless we're able to get fire back."

A program manager explains that 98% of wildfires are easy to put out. The other 2% get away until weather changes, and "There's not a damn thing we're going to do until weather changes – not a damn thing we're going to do that will make a difference." This isn't 'letting it go' or poor management as the Forest Service is often accused of after large wildfire events. "It's like saying we're going to let a hurricane go. Airtankers won't do any good. But if the fire is advancing on structures or critical habitat, we'll day after day go after it – and we'll get it when there's a break in the weather." Fire managers know where they can be successful, yet there is a culture of fighting large, unmanageable wildfires – and public and congressional support for it.

Making a decision to not immediately suppress a wildfire is difficult. A specialist explains, "You gotta be able to accept the risk and that is just tough. You know, when you have a lightning bust you know you just want to put this one out and go to the next." A line officer explains, "You can say, well okay, so it's the 10th of September and this fire is 50 acres and there is only a 10 percent chance it's going to reach the private land by the end of the season. Is 10 percent enough of a risk for you? Are you comfortable with that kind of risk? It just all depends." Considering the risk involved, it may not be surprising that line officers talk of the need to have courage to allow wildfire to burn more acreage rather than immediately suppressing it. One line officer described the decision space, "You remember the concept of wildland fire use? … We still have the ability to do that, but do we really have the courage? … Do I have the courage to allow that fire to progress to that first road? … We are in fear. What happens if we have some unpredicted event and that got away from us? So just putting these stands on a trajectory really isn't a lot more than lip service … unless we are able to take the next step that allows fire to play it out - you know fire is a natural part. We gotta have it."

Yet risk aversion can be an expensive management style (Thomas 1996), and the rapid and complete suppression response is beginning to change. One fire specialist explained his approach, "It depends on the time of year obviously and the load that we're under but I tell my folks I want them to honestly look at a fire and say is there an opportunity here to let fire do some work. Is there opportunity to take, to use existing barriers or stuff like that and give up a little bit of ground but still achieve, not so much achieve objectives, but not cause more damage by suppressing the fire." A line officer described a recent fire that was not immediately suppressed, "The _____ fire, as an example of that at a large scale, you get a 12,000 acre fire and the strategy is confine contain, not suppress, which is a huge policy behavior change for our agency … You know, every line officer is different. I imagine a lot of line officers might have suppressed the fire … the blocks of untreated fuels are too contiguous. We're not there yet where we could get an ignition in July and say, 'You know, it's not going anywhere, it's going to bump up against this thinning and up against this road and no winds are predicted.' We're not there yet." Yet fire specialists and line officers expressed the belief that a transition is taking place. For example, one program manager talked about encouraging fire specialists to compare the values of risk to the values being placed at risk by fighting the fire. Multiple fire specialists talked about the ability to do longer range modeling to look at wildfire management options and values at risk, though each mentioned the limited availability of these modeling teams. There was a sense among those interviewed that fire management policies are changing but a fair amount of road remains to be traveled.

Respondents also talked about the need to use prescribed fire to reduce hazardous fuel conditions and create forests more resilient to wildfire. Obstacles to additional prescribed fire use described by respondents included smoke and public support. Respondents reported that existing air quality regulations create difficulties in using prescribed fire to proactively manage fuel conditions. Fire specialists reported wanting to see recognition of the need for fire on the landscape and air quality regulations that create exemptions for prescribed fire as well as wildfire. (Oregon's air quality regulations currently only exempt wildfire.) Public support was raised as a key factor in the use of prescribed fire, and the public's dislike of smoke was the main aspect of the issue mentioned.

Managing Landscapes

Forty-seven percent of respondents at the district and headquarters levels talked about the importance of managing at a larger scale or at the landscape scale. The language, tone and agreement on this issue were strikingly steady across districts and staff positions. One fire specialist described the difficulty of achieving landscape scale proactive fire management within the current planning structure, "In the past, we haven't really planned well for putting fire on the landscape. So usually a silviculturist would come in and design a project. They would say okay, we want to trim this stand, or that stand … or this one is 40 acres and this one is 100 acres … They are all just scattered. Then in the fuels people would come and follow and say okay, we'll take care of the fuels here and we will take care of the fuels here … but if you are going after 40 acres at a time … You are using as much time as if you went for 200 ... So more and more … our planning is saying okay … we'll include this whole area maybe as one unit, or we'll do it all so that when we're done we will be able to flip fire from road to road, you know increase the acreage." Rather than hundreds of acres, another fuels specialist suggests treating thousands of contiguous acres at one time.

The challenge of planning and managing at the landscape scale is also the result of resource planning by mitigation. One program manager describes this critical piece of planning process, "It's reactive where the silviculture planners and the fuels planners, they will throw out the maps and then the specialists react to it and put mitigation measures on top of it and basically shrink, you know, okay well you were going to treat 20,000 acres and now they have shrunk it down to 10 kind of thing, instead of it going the other way … to me that's old school Forest Service." A line officer adds, "I just can't tell you how many times I've heard this looks nice but we should have treated more." A specialist adds, "What I've learned from past management is that if you do little things to try to be as careful as you possibly can, big events occur and it's all for nothing."

In part, the frequency of natural fire regime, the size of the management area, and the lack of natural fire due to fire suppression combine to create what respondents described as an immense need for active management to achieve landscape resilience to fire. One respondent explained, "If you take the natural disturbance out of the system, then you gotta put something back in. And it takes a lot of acres to keep up." In light of the expressed need for active management, new approaches are being considered. A program manager explained, "I've been pushing really hard for the last few years to have people think about doing things differently, so that instead of, you know, trying to go out into the landscape and treat stand by stand by stand, until you thin your way to Nirvana, which isn't going to happen, you instead try to figure out how you could set up the landscape so that when you get a wildfire you can use that wildfire to do that work."

Public Support

The importance of public support was raised in almost every interview. At headquarters, the importance of engaging the public was mentioned less often than on the districts. While many respondents believed that more public outreach work is needed, respondents also talked about progress the forest has made in engaging the public. Regular wildfire activity and visible Forest Service fuel reduction projects have shaped the public's perception of fire in the area and helped build support for active Forest Service management. Many respondents also talked about the collaborative work that has taken root on the DNF and how that work has built trust between varied interest groups. A line officer described, "The relationships that were developed and built and how that turned the tide on us being able to get work done, became, you know, really noticeable and more and more people started … trying to figure out how you do that." Limitations of collaborative work were also noted, "Yes, [collaboration] helps tremendously, but if you were going to look at the need to restore tens of millions of acres across the interior West, the dry West, from Montana to Arizona to Colorado, collaboration is not a fast enough pace. We need more tools … Collaboration comes one community at a time. It came to Bend, it came to Lakeview, it's coming to John Day, but it's not coming to dozens of other communities across the interior West." A line officer noted that even in an area with active collaboration and the support of most interest groups, a small minority of individuals or groups can have exceptional influence on the progress or outcome of a project. Overall, respondents saw a continued need for public outreach and collaboration to increase support for management objectives.

Modeling Scenarios

Interview data informed management scenarios explored in Chapter 4. The management scenarios created to assess the impact of treatment unit size, treatment amount, and a focus on timber production were developed in direct response to concerns and hopes expressed by interview participants.

Discussion

Public Administration

-- In most positions the "division of powers" theory works unmitigated mischief. The only way to get good service is to give somebody power to render it, facing the fact that power which will enable a man to do a job well will also necessarily enable him to do it ill if he is the wrong kind of man. -Teddy Roosevelt

One of the most significant controls Congress has over administrative behavior is the federal budget (Thomas 1996, Long 1949, Padgett 1981, West 1995). Congress funds executive agencies such as the Forest Service by passing annual appropriations bills which set the level of funding for each federal agency. The multiplicity of line items through which Congress funds agencies exerts a high degree of political control over management activities (Steen 2004, Padgett 1981). For instance, Forest Service Chief Edward Cliff stated that Forest Service programs had long favored commodity production and blamed Congressional budgeting for the imbalance (Steen 2004). This analysis supports such findings.

Interview data suggest that more autonomy and flexibility in Forest Service budgeting would enable local land managers to more easily achieve land management goals. More budget authority and flexibility delegated to the Forest Service by Congress would enable the Forest Service to more rapidly and efficiently respond to changing ecological and social conditions. Steelman and Burke (2007) note that a restructuring of budget arrangements is needed to support, or at least not undermine, the goals of the National Fire Plan, the Healthy Forest Initiative, and the Healthy Forest

Restoration Act, all of which aim to restore frequent-fire forests. Likewise, Thomas (1996) stated that steady funding and enhanced ability to shift funds between budget line items could add stability to programs. Line item discretion can have significant effects on both productivity and morale. A region that had the opportunity to pilot line item discretion increased productivity by 18%, responded more efficiently to unforeseen events, and improved employee morale (Varley 1994). Other research supports the notion that federal agency performance in the United States is best when there is a large measure of autonomy (Rourke 1984). Zellmer (2000) likewise reports that some congressional members recognize micromanagement to be a recipe for disaster, especially for congressional representatives who have difficulty agreeing on budgets. The Forest Service, with its commitment to engaging the public in forest and project planning, is better situated to serve the public interest responsively and effectively (Rourke 1984) than today's highly polarized Congress.

The mismatch between Congressional line item budgeting and land management goals could be remedied by repairing the disconnect between land management plans and the budgeting process. Land management activities are guided by management plans that have been developed for each of the nation's national forests and grasslands. Each management plan involved the public and was informed by current science, and new planning guidelines encourage even more extensive public involvement. Yet forests are not funded to implement their management plans. Support for management plan implementation must instead be patched together from various program areas and line items shared by all national forests, regardless of the unique focus and goals laid out in individual management plans. A budgeting process that focused on funding implementation of forest plans rather than the current system of line item program budgeting could simplify and support local land managers ability to achieve land management goals.

<u>Organization Theory</u>

To support district and forest ability to achieve management goals and adjust to changing social and ecological conditions, administrative changes could be made. Other researchers have likewise identified institutional arrangements as one of the biggest obstacles to adaptive, ecologically-oriented management (Doremus 2001, Nie 2008, Reiners 2011) and innovation (Rourke 1984). Research suggests institutional structures can be difficult to change because of strong inertial forces (Hannan and Freeman 1984). While likely to be challenging, the Forest Service can ease budget constraints felt in the field by revising targets associated with budget line items. While some interests, both internal and external, would have to give up "turf", significant discretion could be allocated to line officers in the field by creating integrated target measures. Reducing the current list of 300+ target measures could be an important internal avenue for addressing constraints felt at the forest and district level. Adjusting targets to better reflect agency values (Cramer et al. 1993, Kennedy et al. 2005) and goals (USDA n.d., Vilsack 2010) would likely improve efficiency and agency morale (Varley 1994) as well.

Interview data also suggests the need for a significant shift in program structure to support integration and improved interaction between program areas and districts. Program specific funding and separation occurs at each level of the Forest Service hierarchy: district, forest, regional office and Washington office. This historic program structure is reflective of an older ecological paradigm that focused on reductionism whereas the importance of integration and a more holisitic approach is increasingly evident (Li 2000, Cadenasso 2006).

Many possible paths to addressing integration and program structure exist. The most relevant seems to come from the field of new public management. While Kettl (2000) suggests that American institutions and traditions do not fit some requirements of new public management, plenty of feasible, if challenging, possibilities exist. Osborne and Gaebler (1992) describe some of these opportunities:

- Use outcome-based budgeting rather than output-based budgeting.
- Create incentives for savings and efficiencies.
- Create entrepreneurial opportunities within agencies.
- Support experimentation.
- Change rewards and incentives.
- Decentralize processes to enable flexibility and adaptive response.
- Use cross departmental teams to engage multiple perspectives, support thinking outside the box and break down turf walls.
- Reduce formal program divisions and increase the number of ad hoc working groups that come together for a specific time to address a specific issue and then move on to the next project.

The common theme in this list is aiming for arrangements that allow for more trial and error, encourage problem solving, and are likely to be more adaptive than arrangements that require conformity and rigid bureaucratic procedures (Jones 2001). The more the Forest Service can focus on injecting adaptive capacity into its systems, the less likely they system is to become brittle and struck by highly disruptive forces (Herrfahrdt-Pahle and Pahl-Wostl 2012).

Conclusion

This study aimed to build a better understanding of how responsive the Forest Service's management systems are to changing ecological, social, and political conditions by looking at management in an area with a great deal of recent ecological and social change: the Deschutes National Forest. This analysis assessed DNF managers' ability to set and achieve management goals and objectives. Overall, the analysis shows the DNF's management goals are influenced by local managers' knowledge and expertise as well Congress, the Administration, and the public. The DNF regularly achieves its objectives. However, the objectives are not achieving the landscape goals DNF managers would like to reach. Creating more adaptable administrative systems would enable the Forest Service to respond to changing ecological and social landscapes in a more strategic, efficient way that increases agency morale. A talented workforce and growing external partnerships create a pool of expertise on which Forest Service leaders can draw to address these challenges.

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Chapter 3: Developing and Evaluating and Agent-based Model for Federal Forest Management

Introduction

Researchers interested in complex landscapes influenced by human and ecological dynamics are increasingly turning to simulation models. Simulation models are often the only way to test alternative management scenarios when decades-long landscape scale experiments are not feasible (Mladenoff and Baker 1999). Simulation models enable researchers to learn about spatial processes and interactions in large, heterogeneous landscapes and explore how landscape patterns emerge from smaller scale dynamics (Caspersen et al. 1999). When disturbances like wildfire occur at large scales and interact with processes like weather, succession, and management over long time frames, a complex system is generated that is difficult to investigate without simulation models (Mladenoff and He 1999). Moreover, wildfire is a cross-scale phenomena that requires understanding of fine-grained details of fire ignition and spread as well as broad scale patterns of climate and topography. Multi-scale, multi-process simulation models enable analysis of such processes and interactions. While a number of forest landscape modeling systems have been created and used in experimental studies, a relatively new class of models called agent-based models (ABMs) are gaining prominence as an effective way to increase understanding of social-ecological systems such as those related to wildfire (An 2012, Bolte et al. 2007, Janssen and Ostrom 2006). Agent-based models allow simulation of agent, or land manager, decisions in a changing landscape and generally incorporate decision-making processes of agents and the social influences on these agents (An 2012). By contrast, traditional landscape simulation models use predetermined management trajectories and thereby lack landscape feedbacks to adjust policies in response to stochastic disturbances.

Like other landscape simulation models, agent-based models generally enable researchers and managers to address system uncertainties through the development of scenarios. For instance, the amount of future wildfire may be difficult to predict due to climate change. Scenarios can be run with varying amounts of extreme fire weather, and landscape response and agent behavior can be explored with a broad range of potential conditions. Scenario planning is a technique developed to explore the outcomes of decisions in the face of uncontrollable, irreducible uncertainty (Peterson et al. 2003). Scenario planning entails systematic consideration of multiple possible futures rather than focusing on the accurate prediction of a single outcome (Peterson et al. 2003). Scenarios reveal information about drivers of change and implications of current policies and alternative courses of action (Peterson et al. 2003). Scenarios analysis is thus useful in situations in which key drivers of change entail some degree of uncertainty.

The Envision Forests People Fire (Envision FPF) model incorporates a physical fire model, vegetation succession, agent decision making, and landscape feedbacks. This model was developed to explore how social and ecological processes interact to shape landscapes over time in central and south central Oregon. The model was developed for use by both researchers and land managers interested in landscape-scale questions related to forest succession, fire and forest management. Use of the model in areas outside central and south central Oregon would require additional model parameterization and development.

This chapter documents verification and validation processes used to evaluate the Envision FPF model. The focus is on model components essential to the research questions addressed in this dissertation. My role was both model building and model testing. I led development of land management decision making for large landowners and supported application, testing, and revision of the fire and vegetation submodel processes. I identified the need for several new functions related to land manager decision making and fire modeling and worked with the modeling team to incorporate the new processes into Envision.

Conceptual Model

The conceptual model for Envision FPF is represented by the area within the large rectangular box of Figure 3.1 (from Spies et al. 2014). Key drivers of landscape change include vegetation succession and fire behavior, which are described in more detail in the Fire and Vegetation Succession

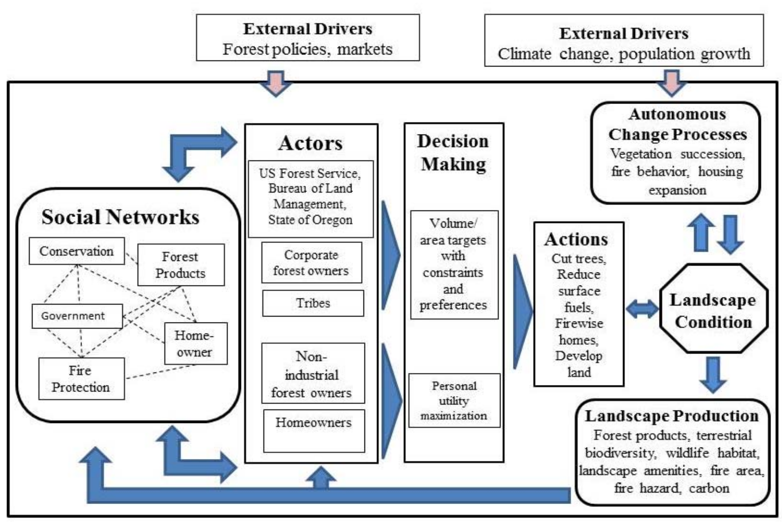

Figure 3.1. Envision conceptual model.

sections following. Housing expansion also affects landscape change in and near developed areas. Some key drivers of landscape change fall outside the scope of the model and include climate change, demographic shifts and timber markets. Landscape conditions are also influenced by different actor groups who make decisions about land management activities. Modeled actor groups include federal land managers, industrial forest owners, non-industrial forest owners, and homeowners. Changing landscape conditions caused by ecological and human processes in turn affect landscape production values such as volume of wood products, terrestrial biodiversity, and wildfire hazard. Social networks are shown in the figure but have not yet been implemented in the computer model.

Envision Framework and Submodels

Envision Modeling Platform

Envision is a spatially explicit landscape modeling framework which provides a platform for integrating submodels. Submodels are incorporated to build a unique model that addresses specified landscape questions in defined geographic areas. Envision utilizes a system of individual decision units, actors, management activities, autonomous processes and landscape indicators.

Envision represents the landscape as individual decision units (IDUs). In this application of Envision, Envision FPF, the average IDU is roughly 3 hectares in size. IDUs are the minimum mapping unit and thus the finest resolution at which data can be viewed. IDUs carry static and dynamic landscape attributes through time. The modeled landscape in the full study area contains 1,041,742 IDUs that span 3,267,030 hectares (~8 million acres). IDUs were created by overlaying ownership, zoning and vegetation information. The minimum IDU size was a little over 1 hectare and the maximum size was about 9 hectares.

Actors represent different classes of land managers that make decisions about landscape management activities. Envision FPF actors include the Forest Service, Warm Springs Tribe, State of Oregon, private industrial forest owners, non-industrial private forest owners, and homeowners. The decision making process of each actor group is represented individually and may also vary within actor groups (e.g. the Forest Service decision making process may vary by district). Decision making and management are discussed in more detail in the Management section that follows.

Autonomous processes drive non-management landscape change. Autonomous processes in Envision FPF include fire, vegetation succession, and population growth. Autonomous and management processes occur at annual time steps, and IDU attributes are updated accordingly. Landscape outputs and condition are assessed using a range of indicators that vary depending upon the research question. Indicators may include fire severity and amount, fire hazard, smoke production, vegetation structure, habitat, management activity and amount, wood production, bioenergy availability, carbon, wildland urban interface (WUI) development, WUI exposure to fire, and WUI fire hazard (see Appendix B for a complete list of indicator categories).

Fire

Requirements for fire modeling included the ability to capture variation in fire behavior created by weather, fuel conditions and topography. In addition, fire modeling had to be computationally efficient in order to enable analysis of landscapes millions of acres in size over a 50-year modeling period.

Envision FPF incorporates a physical model of fire spread using the minimum travel time (MTT) algorithm. MTT spreads fire in a landscape by searching for the minimum time to travel between nodes in a network (Finney 2002). The paths with the shortest travel times are then interpolated to express fire perimeters at a particular instant in time (Finney 2002). MTT has been shown to effectively emulate historical fire perimeters (Ager et al. 2007) and has been used for over a decade in fire research and management (e.g. Finney 2002, Stratton 2004, Ager 2010).

MTT utilizes canopy and surface fuel data, topographic information, and wind and weather inputs to calculate fire spread (Table 3.1). MTT outputs include arrival time, flame length, perimeter and crown fire grids. The following description of the effect of each data input on fire spread is adapted from Finney (1999). Elevation information is used to adjust temperature and humidity calculations based on the adiabatic lapse rate and the input weather stream. Slope and aspect directly affect the rate of spread and are used to determine incident solar radiation (Finney 1999). Surface fuels represented by fuel models affect fire spread and intensity. Canopy cover affects fuel moisture and wind speed through a shading effect and wind reduction factor in higher canopy areas. Crown height affects the wind reduction factor as well as torching and spotting behavior, and crown base height and crown bulk density are used to calculate the threshold for canopy fire.

Table 3.1. Raster themes used by Minimum Travel Time algorithm to spread fire across a landscape (adapted from Finney 1999)

Raster	Units	Usage
Elevation	Meters	Adiabatic adjustment of temperature and humidity with weather input
Slope	Percent	Used in computing fire spread. With aspect, used to determine incident solar radiation.
Aspect	Azimuth degrees	As above (slope).
Fuel model	-------------	Physical description of surface fuel complex used to determine fire behavior (Scott and Burgan 2001)
Canopy cover	Percent	Used to determine shading of surface fuels (Rothermel et al. 1986). Influences wind reduction factor that decreases wind speed from reference velocity (Albini and Baughman 1979).
Crown height	Meters	Influences wind reduction factor, the starting position of embers from torching trees, and the trajectory of embers descending through the wind profile (Albini 1979).
Crown base height	Meters	Influences threshold for transition to crown fire (Scott and Reinhardt 2001).
Crown bulk density	Kilograms /meter^3	Influences threshold for achieving active crown fire (Scott and Reinhardt 2001).

Fuel moistures and weather inputs are based on analysis of historic weather data from 25 RAWS weather stations from 1991-2011. Wind direction is based on Brush Creek RAWS data from 2000 to 2010. Weather inputs utilized empirically-derived relationships between energy release component (ERC) and historic fires to predict daily fire occurrence and fire size (Finney et al. 2011) resulting in a list of probabilities for fire for each day of each simulation year, a predicted fire size, and a burn period. A Monte-Carlo technique was used to select fires to be read by Envision FPF.

Fire probability is thus based on the daily ERC value and associated weather parameters. ERC is an index related to potential fire intensity and is a function of surface fuels and live and dead fuel moistures. ERC is the preferred indicator for the effect of intermediate to long-term fuel moisture levels on fire behavior (Bradshaw et al. 1983) and is directly associated with area burned by wildfire (Finney 2011). The daily ERC value is selected from a distribution based on the monthly mean and its standard deviation.

Ignition locations were selected with a Monte Carlo method from a probability surface based on a logistic regression of historic natural and human-caused ignitions within the project area (Short 2014, Short 2013).

Sources of stochasticity represented in fire submodel include: daily ERC value, probability of fire, burn period (related to fire size), and location of ignitions. The stochastic nature of wildfire results in different weather conditions and differing amounts of wildfire with each Envision run. Thus one 50 year simulation may result in more area burned than another 50 year simulation. To understand the implications of various scenarios, multiple replicates of each scenario must be run to enable exploration of landscape outcomes with varying amounts of wildfire.

Vegetation Succession

Vegetation succession is represented through state and transition models (Merzenich et al. 1999). State and transition models classify the landscape into a discrete set of vegetation states defined by structure and connected by successional pathways. The combination of stand-level forest characteristics across millions of acres of land is infinite, making stand-scale modeling that represents continuous variation in individual forest stand characteristics unrealistic. Classifying stands into discrete categories, or states, according to key characteristics that drive forest succession make a landscape-scale analysis of forest succession feasible. Core state and transition models incorporated in Envision FPF were developed by the Integrated Landscape Assessment Project (ILAP), a joint project of the US Forest Service, Oregon State University College of Forestry, and the Oregon University System Institute for Natural Resources (INR). ILAP state and transition models utilize the Vegetation Dynamics Development Tool (VDDT) (Beukema and Kurz 1998). ILAP transition probabilities were used for vegetation succession while wildfire events and management activities were handled by the fire and management submodels in Envision. An Access database with a complete set of successional probabilities is available at ecoshare.info/ilap/products/models. (Regions 1-4 and 6 were used for the full FPF project area. The area modeled in Chapter 4 uses only Regions 1 and 3.) Envision FPF built from this base set of probabilities and made corrections and adjustments to the original set. For example, management transitions not represented by ILAP models were discovered through interviews with land managers (Chapter 2) and were added. The final set of transition pathways and successional probabilities are available upon request.

The ILAP state and transition models classify the landscape into vegetation states according to potential vegetation type, cover type, tree size, forest canopy cover, and canopy layering (see Appendices C and D for cover type and structure classes). Combinations of th ese attributes create 1266 modeled vegetation states. Potential vegetation type (PVT) is an indicator of the landscape's ability to support particular vegetation ecosystems (Winthers et al. 2005). PVT is a useful indicator of the interaction of soils, topography and climate. Examples of PVT classes in the Envision FPF model include ponderosa pine xeric and subalpine woodland. See Table 3.2 for complete list of forested PVTs in the study area. Cover type is the type of forested or arid cover that exists in an area, for example, sagebrush, ponderosa pine or mountain hemlock (see Appendix C). Size is represented by ten classes ranging from barren to giant trees (>30" dbh) (Appendix D). Canopy cover is represented by 5 classes that range from none to high (> 60%) and also includes a post-disturbance class (Appendix D). Finally, forest canopy layering is represented as single-layered or multi-layered (Appendix D).

Table 3.2. Forested potential vegetation types in the FPF study area

Forested PVTs
Subalpine fir – cold, dry
Subalpine woodland
Subalpine parkland
Mountain hemlock - Cold, dry - Intermediate
Pacific silver fir Warm - Dry - Wet
Grand fir – cool, moist
White fir Cool Intermediate
Ponderosa pine - Dry, with juniper Dry, residual soils Xeric
Mixed conifer - Cold, dry - Dry Dry (pumice soils) - Moist
Lodgepole pine - Dry - Wet
Ponderosa pine-lodgepole pine
Shasta red fir - Dry - Moist
Douglas-fir - Dry Moist
Western hemlock - Cold - Intermediate Wet
Oregon white oak – ponderosa pine
Oregon white oak

Each unique vegetation state has multiple possible successional trajectories, and each successional trajectory has an associated probability. So two ponderosa pine stands with small trees and open cover may develop along separate trajectories. The successional probabilities add an element of stochasticity to vegetation succession. Each stand also has a deterministic threshold such that once it reaches a threshold age, it grows into a new state. For example, a small ponderosa pine stand might grow into a medium ponderosa stand at age 81 if another disturbance has not occurred by then. State and transition models have been used by researchers and land managers to assess landscape change since the 1970s (Waggoner and Stephens 1970, Merzenich et al. 1999, Hemstrom et al. 2007, Strand et al. 2009).

<u>Fuel Modeling</u>

Each vegetation state is associated with canopy and surface fuels required to simulate landscape fire behavior. Canopy fuels were derived from GNN data produced by interpolating Forest Inventory and Analysis tree plot data with satellite data (Ohmann and Gregory 2002). Surface fuels were modeled using Scott and Burgan's (2005) fuel model selection guide. A base fuel model was assigned to each vegetation state (representing a particular combination of PVT, cover type, size, canopy cover and canopy layering) based on GIS analysis of initial landscape conditions. The most common fuel model for each vegetation class was assigned uniformly over the area. Fuel model succession occurs after disturbance. A fuel model variant is assigned after: 1) prescribed fire or surface wildfire, 2) mixed-severity fire, 3) high-severity fire, 4) mowing and grinding, or 5) timber harvest (Table 3.3). The fuel variant remains associated with the vegetation class for a set period of time or until the vegetation class transitions to new state.

In addition to fuel characteristics, each vegetation state is linked to flame length thresholds that translate flame lengths generated by fire into effects on vegetation in terms of severity classes. For example, a 6.5 foot flame length could result in surface fire (<20% tree mortality), mixed-severity fire (20-78% tree mortality), or high-severity fire (>78% tree mortality) depending on a vegetation class's response to a 6.5 foot flame. A large open ponderosa pine stand might exhibit low-severity surface fire whereas dense seedlings and saplings may burn as a high-severity stand-replacing fire at that flame length. Flame length thresholds were developed by modeling vegetation state response to flame length in ArcFuels. ArcFuels integrates several fire behavior models within an ArcGIS toolbar and streamlines wildfire behavior analysis (Ager et al. 2011).

Table 3.3. Fuel model succession in Envision FPF (Scott and Burgan (2005) fuel models)

Baseline	Surface fire	Mixed-severity fire	Stand-replacing fire	Mowing/ mastication	Harvest
93	93	93	93	93	93
99	99	99	99	99	99
101	181	101	181	101	101
102	182	102	181	102	102
103	182	102	181	102	103
121	182	121	181	15	185
122	182	102	181	15	185
141	182	121	181	15	185
142	182	121	181	15	185
161	182	102	181	15	185
164	181	181	181	15	185
165	181	181	181	15	185
181	181	181	181	15	185
182	181	181	181	15	185
183	181	181	181	15	185
184	181	181	181	15	185
185	181	181	181	15	185
186	181	181	181	15	185
187	181	181	181	15	185
188	181	181	181	15	185
189	181	181	181	15	185

<u>Management</u>

Land management activities vary by actor type according to interview and survey data gathered by FPF researchers. Non-industrial private forest owners and homeowners make decisions based on the outcome of empirical econometric models. This approach relied on survey data to develop statistical models of management behavior which result in landowner management actions as a function of landscape, demographic, socioeconomic, and social network variables (Spies et al. 2014).

Research for this dissertation focused on federal land management, and the remainder of this section is devoted to large landowner decision making (federal, industrial, tribal). In general, large landowner decisions are structured by management activity targets, constraints, and preferences. This decision making structure was chosen based on 116 interviews conducted with large landowners and managers by FPF researchers (of which Chapter 2 is a part). Each owner group (i.e. Forest Service, industrial forest owners, Warm Springs Tribe) is associated with a suite of potential management activities and an acreage target for each activity. Management activities and targets may vary by scenario. For example, in one scenario, the Forest Service may have acreage targets for thinning from below, prescribed fire, mowing and grinding, and juniper removal. Another scenario may focus solely on thinning and prescribed fire.

Along with an acreage target, each management activity is constrained by a number of factors. Constraints are used to exclude areas from management or to constrain activities to particular portions of the landscape. Constraints may be related to any attribute carried by IDUs through time. In scenarios developed within Envision FPF, constraints have been associated with federal management zones related to forest management plans or the Northwest Forest Plan, or have been used to limit thinning and prescribed fire to specific forest types. For instance, logging is generally excluded from high elevation forests and wilderness areas, and prescribed fire is generally confined to ponderosa pine and dry mixed conifer forests.

Each management activity also incorporates preferences. Preferences make it more or less likely for a management activity to occur in defined areas. As with constraints, preferences may be developed from any attribute carried by the IDUs through time. Many preferences may exist for a single management activity. Each preference is given a weight, or score, which can be positive or negative. A total preference score for each IDU is created by summing individual preference scores. IDUs with the highest preference scores get selected for management first. Additional IDUs are selected until the acreage target is achieved or constraints exclude the remainder of the landscape. See Table 3.4 for decision rule examples.

The Envision IDU selection process can be seen as "satisficing". In decision theory, satisficing provides an alternative to optimal decision making. Decision makers are limited in their ability to make optimal decisions because generally not all alternatives are known or considered and not all preferences and values can be reconciled (Frederickson and Smith 2003). The satisficing decision maker takes actions that are 'good enough' (Frederickson and Smith 2003). In Envision, this translates into the selection of the first choice that meets the rules set by the targets, constraints, and preferences. There is an element of stochasticity to these management decisions because there are many possible combinations of management activities that meet the conditions set by the targets, constraints, and preferences.

Table 3.4. Example of large landowner decision structure

	Status Quo	Base Scenario	No Treatment
Acreage targets	Current levels	Based on historic fire return intervals	NA
Management activities	Thinning Prescribed fire Mowing & grinding	Thinning Prescribed fire	None
Constraints	Not in wilderness Trees > 5" dbh Only in dry forest types and moist mixed conifer	Not in wilderness Trees > 5" dbh Only in dry forest types and moist mixed conifer	NA
Preferences	WUI (+) Collaborative Forest Landscapes (+) Basal area (+) Late Successional Reserves (-)	High fire hazard (+) Mod. fire hazard (+)	NA

Additional Envision FPF functions allow the user to add more structure to large landowner management activities. One function enables the user to expand an activity from one IDU into neighboring IDUs until a user-specified size is reached or constraints are applied.

New functionality was developed in Envision as a result of management processes identified in interviews (Chapter 2) and informal discussions with land managers. The modeling team was very responsive to such requests and quickly adapted Envision to represent these newly identified key processes. One such addition allows the user to aggregate management activities into defined zones on the landscape. In this project, Forest Service planning areas and clusters of 6^{th} field subwatersheds were used. The average planning area is approximately 12,400 hectares. This new feature can be used to more realistically cluster management activities on the landscape.

Management activities available to large land owners and land mangers include thinning, even-age harvest, salvage logging, prescribed fire, and mowing and grinding (Table 3.5).

Table 3.5. Large landowner management activities in Envision FPF

Activity	Effect of Activity
Prescribed fire	Reduces surfaces fuels; sets fuel model to low flame length, low spread rate (e.g. 181, 182)
Mowing and grinding	Alters distribution of surface fuels, eliminates shrub layers and increases surface fuels, assigns custom masticated fuel bed model
Thinning from below*	Reduces cover to 40-60% and reduces layers from multi to single
Partial harvest*	Reduces cover to 0-40% and reduces layers from multi to single
Heavy partial harvest *	Reduces cover to 0-40%, reduces layers from multi to single, reduces size by 1 class (e.g. large to medium)
Even-age harvest (clear-cut)*	Removes all forest cover

* Assumes piling and burning. Does not preclude prescribed fire.

Decision making theory offers many views on understanding and modeling human decision processes. Following Jones (2001) call to ground models of human choice in observation, large landowner decision making was based on empirical data gathered from over 100 interviews with individuals engaged in making the decisions about land management activities in the project area. Forest Service decision making in Envision FPF was also informed by existing research, notably Herbert Kaufman's (2006) classic on administrative behavior (first published in 1960) and institutional theory focused on the suite of formal and informal rules that govern how decisions are made in public institutions (Tucker and Ostrom 2005). Other studies of Forest Service decision making generally focused on fire suppression decisions and were thus too subject-specific to be applied within Envision FPF (Cortner et al. 1990, Maguire and Albright 2005, Reiners 2011, Steelman and McCaffrey 2011, Williamson 2006, and Wilson 2011). The flexibility of Envision's extensive architecture enabled crafting of land management decisions closely aligned with those described by decision makers in interviews.

Model Verification and Validation

Transparent documentation of evaluative model processes are essential to providing researchers and decision makers with a clear understanding of model development and intended model use (Schmolke et al. 2010). Verification and validation of the Envision FPF model is documented following a framework and terminology offered by Sargent (2005). Sargent (2005) defines model verification as ensuring computer programming and implementation are correct whereas model validation is defined as ensuring model processes satisfy accuracy demands for the model's intended use. The verification-validation process is iterative. Verification and validation processes identify programming or conceptual errors which are corrected, and the revised model is then subjected to additional verification and validation processes.

Conceptual Validation

Envision FPF was validated conceptually using face validation and traces (Sargent 2005). Conceptual validation includes evaluation of theories, assumptions and logic (Sargent 2005). Face validation involved asking knowledgeable individuals and experts if the model and its behavior was reasonable. The FPF research team consists of experts from various research fields including economists, social scientists, programmers, ecologists, fire modelers, and forest management experts. The FPF research team developed, reviewed and revised the overall Envision FPF structure iteratively until a satisfactory framework for the project was developed. The Envision FPF conceptual model was then presented for feedback to local decision makers and community members at four workshops culminating in the spring of 2014. In addition, research team members presented the model at a special session of the 3rd Central Oregon Fire Science Symposium in the spring of 2014.

Submodels were conceptually validated as well. The algorithm that drives fire spread in Envision FPF, MTT, is used by many other fire behavior models and researchers (Ager et al. 2012, Finney 2011, Massada et al. 2009, Stratton 2004) and has a demonstrated ability to replicate historical fire perimeters (Ager et al. 2007). Likewise, the linkage between ERC values and burn period that drives simulated weather inputs has been peer-reviewed (Finney 2011).

Fuel model logic was evaluated using face validation, animation, and traces (Sargent 2005). Face validation involved consultation with fire modeling and fire management experts. The animation technique was used to display fuel model values as the simulation moved through time. Traces and animation tracked change in potential flame length before and after wildfire, prescribed fire, timber harvest and mowing or grinding. Potential flame length is an indicator of fire hazard and represents the flame length if a fire burned a particular area at given weather conditions. Potential flame length was calculated based on both 80th and 97th percentile weather conditions (moderate and severe fire weather). Fuel succession logic, based on fire behavior science and expert consultation, was initially conservative and did not show response to wildfire and prescribed fire consistent with the literature. That is, the model underestimated landscape response to fire. For instance, the initial fuel logic allowed wildfires to burn the same area year after year though accordingly to local land managers the lack of fuels should limit fire spread immediately following high-severity fire events. Similarly, flame length increase in response to harvest operations did not reflect local experience and was not consistent with theory. A pile and burn assumption was incorporated after harvest operations, and fuel succession was adjusted accordingly. A special fuel model was developed for mowing and grinding to represent masticated fuel beds based on Knapp et al. (2011). Animations were used to highlight disturbance locations and were linked to data that tracked each change in each IDU over the course of the simulation. IDU changes were reviewed individually and collectively. For instance, change in potential flame length after prescribed fire was tracked. If a decrease in flame length did not result from prescribed fire (in a single stand or among a whole vegetation class), further analysis was conducted including analysis of vegetation class change after prescribed fire, fuel model change after prescribed fire, fuel model logic, timing of submodel activity in Envision, and programming. If errors in programming or logic were identified, revisions were implemented and new tests were conducted. The iterative process continued until a flame length response to prescribed fire consistent with fire behavior theory was achieved. In this case, a reduction in flame length post-prescribed fire was expected. The magnitude of reduction in flame length was not considered. Conceptual validation and model verification were entwined in this process.

Vegetation succession was conceptually validated with face validation, animation, and traces (Sargent 2005). While all vegetation types were included in the validation process, the focus was on forest types that represented the majority of the forested landscape, including ponderosa pine and dry and moist mixed conifer forests. Graphs were developed for vegetation structural stages that showed the amount of each structural stage by PVT group over time. Individual stand development was assessed using traces in Envision, and animation was used to identify and assess changing landscape patterns in forest cover type and layering. All transition probabilities were reviewed, and probabilities for dry mixed conifer PVTs were adjusted to better reflect recent research (e.g. Merschel 2014).

Management logic for large landowners was conceptually validated through face validation by internal project experts and by consultation with land managers. Federal decision makers reviewed draft decision rules and provided feedback that was incorporated before decision rules were finalized.

Model Verification

Model verification and validation processes occurred in tandem. The model was conceptually validated, implemented, and then computer programming was verified. Yet the iterative nature of the evaluative process led to overlapping, non-linear validation and verification processes. That is, evaluative processes could identify programming bugs or problematic conceptual assumptions, and the model would be adjusted accordingly and subjected to additional evaluation.

Processes used to verify the accuracy of the fire, fuels, vegetation, and management submodels, and the integration of all model subcomponents, include: extreme condition tests, internal validity tests, event validity tests, operational graphics, dynamic testing, animation, and traces (Sargent 2005).

Extreme condition tests were used to test model operations with high amounts of wildfire, and separately, with extreme amounts of management activity (high levels and none). Internal validity tests were used to determine the amount of internal stochasticity in the fire submodel using 5-30 replicates of a no management scenario (Figure 3.2). Event validity of wildfire was verified by comparing simulated wildfire occurrences to actual wildfire occurrences. The amount of fire, wildfire size, and location of fire were verified with operational graphics including plots and GIS maps (Figure 3.3). Dynamic testing simulations were conducted in which different fire weather conditions were used to assess the values obtained. Animation was used to verify the amount of wildfire over time and the location of wildfires. Traces were used to verify fire effects on vegetation and fuels succession.

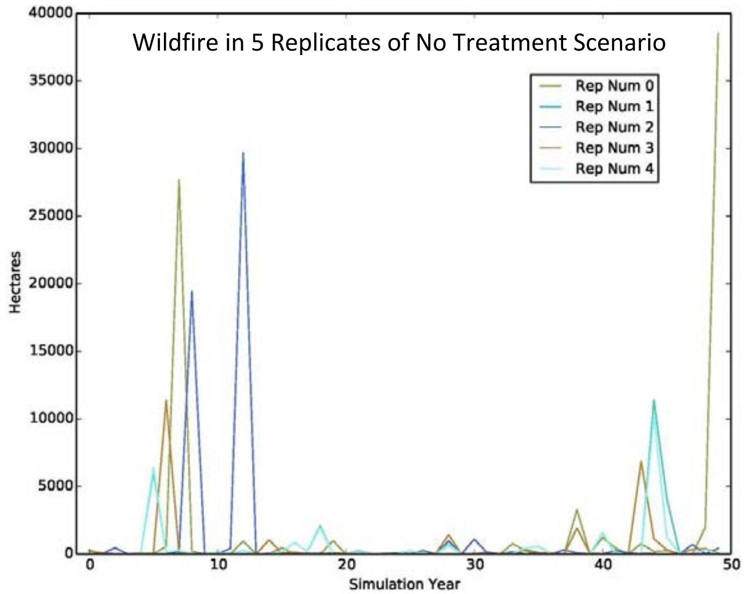

Figure 3.2. Internal stochasticity of wildfire was tested. Each replicate shows a general pattern of many years with little wildfire and several years with moderate or high levels of wildfire. While the location and amount of wildfire is stochastic, the internal variability in wildfire occurrence is roughly consistent.

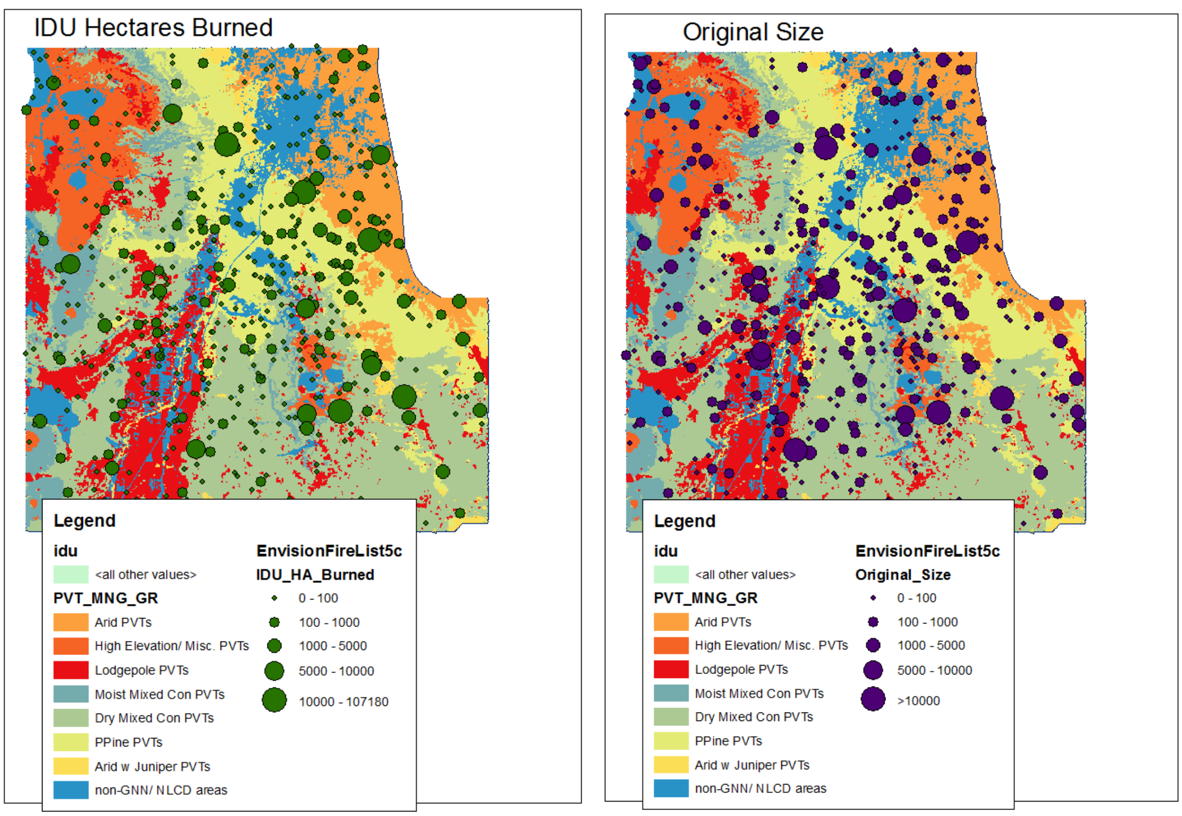

Figure 3.3. GIS plots show actual area burned (IDU Hectares Burned) compared to predicted area burn (Original Size). Predictions of area burned are based the empirical relationship between weather and area burned by wildfire. The model does a good job of representing fires over 1,000 hectares and tends not to burn as much area as predicted by small fires (< 1,000 hectares).

A challenging issue identified during the verification process related to flame length thresholds developed through stand-level fire behavior modeling using ArcFuels (Vaillant et al. 2013) and Forest Vegetation Simulator (FVS) (Dixon 2002). Over 95% of flame length thresholds followed an expected pattern based on fire behavior theory wherein stands with large trees and more open structural conditions had higher flame length thresholds than stands with smaller trees and more closed structural conditions. That is, high-severity fire would occur more easily, at lower flame lengths, in stands with small trees and more closed structural conditions. However, the remaining 4.7 % required further analysis. Over one third of the 4.7% (or 2.1% of all flame length thresholds) were outliers in the overall pattern seen within the rest of the size class for the specified forest type and PVT. This could be due to the simplifying process used to group forest stands into classified states for use in state and transition modeling. Actual stand data was used to represent vegetation classes instead of a simulated vegetation class mean. Use of actual stand data supported maintenance of landscape diversity in simulations yet could also be a cause of the outlier flame length thresholds. For these outliers, the same cover type in the most similar potential vegetation type was used as a model for altering flame length thresholds. In many cases, the flame length thresholds were otherwise identical or followed a very similar pattern as size or canopy cover or layering changed. In five cases, no reasonably comparable PVT was available but the pattern was strikingly clear within the class being assessed, and a change was made using expert judgment (0.3% of all flame length thresholds). In roughly another third of the 4.7%, flame length thresholds were determined to be reasonably plausible or at least unlikely to cause any confusion in analyses.

The final third of the 4.7% revealed systemic seemingly flawed flame length threshold patterns. The flame length thresholds in this small group (2.2% of all flame length thresholds) did not fit patterns that would be predicted by fire behavior theory and were not single outliers in an otherwise observable pattern. In many of these cases, open stands with a single canopy layer had lower flame length thresholds for mixed- and high-severity fire than stands with a higher level of cover or multiple canopy layers (i.e. open stands would experience more mortality than closed stands at a given flame length threshold). In 7 of 8 assessed ponderosa pine classes with small trees, open cover and a single canopy layer, only one had a threshold for surface fire – that is only one could experience surface fire and the rest would always experience mixed- or high-severity fire should a fire occur. This systemic pattern may be explained by the wind reduction factor used in fire model calculations. The wind reduction factor can substantially alter fire behavior calculations and has the potential to overestimate the influence of wind speed on fire behavior in open areas or conversely underestimate the influence of wind speed in closed areas. This issue was most prevalent in dry mixed conifer forest types and was also found in moist mixed conifer and ponderosa pine forest types. In these cases, the flame length threshold pattern for a given forest type and size class was compared to the flame length pattern for other size classes within the given PVT and to multiple size classes of the same forest type in similar PVTs. For the 2.2% of cases in which a systemic flawed pattern of flame thresholds was identified, flame length thresholds were conservatively raised in 58% of the cases based on the assumption that the wind reduction was overestimating the influence of wind in open area and conservatively lowered in 42% of the cases based on the assumption that the wind reduction was underestimating the influence of wind in areas with closed structural conditions.

Vegetation and fuel model succession, and their integration in Envision, were verified using animation, operational graphics and traces (Sargent 2005) to ensure correct successional development through time and after disturbances including wildfire and management activities. Envision's animation and operational graphic features were useful in verifying vegetation and fuel succession processes as well as the corresponding changes in performance indicator values. Traces were conducted using Envision's delta array, which tracks each change to each IDU in the landscape over the course of the simulation. The delta array can be filtered for specific processes such as vegetation or fuel succession. Both individual IDU delta arrays and delta array summaries for the whole landscape were used. As with the fire submodel, programming changes were made and verification processes were repeated.

Management and its integration in Envision was verified using the trace technique by assessing data in a log file that tracked Envision processes, including large landowner management activities. Traces using Envision FPF's delta array were also helpful in ensuring management rules were working as intended and were well integrated with other Envision processes. Animation and operational graphics were used to assess the timing and spatial arrangement of management activities. Changes were made iteratively and verification processes were repeated.

Operational Validity

If a model is determined to have the accuracy necessary for the model's intended purpose, it has operational validity (Sargent 2005). Envision FPF operational validity was assessed by exploring the direction and magnitude of change in over two dozen indicators. Indicator values for wildfire, management activities, and vegetation classes were compared to historic and recent data where possible (e.g. timber harvest levels, wildfire size). In addition, numerous experimental frames were considered from no management to intensive management and from mild fire weather conditions to extreme fire weather. Sensitivity analysis could be used in the future to assess the relative importance of various parameters. Sensitivity analysis can be understood as an examination of how changes in the assumptions of a model affect model outcomes and can be used to study how uncertainty in the output of a model can be apportioned to different sources of uncertainty in the model input (Saltelli et al. 2004). Key parameters for sensitivity analysis testing might include flame length thresholds, wind speed, wind direction, fuel moisture, and management levels. Validation and verification processes demonstrated that the model has enough accuracy to usefully compare different scenarios of landscape change over time as a result of vegetation succession, fire behavior, and management or policy change.

Agent-based Models and Institutions

In traditional agent-based models, individual agents make decisions from a suite of management options. For example, each homeowner makes a decision about whether or not to reduce hazardous fuels on their lands and the result is a heterogeneous pattern of treated and untreated homeowner lands. For institutions such as the Forest Service, the landscape areas involved are much larger and one might not expect as much heterogeneity in landscape outcomes. Yet decisions about land management activities can vary dramatically from district to district within a single national forest (Chapter 2) and also between national forests. In addition to the traditional use of agent-based models to explore the decisions of many small agents, agent-based models can capture and assess this coarser-scale but no less important institutional heterogeneity. A key factor not fully incorporated in Envision FPF is the influence of social factors on changing land management decisions within public institutions like the Forest Service.

Outputs and Applications

Envision FPF outputs a massive array of data that can be used to assess landscape outcomes. There are four general output types.

1) Individual reports can be produced that track particular indicators over time, stratified by different landscape attributes if desired. For instance, a report might track the amount of high-severity wildfire at each time step and stratify the report by potential vegetation type or landowner (e.g. Forest Service, private industrial, etc.). Any of hundreds of attributes can be tracked and reported in this way (see Appendix B for attribute categories.)
2) Envision produces a delta array that tracks every change in every IDU over the course of the simulation making post-processing analysis of landscape attributes possible.
3) Fire rasters and data are produced that track predicted and actual fire sizes, fire perimeters, flame lengths, crown fire, and arrival times.
4) Shapefiles may be produced at designated intervals to allow for mapping of scenario attributes at given points throughout the simulation.

Envision FPF does not currently incorporate an insect and disease model or climate change. Thus it cannot address questions about the complex interaction between insects and disease, climate, fire and vegetation succession over time. In addition, Envision FPF does not account for wholesale changes in vegetation cover type or understory due to disturbance or climate change. Wholesale changes in the understory – for example the very real possibility of cheatgrass invasion in actively managed areas – can significantly affect fire behavior. In the case of cheatgrass, fire spreads more readily when this invasive grass dominates the understory as compared to native bunchgrasses that naturally create less contiguous surface fuel beds. In the future, Envision may also be better able to incorporate dynamic social influences on management behavior.

Outputs are appropriately used to assess the relative differences in landscape outcomes between scenarios. Graphing differences in landscape indicators at an annual timestep allows an understanding of the pace of change and the stability of key indicators. Differences may also be assessed at the end of the modeling period though this provides less detail as to the cause of differences between scenarios. Outputs may be used to compare a suite of potential futures or scenarios, given a set of assumptions about system uncertainties. Researchers and land managers can use scenarios to better understand social-ecological system behavior under a variety of different management scenarios. Envision FPF may be appropriately used to build scenarios about potential future trends that explore the interactions and outcomes of fire, vegetation succession and management at the landscape scale in central and south Central Oregon. Chapter 4 provides this type of analysis.

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Chapter 4: Modeling Forest Change with an Integrated Social-Ecological Landscape Model

Introduction

Wildfire is a pressing issue for natural resource managers, communities and politicians in the western United States. Area affected by wildfire has climbed steadily over the last twenty years (Figure 4.1) and is expected to increase in the future due to climate change (Brown et al. 2004). The influence of wildfire on forestlands and communities can be dramatic and significantly alter both ecological values, such as the amount of old and young forest, and social values such as the view from popular hiking trails or timber production. Natural resource managers sit at the nexus of wildfire's social and ecological dimensions. Managers at the US Forest Service consider wildfire in the context of other land management objectives including conserving endangered species, providing clean water to communities, and providing hunting and fishing opportunities to the public. Balancing these diverse objectives in the context of landscapes dynamically shaped by wildfire is a challenge. In addition to deciding how and where to manage lands to reduce fire hazard, Forest Service decision makers must consider how community members will respond to smoke from prescribed fire, what kind of budget Congress will deliver, and if Administration policies will shift direction. Moreover ecological and social landscapes constantly shift direction and take new forms, creating an element of irreducible uncertainty. Where the next large wildfire will occur is unknown. How forest community composition will respond to climate change can't be predicted with certainty. When or if a biomass plant will be built that would reduce the cost of expensive fuel reduction work may be unpredictable.

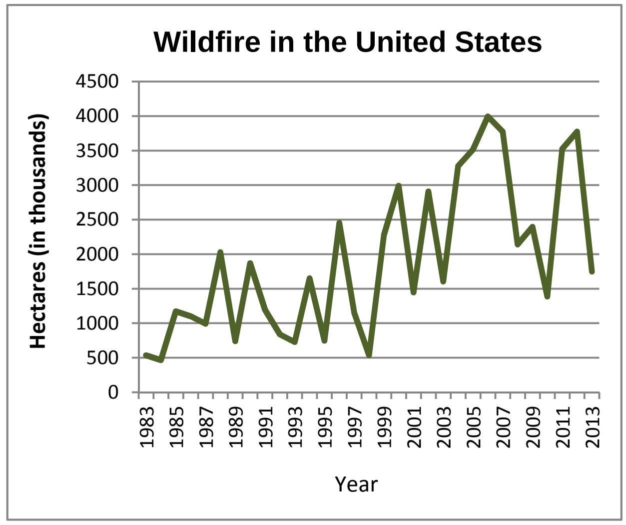

Figure 4.1. Wildfire in the United States (1983 – 2013). Data source: National Interagency Fire Center

Long-term, landscape-scale information about frequent fire landscapes is needed by land managers and policy makers in order to effectively balance social and ecological objectives. Researchers interested in complex landscapes influenced by human and ecological dynamics are increasingly turning to simulation models. Simulation models are often the only way to test alternative management scenarios when decades-long landscape scale experiments are not feasible (Mladenoff and Baker 1999). Simulation models enable researchers to learn about spatial processes and interactions in large, heterogeneous landscapes and explore how landscape patterns emerge from smaller scale dynamics (Caspersen et al. 1999). When disturbances like wildfire occur at large scales and interact with processes like weather, succession, and management over long time frames, a complex system is generated that is difficult to investigate without simulation models (Mladenoff and He 1999). Moreover, wildfire is a cross-scale phenomena that requires understanding of fine-grained details of fire ignition and spread as well as broad scale patterns of climate and topography. Multi-scale, multi-process simulation models enable analysis of such processes and interactions. While a number of forest landscape modeling systems have been created and used in experimental studies, a relatively new class of models called agent-based models (ABMs) are gaining prominence as an effective way to increase understanding of social-ecological systems such as those related to wildfire (An 2012, Bolte et al. 2007, Janssen and Ostrom 2006). Agent-based models allow simulation of agent, or land manager, decisions in a changing landscape and generally incorporate decision-making processes of agents and the social influences on these agents (An 2012). By contrast, traditional landscape simulation models use predetermined management trajectories and thereby lack landscape feedbacks to adjust policies or management activities in response to stochastic disturbances and successional pathways.

This research used an agent-based modeling platform, Envision, to explore questions related to land management and wildfire in central Oregon. The interactions between management activities, wildfire, and forests in central Oregon are complex and influenced by ecological factors such as local forest types and climate as well as social factors such as local uses and expectations of national forestlands (Chapter 2). Central Oregon's most populous city, Bend, is surrounded by frequent-fire forestlands and shrublands. Since 1970, Deschutes County, where Bend is located, has grown by 426% (USDC 2014). Growth has occurred not only at the edges of the heavily roaded and paved urban zone but in large pockets of more remote forestlands as well (e.g. Sunriver 1,336 hectares of forested and developed land 33.8 km south of Bend). Tourism now accounts for 21.5% of Deschutes County's economy (USDC 2014b), and proximity to high quality mountain, desert, and forest recreation is a primary draw. The iconic Cascade peaks and forestlands in the Deschutes National Forest, just west of Bend, play a key role in shaping local culture and supporting the local economy. The resilience of forests in central Oregon is a pressing concern for land managers and local communities alike. Simulation modeling can be used to explore a range of potential futures for central Oregon forests based on different management strategies.

This research compared metrics of landscape resilience for six different management scenarios. Metrics of resilience are defined in Chapter 1. Landscape resilience was assessed for management scenarios that varied in the amount and type of management activity, the distribution of management activities across the landscape, and how treatment areas were targeted. These factors were selected based on interview data gathered in Chapter 2 as well as fire behavior theory. I hypothesized that differences between scenarios would be driven by changes in vegetation characteristics including surface and canopy fuels. The change in vegetation characteristics would in turn affect the disturbance regime. I hypothesized that areas with higher levels of treatment, more contiguous treatment patterns, and larger treatment unit sizes would result in less high severity fire and more landscape resilience than areas with less treatment, distributed treatment patterns, and smaller treatment sizes.

Methods

Study Area

The study area, which covers 429,925 hectares, is bounded on the west by the crest of the Cascade Range and on the east by juniper woodlands and Oregon's shrub-steppe. It encompasses the majority of the Bend-Fort Rock Ranger District (~288,000 ha) on the Deschutes National Forest. Ownership is 78.6% federal, 9.2% homeowner, 6.7% private industrial, 4.6% private non-industrial, and < 1% state (Figure 4.2). Elevation ranges from 962 to 3065 meters. A collection of Cascade peaks and buttes including South Sister, Broken Top, Tumalo Mountain and Bachelor Butte dominate the

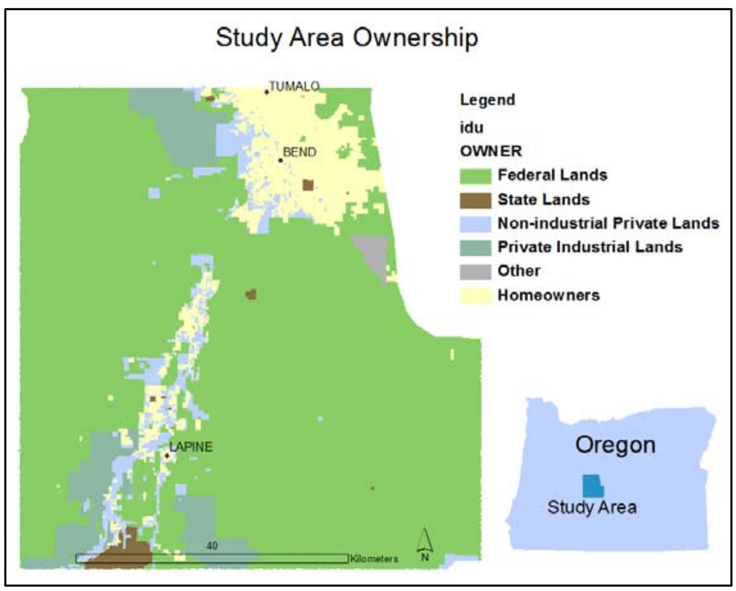

Figure 4.2. Federal lands account for 78.6% of the study area. Homeowners, predominantly around the city of Bend, account for another 9.2%. Private industrial (6.7%), private non-industrial (4.6%) and state (<1%) form the remainder.

landscape in the northwest of the study area (2370 – 3157 m) (Figure 4.3). Further south and east, the Paulina Mountains are the highest landscape features (2286 m). The western portion of the project area is geologically young, characterized by basalts and andesites overlaid with pumice and ash from volcanic eruptions (Franklin and Dyrness 1988). Further east, the study area is characterized by young lava flows often overlaid with alluvium and lake deposits plus eolian sediments (Franklin and Dyrness 1988). Pumice deposits are widespread (Franklin and Dyrness 1988). Topographic gradients and proximity to the Cascades lead to differences in climate variables across the study area. Higher elevation areas near the Cascades have more annual rain and snowfall and slightly cooler weather than lower elevation and eastern areas (Table 4.1).

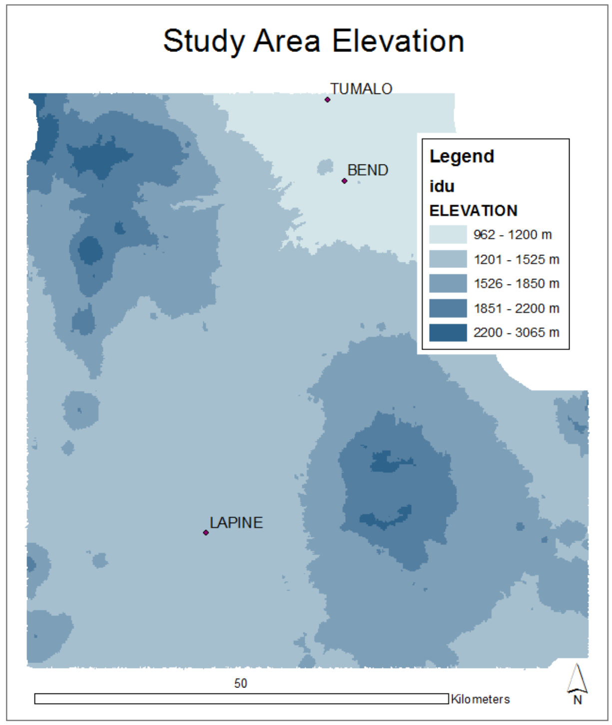

Figure 4.3. Cascade peaks reach 3065 meters in the northwest of the study area and the Paulina Mountains rise over 2200 meters in the east.

Table 4.1. Study area climate variables

	Elevation (m)	Average High Temp. July-Sept. (°C)	Average Low Temp. Dec.-Feb. (°C)	Annual rainfall (cm)	Annual snowfall (cm)
Bend	1116	26.4	-5.1	30.1	83.8
Wickiup	1329	25.5	-7.4	52.6	199.4

The varied topography and climate of the study area support a range of potential forest community types including high-elevation mountain hemlock, mixed conifer, lodgepole and ponderosa pine (Figure 4.4). Dry mixed conifer is the largest vegetation group in the study area (151,315 ha or 35.2% of the landscape) followed by ponderosa pine (72,569 ha or 16.9% of the landscape), lodgepole (52,515 ha or 12.2% of the landscape), and arid lands (48,158 ha or 11.2% of the landscape). High elevation vegetation types make up 7.7% of the study area, and 11.2% is developed, barren or unclassified. The study area is dominated by pole to medium size forest stands

(5-20" dbh) with some stands of large trees (20-30" dbh) and few stands giant trees (>30" dbh) (Figure 4.5). The area has been impacted by past high-grade logging, reducing the presence of large fire-resistant trees and increasing the presence of young plantations (Hessburg and Agee 2003, Kelly 2010).

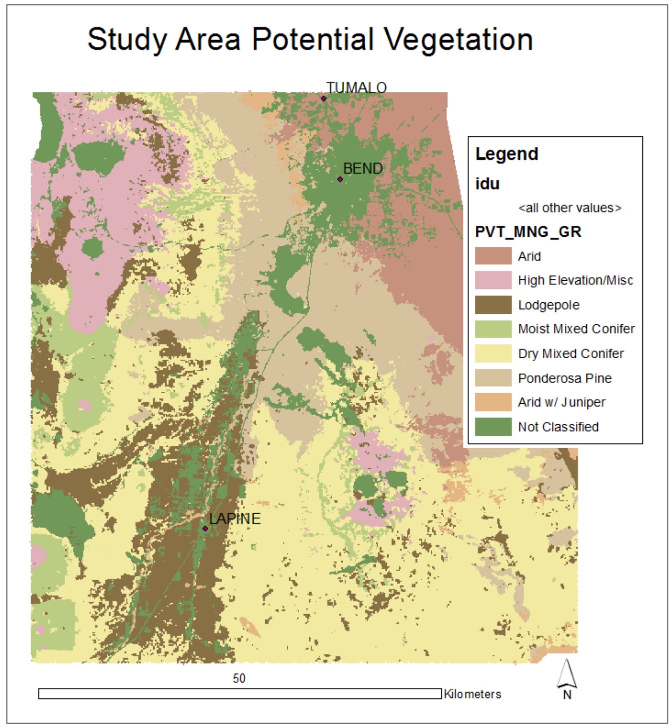

Figure 4.4. The study area is dominated by dry mixed conifer, ponderosa pine and lodgepole forest types. Smaller areas of moist mixed conifer and high-elevation forest types are found along the western study boundary, and arid lands cover the northeast corner.

Frequent historical fires in ponderosa pine and dry mixed conifer forests (Bork 1984, Heyerdahl 2001) resulted in minimal understory competition from seedlings and relatively uniform stand spacing as more closely spaced trees were selectively killed by fire (Agee 1993). Open stands were likely interspersed with occasional patches of young reproduction (Franklin and Dyrness 1988). Baker and Ehle (2001) suggest that uncertainties inherent in the development of fire history data lead to overestimation of the amount of fire historically present in dry western forests which would suggest more historical area with dense or multi-layered structure. Figure 4.6 shows ponderosa pine forest types within the study area are predominantly low cover. The high frequency of multi-layer stands shown in the figure is incongruous with descriptions of historical ponderosa pine successional patterns and fire regimes (Franklin and Dyrness 1988). Change in stand structure due to fire exclusion is thought to be more problematic in dry mixed conifer areas

Figure 4.5. Study area vegetation size distribution is 9.1% developed, 10.2% early successional (meadows, shrubs, seedlings-saplings), 17.5% pole stands (5-10” dbh), 25.9% small tree stands (10-15” dbh), 22% medium tree stands (15-20” dbh), 14.4% large tree stands (20-30” dbh) and 0.9% giant tree stands (>30” dbh).

than ponderosa pine areas because of the higher productivity and in-growth of grand fir at dry mixed conifer sites (Merschel et al. 2014). Fire exclusion in these areas has created homogenous high fuel conditions across large landscapes whereas these conditions were historically confined to smaller protected refugia such as north aspects and canyon bottoms (Agee 1993). Figure 4.6 suggests a similar change in structure within the study area with well over half of the landscape dominated by stands with moderate and high canopy cover. Such structural changes directly affect disturbance regimes (Mitchell et al. 1983, Larsson et al. 1983) and may have long-term effects on disturbance trajectories (Hessburg and Agee 2003).

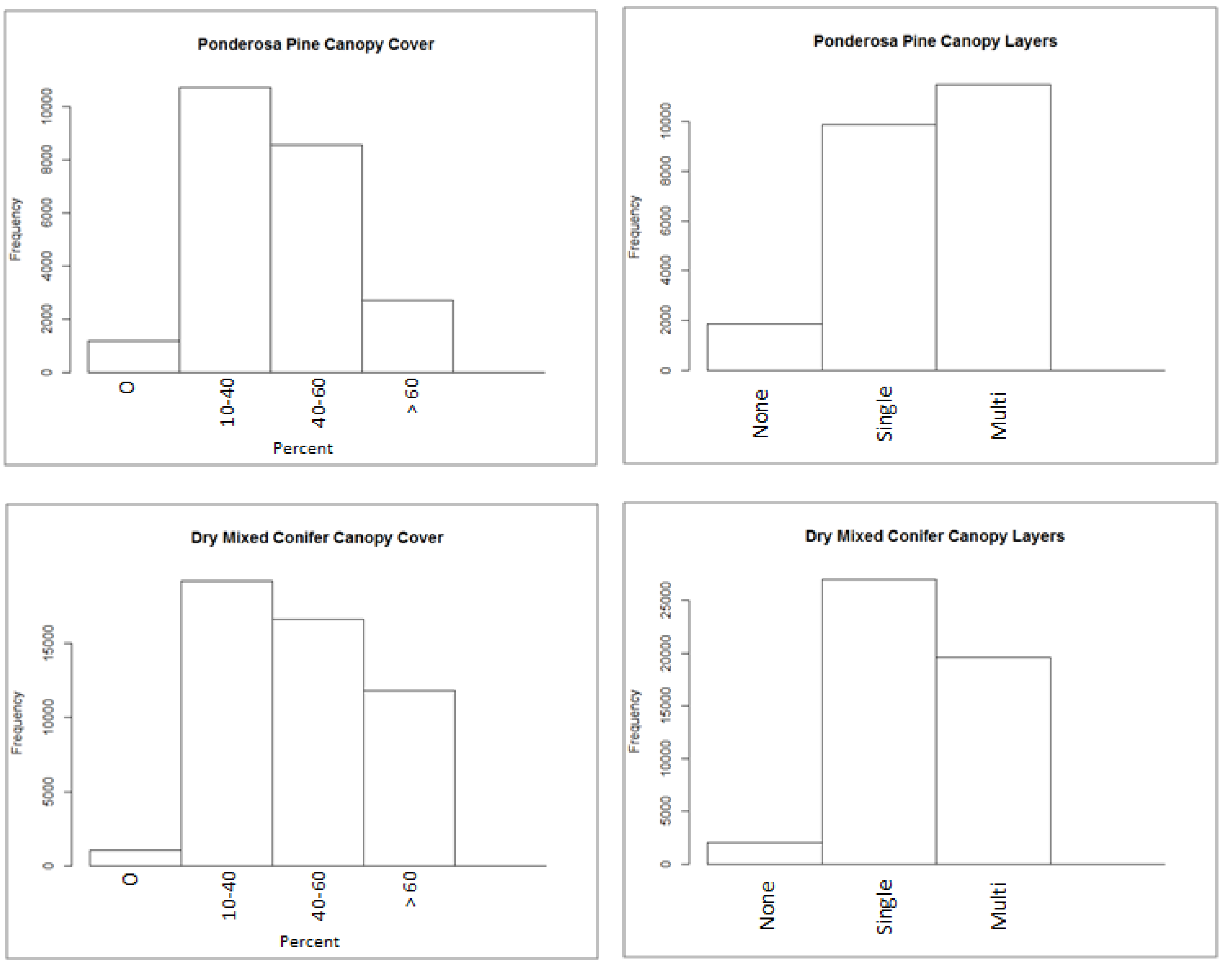

Figure 4.6. Canopy layers in ponderosa pine forest types and canopy cover in dry mixed conifer types are likely above historic levels in the study area.

The structural changes within the study area coincide with the relatively low level of wildfire within the study area since about 1950. A conservative estimate of 57,981 hectares have burned within the project area since the early 1900s (Data Resource Management/Fire a, Pacific Northwest Region, Forest Service, 20090624, S_R06.FireHistoryPl) (Figure 4.7). Prior to 1900, the majority of the landscape would have been likely to burn several times over a 60 year period (Barrett et al. 1997, Heyerdahl et al. 2014).

The project area has been heavily managed since the 1950s (Oliver et al. 1994) with the exception of the high elevation northwest area and Newberry National Volcanic Monument (Figure 4.8). Industrial logging on roughly 80,000 hectares of study area lands (later acquired by the Forest Service) left a legacy of homogenous, dense ponderosa pine that is now actively managed by the Deschutes National Forest.

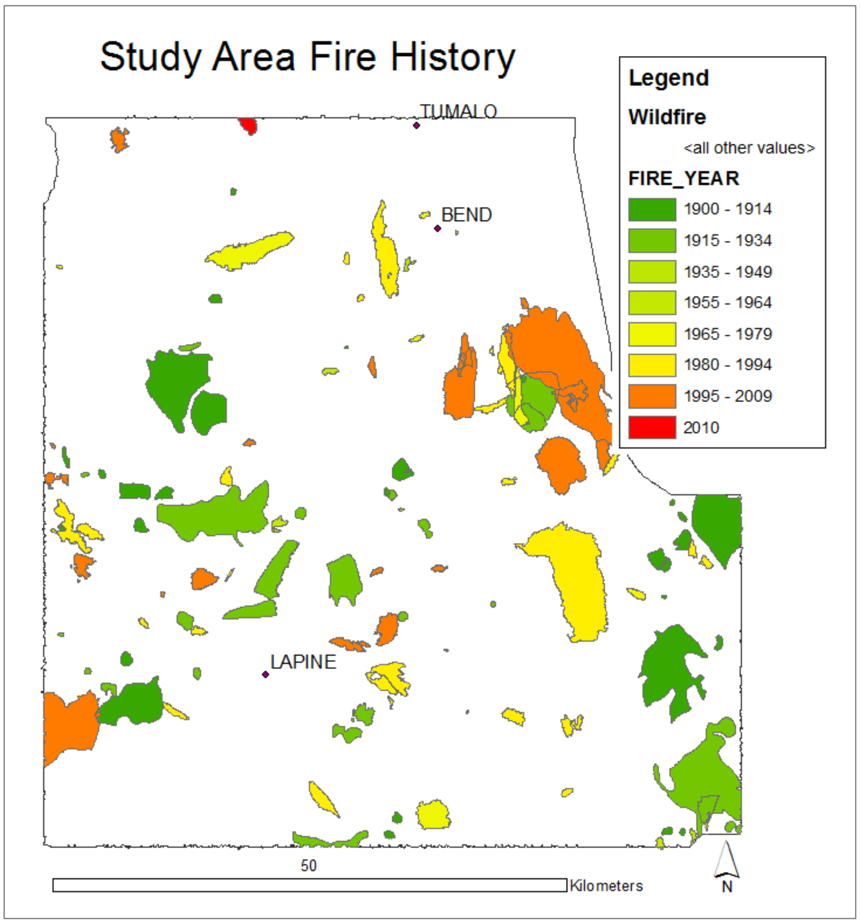

Figure 4.7. There have been fewer fires in the study area since the 1950s than would be expected from the historic record. Yet fire suppression has not been able to exclude all wildfire.

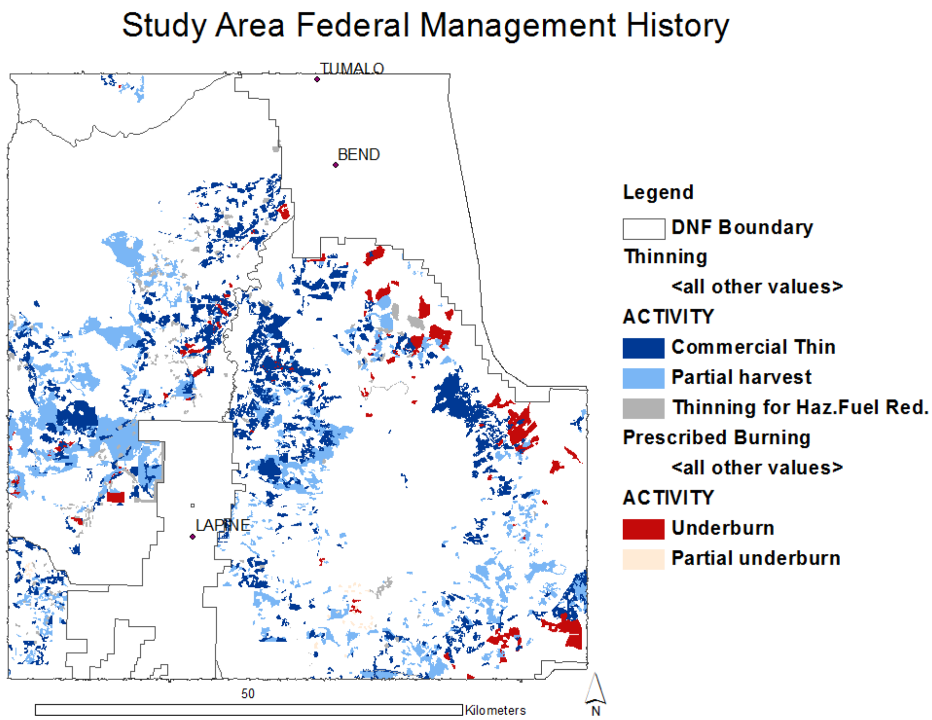

Figure 4.8. The project area has been heavily thinned since the 1950s. Use of prescribed fire has been limited to the eastern portion of the study area and scattered pockets elsewhere.
Data source: Deschutes National Forest.

Model Development and Validation

For a more detailed description of model development and validation processes, see Chapter 3.

Envision Modeling Platform

Envision is a spatially explicit modeling framework that simulates landscape change through the interaction of individual decision units, actors, management activities, autonomous processes and landscape indicators. Within Envision, the landscape is represented as individual decision units (IDUs). IDUs are vectors and are handled as the minimum mapping unit, or resolution, in Envision. The average IDU was roughly 3 hectares in size. IDUs carried static and dynamic landscape attributes through time. Actors are different classes of agents that make decisions about landscape management activities. For this project, actors included the Forest Service, private industrial forest owners, non-industrial private forest owners, and homeowners. Autonomous processes drive non-management landscape change. Autonomous processes in this project included fire, vegetation succession, and population growth. Autonomous and management processes occurred at annual timesteps. Indicators of forest and landscape condition were used to assess landscape change over time and included measures of fire severity and amount, fire hazard, vegetation structure, and management activity and amount.

Fire

Discrete wildfire events were simulated using the MTT fire growth algorithm (Finney 2002). The MTT algorithm replicates fire growth by Huygens' principle where the growth and behavior of the fire edge is modeled as a vector or wave front (Knight and Coleman 1993). This method results in less distortion of fire shape and response to temporally varying conditions than techniques that model fire growth from cell-to-cell on a gridded landscape (Finney 2002). Extensive application has demonstrated that the Huygens' principle in general, and the MTT algorithm in particular can accurately predict fire spread and replicate large fire boundaries on heterogeneous landscape (Finney et al. 2011b). The MTT algorithm is imbedded in a number of wildfire modeling platforms including FlamMap and FSPro and is widely used by the fire management community for strategic and tactical wildfire management planning and operational wildfire problems throughout the U.S. (Ager et al. 2011, Noonan-Wright et al. 2011).

MTT simulates fire on a two-dimensional lattice using gridded inputs on canopy fuels, surface fuels, elevation, slope, and aspect. Outputs include fire perimeters, intensity grids, crown fire activity, and a number of other fire behavior metrics (Ager et al., 2011). Initial landscape values for canopy cover, crown height, canopy base height and canopy bulk density were based on the GNN layer created by the LEMMA working group (2008) and expert opinion. Fuel moistures and weather inputs were based on analysis of historic weather data from 25 RAWS weather stations from 1991-2011. Wind direction was based on Brush Creek RAWS data from 2000 to 2010. Daily fire probability was determined by daily energy release component (ERC) values. ERC is an index related to potential fire intensity and is a function of fuel models and live and dead fuel moistures. ERC is the preferred indicator for the effect of intermediate to long-term fuel moisture levels on fire behavior (Bradshaw et al. 1983) and is directly associated with area burned by wildfire (Finney 2011). Ignition locations were selected with a Monte Carlo method from a probability surface based on a logistic regression of historic natural and human-caused ignitions within the project area (Short 2014, Short 2013).

Vegetation Succession

Vegetation succession was represented with state and transition models that classified the landscape into a discrete set of vegetation states. Transition probabilities developed by the Integrated Landscape Assessment Project (ILAP) were used for vegetation succession while fire and management activities were handled by other Envision processes. Additional management transitions were added to the ILAP models to represent management activities described by interview respondents from the Deschutes National Forest (Chapter 2). ILAP vegetation states were defined by potential vegetation type, cover type, tree size, forest canopy cover, and canopy layering. A full list of forested PVTs in the study area is provided in Table 4.2. There were 124 possible cover types, and size was represented by ten classes ranging from barren to stands of giant trees (>30" dbh). Canopy cover was represented by 5 classes that ranged from none to high (> 60%) and also included a post-disturbance class. Forest canopy layering was represented as single or multi-layered. Each unique vegetation state had multiple possible successional trajectories, and each successional trajectory had an associated probability. The successional probabilities added an element of stochasticity to vegetation modeling. Each stand also had a deterministic age threshold. Once the threshold was reached, a stand would transition to a new successional state. State and transition models have been used by researchers and land managers to assess landscape change since the 1970s (Waggoner and Stephens 1970, Merzenich et al. 1999, Hemstrom et al. 2007, Strand et al. 2009).

Table 4.2. Study area forested potential vegetation types

Forested PVTs
Subalpine fir – cold, dry
Grand fir – cool, moist
Ponderosa pine - Dry, with juniper - Dry, residual soils - Xeric
Mountain hemlock - Cold, dry - Intermediate
Mixed conifer Cold, dry - Dry - Dry (pumice soils) Moist
Subalpine woodland
Subalpine parkland
Lodgepole pine Dry - Wet
Ponderosa pine-lodgepole pine
Shasta red fir – dry
Pacific silver fir – intermediate
Western hemlock - wet

Management

Land management activities varied by actor type according to interview and survey data gathered by several Forests People Fire (FPF) research team members. Non-industrial private forest owners and homeowners made decisions based on the outcome of empirical econometric models. This approach relied on survey data to develop statistical models of management behavior which resulted in landowner management actions as a function of landscape, demographic, socioeconomic, and social network variables (Spies et al. 2014). Research for this dissertation focused on federal land management. Following Jones (2001) call to ground models of human choice in observation, a decision making structure was chosen based on 116 interviews conducted with large landowners and managers by FPF researchers. The decision making structure used the conceptual framework of institutional theory and thus focused on rules that guide management decisions (Frederickson 2003).

Federal management decisions were structured by management activity targets, constraints, and preferences. Each management activity was associated with an acreage target, and management activities and targets varied by scenario. Management activities used in scenarios are listed in Table 4.3.

In addition to an acreage target, activities were constrained by a number of factors. Constraints were used to exclude or constrain management activities to particular areas of the landscape. Constraints may be related to any attribute carried by IDUs through time and may vary by activity. For example thinning may be excluded from wilderness areas while prescribed fire may be allowed. Constraints used in management scenarios are described in the scenario development and validation section that follows.

Table 4.3. Management activities in study area simulation

Activity	Effect of Activity
Prescribed fire	Reduces surfaces fuels; sets fuel model to low flame length, low spread rate (e.g. 181, 182)
Mowing and grinding	Alters distribution of surface fuels; eliminates shrub layers and increases surface fuels; custom masticated fuel bed model assigned
Thinning from below*	Reduces cover to 40-60% and reduces layers from multi to single
Partial harvest*	Reduces cover to 0-40% and reduces layers from multi to single
Heavy partial harvest *	Reduces cover to 0-40%, reduces layers from multi to single and reduces size by 1 class (e.g. from large to medium)

* Assumes piling and burning. Does not preclude prescribed fire.

Preferences were used to make it more or less likely for a management activity to occur in areas defined by the preferences. As with constraints, preferences may be developed from any attribute carried by the IDUs through time. Many preferences may exist for a single management activity. Each preference was given a weight, or score (which can be positive or negative). A total preference score for each IDU was created by summing preference scores. IDUs with the highest preference scores were selected for management first. Additional IDUs were selected until the acreage target was achieved or constraints excluded the remainder of the landscape. An IDU selected for treatment was expanded to incorporate neighboring IDUs up to a defined size, or until constraints excluded the management activity. For example, if an 8 hectare IDU was selected and the expansion threshold was set to 100 hectares, Envision would grow the 8 hectare treatment parcel to 100 hectares. If constraints were met before the target size was reached, a smaller treatment unit would result.

Envision Verification and Validation

Verification and validation of the Envision FPF model is documented following Sargent (2005). Sargent (2005) defines model verification as ensuring computer programming and implementation are correct whereas model validation is defined as ensuring model processes satisfy accuracy demands for the model's intended use. For a more complete discussion of model validation and verification processes, see Chapter 3.

Face validation and traces were used to conceptually validate the model (Sargent 2005). Face validation involved asking knowledgeable individuals and experts if the model or its behavior was reasonable. The tracing technique involved following the behavior of different entities or processes in the model to determine if logic correct and accuracy was attained. Fuel model logic was evaluated using face validation, traces, and animation (Sargent 2005). The animation technique was used to display a model component or process as the simulation moved through time. Traces and animation tracked change in potential flame length before and after wildfire, prescribed fire, timber harvest and mowing or grinding. Potential flame length is an indicator of fire hazard and represents the flame length if a fire burned a particular area at given weather conditions. Vegetation succession logic was validated with animation, face validation and traces (Sargent 2005) which allowed analysis of change in structural stage and cover type over time and individual stand development trajectories. Management logic for large landowners was conceptually validated through face validation by internal project experts and consultation with land managers. Federal decision makers reviewed draft decision rules and provided feedback that was incorporated before decision rules were finalized.

Processes used to verify the accuracy of the fire, fuels, vegetation, and management submodels, and the integration of all model subcomponents, include: extreme condition tests, internal validity tests, event validity tests, operational graphics, dynamic testing, animation, and traces (Sargent 2005) (Table 4.4). Verification processes led to iterative changes and additional verification procedures.

Table 4.4. Verification techniques used to evaluate model processes and integration

Technique	Fire	Fuels Succession	Vegetation Succession	Management
Operational graphics	x	x	x	x
Animation	x	x	x	x
Traces	x	x	x	x
Extreme condition tests	x	x		x
Internal validity tests	x		x	
Event validity tests	x			x
Dynamic Testing	x	x		

Envision FPF operational validity was assessed by exploring the direction and magnitude of change in over two dozen indicators (see Appendix B for indicator classes). Indicator values were compared to historic and recent data where possible (e.g. timber harvest levels, wildfire size). Validation and verification processes demonstrated that Envision FPF has the accuracy needed to compare the relative outcomes of different scenarios on landscape values such as fire hazard, basal area, and structural vegetation classes.

<u>Scenario Development and Validation</u>

Six scenarios for simulation modeling were developed based on the factors described in the Introduction. Each scenario was run for 50 simulation years, and 30 replicates of each scenario were produced. See Table 4.5 for a scenario overview.

Table 4.5. Scenario overview

Scenario	Key Feature
No Treatment	There was no active management.
Base	Treatment was modeled on historic disturbance regimes.
Size	Treatment unit sizes were small and distributed rather than large and contiguous.
Basal Area	Treatments prioritized stands with high basal area rather than high fire hazard.
Current Level	Thinning and prescribed fire occurred at current treatment levels.
Backlog	Thinning was doubled from Base scenario levels for first five simulation years and prescribed fire was doubled for first ten.

No Treatment Scenario

The No Treatment scenario assumed no active management and wildfire consistent with levels in the recent past (1991-2011). This scenario reflected concerns raised by land managers and others about the sustainability of existing wood-processing facilities. Lumber mills have been closing across Oregon for many decades, and a spate of recent mill closures has created acute awareness of the difficulty of achieving federal land management objectives with reduced or negligible wood-processing infrastructure. This scenario was developed to explore the impact of the complete loss of wood processing facilities and logging companies.

Base Scenario

The Base scenario was built to emulate the historical disturbance regime. Analysis for the Base scenario was based on methods used by North et al. (2012). The Base scenario actively managed four forest types: ponderosa pine, dry mixed conifer, moist mixed conifer and lodgepole. In lodgepole, only prescribed mixed-severity fire was used. In the other forest groups, both thinning and prescribed surface fire were used. The acreage targeted for treatment each year was based on the total acreage of the forest type and the estimated historic fire return internal. For example, an estimated fire return interval of 60 years was used for lodgepole pine. The annual acreage target was set to $1/60^{th}$ of the lodgepole in the study area. Estimated historical fire return intervals were intentionally conservative, i.e. fire likely burned more often in many these areas than assumed by the Base scenario (Table 4.6). North et al. (2012) developed a conservative estimate of historical area burned by calculating the mean of the highest quartile of historic fire return intervals from the literature. Many more fire histories were available for the North et al. (2012) analysis (a much larger study area) than were available for this study area. Rather than a mean of the highest quartile of fire return intervals, I chose a mean HFRI value from an individual study that represented the higher end of the HFRI range. Research within or nearest the study area was preferred as was research using cross-dated fire scar methods. In the Base scenario, targets were equivalent for both thinning and prescribed fire. Thinning was excluded from wilderness areas and all open canopy, single layer stands. Areas with potential for high-severity fire were most likely to be thinned, and areas with potential for mixed-severity fire were next most likely to be thinned. Lodgepole stands could be managed with mixed-severity prescribed fire if there had not been a fire in the stand for at least 60 years and stands were not in wilderness. Areas with potential for high-severity fire were prioritized within lodgepole forest types. Prescribed fire was not used in areas with high canopy cover and multiple canopy layers. Areas with potential for high-severity fire were most highly preferred for prescribed fire, and areas with potential for mixed-severity fire and that had recently been thinned had equivalent secondary preference scores. The size of individual treatment units for thinning varied based on estimated patch sizes created by historical fire disturbance regimes. Thinning in dry mixed conifer and ponderosa pine forest types was allowed to expand to 10,000 hectares based on data and theory suggesting low-severity fire regimes were common in these forest types, leaving behind forests very similar to pre-fire conditions (Heyerdahl et al. 2001, Bork 1984, Weaver 1959, Agee 1999). The resulting landscape would have similar stand structure across vast areas but discontinuous fuels from many small fires as well as small pockets in early phases of stand development (Agee 1998, Spies et al. 2006). Thinning in moist mixed conifer forests was allowed to expand based a normal distribution with a mean of 51 hectares and a standard deviation of 20 hectares. Fire science suggests most patches were generally tens to hundreds of acres in mixed-severity fire regimes typical of moist mixed conifer forests. (Perry et al. 2011, Agee 1993).

Table 4.6. Conservative fire return intervals used to parameterize Base scenario

Forest Type	Assumed Fire Return Interval	Informed by
Lodgepole	60	Heyerdahl et al. 2014, Bend-Fort Rock District, DNF
Moist mixed conifer	53	Heyerdahl et al. 2001, Blue Mountains; Wright and Agee 2004, Wenatchee National Forest
Dry mixed conifer	36	Heyerdahl et al. 2001, Blue Mountains; Wright and Agee 2004, Wenatchee National Forest
Ponderosa pine	17	Bork 1984, Deschutes National Forest

Size Scenario

The Size scenario was the same as the Base scenario but altered the size of treatment units. The Size scenario tested the effect of treatment unit size while holding total area treated constant. While treatment unit size has been suggested as an important influence on landscape fire behavior (Sneeuwjagt et al. 2013, Millar et al. 2007, Hessburg et al. 2007, Finney et al. 2005), some studies show size to be unimportant (Finney et al. 2007). The Size scenario used smaller treatment unit sizes than the Base scenario and emulated current DNF treatment unit sizes based on data gathered in interviews (Chapter 2).

Basal Area Scenario

The basal area scenario replicated the Base scenario but prioritized high basal area and canopy cover rather than high fire hazard areas. Timber targets are still an important influence on federal land manager decisions on the DNF (Chapter 2), and this scenario was developed to test the impact a timber focus might have on landscape resilience in the study area. However, basal area and canopy cover are inadequate indicators for timber-focused management. In the future, a preference for larger diameter stands could be included, and trees per hectare thresholds could be used as well.

Current Level Scenario

The Current Level scenario used current treatment levels rather than treatment levels based on the historic fire return interval. All other scenario variables were held constant as compared to the Base scenario. The Current Level scenario was parameterized with data from interviews with 34 staff involved directly in land management planning and implementation on the DNF (Chapter 2). While this scenario is modeled on current management activities and levels, it does not use the small treatment unit sizes that are also typical of current management.

Backlog Scenario

The Backlog scenario tested the impact of doubling thinning acreage for the first five years and doubling the prescribed fire acreage for the first ten years to more quickly manage forest areas with cover, layering, and surface fuels above historical levels for dry forests in the study area. This scenario was developed in response to interview data as well as recent policies aimed at reducing a substantial build-up of forest fuels conducive to large-scale high-severity fire. The build-up of areas at risk of high-severity fire outstrips the capacity of managers to address such issues, creating a backlog of areas thought to be at risk of uncharacteristic high-severity fire.

All scenarios held management on private non-industrial, homeowner and private industrial lands constant at current management levels. Scenarios thus focused on altering management strategies on federal lands (78.6% of study area) (Table 4.7).

Verification focused on ensuring scenarios correctly represented the management strategies selected. The Base scenario was run with different constraints, preferences and options to determine how Envision was interacting with scenario elements. Scenario variables were tested until confidence in scenario programming was achieved. That is, verification processes were used to ensure correct programming of scenarios such that if small treatment areas were programmed, small treatment areas resulted on the landscape.

Table 4.7. Scenario description and summary of key scenario variables

	No Treatment	Base	Size	Basal Area	Current Level	Backlog*
Management activities and amount (ha)	None	PP thin (4269) DMC thin (4262) MMC thin (451) Mixed-sev. fire (875) Surface fire (8982)	PP thin (4269) DMC thin (4262) MMC thin (451) Mixed-sev. fire (875) Surface fire (8982)	PP thin (4269) DMC thin (4262) MMC thin (451) Mixed-sev. fire (875) Surface fire (8982)	PP, DMC & MMC thin (4047) Surface fire (1039)	PP thin (8538) DMC thin (8525) MMC thin (901) Mixed-sev. fire (1751) Surface fire (17,964)
Treatment unit size (ha)	NA	PP & DMC thin + Surface fire (10,000) MMC thin (11-91) Mixed-severity fire (3000-7000)	All activities (17-37)	PP & DMC thin + Surface fire (10,000) MMC thin (11-91) Mixed-severity fire (3000-7000)	PP & DMC thin + Surface fire (10,000) MMC thin (11-91) Mixed-severity fire (3000-7000)	PP & DMC thin + Surface fire (10,000) MMC thin (11-91) Mixed-severity fire (3000-7000)
Preferences	NA	High- and mixed-severity fire potential	High- and mixed-severity fire potential	Basal area & Canopy cover	High- and mixed-severity fire potential	High- and mixed-severity fire potential

* Backlog thinning targets for first five years; surface fire targets for first ten years.

Results

Thirty replicates of each scenario were run, and the mean values for each indicator were used to summarize results. The research goal to compare the relative outcomes of various management scenarios is well-suited to the use of means for comparisons. Moreover, for most scenarios the standard deviation was not as large as might be anticipated when the amount of wildfire for an entire 50 year simulation period was considered (as opposed to the standard deviation for wildfire in a single year) as can be seen in the results below. That is, most scenarios had at least one or two years with large wildfires, though the large wildfire might occur in different years during the simulation.

Management

In dry mixed conifer forest types, the Current Level scenario thinned the least amount of area over the 50 year simulation period (8.2% less than Base) while the Backlog scenario thinned the most (14.1% more than Base) (Figure 4.9). In moist mixed conifer and ponderosa pine forest types, there was a similar level of thinning among all scenarios except the Backlog scenario (Figure 4.9). The Backlog scenario cumulatively thinned more than twice as much moist mixed conifer forest and almost twice as much ponderosa pine forest compared to other scenarios.

The Current Level scenario generated far less prescribed fire than any other management scenario in all forest types: 86.9% less than Base in dry mixed conifer, 92.7% less than Base in moist mixed conifer, and 89.2 % less than Base in ponderosa pine (Figure 4.10). The Basal Area scenario had a higher level of prescribed fire than the remaining scenarios in dry mixed conifer forests (Figure 4.10). The Base and Backlog scenarios had the highest amount of prescribed fire in moist mixed conifer forest types (Figure 4.10). In ponderosa pine forest types, the Basal Area and Backlog scenarios had 31.6% and 14.9% more prescribed fire than the Base scenario, respectively.

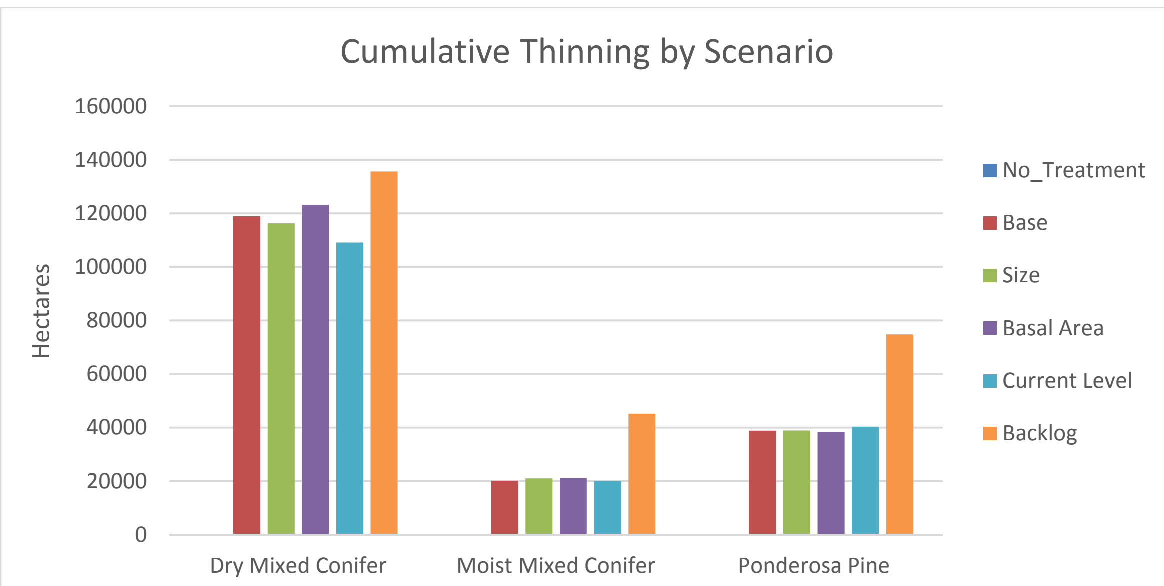

Figure 4.9. Thinning levels were highest in the Backlog scenario in all forest types. Levels were similar for all other scenarios in moist mixed conifer and ponderosa pine types. In dry mixed conifer types, the Current Level scenario thinned the least of any of the management scenarios. Level of thinning is the average from 30 replicates of each scenario over a 50 year simulation period.

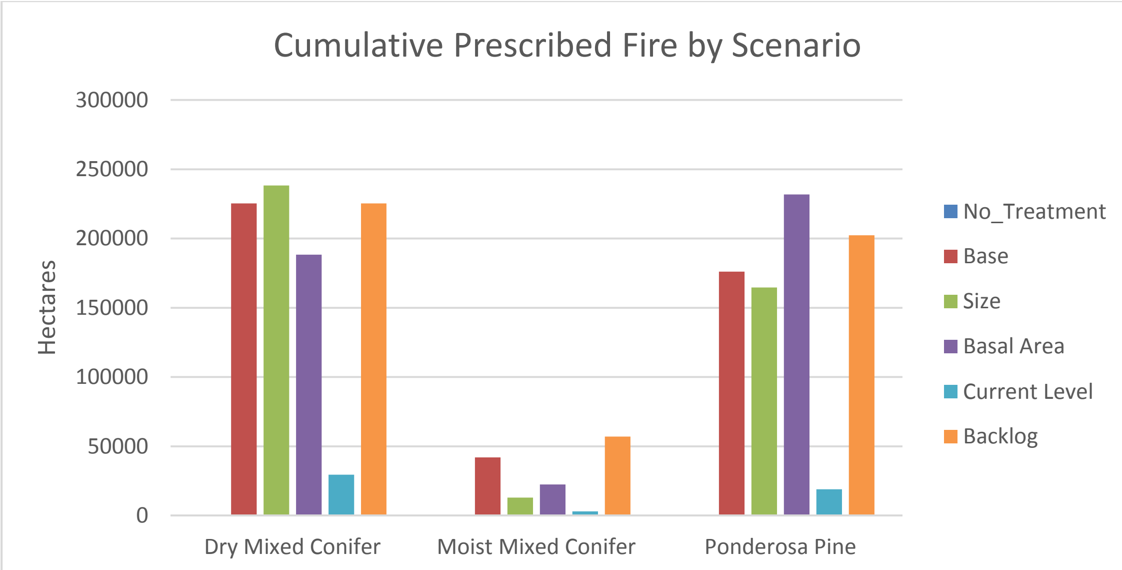

Figure 4.10. The Current Level scenario had the least amount of prescribed fire in all forest types. All scenarios had low levels prescribed fire in moist mixed conifer types. Level of prescribed fire is the average from 30 replicates of each scenario over a 50 year simulation period.

<u>Fire</u>

There was 66.2% more high-severity fire in the No Treatment scenario than in the Base scenario (Figure 4.11). The Size scenario resulted in about 9.8% more high-severity fire than the Base scenario (Figure 4.11). The Basal Area scenario resulted in 6.2% less high-severity fire than the Base scenario (Figure 4.11). The Current Level scenario resulted in 68.2% more high-severity fire than the Base scenario (Figure 4.11). The largest differences between the Current Level and Base scenarios were in the dry mixed conifer and ponderosa pine forest types though all forest types had less high-severity fire in the Base scenario than in the Current Level scenario, including forest types that were not actively managed (Figures 4.12 – 4.13). The Backlog scenario resulted in 2.4% less stand-replacing fire than the Base scenario (Figures 4.12 – 4.13). The difference in stand-replacing fire between scenarios was most pronounced in years with high amounts of wildfire (or extreme fire weather) (Figure 4.14).

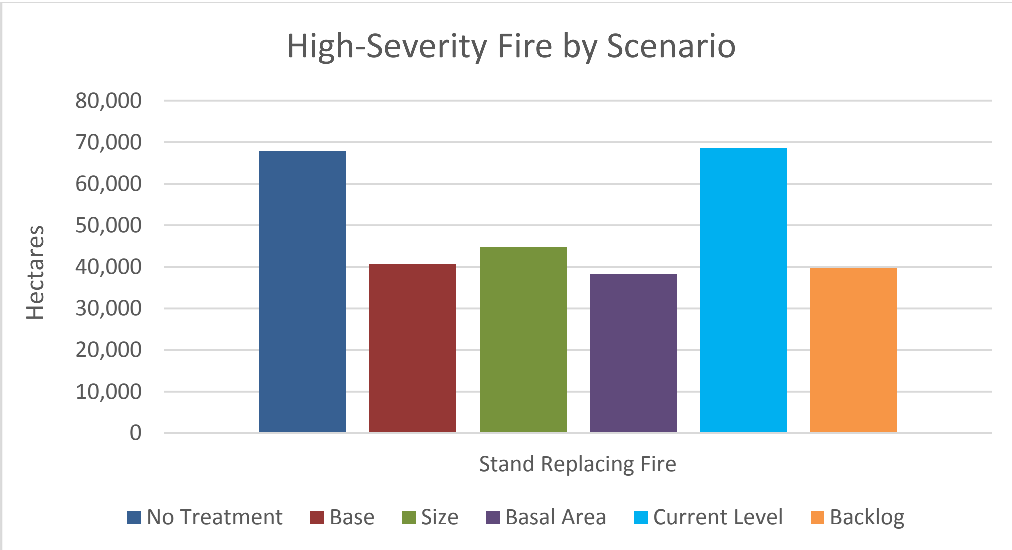

Figure 4.11. Hectares of high-severity fire was highest in the No Treatment and Current Level scenarios. The other four scenarios had similar levels of high-severity fire, with the Basal Area scenario experiencing slightly less high-severity fire than the Base and Backlog scenarios and the Size scenario experiencing slightly more high-severity fire the Base and Backlog scenarios.

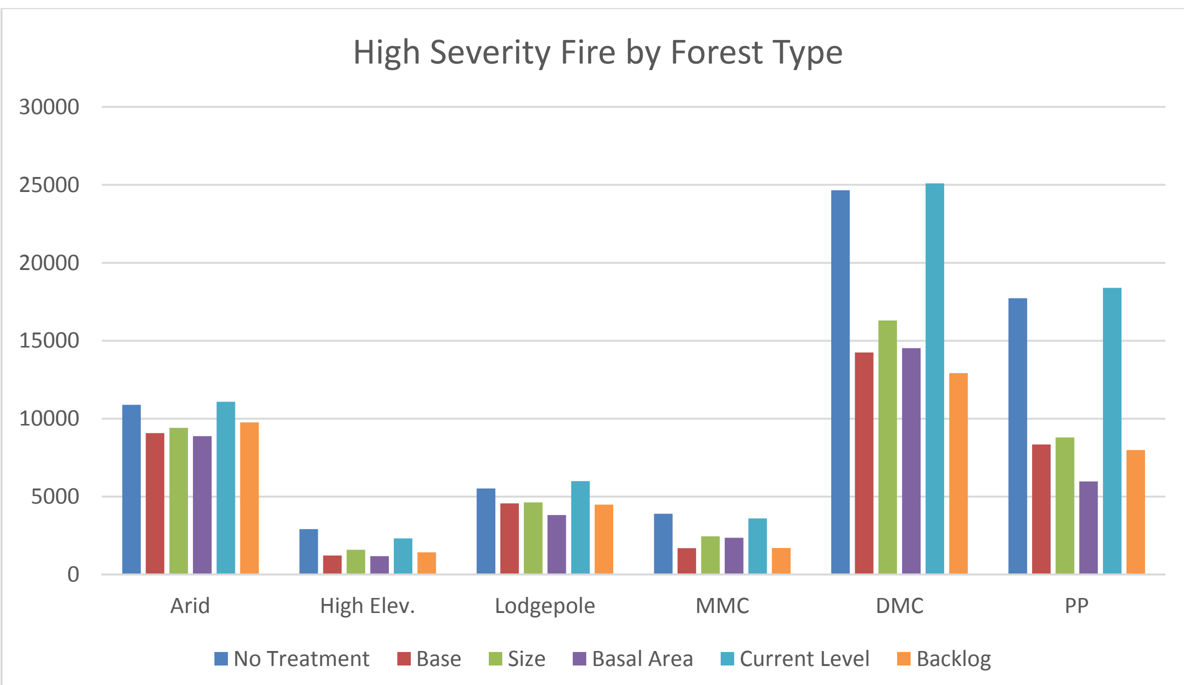

Figure 4.12. The largest differences between scenarios in the occurrence of high-severity fire occurred in dry mixed conifer (DMC) and ponderosa pine (P Pine) forest types.

Table 4.8. Cumulative hectares burned by high-severity fire for each scenario. Hectares represent mean of 30 replicates. Standard deviations are shown as well.

Scenario	Arid (ha)	sd	High Elev. (ha)	sd	Lodgepole (ha)	sd	MMC (ha)	sd	DMC (ha)	sd	PP (ha)	sd
No Treatment	10,892	289	2,919	122	5,525	195	3,900	148	24,655	765	17,723	508
Base	9,076	254	1,226	47	4,565	180	1,692	75	14,248	448	8,348	247
Size	9,410	256	1,590	56	4,634	174	2,459	104	16,306	507	8,803	293
Basal Area	8,881	244	1,179	44	3,825	154	2,365	108	14,522	487	5,973	195
Current Level	11,087	285	2,321	84	5,996	200	3,606	134	25,098	751	18,396	557
Backlog	9,761	263	1,427	49	4,486	172	1,710	76	12,919	391	7,983	237

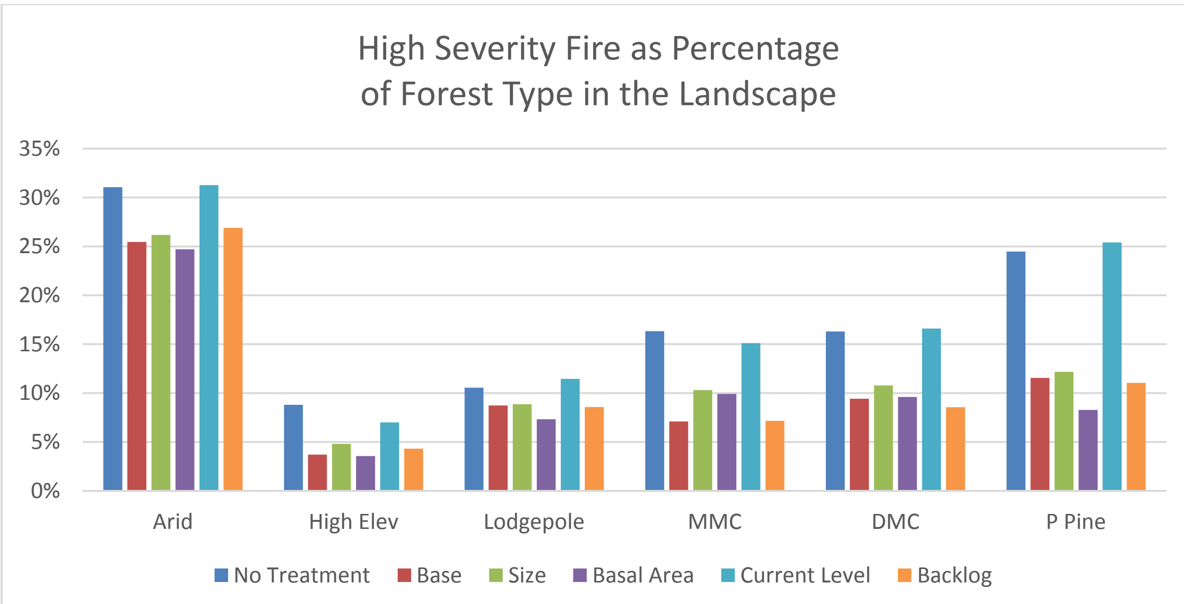

Figure 4.13. Occurrence of high-severity fire shown as a percentage of forest type. Arid lands and ponderosa pine forest types show the largest proportion burned at high-severity. The No Treatment and Current Level scenarios result in higher proportion of forest type burned at high severity than all other scenarios in all forest types.

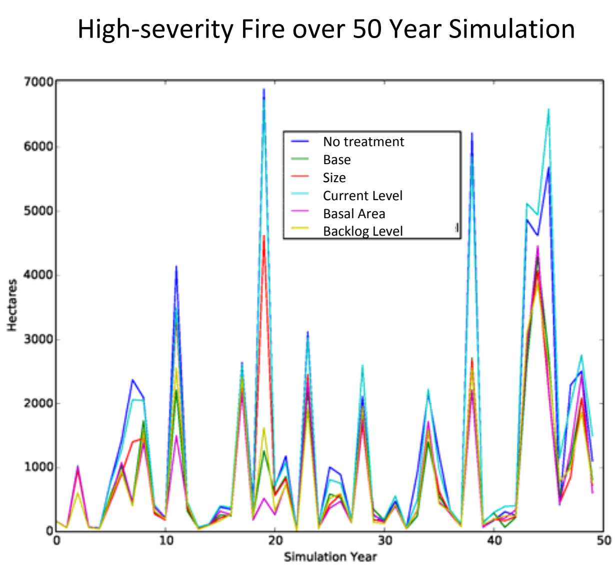

Figure 4.14. High-severity fire by scenario over the course of 50 years. Each line represents the average level of fire from 30 replicates over time.

Vegetation Change

In the No Treatment scenario, unlike all other scenarios, the area dominated by stands of medium, large and giant trees (>15" dbh) in open structural conditions declined over time (Figures 4.15 – 4.16), and the area with stands of medium, large and giant trees in closed structural classes increased Figures 4.17 – 4.19). The Base, Size and Basal Area scenarios all had very a similar rate and direction of change for vegetation classes. The Base, Size and Basal Area scenarios showed asymptotic increases in the amount of area dominated by stands of medium, large and giant trees in more open structural conditions, and the trajectories began to flatten and stabilize at about year 20 (Figures 4.15 – 4.16). The Base, Size and Basal Area scenarios show a corresponding asymptotic decrease and stabilization in the amount of area dominated by stands of medium, large and giant trees with more closed structural conditions (Figures 4.17 – 4.19). The Current Level scenario showed the same directional trends as the Base, Size and Basal Area scenarios but the rate of change was slower, and the trend flattened later in the simulation (at about year 38) resulting in lower levels of open structural conditions and higher levels of closed conditions (Figures 4.15 – 4.19). The Backlog scenario trajectories also showed asymptotic trends in the same directions, but the trajectories flattened much earlier, around years 5-7 instead of year 20 as in the Base scenario. In addition, the Backlog scenario resulted in less open forest structure in the medium to giant size classes than the Base scenario (Figures 4.15 – 4.16). Tables 4.9 and 4.10 summarize area in medium to giant vegetation classes at the end of the simulation.

Total area dominated by pole and small trees (5-15" dbh) decreased steadily over time in all scenarios though the decline was steeper in the No Treatment, Basal Area and Current Level scenarios than in the Base, Size, and Backlog scenarios (Figure 4.20). The area with stands of seedlings and saplings (<5" dbh) increased in all scenarios (Figure 4.21). The greatest increase occurred in the Basal Area scenario, followed by the No Treatment and Current Level scenarios. The area of meadow and shrub increased in all scenarios over time in punctuated jumps from one level to the next (Figure 4.23) as a direct result of the amount of high-severity fire. The greatest increase in meadow and shrub area occurred in the No Treatment and Current Level scenarios and the smallest increase occurred in the Base and Backlog scenarios. The trajectories of vegetation change for these early successional and small vegetation classes did not stabilize over the course of the simulation. Table 4.11 summarizes area in young vegetation classes at the end of the simulation.

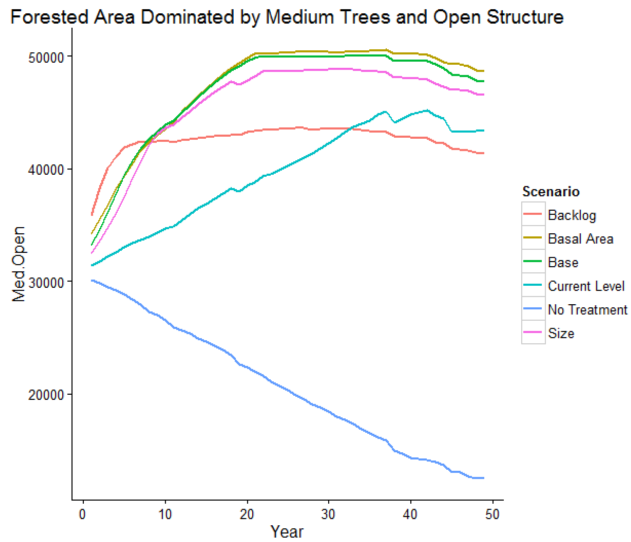

Figure 4.15. Area dominated by medium size trees (15-20” dbh) with open canopy cover (< 40%). Each line shows the average of 30 replicates for each scenario over 50 simulation years. Area declined over time in the No Treatment scenario and increased the most in the Base, Size, and Basal Area scenarios.

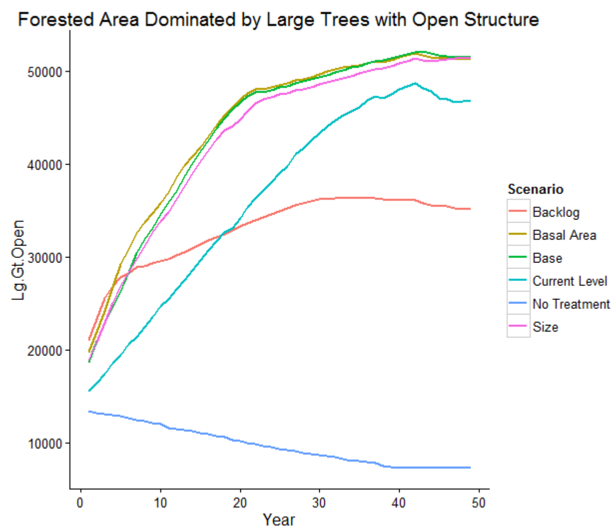

Figure 4.16. Area dominated by large and giant trees (>20” dbh) with open canopy cover or medium canopy (40-60%) and a single canopy layer. Each line shows the average of 30 replicates for each scenario over 50 simulation years. Area declined over time in the No Treatment scenario and increased the most in the Base, Size, and Basal Area scenarios.

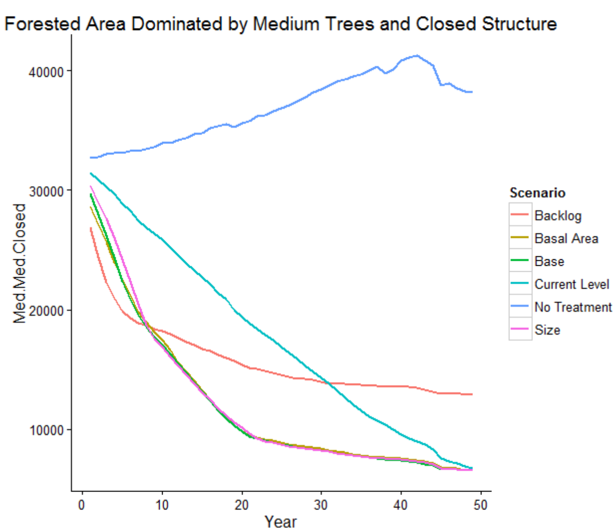

Figure 4.17. Area dominated by medium trees with medium or closed canopy. Each line shows the average of 30 replicates for each scenario over 50 simulation years. Area increased over time in the No Treatment scenario and decreased the most in the Base, Size, and Basal Area scenarios.

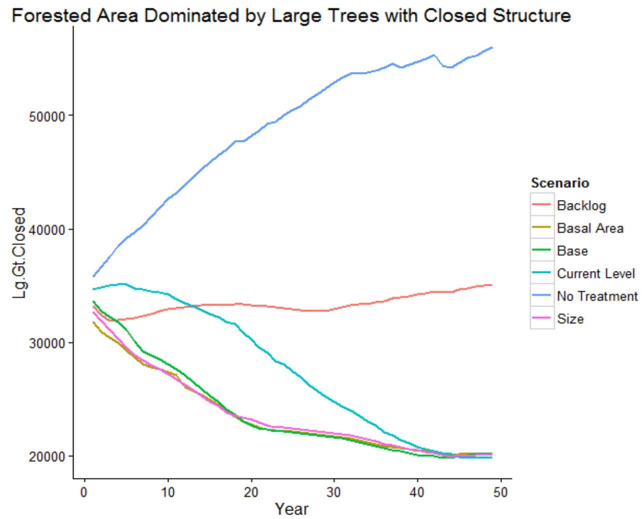

Figure 4.18. Area dominated by large and giant trees with closed canopy and multiple canopy layers. Each line shows the average of 30 replicates for each scenario over 50 simulation years. Area increased over time in the No Treatment scenario and decreased the most in the Base, Size, and Basal Area scenarios.

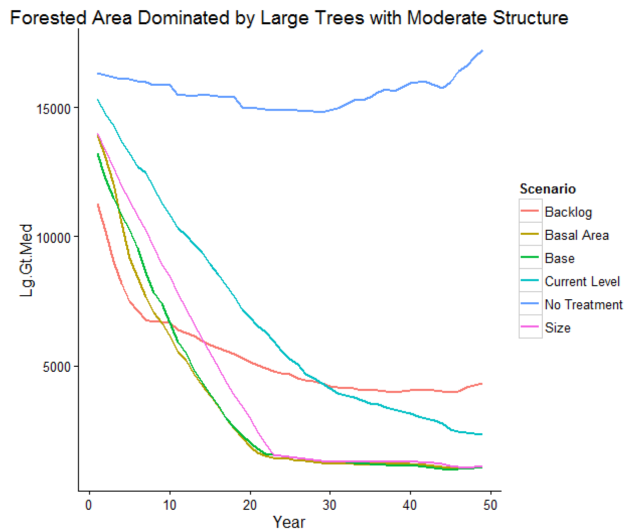

Figure 4.19. Area dominated by large and giant trees with closed canopy and a single canopy layer or moderate canopy with multiple canopy layers. Each line shows the average of 30 replicates for each scenario over 50 simulation years. Area increased gradually over time in the No Treatment scenario and decreased the most in the Base, Size, and Basal Area scenarios.

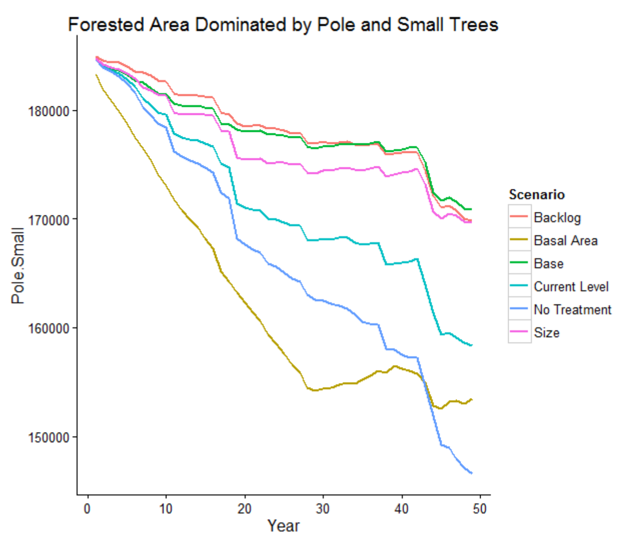

Figure 4.20. Area dominated by pole and small size trees (5-15" dbh). Each line shows the average of 30 replicates for each scenario over 50 simulation years. Area declined in all scenarios and declined most in the No Treatment and Timber scenarios.

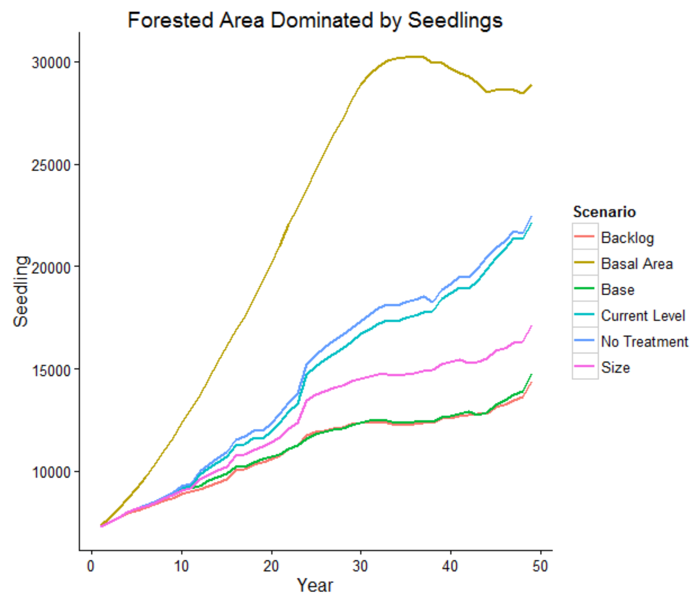

Figure 4.21. Area dominated by seedlings and saplings. Each line shows the average of 30 replicates for each scenario over 50 simulation years. Area increased most in the Basal Area scenario and least in the Base and Backlog scenarios.

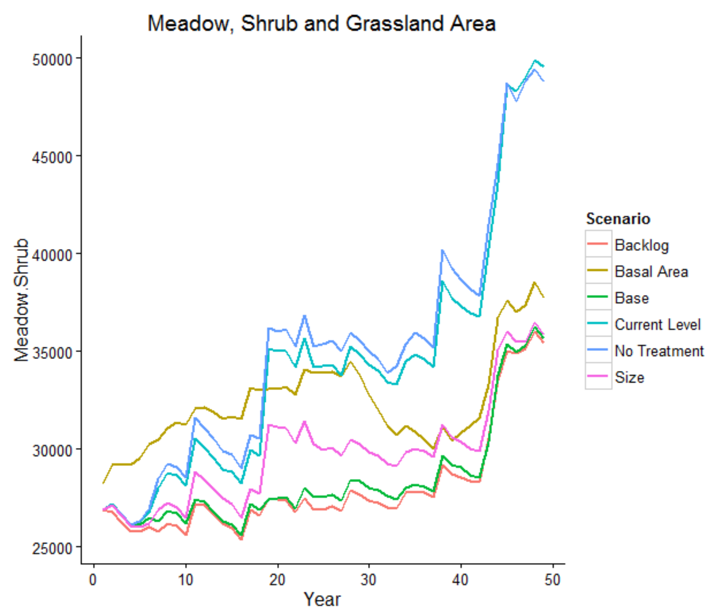

Figure 4.22. Area dominated by meadows and shrubs. In all scenarios, meadow and shrub area increased in punctuated jumps followed by a steady decline from one level to the next. The largest increase in area was in the No Treatment and Current Level scenarios.

Table 4.9. Area of medium size vegetation classes at end of simulation

Scenario	Med Size, Open Canopy (ha)	Med Size, Med & Closed Canopy (ha)
No Treatment	12,453	38,161
Base	47,736	6,554
Size	46,584	6,562
Timber	48,634	6,586
Current Level	43,321	6,760
Backlog	41,383	12,931

Table 4.10. Area of large and giant size classes at end of simulation

Scenario	Lg-Gt Open Canopy (ha)	Lg-Gt Med Canopy (ha)	Lg-Gt Closed Canopy (ha)
No Treatment	7,284	17,223	56,020
Base	51,480	1,077	20,193
Size	51,374	1,096	20,115
Timber	51,304	1,077	20,192
Current Level	46,797	2,331	19,803
Backlog	35,141	4,323	35,089

Table 4.11. Area of young vegetation classes at end of simulation

Scenario	Meadow-Shrub (ha)	Seedling-Sapling (ha)	Pole-Small (ha)
No Treatment	48,766	22,510	146,521
Base	35,678	14,785	170,876
Size	35,850	17,167	169,658
Timber	37,698	28,919	153,488
Current Level	49,549	22,159	158,330
Backlog	35,445	14,395	169,816

Landscape Resilience Summary

The No Treatment and Current Level scenarios demonstrated less landscape resilience than all other scenarios. The No Treatment and Current Level scenarios had roughly 60% more high severity fire than the other scenarios and showed stabilization in just 1 and 2 of the 8 vegetation classes, respectively. The Base, Size, Basal Area and Backlog scenarios showed stabilization in 5 of the 8 vegetation classes and had roughly similar levels of high severity fire (Table 4.11).

Table 4.12. Summary of landscape resilience metrics

Scenario	High-Severity Fire (ha)	Stable Vegetation Classes
No Treatment	67,758	1
Base	40,762	5
Size	44,772	5
Basal Area	38,230	5
Current Level	68,546	2
Backlog	39,802	5

Discussion

Differences in the amount of high-severity fire between the No Treatment scenario and the Base scenario were most pronounced in forest types that were actively managed. This finding complements stand scale empirical research that has shown a decrease in fire severity with thinning and fuel reduction treatments (Schwilk et al. 2009, Arkle et al. 2012, Martinson and Omi 2013, Safford et al. 2012) and suggests that active management of stand conditions also affects the amount of high-severity fire and resilience at the landscape scale over time. Notably, the amount of high-severity fire was also less in the Base scenario compared to the No Treatment and Current Level scenarios in areas of the landscape that were not actively managed. This is likely a result of slower fire spread rates in neighboring, treated forest types (Finney 2005). Compared to the No Treatment and Current Level scenarios, the more open forest structure and reduced surface fuels in the Base scenario seemed to have a dampening effect, or negative feedback, on high-severity fire. The altered vegetation conditions and disturbance regime was associated with vegetation class stability in five of eight structural vegetation classes (stands with medium to giant trees) compared to just one for the No Treatment scenario. It is noteworthy that the No Treatment scenario results in higher levels of stands with medium and large trees and closed structure than all other scenarios. Generally these stands are considered to have very low resistance to wildfire. However, this pattern is at least in large part a result of the management regimes applied. The analysis did not consider how much of this forest type burned in each scenario and whether proximity to treated areas had any effect on retention of these stands within the landscape. Yet it is also likely that in the 30 replicates on which this analysis is based, weather conditions and ignition locations did not align to initiate large wildfires in these areas. Areas with medium and large trees and closed structure covered just 20% of the landscape at the initiation of the simulation.

Based on the resilience metrics defined in Chapter 1, the Base scenario, which emulated historical disturbance regimes, showed more landscape resilience than the No Treatment and Current Level scenarios. Yet even the Base scenario did not show stability in the vegetation trajectories for early successional and young forest classes. These young forest types blanket over 60% of the landscape in all scenarios (Figure 4.24). Dry forests dominated by small size classes such as saplings and polesized trees are inherently less resistant to fire and more susceptible to high-severity fire. Until less of the landscape is dominated by these classes, landscape resilience may be difficult to attain.

The Size scenario had more high-severity fire than the Base scenario along with greater amounts of meadow-shrub and seedling-sapling classes (~1% more than Base) balanced by slightly less of the medium-giant open classes. Overall, small treatment unit sizes resulted in slightly more high-severity fire and more area in younger vegetation classes than the Base scenario. Some research has found that treatment unit size affects fire behavior (Finney et al. 2005, Arkle et al. 2012) while others found no effect (Finney et al. 2007). It could be that treatment unit size is less significant than other factors and so may be obscured by other changes.

The Basal Area scenario had 6.2% less high-severity fire than the Base scenario. The lesser amount of high-severity fire in the Basal Area scenario was likely due to the use of lodgepole clear-cuts and a higher level of prescribed fire in ponderosa pine forest types. There was more area of seedlings and saplings and less area of pole and small trees in the Basal Area scenario compared to Base, suggesting at first glance it might take longer to reach more fire resistant conditions in the Basal Area scenario. However, the difference was due to lodgepole clear-cuts used in the Basal Area scenario, and lodgepole is not a fire resistant species. In fact, lodgepole do extraordinarily well after stand-replacing fire in terms of regeneration and resource capture (Agee 1993). The difference in structural classes may not be significant in terms of resilience to fire. The overall landscape resilience of the Basal Area and Base scenarios was quite similar.

The Current Level scenario had as much high-severity fire as the No Treatment scenario even though thinning levels were comparable to other active management scenarios. The amount of prescribed fire in the Current Level scenario was substantially less than all other active management scenarios. Reduction of surface fuel levels is known to have effects on fire behavior at the stand scale (Martinson and Omi 2013). This research suggests a dramatic effect at the landscape scale as well. While only two vegetation classes showed stabilizing trends in the Current Level scenario, it could be that a longer simulation would demonstrate additional vegetation class stability over a longer time frame. Regardless, the higher level of high-severity fire and the higher proportion of younger, unstable vegetation classes make the Current Level scenario less resilient than the Base scenario.

As with the Base scenario, the Backlog scenario showed a tendency toward stabilization in five of eight vegetation classes. However, vegetation classes in the Backlog scenario stabilized more quickly in each case than the Base scenario. Notably, the Backlog scenario stabilized at different levels than the Base scenario, with less open conditions and more closed conditions in medium – giant size classes (~6% less open conditions in large and giant classes and 2% less in the medium size class). There was 2.4% less stand-replacing fire in the Backlog Scenario compared to the Base scenario, comprised of less stand-replacing fire in lodgepole and ponderosa pine and more stand-replacing fire in moist mixed conifer areas. The Backlog scenario used more prescribed fire in ponderosa pine and less in moist mixed conifer areas, which could account for the small difference in fire behavior. This would seem to suggest that surface fuel levels are more important than structural conditions in reducing the likelihood of stand-replacing fire. This is consistent with other research suggesting surface fuel reduction should be a priority to reduce the potential for high-severity fire (Martinson and Omi 2013). The Backlog and Base scenarios both had roughly the same amount of high-severity fire and the same number of stabilized vegetation classes. The landscape resilience of the vegetation communities under both scenarios was thus similar.

No modeling project can capture all aspects of landscape change. This analysis focused on landscape change as a result of management and wildfire disturbances. As such, it did not include assessment of insect and disease disturbance and how such disturbances might interact with wildfire and management. In addition, wildfire estimates were conservative as no assumptions regarding longer fire seasons or hotter, drier conditions were assumed. Climate change scenarios could relatively easily be incorporated in future analyses. Moreover, the model simulation period spanned 50 years. A longer simulation period could reveal surprises regarding stabilization of vegetation classes or additional stabilizing tendencies in the No Treatment or Current Level scenarios. Last, the effect of canopy cover and multiple canopy layers on fire behavior in different forest cover types and potential vegetation types should be further explored. A more exact understanding of fire behavior (shading effects on fuel moistures and canopy effects on wind) would enable more precise fire modeling and a better understanding of stand and landscape-level fire behavior.

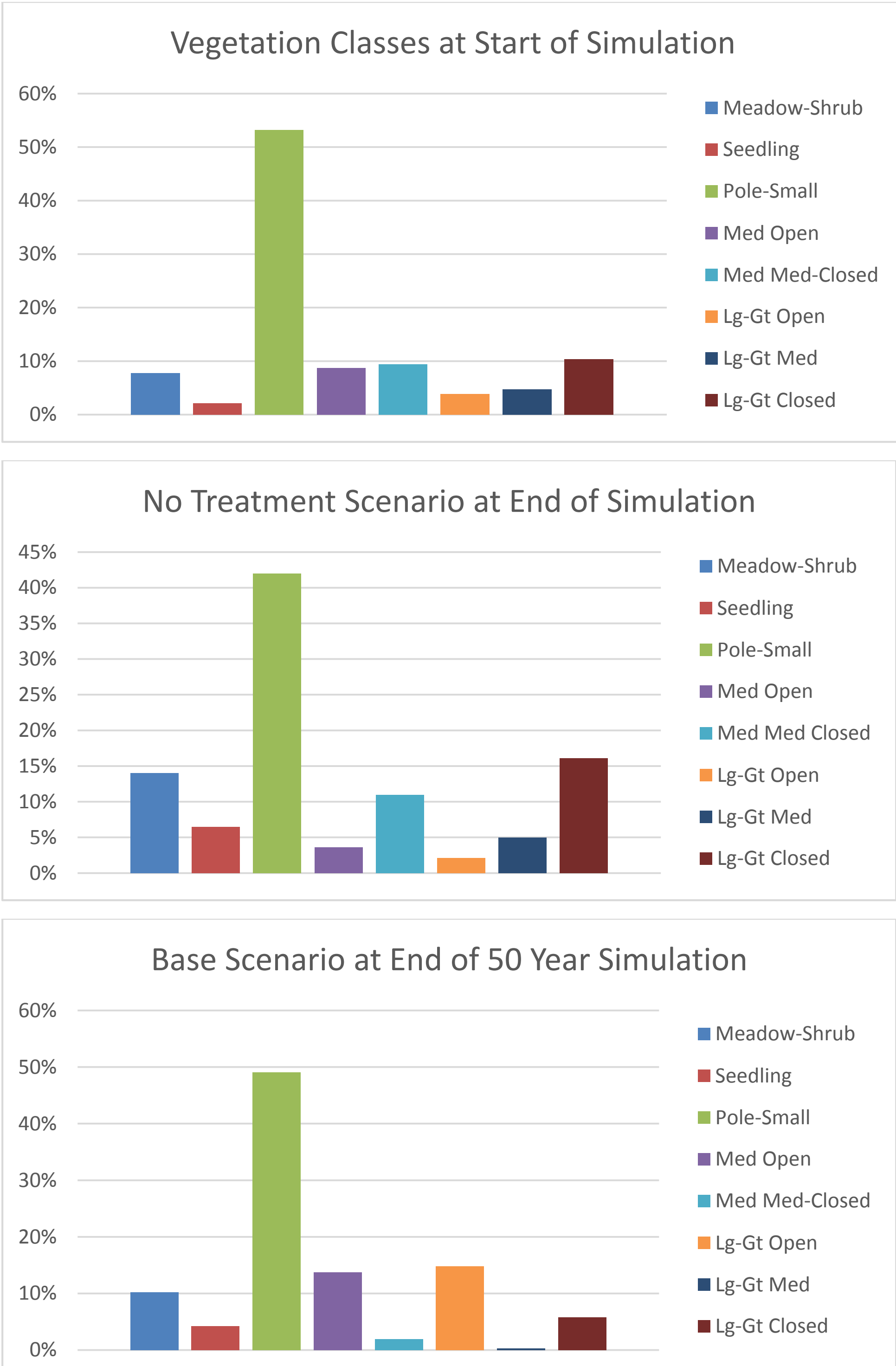

Figure 4.23. Structural class change in two scenarios selected to show range of conditions at end of simulation. In all scenarios, the landscape is dominated by pole and small size classes at the end of the simulation. The scenarios involving active management have more open structural classes than the No Treatment scenario.

The metrics of landscape resilience were useful in assessing differences between scenarios. The amount of high severity fire differed among management scenarios and was easy to quantify and compare. Assessing the stability of vegetation classes relied on a qualitative comparison of the trajectories of the amount of each vegetation class over time. This type of analysis would be more reliable using a longer simulation period. Moreover, the landscape resilience metrics would be more useful and practical if they were linked back to stand scale characteristics. For instance, if one scenario results in a higher proportion of younger age classes, does that affect landscape scale resilience beyond the 50 year simulation period? Which stand characteristics are most closely associated with resistance to high severity fire and vegetation class stability at the landscape scale? In Chapter 1, I hypothesized that stand characteristics associated with resistance to wildfire would lead to higher levels of landscape resilience. Proposed metrics of resistance included: 1) large and giant trees, 2) surface fuel model, 3) canopy cover, and 4) cover type. These stand characteristics could be tested to identify those most closely associated with landscape resilience. Such an analysis would also enable a longer-term assessment of the effect of a high proportion of the landscape in low resistance states.

The metrics of landscape resilience did not behave entirely as expected. For instance, the amount of high severity fire in the Current Level scenario was comparable to the No Treatment scenario. I anticipated at least a small reduction in the level of high severity fire with current levels of treatment. Likewise, I anticipated a greater reduction in high severity fire in the Backlog scenario (which thinned and used more prescribed fire) than in all other active management scenarios yet the amount of high severity was quite similar to the other scenarios. The similarity in the amount of high severity fire between the Backlog scenario and the Base, Size and Basal Area scenarios suggests a threshold of diminishing returns for treatment investments. This critical question could be more explicitly explored in a future simulation analysis.

The metrics for vegetation class stability behaved as expected in the sense that the scenario with a lower rate of treatment took longer to reach stable vegetation class levels (or did not stabilize) and the scenario with a higher rate of treatment more quickly achieved stability. However, the Backlog scenario, which treated more acreage than the Base, Size and Basal Area scenarios, stabilized at lower levels than these scenarios for open vegetation classes and stabilized at higher levels for more closed vegetation classes. The Backlog scenario attempted to thin twice as much as the Base, Size, and Basal Area scenarios in the first five years of simulation and used twice as much prescribed fire for the first ten years of the simulation. Not surprisingly then, the Backlog scenario more quickly reached target conditions for open single story stands in ponderosa pine and dry mixed conifer forest types. Management may have created a flush of new growth in open stands which required continuous high levels of treatment. However, the Backlog scenario reverted to Base levels of treatment that could not keep up with the increasing level of closed structural conditions. So although the Backlog scenario began by treating more acreage, it resulted in higher levels of closed structural conditions over time. While the Backlog scenario demonstrated stability earlier in the simulation than other scenarios, the tradeoff in resulting structural conditions is an important consideration. High levels of investment in doubling the amount of treatment do not necessarily result in the open structural conditions anticipated over the long-term. If high levels of treatment were maintained over the full 50 year simulation period, this outcome could of course be expected to change.

I am not aware of other research that has attempted to quantify landscape resilience with metrics such as those proposed in this analysis. I hope this research serves as a starting point for a dialogue about robust and practical measures of landscape resilience.

Conclusion

This research suggests that current levels of management result in the same amount of high severity fire as a management scenario in which there is no active management. This research also suggests that investing in additional prescribed fire will have a far more significant effect on levels of high severity fire than investing in additional thinning work. Regardless of investments, extreme weather conditions will continue to play an important role in shaping frequent-fire landscapes. Second, this research shows that under all management scenarios, the study area is still dominated by pole and small size trees in 50 years. If larger, more fire-resistant trees are desired, scenarios that maintain stands in current age classes create more opportunities to reach desired age classes in the future. Once again, the current level of treatment (and no active management) fares poorly on this front because the relatively high level of high-severity fire creates a longer time lag through which stands must develop in order to reach older age classes. Third, this research suggests that active management can have a dramatic effect on landscape resilience and fire behavior at the landscape scale, including areas of the landscape not actively managed.

This analysis suggests future lines of research that this dissertation was not able to answer definitively. Does high-severity fire created a positive feedback that leads to more high-severity fire? Under what conditions or within what temporal frame? How does a landscape dominated by young vegetation classes affect landscape resilience? Agent-based landscape simulation models like Envision have the potential to further research on landscape change in many ways and can be a useful tool for understanding drivers of landscape change.

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Chapter 5: Conclusion

Managing public lands for resilience entails clear ecological and social challenges, and management informed by both social and ecological sciences is most likely to result in resilient public lands. Ecological sciences can help determine how management activities are likely to shape the landscape, and social sciences can help managers identify and overcome administrative challenges. Focusing on just one facet of the management challenge ignores the critical importance of both and the influence of each on the other.

This analysis of managing frequent-fire forests for landscape resilience was informed by administrative theory, organizational theory, ecology, and modeling. The administrative and organizational results presented in Chapter 2 complement the ecological and modeling results presented in Chapter 4. Collectively, both chapters present a more complete understanding of challenges and opportunities related to managing for landscape resilience than could either approach on its own.

One common thread identified in both approaches is the importance of bringing more fire onto the landscape, either through the use of prescribed fire or carefully managed wildfire. Both interview respondents and modeling results demonstrate the importance of using managed fire to reduce the risk of high-severity wildfire. Interview respondents clearly outlined challenges related to the use of fire including public dislike of smoke and air quality regulations. Notably, respondents did not see the risk of prescribed fire escape as a pressing challenge. The Forest Service has effectively addressed important issues related to wildfire in the past – Smokey Bear is still a national icon – and the time could be right for another round of actively engaging the public in a new wildfire management approach.

Another compelling result of the analysis stemmed from the modeling simulations that showed current levels of management to lead to the same amount of high-severity fire as a no management scenario. The key difference between the current management scenario and scenarios that had less high severity fire was the use of prescribed fire. While some of the challenges of using prescribed fire are listed above, managers can also use administrative and organizational theory to address this challenge. If reducing the risk of high-severity fire is a management goal, then budgets, targets, and incentives should align with this goal. The current system clearly does not adequately prescribed fire. Targets for hazardous fuels reduction, for example, could include use of prescribed fire or managed wildfire. Acres that have been treated to achieve management objectives with managed wildfire could count toward targets. Planning documents and fire modeling work could be done in advance of wildfire season to create a series of wildfire management contingency plans in order to create additional opportunities for managing wildfire to achieve management goals and objectives.

Finally, managing for landscape resilience requires long-term, landscape scale plans that integrate management objectives into a single, seamless management plan. As the modeling results demonstrated, not every acre has to be managed to reduce wildfire risk across a larger landscape. Forest plans could fulfill this role. Yet years of public involvement and the development of a scientifically-based management plan avail nothing unless the plan is implemented. Forest Service funding based on implementation of forest plans rather than the current programmatic line-item budgeting system could lead to more efficient, effective, and responsive public administration of federal lands.

APPENDICES

Appendix A: Coding Categories

Context

Overall I'm looking to answer the following questions: 1) Can the FS create resilient forests in central Oregon with its current administrative structure? 2) Can the FS achieve management goals and objectives with its current administrative structure?

Modeling will be the primary method used to explore question one, but data from the interviews will be used to inform the modeling scenarios. I am particularly interested in how adaptable FS systems are because of the dynamic nature of forests in fire-prone central Oregon, the imminent but somewhat uncertain changes that can be expected due to climate, and the ever-shifting political and social aspects of forest management.

Using the Coding Scheme

Coder reliability is likely to be higher between the initial analysis and people with a background in forest ecology, fire ecology, and national forest management policies and activities.

The code categories are based on a hierarchical coding scheme where codes are clustered into either landscape resilience (LR) categories or institutional resilience (IR) categories. Although the label institutional resilience was used throughout initial coding, it is probably more accurate to think of this cluster as institutional adaptability.

Two codes may be used at the same place in the data when two separate but critical concepts are discussed or clearly linked. Codes can be added as comment boxes in electronic versions of transcripts. A description of each code category is included below.

Landscape Resilience

Current Conditions (LR CC)
Any data that describe current landscape or district conditions (dense trees, lots of surface fuel, etc.) belong in this category. This category is for ecological conditions. Social and political conditions should be captured in other categories. Historic management that created current conditions belongs in this category.

Treatment Effect (LR treatment effect)
This category is intended to capture the effect of current management activities, e.g. is prescribed fire effective, is thinning working, is enough treatment occurring to have an effect? This includes both localized treatment effects and landscape-scale treatment effects. The ecological result of current management activities belongs in this category whereas the ecological result of historic management activities (e.g. 50s-80s) belongs in current conditions.

Landscape Resilience Needs (sub-categories below)

Public Support (LR public support)
All data related to the importance or role of public involvement and public support in meeting management objectives or addressing landscape resilience challenges are placed in this category. Public opposition, education, and community outreach all fall within this category as well. Appeals and litigation data belong here if they are about management activities that might cause appeals or litigation or other public opposition. However, if the appeals and litigation comment is about the processes created by appeals and litigation (e.g. long NEPA processes), it belongs in the IR plan category. If the comment is about the public's influence on targets, it belongs in IR budget targets category.

Landscape (LR landscape)
Any data related to the need to plan, implement or otherwise act at the landscape scale or at a generally larger scale were placed in this category. Placement in this category does not assume someone's idea of larger scale means landscape - that is just the term used most frequently.

Complexity (LR complex)
Concepts grouped in this category include addressing mixed conifer issues, roadless and wilderness area treatments, invasive weeds, ecosystem services, tradeoffs between owl management and fire hazard, tradeoffs between shrub control and deer management, and other issues that were generally shared in the spirit of, 'we need to get to these issues – we're not there yet.' These are generally complex ecological issues, but complex social-ecological issues – such as ecosystem services – may also be included here. This should be seen a secondary category, i.e. if a subject is commenting on the complexity of the budget process or the planning process or getting prescribed fire implemented, the comment should be coded as IR budget or IR planning or LR fire, respectively. LR complexity should be used only when no other categories are suitable.

Fire and Suppression (LR fire)
The importance of fire on the landscape and challenges related to using prescribed fire, including smoke, are gathered in this category. Comments related to the current suppression decisions or the importance of changing the current suppression policy belong here as well. How people feel about fire or the amount of fire on the landscape and their frustrations or what they wish they could do related to wildfire or prescribed are all captured in this category. Comments about challenges in attaining the desired amount of fire also belong here. This category isn't about how managers may be prioritizing the landscape for treatment to address fire hazard. Those comments belong in the LR activities category.

Economics (LR economics)
Small diameter logging and markets for small trees and biomass are the main focus of this category. Data related to declining budgets and federal fiscal issues are not included in this category and instead belong in the IR budget category.

General (LR general)
General comments made in answer to the question about what's needed to make forestlands more resilient that don't fit in the other LR categories are placed here (e.g. 'We need to do more of what we're already doing. We need to be more aggressive in thinning to lower densities'). This category

was a catch-all to make sure nothing important was missed. Data from this category may be used to create new categories as necessary.

Institutional Resilience/ Institutional Adaptability

Program Structure (IR program structure)
Data related to staffing and the current staff hierarchy structure belong in this category. Comments are often related to how program specialists interact (e.g. on ID teams) or how district staff interact with other districts or headquarters staff. Comments about planning team dynamics belong here. 'Stovepiping' or related structural issues also belong here (e.g. programs run along separate, parallel tracks instead of a single track, timber is separate from fisheries is separate from fire, etc.).

Local Control (IR local control)
Local flexibility, local adaptability, and response time all belong here. Data related to the district's ability to focus on unique local issues is placed in this category as is data related to how quickly the district can act on a desired outcome. This category is not intended to capture what districts do but rather who has control over local decisions, setting local goals and objectives, etc. This category flexibility or responsiveness in the process of setting or influencing local priorities.

Management Activities (IR activities)
This code captures information about specific management activities the district is prioritizing and implementing. It may also capture information about particular areas of the landscape that are high priorities (e.g. WUI, ponderosa pine, etc.). [This code was used to parameterize modeling work and was not used in the inter-coder reliability assessment.]

Planning and Policy (IR plan)
This category includes data related to obstacles or opportunities posed by regulations, the forest plan, NEPA, the planning process, or other policies. This category could include opportunities and benefits of policies, planning, and regulations. This category is intended to capture information about formal agency planning processes. Informal processes such as outyear timber planning and hazardous fuel planning do not belong here. Words that may be used that relate to formal planning processes include forest management plan, management plan, eastside screens, Northwest Forest Plan, Late Successional Reserve, wilderness, roadless, RHCAs, riparian reserves, and 21" rule. Appeals and litigation data belong in this category if related to the formal processes caused or affected by appeals and litigation. If the data are about the kinds of activities that might lead to appeals and litigation, they belong in LR public support. This category does not include policies around smoke management, which belong in the LR fire.

Budget

Budget Process (IR budget process)
Data describing the budget process were gathered under this code.

Influence + Targets/ Performance Measures (IR budget targets)
Data on influences on the budget including Congress, timber or logging, and the public fit here. This category also includes comments on targets and data related to the misalignment of targets with

district or forest objectives. General comments about the influence of the budget on management activities belong here as well.

Color (IR budget color)
As in color of money. Comments about the difficulty of funding particular types of work belong here. This is not about an overall lack of funding or capacity. Instead it is about the line items that are being funded.

Capacity
Capacity was mentioned regularly in the interviews but isn't a subject of this research so doesn't need to be tracked for the purposes of this study.

Appendix B: Envision FPF Indicators

Category	Indicator
Basal area	Amount of area with various levels of basal area: [REVIEW LEVELS AND TRANSLATE TO SQ MTRS/HA] (1) Under 40 (2) Between 40 and 80 (3) Between 80 and 120 (4) Between 120 and 180 (5) Over 180
Bioenergy	(1) Volume of material available for bioenergy production (2) Volume of material available for bioenergy production around 30 miles of Klamath Falls (3) Volume of material available for bioenergy production around 30 miles of Lakeview (4) Volume of material harvested for bioenergy production (5) Volume of material harvested for bioenergy production around 30 miles of Klamath Falls (6) Volume of material harvested for bioenergy production around 30 miles of Lakeview
Category	**Indicator**
Carbon	(1) Total live carbon (2) Total dead carbon (3) Total live and dead carbon
Category	**Indicator**
Dwellings	(1) New structures
Category	**Indicator**
Fire Experience	(1) Number of dwellings exposed to fire
Fire hazard - structures	(1) Number of structures within 1 km of high fire hazard forest conditions
Firewise	(1) Portion of structures adopting firewise behavior
Fire Hazard	(1) Proportion of area with potential for surface fire at 80th percentile weather conditions (2) Proportion of area potential for mixed severity fire at 80th percentile weather conditions (3) Proportion of area with potential for stand replacing fire at 80th percentile weather conditions
Fire Occurrence	(1) Area experiencing surface fire (2) Area experiencing mixed severity fire (3) Area experiencing stand replacing fire
Category	**Indicator**
Forest structure	(1) Annual area total of in the following structural classes: a. Meadow, shrub and grass-forb b. Seedling-sapling c. Pole and small size d. Medium size with open cover e. Medium size with medium and closed cover f. Large and giant sizes with open and moderate cover, single story

	g. Large and giant sizes with closed cover and a single layer or moderate cover and multiple layers h. Large and giant sizes with closed cover and multiple layers
Category	**Indicator**
Management	(1) Amount of thinning or other harvest (2) Amount of prescribed fire (3) Amount of mowing and grinding (4) Amount of salvage logging
Category	**Indicator**
Wildlife	(1) Northern Spotted Owl habitat (2) American marten habitat (3) Black-backed woodpecker habitat (5) White-headed woodpecker habitat (6) Pileated woodpecker habitat (7) Northern goshawk habitat (8) Western bluebird habitat (9) Red-naped sapsucker habitat (10) Mule deer habitat (11) Downy brome presence
Category	**Indicator**
Wood Production	(1) Total live volume (2) Total volume harvested, all size classes (3) Total volume of saw timber harvested (4) Total saw timber volume destroyed by fire

Appendix C: Forested and Arid Cover Types in the FPF Study Area

Description	Full description	Abbrev	CTID
Developed - Low Density	Developed - Low Density	LDV	100
Developed - Med Density	Developed - Med Density	MDV	110
Developed - High Density	Developed - High Density	HDV	120
Agriculture	Agriculture	AGR	150
BareGround	BareGround	B	199
GrassShrub	Grass / Shrub plus NLCD wetlands and veg	GS	200
SubAlp parkland	Subalpine parkland	PK	205
Alder	Red alder	Al	250
Asp_Willow	Trembling aspen / Willow	AW	255
Oak	Oregon white oak	Oa	300
OakPine	Oregon white oak / Ponderosa pine	OP	305
Tanoak	Tanoak	TO	310
DFirAlder	Douglas-fir / Red alder	DFal	350
DougFir	Douglas-fir	DF	400
DFirMix	Douglas-fir mix	DFmx	405
DFWF	Douglas-fir / White fir	DFWF	410
DFWH	Douglas-fir / Western hemlock	DFWH	415
DFGF	Douglas-fir / Grand fir	DG	420
GfirEspruce	Grand fir / Engelmann spruce	GFES	425
LPPWlarch	Lodgepole pine / Western larch	LPWL	430
Sfmix	Pacific silver fir / Douglas-fir	SFDF	435
WlarchLPP	Western larch / Lodgepole pine	WLLP	440
WHem	Western hemlock	WH	445
GrandFir	Grand fir	GF	450
White_Fir	White fir	WF	455
RedFir	Shasta red fir	RF	505
RFWF	Red fir / White fir	RFWF	510
Conifer	Conifer	Co	520
EspruceSAfir	Engelmann spruce / Subalpine fir	ESAF	600
MtnHem	Mountain hemlock	MH	605
WhiteBkPine	Whitebark pine	WB	610
Lodgepole	Lodgepole pine	LP	705
LPWUI	Lodgepole pine / Wildland-Urban Interface	LPWI	710
MixPine	Mixed pine	MXPI	750
Ponderosa	Ponderosa pine	PP	755
PP_LP	Ponderosa pine / Lodgepole pine	PPLP	760
WhitePine	Western white pine	WP	765
JeffreyPine	Jeffrey pine	JP	770

Sitkasp	Sitka spruce	SK	800
Grass	Conifer_NatPerenGrass	CoNg	845
Grass	ExoticAnnualGrass	Eg	850
Grass	ExAnnGrass_Bitterbrush	EgBt	851
Grass	ExAnnGrass_Juniper	EgJu	852
Grass	ExAnnGrass_LowSage	EgLs	853
Grass	ExAnnGrass_MtnMahogany	EgMm	854
Grass	ExAnnGrass_MtnBigSage	EgMs	855
Grass	ExAnnGrass_RigidSage	EgRs	856
Grass	ExAnnGrass_SaltDesertShrub	EgSd	857
Grass	ExAnnGrass_WyoBigSage	EgWs	858
Grass	Forb	Fb	859
Grass	Forb_Bitterbrush	FbBt	860
Grass	Forb_MtnBigSage	FbMs	861
Grass	NativePerennialGrass	Ng	862
Grass	NatPerenGrass_Bitterbrush	NgBt	863
Grass	NatPerenGrass_ExAnnGrass	NgEg	864
Grass	NatPerenGrass_ExAnnGrass_WyoSage	NgEgWs	865
Grass	NatPerenGrass_Forb	NgFb	866
Grass	NatPerenGrass_Juniper	NgJu	867
Grass	NatPerenGrass_LowSage	NgLs	868
Grass	NatPerenGrass_MtnMahogany	NgMm	869
Grass	NatPerenGrass_MtnBigSage	NgMs	870
Grass	NatPerenGrass_RobustGrass_Forb	NgRgFb	871
Grass	NatPerenGrass_SaltDesertShrub	NgSd	872
Grass	NatPerenGrass_WyoBigSage	NgWs	873
Grass	RobustGrass	Rg	874
Grass	RobustGrass_ExAnnGrass	RgEg	875
Grass	RobustGrass_Forb	RgFb	876
Grass	RobustGrass_LowSage	RgLs	877
Grass	RobustGrass_RigidSage	RgRs	878
Grass	RobustGrass_SaltDesertShrub	RgSd	879
Grass	SeededGrass	Sg	880
Grass	SeededGrass_WyoBigSage	SgWs	881
Juniper	Western juniper	JU	900
Juniper	Juniper_ExAnnGrass	JuEg	901
Juniper	Juniper_ExAnnGrass_Forb	JuEgFb	902
Juniper	Juniper_Forb_ExAnnGrass	JuFbEg	903
Juniper	Juniper_LowSage_NatPerenGrass	JuLsNg	904
Juniper	Jun_LowSage_RobustGrass_ExAnnGrass	JuLsRgEg	905
Juniper	Juniper_MtnSage_ExAnnGrass_Forb	JuMsEgFb	906

Juniper	Juniper_MtnSage_NatPerenGrass	JuMsNg	907
Juniper	Jun_MtnSage_RobustGrass_ExAnnGrass	JuMsRgEg	908
Juniper	Juniper_NativePerennialGrass	JuNg	909
Juniper	Juniper_NatPerenGrass_ExAnnGrass	JuNgEg	910
Juniper	Juniper_RobustGrass_ExAnnGrass	JuRgEg	911
Juniper	Juniper_WyoBigSage_ExAnnGrass	JuWsEg	912
Juniper	Jun_WyoSage_NatPerenGrass_ExAnnGrass	JuWsNgEg	913
Juniper	Juniper_Bitterbrush_ExAnnGrass	JuBtEg	914
Juniper	Juniper_Bitterbrush_Forb	JuBtFb	915
Juniper	Juniper_Bitterbrush_NatPerenGrass	JuBtNg	916
Juniper	Jun_WyoSage_NatPerenGrass	JuWsNg	917
Sagebrush-steppe	Sagebrush	SBS	950
brush	Bitterbrush_ExAnnGrass	BtEg	951
brush	Bitterbrush_ExAnnGrass_Juniper	BtEgJu	952
brush	Bitterbrush_Forb	BtFb	953
brush	Bitterbrush_Forb_Juniper	BtFbJu	954
brush	Bitterbrush_NatPerenGrass	BtNg	955
brush	Bitterbrush_NatPerenGrass_Juniper	BtNgJu	956
brush	MtnMahogany_ExAnnGrass	MmEg	957
brush	MtnMahogany_NatPerenGrass	MmNg	958
brush	MountainBigSage	Ms	959
brush	MtnBigSage_ExAnnGrass	MsEg	960
brush	MtnSage_ExAnnGrass_Forb_Juniper	MsEgFbJu	961
brush	MtnBigSage_Forb	MsFb	962
brush	MtnBigSage_NatPerenGrass	MsNg	963
brush	MtnBigSage_NatPerenGrass_Juniper	MsNgJu	964
brush	MountainBigSage_RobustGrass	MsRg	965
brush	MtnSage_RobustGrass_ExAnnGrass_Jun	MsRgEgJu	966
brush	MontaneShrub	Sh	967
brush	RigidSage	Rs	968
brush	WyomingBigSage	Ws	969
brush	WyomingBigSage_ExAnnGrass	WsEg	970
brush	WyoBigSage_ExAnnGrass_Juniper	WsEgJu	971
brush	WyoBigSage_NatPerenGrass	WsNg	972
brush	WyoSage_NatPerenGrass_ExAnnGrass	WsNgEg	973
brush	WyoSage_NatPerenGrass_ExAnnGrass_Jun	WsNgEgJu	974
brush	WyoSage_NatPerenGrass_Juniper	WsNgJu	975
brush	WyoBigSage_SeededGrass	WsSg	976
brush	LowSage	Ls	977
brush	LowSage/ExAnnGrass	LsEg	978
brush	LowSage/NatPerenGrass	LsNg	979

brush	LowSage/NatPerenGrass/Juniper	LsNgJu	980
brush	LowSage/RobustGrass	LsRg	981
brush	LowSage/RobustGrass/ExAnnGrass/Jun	LsRgEgJu	982
brush	ThreeTipSage	Ts	983
brush	ThreeTipSage/ExAnnGrass	TsEg	984
brush	ThreeTipSage/NatPerenGrass	TsNg	985

Appendix D: Size-Structure Classes in the FPF Study Area

Barren	0	None	0	None	0
Development	1	Low (open, 10-40%)	1	Single	1
Meadow	2	Medium (40-60%)	2	Multi	2
Shrubs	3	High (closed, >60%)	3		
Seedling/sapling	4	Post-disturbance	4		
Pole (5-10" dbh)	5				
Small tree (10-15" dbh)	6				
Medium tree (15-20" dbh)	7				
Large tree (20-30" dbh)	8				
Giant tree (>30" dbh)	9				