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Silviculture and Monitoring Guidelines for Integrating Restoration of Dry Mixed-Conifer Forest and Spotted Owl Habitat Management in the Eastern Cascade Range

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Cover photograph: Northern spotted owl (*Strix occidentalis caurina*), by Tom Iraci.

Abstract

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This report addresses the need for developing consistent regional guidelines for stand-level management that integrates goals and objectives for dry forest restoration and habitat management for the northern spotted owl. It is an outcome of a focused 3-day workshop attended by 25 scientists, managers, and regulators in Hood River, Oregon, September 5–7, 2012. The workshop's goals were to (1) develop novel and feasible stand-level silvicultural prescriptions that integrate dry forest restoration and conservation of the northern spotted owl, among other ecological values; and (2) develop options for monitoring such prescriptions in an adaptive management framework, ideally in a coordinated network of management studies. We review background issues, objectives, and information for forest restoration (chapter 2), northern spotted owl habitat management (chapter 3), and monitoring and adaptive management (chapter 5). The core of this report is chapter 4, which reviews guidelines for developing new silvicultural prescriptions that address these issues. Finally, we discuss some relevant social, economic, and organizational issues affecting successful implementation of such a program of work (chapter 6).

Keywords: Silviculture, northern spotted owl, restoration, dry forest, Cascade Range.

Preface

This report is an outcome of a focused 3-day workshop attended by 25 scientists, managers, and regulators in Hood River, Oregon, September 5–7, 2012. The goals of the workshop were to (1) develop novel and feasible stand-level silvicultural prescriptions that integrate dry forest restoration and conservation of the northern spotted owl, among other ecological values; and (2) develop options for monitoring such prescriptions in an adaptive management framework, ideally in a coordinated network of management studies.

The workshop and this publication built on interagency and nongovernmental efforts that began in 2005 with a workshop in Redmond, Oregon. Subsequent workshops were held in Ashland, Oregon (in 2006), Wenatchee, Washington (in 2007), and again in Redmond (in 2009; see the detailed report to the Joint Fire Science Program at http://www.fws.gov/oregonfwo/ExternalAffairs/Topics/DryForestWorkshop/2009DryForestWorkshop.asp). The 2009 workshop was intended to develop silviculture and adaptive management templates, but those goals were not fully realized. The 2012 workshop and this report were designed to renew and complete that effort.

The geographic scope of this report is the eastern Washington and eastern Oregon Cascades Provinces described in the Northwest Forest Plan. The guidelines we describe for silvicultural prescriptions and monitoring apply equally to a continued implementation of the reserve-network conservation strategy of the Northwest Forest Plan and to a new whole-landscape management strategy proposed in the 2011 *Revised Recovery Plan for the Northern Spotted Owl*. The spatial scale of the guidelines is at the stand level.

Contents

Chapter 1: Rationale for Integrating Spotted Owl Habitat Management and Restoration of Cascade Range Dry Forests

John F. Lehmkuhl,[1] *William L. Gaines,*[2] *and Paul F. Hessburg*[3]

Ecosystem Restoration and Northern Spotted Owl Conservation

The declining health and resilience of forests of the interior Western United States have been challenging management issues since at least the early 1990s. Basic research on disturbance ecology (e.g., Agee 1993, 2003; Everett et al. 2000) and various regional assessments (e.g., Eastside Forest Health Assessment [Everett et al. 1994], Interior Columbia Basin Ecosystem Project [Hann et al. 1997, 1998; Hessburg and Agee 2003; Hessburg et al. 1999, 2000, 2005] revealed the scope and magnitude of forest structural and functional changes in the eastern Cascade Range. The research, development, and management policy issues are at a critical stage for reversing decades of forest ecological dysfunction and sustaining ecological and social forest resources (Franklin and Johnson 2012, USFWS 2011).

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Following principles for restoration of characteristic fire regimes (Agee and Skinner 2005, Noss et al. 2006) or for the restoration of dry forest ecosystems (Franklin and Johnson 2012, Spies et al. 2012), foresters have been developing and implementing programs to actively restore and manage dry forest landscapes. The proposed forest plan revision for the national forests in northeastern Washington (the Okanogan-Wenatchee and Colville National Forests) and the current Forest Restoration Strategy of the Okanogan-Wenatchee are based on such a "whole-landscape" active management approach to northern spotted owl (NSO) (*Strix occidentalis caurina*) conservation and forest restoration (USDA FS 2012a). A whole-landscape approach refers to the lack of zoning found in the conventional reserve conservation design (Everett and Lehmkuhl 1996, Everett et al. 1995). Other national forests in the eastern Cascades NSO zones (the Deschutes and Fremont-Winema National Forests) may follow that lead.

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Dry forest restoration and fuel reduction projects often have been perceived to conflict with conservation of the threatened northern spotted owl (Agee and Edmonds 1992, Courtney et al. 2004, Hanson et al. 2009, Lehmkuhl et al. 2007). Since 1994, Federal forest lands, which contain most of the NSO population, have been managed primarily as a network of "late-successional reserves" designed to maintain or promote old forests for the NSO and other species (FEMAT 1993). At that time, the problem of maintaining the desired attributes of reserves with predominantly passive management in the disturbance-dynamic dry forest landscape was recognized (Agee and Edmonds 1992), so provisions were made in the Northwest Forest Plan for active management when it maintained or improved late-successional forest conditions.

Instead of limiting the ecological objectives for owl conservation only to reserves, the whole landscape would be managed to maintain or create owl habitat in the context of restoring sustainable forest patterns and processes.

In response to the issues of forest restoration, sustainability of NSO habitat (Davis and Lint 2005), and a documented decline of about 4 percent per year in NSO numbers since 1994 (Forsman et al. 2011), the 2011 Recovery Plan of the Northern Spotted Owl (USFWS 2011) described a strategy and management actions to restore the NSO based on active landscape-scale management. Instead of limiting the ecological objectives for owl conservation only to reserves, the whole landscape would be managed to maintain or create owl habitat in the context of restoring sustainable forest patterns and processes. One way to understand the strategy is that the whole landscape, including the matrix (i.e., the area outside reserves), would be managed similarly to the management direction for east-side late-successional reserves in the Northwest Forest Plan, which focuses on restoring dry-forest ecosystem processes and functions. The 2012 Final Revised NSO Critical Habitat Rule (USFWS 2012), a regulatory document, relies strongly on that active restoration strategy.

The whole-landscape approach was conceived in recognition that reserve-based approaches may be ineffective at providing for late-successional-associated species in ecosystems in which large-scale disturbances play dominant roles in shaping the structure and composition of landscapes (Agee and Edmonds 1992, Gaines et al. 2010, Hessburg et al. 2007). In addition, reserve-based designs depend on our ability to accurately identify and prioritize the best locations on the landscape to conserve for late-successional-associated species (such as the northern spotted owl), which is increasingly difficult considering likely climate changes (Carroll 2010, Carroll et al. 2010, Littell et al. 2010) and barred owl–spotted owl interactions (Singleton 2013, Singleton et al. 2010).

The proposed departure from a mostly passive reserve network generated scientific and public concern about a purported lack of supporting science for effective concurrent restoration and spotted owl conservation, and weak adaptive management plans (Hanson et al. 2009). Yet scientists in the Pacific Northwest have developed a strong scientific basis for active restoration as a foundation for development of novel silvicultural prescriptions (e.g., Churchill et al. 2013) to integrate multiple ecological and restoration objectives and climate change issues, and have much experience in adaptive management. Scientists with the USDA Forest Service's Pacific Northwest Research Station have been modeling "landscape silviculture" options to address **where** to do restoration (Ager et al. 2007, 2010; Hummel et al. 2001; Kennedy et al. 2008; Lehmkuhl et al. 2007) and conserve spotted owls; missing is **how** or **what** actual stand-scale silviculture managers effectively might implement for restoration (Johnson et al. 1991) and how to monitor and evaluate those actions.

There is a critical science delivery need to develop and demonstrate novel stand-scale management prescriptions in spotted owl habitat, and to develop an effective template for monitoring and adaptive management.

Thus there is a critical science delivery need to develop and demonstrate novel **stand-scale** management prescriptions in spotted owl habitat, and to develop an effective template for monitoring and adaptive management (see chapter 5 in this report). Lehmkuhl et al. (2007) described the scientific basis for just such an integration of restoration and spotted owl management, which we expand on in this report. Ultimately, such prescriptions and template can be the foundation for a program of knowledge discovery, hence more effective management, if implemented in an integrated network of study sites (e.g., the Fire and Fire Surrogate Study [McIver et al. 2013]; (see chapter 5). The need for consistent regional guidelines for stand-scale silviculture and for monitoring exists regardless of implementation of a semi-managed reserve network under the Northwest Forest Plan or under a new paradigm of active whole-landscape management.

Stand-Scale Restoration Objectives

The primary goals for restoration of dry conifer forests of the Pacific Northwest have been to enhance the resilience and sustainability of forests and forested landscapes by altering forest structure and fuels to restore sustainable patterns and disturbance processes (mainly fire, insects, and disease) (Franklin and Johnson 2012, Stine et al. 2014) (see chapter 2). That coarse-filter approach to restoration, i.e., restoring forest pattern and process, is assumed to also maintain other components of biodiversity such as viable wildlife populations (Lehmkuhl et al. 2007). Yet policy goals for biodiversity conservation and legal mandates governing management of habitat for threatened and endangered species, as well as sociopolitical pressure to manage wildfires to protect human life and property, require an additional, more nuanced approach to restoration that requires fine-filter (e.g., species level) considerations at all scales (Franklin et al. 2008, Spies et al. 2010).

Many biodiversity objectives may be met over time by restoring forest structure and composition to target conditions developed from the historical range of variability or desired future conditions (Keane et al. 2009, Stine et al. 2014) (see chapter 2). That approach typically calls for reducing stand densities and overstory canopy cover, retaining and protecting large trees of fire-resistant species and very old trees, and creating spatial patchiness within stands (Agee and Skinner 2005, Brown et al. 2004, Franklin and Johnson 2012). That prescription can increase understory plant diversity (Dodson and Peterson 2010, Dodson et al. 2008, McConnell and Smith 1970), and associated wildlife diversity as well (Lehmkuhl et al. 2007).

Such blanket coarse-filter prescriptions for stand-scale restoration may not be effective for meeting some biodiversity objectives (see chapter 2). Snags and large down wood provide important habitat function for other wildlife and may be significantly reduced by thinning and prescribed fire treatments (Harrod et al. 2009, Jain et al. 2012). Restoration treatments may also increase the spread and dominance of exotic plant species by disturbing soils and reducing overstory shading, though such effects are apparently not large in these types of forests (Dodson and Peterson 2010, Nelson et al. 2008, Stoddard et al. 2011).

A key to integrating dry forest restoration and spotted owl conservation is to decouple the nesting-roosting functions from the foraging function.

For spotted owls in particular, using generalized restoration and fuels prescriptions that reduce stand density, closed canopies, and large down wood typical of late-successional forest may degrade required nesting, roosting, and foraging (NRF) habitat (Gaines et al. 2010, Lehmkuhl et al. 2007) (see chapter 3). Spotted owl NRF habitat typically is designated based on optimum conditions for all three habitat functions: nesting, roosting, and foraging. A key to integrating dry forest restoration and spotted owl conservation that we explore in chapter 3 is to decouple the nesting-roosting functions from the foraging function (Lehmkuhl et al. 2007), similar to a widely accepted management strategy for goshawks (*Accipiter gentilus*), another food-limited raptor species (Reynolds et al. 1992, 2007).

A first step is to protect core or occupied NRF and restore forests adjacent to these areas to reduce the risk of habitat loss due to high severity fire, keeping in mind how fire is likely to move across the landscape (e.g., Ager et al. 2007, Kennedy et al. 2008). Second, maintain or improve habitat value of unoccupied NRF stands that are at risk of loss or with low habitat value owing to landscape position (e.g., small, isolated, surrounded by high fire risk non-habitat) by using novel light treatments that maintain canopy cover and within-stand patchiness of fuels and understory (Agee and Skinner 2005). Third, and probably most important in terms of opportunity, develop and implement novel integrative restoration treatments that maintain or create foraging habitat, which encompasses a wider range of stand composition and structure than nesting-roosting habitat. Treatments in foraging habitat are based on the plastic foraging behavior of spotted owls (Irwin et al. 2012, 2013) and the habitat needs of various forage prey species that inhabit different niches within the range of foraging habitat variation (Lehmkuhl et al. 2007). These issues and opportunities are thoroughly explored in chapters 3 and 4.

The Importance of Landscape Context

Landscape, Fire, and Other Disturbance Dynamics

Regardless of the climatic era, historical landscapes exhibited spatial patterns of successional stages and fuel beds in each forest type, which constrained the native fire regime and its variation (Hessburg et al. 2007). Constraint was apparent in the size distribution of fire events and of fire severity patches. Here, it is useful to think of fire severity patterns and patches as successional patches. These patterns both drove and constrained processes (insect outbreaks, disease centers, and wildfire and windthrow events). Likewise, processes both drove and constrained patterns. These two axioms reflect the primary resilience mechanisms of historical and contemporary landscapes.

But at no time in the past were all patches of a landscape in a resilient condition (Camp et al. 1997). Some patches were always susceptible to insect attack, stand-replacing fires, dwarf mistletoes, and root diseases. At any one time, as much as one-third of the forest had been recently burned by high-severity fire, and a significant area was in an early seral (grass, shrub, or seedling/sapling) or recently burned condition (Hessburg et al. 2007). This is how forest habitats with complex structure and age classes emerged on the landscape (Stine et al. 2014). The landscape, but not all stands, was resilient to disturbances.

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In the historical forest, each forest type likely exhibited some amount of low-, mixed-, and high-severity fires (Stine et al. 2014); the amount of each varied by forest type and by the physical geography. Today, change in the distribution of patch sizes of fire events and fire severity is the primary change in wildfire regimes of each forest type. This change represents a decoupling of the chief resilience mechanism of the native forests—that of patterns supporting a range of wildfire patch sizes and severities. This decoupling drives fire event and fire severity patch sizes, both now and with climatic warming.

During every historical climatic period, a range of patterns and patch sizes of forest successional stages likely emerged (Hessburg et al. 2007, Stine et al. 2014). This emergent natural phenomenon has been dubbed the natural or historical range of variation, or the NRV/HRV. Simulation experiments and empirical reconstructions both show that this characteristic variation emerged from patterns of burned and recovering vegetation, because prior disturbances and their resultant successional patterns constrain the size and severity of future disturbances (Moritz et al. 2011, Perry et al. 2011). As the climate shifted, so did the NRV. The NRV was always non-stationary, and it shifted with the climate. Stationarity of the NRV is a common misperception (Keane et al. 2009). Prolonged periods of warming or cooling, wetting or drying, or combinations of these would push the NRV in new directions. But sudden and extensive shifts in the NRV were typically prevented, except under the most extreme climatic circumstances, by the lagged landscape memory encoded in the existing pattern variation (Moritz et al. 2011). That was landscape resilience in the natural system.

To restore this kind of characteristic coupling between patterns and processes (wildfire, insect, pathogen, and weather), landscape patterns may be modified (see discussion in Stine et al. 2014). Pattern modifications should be consistent with the natural or desired disturbance regimes of large landscapes and forest types. Completely natural or historical landscape patterns need not be the goal in a modern society; however, a reasonable coupling between the patterns of patch sizes of successional stages and the disturbance regimes of interest is needed, because regardless of land management allocation or zoning, patterns will to a large extent drive processes.

Principles for Integrating Landscape and Stand Management

The following principles are detailed in several extant management (USDA FS 2012a) and synthesis papers (Stine et al. 2014). Below is a brief recap of principles for consideration.

- Restore characteristic fire regimes in each major vegetation type.
- Restore characteristic patch size distributions.
- Restore landscape pattern complexity and variability.
- Restore a landscape backbone of medium and large-sized early seral trees.
- Develop prescriptions for entire landscapes.
- Make explicit use of topography and edaphic environments.
- Restore stand-scale "landscapes" within larger landscapes.

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The Importance of Social Context

Considering the social context, the outlook for successful integration of dry forest restoration and habitat conservation for northern spotted owls appears to be mixed (see chapter 6). Both goals long have been supported by policy given in the Northwest Forest Plan (USDA and USDI 1994), the Healthy Forest Restoration Act (HFRA 2003) , and lately the *Revised Recovery Plan for the Northern Spotted Owl* (USFWS 2011), among others, and policy support seems to be expanding (see chapter 6). Yet it has been 20 years since the issues have been identified, so why does the outlook seem mixed?

Economic and public trends, in part, have limited the ability to integrate these goals (see chapter 6). Economic trends have been in flux because of changes in land ownership patterns, decreases in community economic stability and infrastructure, and fluctuation in wood product and energy markets that create uncertainty. Public support for restoration, or "social license," has increased with awareness of restoration issues, in particular wildfire risk (e.g., Absher 2006) and the need for spotted owl conservation (Carey 2003). Yet a barrier to successful implementation remains a question of public trust (chapter 6). Federal agencies have begun to address this issue by involving the public in forest management planning and decision making via the Collaborative Forest Landscape Restoration Program (CFLRP 2009).

Organizational barriers also have limited efforts to integrate restoration and spotted owl habitat conservation (see chapter 6). Early efforts, since 1994, often were limited in part by a lack of scientific information to support management; since then, however, the scientific basis for integration has expanded (Courtney et al. 2004, USFWS 2011 (see chapters 3 and 4). At the same time, organizational barriers remained for integrating that new science with management in a learning-based process, i.e., via adaptive management (Stankey et al. 2006) (see chapter 5). Those organizational barriers hopefully will begin to be dismantled by implementation of the new Forest Planning Rule (USDA FS 2012b). A complete examination of social and organizational issues for implementation of restoration and spotted owl habitat conservation are explored in chapter 6.

Stand-Level Management to Integrate Restoration and Northern Spotted Owl Recovery Objectives

This report addresses the need for developing consistent regional guidelines for **stand-level** management that integrates goals and objectives as building blocks for dry forest landscape restoration and habitat management for the northern spotted owl in the eastern Cascade Range of Washington and Oregon (fig. 1-1). The report does not address landscape-scale issues, e.g., how much area and where to do treatments, for integrating restoration and spotted owl conservation—that is, a full topic suitable for a separate review and process document (e.g., Gaines et al. 2010). We assume that appropriate landscape-scale analyses will be done to determine the type, location, spatial extent, and persistence over time of the stand-scale practices we envision.

This report addresses the need for developing consistent regional guidelines for stand-level management that integrates goals and objectives as building blocks for dry forest landscape restoration and habitat management for the northern spotted owl.

We believe that the information in this report is relevant for implementing stand-level management as building blocks of larger-scale landscape management strategies based on either a semi-managed reserve network under the Northwest Forest Plan, as proposed by some (e.g., Hanson et al. 2010), or active whole-landscape management without defined reserves (USFWS 2011). In the following chapters, we review background issues, objectives, and the science for forest restoration (chapter 2); northern spotted owl habitat management (chapter 3); and monitoring and adaptive management (chapter 5). The core of the report is chapter 4 on issues and guidelines for developing new silvicultural prescriptions that address these issues. Finally, we discuss some relevant social, economic, and organizational issues affecting successful implementation of such a program of work (chapter 6).

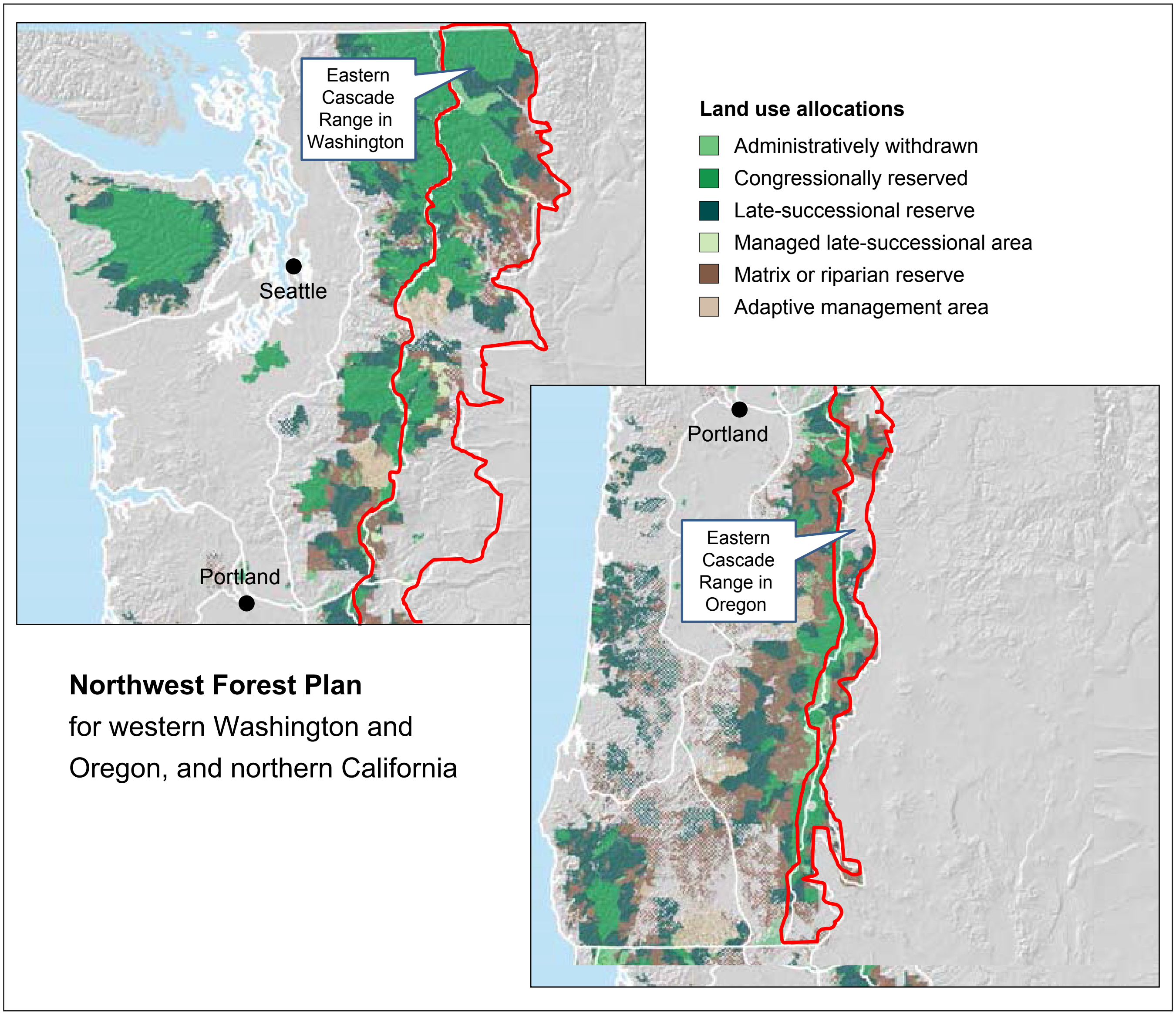

Figure 1-1—Current conservation strategy. The Northwest Forest Plan zoned the landscape into reserved areas and matrix allocations. We are concerned with the dry forest Eastern Cascades Province, where 77 percent of the landscape is in reserved status.

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Chapter 2: Restoration of Mixed-Conifer Forests in the Pacific Northwest: Context, Motives, and Objectives

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The U.S. Forest Service has adopted an ecological restoration framework as a foundation for management of national forest lands (USDA FS 2012). The Forest Service defines restoration as the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed. Ecological restoration focuses on reestablishing the composition, structure, pattern, and ecological processes necessary to facilitate terrestrial and aquatic ecosystems sustainability, resilience, and health under current and future conditions (Franklin and Johnson 2012, USDA FS 2012). As a practical matter, restoration objectives for composition, structure, pattern, and process are variable and highly context-dependent. Ultimately, the goal of ecological restoration is to restore and maintain ecosystem resiliency to disturbances such as wildfire and insect outbreaks, to maintain biodiversity, and to increase ecosystem sustainability in the face of disturbances and a changing climate (Allen et al. 2002, USDA FS 2012).

One goal of ecological restoration is to increase ecosystem sustainability in the face of disturbances and a changing climate.

Specific objectives for ecological restoration can be developed in different ways. Past forest restoration efforts have often focused on restoring forest structure and species composition to conditions within a reconstructed "natural range of variability" or "historic range of conditions," under the assumption that restoring forest structure and composition to historical conditions will also tend to restore ecological processes (e.g., nutrient cycling, disturbance processes) and provide conditions that support high native biodiversity (Keane et al. 2009, Landres et al. 1999). Other restoration efforts have focused more on functional outcomes and keystone processes, such as restoring forest structure, composition, and fuels to the point where natural processes, including fire, can operate naturally (Allen et al. 2002).

In this chapter, we first briefly describe the forest types associated with northern spotted owl habitat in the eastern Cascade Mountains of Washington and Oregon, their historical fire regimes, and the human-caused changes in forest structure and composition that produce the need for restoration-based forest management. We then review the key restoration objectives that are currently driving forest management in these forests and the primary restoration treatment options that are available.

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Dry Mixed-Conifer Forests of the Interior Pacific Northwest

Mixed-conifer forests dominate the middle elevations of the forest zone in the eastern Cascade Mountains of Washington and Oregon (Agee 1993, Franklin and Dyrness 1973, Jain et al. 2012). These forests typically feature ponderosa pine (*Pinus ponderosa*) and western larch (*Larix occidentalis*) as early seral species, Douglas-fir (*Pseudotsuga menziesii*) as an early or late seral species, and true firs—mostly grand fir (*Abies grandis*) or white fir (*Abies concolor*)—as late seral species (Agee 1993). Several other conifer species may be found in these forests and can be locally abundant, including lodgepole pine (*Pinus contorta*), incense-cedar (*Calocedrus decurrens*), western white pine (*Pinus occidentalis*), Jeffrey pine (*Pinus jeffreyi*), and sugar pine (*Pinus lambertiana*). Mixed-conifer forests of southwestern Oregon can also include a significant hardwood component dominated by tanoak (*Lithocarpus densiflorus*) or Pacific madrone (*Arbutus menziesii*). The focus of this document is the dry mixed-conifer forests of eastern Washington and Oregon. This group includes forests within the *Pseudotsuga menziesii* forest zone (Douglas-fir series) and the drier forest types within the *Abies grandis* forest zone (grand fir series), as described by Franklin and Dyrness (1973) and Agee (1993).

Biophysical environments for mixed-conifer forests in the *Pseudotsuga menziesii* and *Abies grandis* forest zones are intermediate with respect to other forest zones in eastern Washington and Oregon. These mixed-conifer forests typically experience cold winter temperatures and persistent winter snowpacks, but low winter temperatures are less extreme and spring snowmelt is earlier than in the subalpine fir (*Abies lasiocarpa*) forest zone found at higher elevations. They also experience regular summer soil moisture deficits, but soil moisture availability is greater than in the drier *Pinus ponderosa* and *Juniperus occidentalis* forest zones found at lower elevations.

Intermediate environmental conditions within mixed-conifer forests produce the potential for relatively high ecosystem productivity compared to neighboring forest types. Longer and warmer annual growing seasons in mixed-conifer forests provide better growing conditions and promote higher ecosystem productivity compared to upper montane and subalpine forests. Higher soil moisture availability allows mixed-conifer forests to support higher leaf area index (LAI) values compared to drier ponderosa pine forests (Grier and Running 1977), and higher LAI values are associated with greater light interception and ecosystem net primary productivity (Gholz 1982, Runyon et al. 1994).

Intermediate environmental conditions also promote high species and structural diversity in mixed-conifer forests. Higher soil moisture availability in mixed-conifer forests increases the pool of potential overstory tree species relative to lower elevation forests by reducing drought stress and allowing drought-sensitive species like grand fir and white fir to establish and persist (Lopushinsky and Klock 1974, Minore 1979). The presence of shade-tolerant tree species increases the potential for forest stands to develop multiple canopy layers and higher levels of overstory canopy closure. In addition, spatial heterogeneity in vegetation structure and composition produced by topographic controls on biophysical settings and disturbance processes may further promote high species and structural diversity at multiple spatial scales (Perry et al. 2011).

Historical Role of Disturbances

Dry mixed-conifer forests of the interior Pacific Northwest historically supported low-severity fire regimes or mixed-severity fire regimes (Agee 1993, Hessburg and Agee 2003, Perry et al. 2011). Wildfires of low intensity and severity were common as frequent burning precluded the widespread accumulation of large amounts of surface woody fuels, but occasional long fire-free intervals or periods of severe fire weather also produced fires of mixed severity. Fire history studies indicate that dry Douglas-fir forests typically featured mean fire intervals of 5 to 20 years (Agee 1993, 2003; Everett et al. 2000).

Frequent, low-severity fires in dry mixed-conifer forests contributed to the development and maintenance of open, park-like, early-seral forests dominated by ponderosa pine and, occasionally, Douglas-fir (Agee 1993, 2003). High fire frequencies favored fires of low intensity and severity because frequent burning prevented the accumulation of large amount of surface woody fuels. High fire frequencies also favored ponderosa pines over other species at the seedling stage because ponderosa pine seedlings developed thicker bark that protected their cambial tissues from excessive heating. Mature ponderosa pines were highly resistant to wildfires owing to their thick bark and high crown bases. Douglas-firs also established and persisted on sites with low-severity fire regimes despite being less fire-resistant at the seedling stage, probably because seedlings established and developed fire resistance during occasional longer fire-free intervals, while thick bark allowed adult trees to persist and serve as local seed sources for centuries.

Dry mixed-conifer forests in the *Abies grandis* forest zone also supported low- or mixed-severity fire regimes in which low-severity fires were common. Mean fire return interval estimates for dry grand fir forests on the Wenatchee National Forest range from 11 to 24 years (Camp et al. 1997, Everett et al. 1992, Wright and Agee 2004). As in the *Pseudotsuga menziesii* zone forests, frequent fires in the *Abies grandis* zone favored open forest stands dominated by early-seral, long-lived, and fire-tolerant species like ponderosa pine, Douglas-fir, and western larch.

The somewhat longer mean intervals between fires probably favored Douglas-fir regeneration relative to ponderosa pine by providing more time between fires for saplings to develop fire resistance. Douglas-fir regeneration may also have benefited from increased canopy closure on mesic sites as Douglas-fir is more shade-tolerant than ponderosa pine. Although dry *Abies grandis* zone forests could, by definition, support fir regeneration and growth, the species was likely rare or uncommon as a forest overstory species as seedlings and saplings have thin bark and are easily killed by fire. Overstory grand fir and white fir were probably most common in the wetter portions of the *Abies grandis* zone and in topographic refugia, where longer fire return intervals allowed regeneration to develop resistance to low intensity wildfire and produce local seed sources to facilitate re-colonization of drier sites following wildfire.

Historical fire return intervals and associated fire behavior and effects were temporally and spatially variable, responding to spatial and temporal variability in climate and spatial variability in topographic influences. Warmer and drier sites typically supported shorter fire return intervals and lower fire severities than colder and wetter sites (Wright and Agee 2004). Heyerdahl et al. (2007) found that mean fire return intervals were shorter on south-facing aspects (14 years) than on north-facing aspects (24 years) in ponderosa pine-Douglas-fir forests in British Columbia. Hessl et al. (2004) showed that fire occurrences were often associated with regional droughts, thereby linking temporal variability in fire interval length with interannual and interdecadal climatic variability.

Topography also interacted with climate and hydrological processes to influence historical fire regimes. Fire refuges occurred where local topography reduced fire frequency, allowing development of old forest structure, persistence of populations of fire-intolerant species, and postfire seed dispersal. In mixed-conifer forests of eastern Washington, Camp et al. (1997) found that fire refuges occurred in topographically protected areas like stream confluences, lower slopes, benches, and headwalls, occupying about 12 percent of the local landscape.

Human Influences and Recent Vegetation Changes

Human activities have significantly altered disturbance regimes and forest structure and composition in dry coniferous forests. Evidence suggests that Native Americans may have used fire as a tool to manipulate vegetation structure in grasslands and dry forests and increase availability of important plant resources by increasing fire frequency (Hessburg and Agee 2003). As Euro-American settlers replaced Native Americans as the dominant human influences in the late 19th century, they lengthened fire return intervals (reduced fire frequency) as the dominant view shifted from fire as a tool for resource management to fire as a threat to human life, property, and resource availability (Hessburg and Agee 2003). Livestock grazing further reduced fire frequencies by removing fine fuels and retarding fire spread (Cooper 1960). Roads, trails, and agricultural land conversions fragmented landscapes and reduced potential for fire spread (Covington and Moore 1994). Active fire suppression lengthened fire return intervals even more during the 20th century (Cooper 1960, Covington and Moore 1994, Franklin and Johnson 2012).

Longer fire return intervals in the dry forest types following Euro-American settlement produced significant changes in forest structure and composition at stand to landscape scales (Covington and Moore 1994, Keane et al. 2002, and references therein). Cohorts of seedlings that would normally have been killed by frequent fires were able to persist, grow, and develop fire resistance, thereby increasing forest stand densities and canopy closure (Camp 1999, Cooper 1960, Keeling et al. 2006, Weaver 1943). In ponderosa pine forests, establishment and release of seedlings created thickets of small, suppressed trees (Cooper 1960, Weaver 1943). In Douglas-fir and grand fir forests, long fire intervals altered forest species composition and structure by allowing shade-tolerant tree species to establish (from seed sources in refugia), and to persist and grow. These shade-tolerant trees increased stand densities, facilitated the development of multilayer canopy structures, and continue to serve as a local seed source (Camp 1999, Hessburg and Agee 2003). Landscapes became more homogeneous, with increases in patch size, patch evenness, patch dominance, and contagion (Hessburg et al. 2005, Keane et al. 2002).

In addition to altering fire frequencies, Euro-American settlers altered mixed-conifer forest structure and composition through logging and plantation development (Franklin and Johnson 2012, Nacify et al. 2010). Early logging activities often altered forest structure and species dominance patterns by removing large trees (e.g., commonly the dominant ponderosa pines and Douglas-firs) and leaving smaller and more shade-tolerant trees (Cooper 1960, Hessburg and Agee 2003; Hessburg et al. 2005). In more recent decades, logging practices have included subsequent establishment of plantations with simplified vertical structures, high tree densities, simplified stand-level tree spatial patterns, and reduced landscape-level patch diversity.

Resilience and Sustainability of Modern Mixed-Conifer Dry Forests

Changes in forest structure and composition and landscape patterns have, in turn, altered disturbance regimes, especially for insects, diseases, and fire. Increased tree densities and increased dominance of Douglas-fir and grand fir (or white fir) have increased forest susceptibility to root pathogens, bark beetles, defoliators, and dwarf mistletoe (Camp 1999, Hessburg et al. 1994). In addition, the greater size and abundance of these high-density stands dominated by susceptible species within the mixed-conifer zone has allowed insect and disease outbreaks to affect larger areas.

Wildfire hazards have increased in concert with changes in forest structure and composition at the stand and landscape levels (Covington and Moore 1994, Keane et al. 2002). At the stand level, longer intervals between fires have facilitated the establishment and growth of young trees, often of shade-tolerant species, that serve as ladder fuels and increase the potential for torching during wildfires. Similarly, increased tree density and dominance of shade-tolerant species have increased canopy bulk densities and crown fire potential. Longer intervals between fires have also increased mean surface woody fuel levels and potential surface fire intensity and severity by increasing total stand biomass, biomass turnover (litter production) and increased tree mortality from self-thinning and increased insect and disease activity. Increased horizontal fuel continuity at stand to landscape scales has also increased risks of large fires. Contemporary fire suppression policies further reinforce this tendency for large, high-severity wildfires by encouraging fire managers to extinguish wildfires wherever possible; it is therefore the wildfires burning under extreme fire weather conditions that are most difficult to extinguish and often burn the largest areas (Dombeck et al. 2004).

Sustainability of late successional mixed-conifer forests is increasingly threatened by changes in disturbance regimes and the frequency and distribution of forest successional stages on ponderosa pine and mixed-conifer landscapes. Late-successional forest structure and composition was formerly confined to refugia within landscapes, where topoedaphic controls on biophysical environments, ignitions, and fire spread created localized patches with longer fire-free intervals and mixed fire severity (Camp et al. 1997). The development of late-successional forest structure and composition outside of topographically protected areas has increased the frequency and extent of high-severity burn patches, especially for fires burning under extreme fire weather. Greater landscape connectivity of late-successional forest structures also reduces forest sustainability, as fires are more likely to spread between patches as high-intensity surface or crown fires rather than as low-intensity surface fires.

Climatic changes also threaten the sustainability of current forest structure and composition in ponderosa pine and mixed-conifer forests. Projected warming temperatures and earlier snowmelt are likely to exacerbate current fire risks in these forests by extending the fire season and increasing the frequency or duration of extreme fire weather. Warming temperatures are also likely to increase drought stress, making trees more vulnerable to insects and diseases (Larsson et al. 1983), and may alter the geographical distribution of insect and disease species (Bentz et al. 2010, Kliejunas et al. 2009, Raffa et al. 2008). Finally, climatic changes may reduce forest resilience to disturbances if the altered climate is less favorable for establishment and persistence of trees regenerating from locally available seed sources (e.g., true firs or Douglas-fir).

Restoration Goals and Objectives

The primary restoration goals for dry coniferous forests of the Pacific Northwest, including mixed conifer forests, are to (1) enhance the resilience and sustainability of forests and forested landscapes to fire and other disturbances and (2) maintain and enhance biodiversity. Increasing forest resilience to fire requires restoring and managing forest structure, composition, and fuels to be consistent with fire regimes in which low-severity wildfires are the norm under all but the most extreme fire weather conditions and in most landscape contexts, thereby reducing wildfire impacts on forest ecosystem structure and function and reducing wildfire threats to human health and property (Allen et al. 2002, Brown et al. 2004, Reinhardt et al. 2008). Maintaining and enhancing biodiversity calls for restoring native biodiversity and ecosystem processes to conditions within the historical or natural range of variability or some desired future condition (Allen et al. 2002, Covington et al. 1997, Keane et al. 2009, Spies et al. 2012). Management objectives and priorities developed to achieve these goals are also influenced, however, by legal mandates governing management of habitat for threatened and endangered species and by sociopolitical pressure to manage wildfires to protect human life and property in the wildland-urban interface.

Reducing surface woody fuels, ladder fuels, and canopy density can enhance forest resilience to wildfire.

Efforts to enhance forest resilience to wildfire at the stand level focus on a set of management objectives for fuels , including reducing surface woody fuels, reducing ladder fuels, reducing crown densities, and retaining large trees of fire resistant species (Agee and Skinner 2005, Brown et al. 2004). Reducing surface woody fuels helps reduce potential surface fire intensity (heat release), flame lengths, and severity (effects on soils and trees). Reducing ladder fuels disrupts vertical continuity of fuels and reduces the probability of torching and crown fire initiation. Reducing the density of overstory canopy fuels reduces the amount and horizontal connectivity of canopy fuels available to support the spread of crown fires. Finally, retaining large trees of fire-resistant species seeks to maintain stand structural and compositional stability by keeping existing trees that are most likely to persist through future fires and retaining seed sources that facilitate regeneration of fire-resistant species.

Efforts to restore fire resiliency at the landscape level focus on restoring historical landscape patterns and prioritizing restoration treatment areas (deciding where to actively manage) to most efficiently manage fire behavior and effects (Allen et al. 2002, Brown et al. 2004, DellaSala et al. 2004). Landscape-level fire management objectives include managing patch sizes and the distribution of stand structural conditions to limit the frequency and extent of high-severity wildfire and to create safety zones and anchor points for future wildfire management. Prioritization of treatment area is important because forest restoration and management efforts are limited in scope by funding limitations, conservation concerns, access problems (e.g., roadless areas), mixed forest land ownership, and the need to maintain treated areas (DellaSala et al. 2004, North et al. 2012). Some have argued that restoration treatments should first be concentrated on forests with historical low-severity fire regimes (with mixed-severity fire regimes being a secondary priority) based on levels of departure from historical ranges of variability (Brown et al. 2004, Noss et al. 2006). Others have argued for concentrating restoration efforts in and near the wildland-urban interface (DellaSala et al. 2004).

Spatially explicit fire models have also been used to assess spatial variability in fire hazards and fire behavior and to assist in effective placement of restoration treatments within landscapes. Applying fuel treatments at different patch sizes and spatial patterns can influence subsequent fire behavior and effects within landscapes (Finney 2001, 2004). Similarly, models have been used to simulate fire flow patterns, variability in fire frequency, and source-sink relationships for fire in order to identify areas within landscapes where fuel treatments can be most effective (Ager et al. 2012). These fire models have also been used to design landscape-level fuel treatments that consider potential tradeoffs between meeting fire management objectives and conserving habitat for northern spotted owls (Lehmkuhl et al. 2007).

Forest restoration seeks to maintain biodiversity by restoring forest structure, increasing understory plant diversity, and restoring favorable habitat conditions for diverse animal populations

The other major forest restoration goal is to enhance and maintain biodiversity. Specific objectives related to this goal include restoring forest structure and composition; increasing understory native plant cover and diversity; limiting the spread and dominance of exotic plant and animal species; and restoring and maintaining favorable forest habitat conditions for diverse animal populations, including rare and endangered species (Allen et al. 2002, Carey 2003, Covington et al. 1997, Franklin and Johnson 2012, Franklin et al. 2008, Spies et al. 2012).

Many biodiversity objectives may be met over time by restoring forest structure and composition to target conditions developed from the historical range of variability (Keane et al. 2009). Restoration of historical forest structures typically calls for retaining and protecting large trees of fire-resistant species and very old trees, regardless of size (Agee and Skinner 2005, Brown et al. 2004, Franklin and Johnson 2012). Reducing mean stand densities and overstory canopy cover can increase understory plant biodiversity (Dodson et al. 2008, McConnell and Smith 1970), particularly if treatments produce significant spatial heterogeneity in stand structure and treatment intensity within and among stands (Dodson and Peterson 2010). However, thinning effects on understory vegetation are highly variable and short-term effects may differ from long-term outcomes (Bartuszevige and Kennedy 2009, Nelson et al. 2008).

However, forest restoration treatments may not be effective for meeting some biodiversity objectives. For example, modern forest and landscape structures that are favorable for endangered species like the northern spotted owl are not resilient to wildfire, and efforts to increase fire resilience are likely to degrade their habitat suitability (Gaines et al. 2010, Lehmkuhl et al. 2007). Snags and surface woody debris that provide important functions for wildlife habitat may be significantly reduced by thinning and prescribed fire treatments (Harrod et al. 2009, Jain et al. 2012). Restoration treatments may also increase the spread and dominance of exotic plant species by disturbing soils and reducing overstory shading, although such effects are apparently not large in these types of forests (Dodson and Peterson 2010, Nelson et al. 2008, Stoddard et al. 2011). These limitations to the restoration benefits of fuel treatments should not preclude the application of fuel treatments to reduce fire hazards, but do argue for spatial heterogeneity in the type, intensity, and spatial extent of treatment applications within landscapes, and for reliance on natural processes to achieve restoration objectives where possible.

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Chapter 3: Northern Spotted Owl Issues and Objectives

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Introduction

Because of the role that fire plays in the mixed-conifer forest ecosystems in the eastern Cascade Range, fire management is central to the conservation of a wide range of wildlife species (Driscoll et al. 2010, Irwin et al. 2004, Myers 1997), and restoration of natural fire regimes has been suggested as a coarse filter conservation approach (Agee 2003, Prather et al. 2008). However, there are potential conflicts between the restoration of fire regimes and the conservation of rare or protected species (Agee 2003, Irwin and Thomas 2002, Lehmkuhl et al. 2007, Myers 1997, Prather et al. 2008). Interactions between the application of restoration treatments and habitat conservation for the northern spotted owl (*Strix occidentalis caurina*) are of particular interest within the fire-prone dry forests of the eastern Cascade Range (Gaines et al. 2010, Irwin et al. 2004, Kennedy et al. 2008, Lehmkuhl et al. 2007, Loehle et al. 2011).

Conservation strategies for northern spotted owls within dry forest landscapes of the eastern Cascades need to address the potential effects of wildfire, insects, and disease on habitat (Agee and Edmunds 1992, Bond et al. 2002, Collins et al. 2010, Courtney et al. 2008, Davis and Dugger 2011, Everett et al. 1997, USFWS 2011). However, there is disagreement over the risk that fire, in particular, poses to spotted owl recovery and how recovery actions should address fire risk (Hanson et al. 2009a, 2009b; Spies et al. 2009). How restoration treatments should be designed and where they should occur in relation to spotted owl habitat is of critical interest (Gaines et al. 2010, Lehmkuhl et al. 2007, USFWS 2011). Understanding the effects of restoration treatments aimed at restoring forest structures and functions, such as fire regimes, at various spatial scales is essential to effective adaptive implementation of conservation strategies for spotted owls (Courtney et al. 2008, DellaSalla et al. 2004, Gaines et al. 2010).

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Restoration treatments have been recommended in and around northern spotted owl habitat to reduce the risk of habitat loss from uncharacteristically severe wildfires (Agee and Edmunds 1992, Ager et al. 2007, Davis and Lint 2005, Everett et al. 1997, Franklin et al. 2008, Gaines et al. 1997, Lee and Irwin 2005, Lehmkuhl et al. 2007). These studies have identified specific situations in which limited treatments may be needed within spotted owl habitat (short-term habitat effects) to gain longer term habitat recruitment, fire-risk reduction, and restoration of forest resiliency. Fires have had the single largest impact on the amount of spotted owl habitat in the eastern Cascades since the implementation of the Northwest Forest Plan in 1994 (Davis and Dugger 2011, Davis and Lint 2005). Yet this view should be tempered somewhat by a limited amount of recent research on spotted owl response to fire and associated changes in habitat structure.

Wildfires that create large patches of high-severity burned area appear to have a negative impact on spotted owl habitat, particularly nesting/roosting habitat (Bond et al. 2009, Clark et al. 2011, Elliot 1985, Gaines et al. 1997, MacCracken et al. 1996). Such high-severity wildfire alters the structure of coniferous forests associated with spotted owl nest and roost sites: high canopy closure, large-live tree basal area, and total live-tree basal area (Bond et al. 2009, Gaines et al. 1997, Roberts 2008). Although nesting in areas burned during high-severity fire is precluded, selective use of high-severity burn patches for foraging by California spotted owls (*Strix occidentalis occidentalis*) has been observed where burn patch size was small and relatively high amounts (>30 percent) of unburned area remained on the landscape (Bond et al. 2009, Lee et al. 2012), and after shrubs and associated prey species have responded. Low- to moderate-severity wildfires may have little or slightly positive impacts on spotted owl habitat (Bond et al. 2002, 2009; Lee et al. 2012; Roberts 2008; Roberts et al. 2011; Seamans and Gutierrez 2007), particularly foraging habitat. For example, Irwin et al. (2013) observed preferential use by northern spotted owls in burned areas in winter in the Klamath Region. Patterns of habitat use vary substantially between northern spotted owls in eastern Washington (Buchanan et al. 1995, King 1993) and the range of California spotted owls (Verner et al. 1992) which complicates extrapolation of results from the range of the California subspecies north to dry forests in Washington and Oregon. Furthermore, most investigations of spotted owl response to fire were of short duration or involved very small sample sizes, and only two small studies were from the range of the owl covered by this report (Bevis et al. 1997, Gaines et al. 1997).

The focus of this chapter is on the development of a set of stand-level habitat objectives based on our current knowledge of spotted owl habitat use. The landscape context of where and how restoration treatments occur is imperative to understand and consider in project planning. Fire modeling has been used to evaluate treatment options that reduce fire risk while minimizing the loss of spotted owl habitat from either treatments or fires at the landscape- (Ager et al. 2007, Kennedy et al. 2008, Lehmkuhl et al. 2007) and stand- (Lee and Irwin 2005) scales. Stands are embedded in landscapes, and landscape context influences both the disturbance regime and the habitat functions of stands. Interactions and feedbacks across scales are inherent features of complex systems, and understanding cross-scale processes is essential to both model development and ecosystem restoration (Hessburg et al. 2013, Parrott and Meyer 2012). Thus, this chapter will:

- Review current information about nesting, roosting, and foraging habitats for northern spotted owls in the mixed-conifer forests of the eastern Cascade Range.
- Review landscape evaluation approaches that inform the location, amount, and priorities for restoration treatments, including:
    - Northern spotted owl habitat selection at the landscape scale;
    - Interactions between spotted owls and barred owls;
    - The influence of forest disturbances;
    - An integrated landscape evaluation process.
- Describe stand-scale northern spotted owl habitat objectives.

Northern Spotted Owl Habitat

The northern spotted owl recovery plan (USFWS 2011) and critical habitat rule (USFWS 2012) identified three essential functions served by spotted owl habitat: (1) nesting/roosting, (2) foraging, and (3) dispersal. Little is known about the features that affect spotted owl selection of habitats during dispersal (Buchanan 2004). However, Sovern et al. (2015) found that dispersing juvenile spotted owls used stands with some large trees (>50 cm dbh) and high canopy cover (>70 percent) as roosting habitat. For spotted owls to be sustained on a landscape, sufficient nesting, roosting, foraging, and dispersal habitat that meets their life history needs must be available. Nesting habitat provides structural features for nesting, protection from adverse weather conditions, and cover to reduce predation risks. Roosting habitat provides for thermoregulation, shelter, and cover to reduce predation risk while resting or foraging. Habitat requirements for nesting and roosting are assumed to be nearly identical; therefore, for the purposes of our discussion, nesting and roosting habitat categories are combined. Foraging habitat provides a food supply for survival and reproduction and appears to include a broader range of forest conditions than are found in nesting and roosting habitat. Foraging habitat is closely tied to habitat used by primary prey species, although the range of prey habitats that are used by spotted owls in dry forests of Washington and Oregon is not clear. Most northern spotted owls expand their home ranges in winter, and some move to lower elevations, including some in Washington (Brewer and Allen 1985) and southwestern Oregon (Irwin et al. 2013).

Nesting/Roosting Functions

Forest conditions that provide for nesting/roosting functions for northern spotted owls in the eastern Cascades are generally characterized as providing a comparatively greater degree of structural complexity than foraging habitat. These forests have a high canopy closure (e.g., >70 percent) and multiple canopy layers (e.g., multiple age- or size-classes of trees present such that below the dominant or co-dominant canopy layer there is a cohort of intermediate trees, and to a lesser extent, suppressed trees). Moreover, these mid- to late-successional forests (e.g., generally >80 years of age, although sometimes younger) typically are composed of grand fir (*Abies grandis*), Douglas-fir (*Pseudotsuga menziesii*) forested plant associations in dry forest areas or western hemlock (*Tsuga heterophylla*) in moist forest associations (Buchanan et al. 1995, Herter et al. 2002, Irwin et al. 2000, Loehle et al. 2011). The presence of large snags and coarse downed wood is quite variable, but mistletoe appears to be regularly associated with nesting habitat (Buchanan et al. 1995, Loehle et al. 2011, Marshall et al. 2003). Forests that comprise spotted owl "neighborhoods" around nests have multilayered canopies and more small and large trees than areas outside of the neighborhoods (Everett et al. 1997). Spotted owl habitat conditions vary across the eastern Cascades in Washington (Buchanan and Irwin 1998).

Singleton (2013) studied the habitat associations of spotted owls in the eastern Cascades of Washington. He found that northern spotted owl habitat selection increased with increasing tree size, more Douglas-fir, moderate amounts of grand fir, lower topographic position, moderate amounts of solar radiation, and moderately steep slopes. The best spotted owl habitat (defined as habitat with the greatest frequency of use) was characterized as forests with mean tree diameter at breast height (dbh) >25 cm, canopy closure >50 percent, and a substantial component of Douglas-fir and grand fir located on moderate to steep slopes (6 to 33 degrees), in lower- to mid-topographic positions (5 to 55 percent) (Singleton 2013). Similarly, previous studies have found key characteristics of spotted owl habitat to include high canopy closure (Buchanan et al. 1995, Everett et al. 1997, Gaines et al. 2010, Loehle et al. 2011, Sovern et al. 2015), medium and large trees (Buchanan et al. 1995, Everett et al. 1997, Gaines et al. 2010, Loehle et al. 2011, Sovern et al. 2015), Douglas-fir and grand fir (Buchanan et al. 1995, Everett et al. 1997, Loehle et al. 2011), and moderate slopes (Buchanan et al. 1995, Gaines et al. 2010).

Since Euro-American settlement, tree density and the proportion of shade-tolerant tree species have both increased significantly in currently occupied spotted owl nest sites (Everett et al. 1997). Exclusion of fire from dry and mesic forests has increased the total area supporting habitat conditions for spotted owls, but simultaneously resulted in greater risk of habitat loss to fire (Everett et al. 1997). Everett et al. (1997) suggested that although vegetation manipulation to reduce fire hazard may create less optimal habitat for northern spotted owls, habitat effects from vegetation treatments should be weighed against the risk of stand-replacement fires and the loss of nesting and roosting habitat over large areas. More than 50 percent of the northern spotted owl nest-sites in the eastern Cascades of Washington occur within dry and mesic forests (Buchanan 2009, Gaines 2001) that are at risk of uncharacteristically severe wildfire owing to a combination of fire exclusion and other factors that have altered forest composition and structure (Agee and Edmunds 1992, Everett et al. 2000, Hessburg et al. 2007).

Foraging Function and Habitat for Primary Prey Species

Foraging habitat is thought to be the most variable of the habitats used by territorial spotted owls, and may be tied to forest conditions associated with primary prey species (Irwin et al. 2007, USFWS 2011). Diet (Forsman et al. 2001, 2004) and telemetry (Irwin et al. 2007, 2012) studies indicate that spotted owls in some areas use a variety of open and closed-canopy stand types, including stands that had recently burned (Bond et al. 2009, Clark et al. 2012, Irwin et al. 2013) as foraging habitat. Foraging habitat includes nesting and roosting habitat, but foraging habitat, because of its hypothesized wider range of conditions (Irwin et al. 2007, 2012; USFWS 2011), may also include forest conditions that do not support successful nesting pairs. Uncertainty in habitat associations of foraging spotted owls that are inferred from studies of habitat use by prey species occurs because information on patch use by foraging owls is lacking; consequently, whether owls use the entirety of open cover types or forage primarily along the ecotone between closed-canopy forest and open areas remains to be clarified in dry forest landscapes.

In the portions of the spotted owl range where northern flying squirrels (*Glaucomys sabrinus*) are a major prey item, spotted owls forage almost exclusively in old forests or forests with complex structure (Forsman et al. 2001, 2004). In areas where woodrats (*Neotoma* spp.) are a major component of their diet (e.g., dusky-footed woodrats [*N. fuscipes*] in northern California and parts of Oregon, and bushy-tailed woodrats [*N. cinerea*] rangewide), northern spotted owls are likely to use a wide variety of forest patch conditions, including young stands (Carey et al. 1992, Franklin et al. 2000, Irwin et al. 2013, Zabel et al. 1993) and burned stands, in the case of the related California spotted owl (Bond et al. 2009, Lee et al. 2012). Although limited information is available on the foraging habitat used by northern spotted owls in the dry mixed-conifer forests in the eastern Cascades, habitat features important to survival and reproduction of major prey species, northern flying squirrels and woodrats, have been studied.

The primary prey species of spotted owls in terms of annual biomass consumed in the eastern Cascades is the northern flying squirrel (about 50 percent of diet) followed by bushy-tailed (*Neotoma cinerea*) or dusky-footed (*Neotoma fuscipes*) woodrats (about 18 percent), and juvenile snowshoe hares (*Lepus americana*) (about10 percent) (Forsman et al. 2001, 2004). The bushy-tailed woodrat is found in both Washington and Oregon, and the dusky-footed woodrat is found only in the very southern portions of the eastern Cascade range, from about Klamath Falls south and west (Verts and Carraway 1998). The full fauna of other small mammals is represented in the diet, with most species representing ≤1 percent of the diet biomass; but, gophers (mostly *Thomomys talpoides*) (about 7.5 percent of diet) and the southern red-backed vole (*Myodes gapperi*) (about 2.5 percent of diet) seem to be the most important. Mice and voles represent low percentages of average biomass in the spotted owl diet, but these species show high temporal variation in abundance, and some studies have found a positive correlative (but not cause and effect) relationship between spotted owl reproductive success and abundance of these species (Rosenberg et al. 2003, Ward 2001).

Lehmkuhl et al. (2006b) studied the demography of northern flying squirrels in three different habitats in the eastern Cascades of Washington. In mixed-conifer forests (*Pseudotsuga menziesii, Abies grandis*) more individual flying squirrels were captured, home ranges were smaller, densities were higher, and recruitment was higher when compared to drier ponderosa pine forests. Mature mixed-conifer forests provided the best habitat conditions for northern flying squirrels, with the single best correlate of high squirrel density being tree canopy cover >55 percent. Important habitat features for northern flying squirrels included large trees and snags, woody debris, and the diversity of understory plants, truffles, and lichens (Lehmkuhl et al. 2004, 2006b).

Bushy-tailed woodrats in the dry forests of the eastern Cascades in Washington had similar densities whether in open ponderosa pine, young mixed-conifer, or mature mixed conifer forests (Lehmkuhl et al. 2006a). Woodrat densities were best predicted by the type and amount of cover provided by large (>16 inches) snags, clusters of mistletoe-infected braches (“brooms”), and soft (decayed) downed logs.

Landscape Scale—Informing Spotted Owl Habitat Objectives and Restoration Treatment Prescriptions

Landscape-scale influences on spotted owl populations and ecosystem resiliency suggest strong interactions among how spotted owls use landscapes, their competition with the conspecific barred owl, and large disturbances such as fires and defoliation by forest insects (Raphael et al. 2013). These interactions are, and will continue to be, influenced by rapidly changing climatic conditions. Thus a process that allows managers to assess these key interactions will best inform spotted owl habitat objectives and restoration treatment options at both the landscape- and stand-scales. Three primary topic areas that are important to understand in relation to how spotted owls interact with other components of dry- and mesic-forest ecosystems are (1) patterns of landscape use, (2) interactions between spotted owls and barred owls, and (3) the sustainability of spotted owl habitat. Our current understanding of these areas is presented below along with an approach that allows the integration of this information in a landscape evaluation process.

Spotted Owls and Landscapes

Spotted owls have very large home ranges and use substantial areas of habitat. In Washington, for example, the median annual home range in the Cascade Range is about 2500 ha (USFWS 2011). Spotted owl home ranges vary in size and shape, and some include distinctly separate areas used during breeding or non-breeding seasons.[6] In Oregon, Carey and Peeler (1995) found that areas used in one season or year may be used much less or not at all in subsequent seasons or years, suggesting that prey resources were temporarily depleted. Similarly, radiotelemetry research in Oregon (Irwin et al. 2012) indicated that spotted owls frequently used certain topographic locations (e.g., upper slopes, ridgetops) less than expected, which might reflect energetic efficiencies associated with foraging behavior and feeding young. These findings suggest that spotted owls use parts of their home range more intensively than others, but that use also varies among seasons or years. Given the size of home ranges and amount of habitat associated with territorial owl sites (e.g., Washington State Forest Practices Board 1996), the distribution of habitat on the landscape is important. Landscape areas with little habitat or widely spaced patches of habitat may be unable to support breeding owls. Nonbreeding spotted owls, commonly referred to as floaters, are also present in many landscapes, and may occupy peripheral areas or even areas embedded within territories occupied by reproduc-

[6] Sovern, S. 2005. Personal communication. Senior faculty research assistant, Oregon State University 200 SW 35th Street, Corvallis, OR 97331.

tive owls; it is possible that the occurrence of such birds may be influenced by the amount and capacity of habitat present in the landscape.

Young of the year and adults that elect to change territories between years engage in dispersal; the two types of dispersal are referred to as natal dispersal and breeding dispersal (Forsman et al. 2002). Dispersing owls move across landscapes in search of territories where they can become resident. Natal dispersal distances, measured from natal areas to eventual home ranges, tend to be greater for females (24 km) than males (13.7 km) (Forsman et al. 2002). Median maximum dispersal distances for male spotted owls was 20.3 km and for females was 27.5 km (Forsman et al. 2002). Natal dispersers are naïve and lack knowledge of landscape conditions along the directionally random pathway they follow. Landscapes with conditions that facilitate safe passage and allow opportunities to forage will be more conducive to successful dispersal than landscapes with lesser conditions. For example, Sovern et al. (2015) found that roosting habitat used by spotted owls during natal dispersal included some large trees (>50 cm dbh) and high canopy cover (>70 percent). Consequently, landscapes with greater areas of foraging habitat will better provide for the needs of owls engaged in natal or breeding dispersal. In combination then, dry forest landscapes with nesting and roosting habitat in a mosaic of forest with a plentitude of foraging habitat provide excellent conditions for foraging and survival, but also result in conditions vulnerable to large-scale stand-replacement fires. The challenge in this case is to identify landscape patterns that are more resilient to disturbances such as stand-replacement fire and judiciously manage patches within the landscape to reduce risk and transition to more sustainable forest conditions (e.g., Gaines et al. 2010, Prather et al. 2008).

Barred Owl and Spotted Owl Interactions in the Eastern Cascades

Expansion of barred owls into the range of the northern spotted owl has resulted in a clear negative association between barred owl presence and spotted owl survival (Dugger and Davis 2011, Forsman et al. 2012, Sovern et al. 2014, Wiens et al. 2014). Barred owls and spotted owls in eastern Washington use forests with similar structural characteristics; however, barred owls appear more closely associated with moist forests on gentle slopes in valley bottoms (Singleton 2013, Singleton et al. 2010), although they use other areas, including dry forest sites, and have an upper elevation range well above that of the spotted owl (Singleton 2013). There is considerable overlap between habitats used by both species at the landscape scale. For example, across the entire Okanogan-Wenatchee National Forest, less that 25 percent of the “good” spotted owl habitat coincides with “poor” habitat for barred owls (Singleton 2013) under current conditions. This relationship is noteworthy because areas with good spotted owl habitat that overlapped with poor barred owl habitat were important for spotted owl pair site persistence in eastern Washington forests (Singleton 2013). The areas where good spotted owl habitat overlaps with poor barred owl habitat are often in drier mid-slope settings, and the most likely areas where spotted owls can minimize interactions with barred owls, at least in the near-term, are generally in the drier forest types (Gaines et al. 2010, Singleton 2013, Singleton et al. 2010).

Interactions Between Forest Disturbances and Spotted Owl Habitat

Discussions about the sustainability of spotted owl habitat in dry forests have been ongoing for at least two decades (Agee and Edmunds 1992, Buchanan et al. 1995, Everett et al. 1997, Gaines et al. 2010, USFWS 2011). Exclusion of fire from dry and mesic forests have created conditions difficult to sustain and resulted in greater risk of habitat loss to fire (Buchanan et al. 1995; Everett et al. 1997; Hessburg et al. 2005, 2007). These risks can be attributed to consequences of fire exclusion: (1) increases in horizontal and vertical connectivity of vegetation, (2) changes in tree species composition, including a greater presence of fire intolerant species, (3) an overall greater amount of closed-canopy forest across the dry forest landscape, and (4) concomitant increased susceptibility to insects and disease. Habitat loss from fire in the eastern Cascades of Oregon and Washington is currently the largest factor contributing to the loss of spotted owl habitat (Davis and Dugger 2012). Overall habitat loss in the past decade in the eastern Cascades of Oregon has been -6.5 percent and even greater, -6.9 percent, for more contiguous core habitat (larger patches with less edge effect) (Davis and Dugger 2012). Similarly, in the eastern Cascades of Washington overall habitat loss has been -4.5 percent and core habitat loss -6.8 percent (Davis and Dugger 2012). Forest managers must weigh the consequences of habitat loss to restore fire regimes against potential habitat loss from large and uncharacteristically severe wildfires (Everett et al. 1997, Hessburg et al. 2005). The application of strategically placed restoration treatments to interrupt landscape fire movement may have the potential to limit habitat loss resulting from treatments while reducing risks associated with habitat loss from fire.

An important premise of landscape restoration to provide functional spotted owl habitat networks is the optimization of restoration treatment location to reduce landscape level fire risk (Finney 2001, Finney et al. 2006). For the purposes of this discussion, we consider optimization to reflect the use of active management to achieve fire risk reduction objectives while minimizing treatments that occur within spotted owl habitat (Kennedy et al. 2008). Several studies have modeled scenarios that integrate spotted owl habitat, fire behavior and movement models, and treatments to provide managers with insights and tools that can be used to determine amount and location of optimal treatments (Ager et al. 2007, Kennedy et al. 2008, Lehmkuhl et al. 2007). Generally these studies suggest that if 20 to 30 percent of the landscape can be treated in optimal locations (which may differ over space and time) there is a corresponding decrease in the risk of landscape-level fire. These studies also suggested that when treatment locations cannot be optimized, such as when there are constraints related to a land allocation, the amount of area that needs to be treated to achieve the same level of risk reduction increases substantially (Finney et al. 2006). Fortunately, tools for modeling fire movement and behavior are now being more commonly used in landscape evaluations (Hessburg et al. 2013, USFS 2012) and for project-level planning. This type of evaluation is important for understanding the dynamic nature of dry forest landscapes, and for building a strong rationale for impacting owl habitat functionality to achieve broader landscape conservation and restoration goals (USFWS 2012).

Spotted Owls and Climate Change

Climate change impacts to wildlife include changes in species' ranges, timing of breeding, survival and extinction risks, and in the interactions among species (several papers cited in Gaines et al. 2012). Considerable change has already occurred in the distribution of some species, notably birds (Root 1992, 1993; Thomas and Lennon 1999). Most climate change models predict warmer, wetter winters and hotter, drier summers for the Pacific Northwest in the first half of the 21st century (Elsner et al. 2009, Mote 2003, Mote et al. 2005). Results from Glenn et al. (2010) suggest that these conditions have the potential to negatively affect annual survival, recruitment, and population growth rates for northern spotted owls. Consequently, climate change is expected to alter the distribution of forests, with a trend that is generally upward in elevation and northerly in latitude. Littell et al. (2009) predicted that by the mid 21st century, some areas of the eastern Cascade Range are likely to experience substantial declines in climatically suitable areas for sustained Douglas-fir growth. Spotted owls in the eastern Cascades show a strong preference for Douglas-fir as a nest tree (Buchanan et al. 1993) and as a dominant tree in spotted owl neighborhoods (Everett et al. 1997).

Since the mid 1980s, the size and intensity of large wildfires in the western United States have increased markedly (Westerling et al. 2006), in part because of a reduction in fuel moisture driven by increased temperature and lower snowpack. Increases in fire risk and severity have been also been driven, in part, by increased fuel loads because of fire suppression practices used over the last century (McKenzie et al. 2004). Predicted increases in spring and summer temperature identified in many climate change models would exacerbate the frequency and intensity of disturbances such as fire (McKenzie et al. 2004, Wotton and Flannigan 1993) and defoliation by forest insects (Littell et al. 2009). In the interior Columbia Basin, Littell et al. (2009) predicted that the area burned is likely to double or even triple by 2050. Climate-driven changes in fire regimes will likely be the dominant driver of changes to forests in the Western United States over the next century (McKenzie et al. 2004).

An Integrated Landscape Evaluation

Landscape evaluations used to assess the interactions described above were identified as an important tool in the implementation of the northern spotted owl recovery plan and critical habitat rule (USFWS 2011, 2012). Landscape evaluations improve the ability to estimate effects of management actions on the function of spotted owl habitat and better identify and prioritize treatment areas and actions to restore landscapes while conserving spotted owl habitat (USFWS 2012). The Okanogan-Wenatchee National Forest Restoration Strategy (FRS) includes a landscape evaluation component that allows an objective assessment of key ecosystem elements; provides a process for integration across competing resources (e.g., conservation of owl habitat vs. treatment of fuels); identifies priority treatment areas where limited resources to implement restoration treatments can have the greatest impact; and allows managers to evaluate alternative landscape treatment scenarios to better inform and increase the efficiency and efficacy of project level planning and implementation (Hessburg et al. 2013, USDA FS 2012).

The approach to landscape evaluation described in the FRS is based on comparing a set of ecological indicator measures against their associated reference conditions (Hessburg et al. 2013, Reynolds and Hessburg 2005). By comparing current landscapes to reference landscapes (historical and future), insights are gained about changes in habitats for focal species (such as the northern spotted owl), in stand- and landscape-level fire risk, and landscape composition and pattern. The future reference conditions are based on the concept of the future range of variability, which accounts for warmer and drier climate (see Gartner et al. 2008). From this, landscape prescriptions are developed that enhance ecological functionality and improve landscape resilience (Hessburg et al. 2013). Thus, stand-level treatments, whose prescriptions would be derived from information in this technical report and are supported by a landscape evaluation, would be building blocks for landscape-level ecosystem restoration of fire-prone dry and mesic forests of the eastern Cascades, within which spotted owl conservation is embedded (Gaines et al. 2010).

Providing information that land managers can use to guide the location of and prescriptions for strategic restoration treatments that incorporates climate change science is challenging. Landscape evaluations can be used to identify areas spatially and temporally that are valuable for northern spotted owl conservation and recovery, as well as areas important for strategic management and restoration to achieve greater ecosystem function and resilience (Franklin et al. 2008, Franklin and Johnson 2012, Prather et al. 2008, Spies et al. 2010). The USFWS (2012) identified an approach for landscape evaluations for the eastern Cascades that we modified from Hessburg et al. (2013) and summarized here as an example.

- Identify the landscape evaluation area.
- Generally use watershed boundaries (two or more 6^{th}-field HUCs [hydrologic unit code]) for a total area of approximately 40,000 to 60,000 acres.
- Evaluate landscape pattern and departure.
- Compare the current condition to reference conditions (e.g., historical and anticipated future range of variation).
- Determine departure in amount and spatial arrangement of cover and structure types.
- Determine departure of risk of forest insects based on amount and spatial arrangement of cover and structure types.
- Identify restoration priorities.
- Evaluate landscape and patch-scale fire danger.
- Base landscape on fire movement modeling.
- Base patch scale on fuel and stand structure comparing current condition to reference conditions.
- Identify priorities (e.g., ecological, economic, policy) for restoration of fire regimes.
- Evaluate key wildlife habitat spatial pattern and departure.
- Map existing northern spotted owl habitat and nest sites.
- Emphasize known occupied spotted owl sites. On some lands where take of spotted owl habitat has been authorized, this emphasis may not be primary.
- Compare amount and spatial arrangement to reference conditions to determine departure.
- Identify habitat that has a priority for protection and restoration, also considering information about barred owl preferred habitat and/or known status or occurrence.
- Integrate priorities for restoration of landscape pattern, fire regimes, and wildlife habitats.
- Identify the most sustainable locations, or those that can be made more sustainable, for spotted owl habitat based on the above generated information.
- Identify key places for habitat restoration to provide future spotted owl habitat using departure and spatial arrangement information.

- Identify key places for judicious, strategic management of owl habitat.
- Develop an integrated map of priority areas for restoration treatments. This map will need to be updated regularly and the location or prioritization of restoration locations may change through time.
- Identify a potential landscape treatment area of several thousand acres and an integrated prescription for this area that can be used in project-level planning.

In locations where high restoration or strategic management priorities intersect existing high-value northern spotted owl habitat, a landscape evaluation can build strong rationale for affecting the functionality of owl habitat to achieve broader landscape conservation and restoration goals. In these situations, additional considerations apply:

- The patch of habitat is located in an area where it is likely unsustainable and has potential for conveying natural disturbances across the landscape in ways that jeopardize large patches of northern spotted owl habitat.
- There are nearby areas that are more likely to sustain northern spotted owl habitat and are either currently habitat or likely to become habitat within a short time frame (e.g., 30 years).
- The patch of habitat does not appear to be associated with a northern spotted owl home range or to promote successful dispersal between existing home ranges or territory clusters.
- The area will still retain some habitat function after treatment, while still meeting the intended restoration objective. For example, stands that function as foraging habitat may be slightly degraded post-treatment for flying squirrels (Lehmkuhl et al. 2006b) but not for woodrats and other prey (Lehmkuhl et al. 2006a), thus retaining or rapidly recovering in less than 5 years) their functionality (Irwin et al. 2012).

Based on the landscape evaluation, a set of stands will be identified as priority for application of restoration treatments. These stands will be identified to support broader landscape goals such as the restoration of disturbance regimes, restoration of landscape resiliency, and habitat functions, both current and future, for spotted owl conservation.

The Stand-Scale—Northern Spotted Owl Habitat Objectives

The development of objectives for spotted owl habitat functions is important to guide treatments that might occur within spotted owl habitat or treatments with the objective of creating replacement (future) northern spotted owl habitat (chapter 4).

Table 3-1—Desired conditions for key elements of northern spotted owl habitat within different forest types in the eastern Cascades of Oregon and Washington[a]

Habitat Capable—Mesic Forests—Mixed Conifer—Mixed Severity Fire Regime									
Habitat condition	**Diameter distribution[f,g,h,i,,j]**	**Species composition[f,g]**	**Age class distribution[f,g,h,i,j]**	**Canopy closure[f,g,h,i,j,k]**	**Canopy layers[f,g]**	**Dead and down[f,g,h]**	**Mistletoe[f,g]**	**Understory[n]**	**Spatial pattern**
Nesting, roosting[b]—desired condition	Retain medium and large trees	Favor PSME	Moderate to old	70 to 90 percent	Two or more	Abundant, diversity of size classes including large	Present with large brooms	Shrubs in gaps	0–10 percent Open, 10–20 percent Single story, 70–80 percent multi-story
Nesting, roosting capable—long[c]	Develop medium and large trees	Favor PSME							
Nesting, roosting capable—short [d]	Develop second canopy layer	Favor PSME							
Foraging[e]—desired condition	Medium and/or large trees[i,j]	Favor PSME[i]	Limit small (5 to 8 inches d.b.h.)	50 to 80 percent[h]	One or more	Abundant, diversity of size classes including large[h,i]	Present with brooms[h,i]	Shrubs in gaps[j]	0 to 25 percent open, 0 to 25 percent single, 50 percent or more multi
Foraging—capable—long[c]	Develop medium and/or large trees	Favor PSME							
Foraging—capable—short[d]	Retain medium and/or large trees	Favor PMSE							

Table 3-1—Desired conditions for key elements of northern spotted owl habitat within different forest types in the eastern Cascades of Oregon and Washington[a] (continued)

Habitat Capable—Dry Forests—Historically a Low-Severity Fire Regime									
Habitat condition	**Diameter distribution**	**Species composition**	**Age class distribution**	**Canopy closure**	**Canopy layers**	**Dead and down**	**Mistletoe**	**Understory**	**Spatial pattern**
Nesting, roosting[b]—desired condition	Retain medium and large trees	PSME, PIPO	Moderate to old	70 to 90 percent	Two or more	Abundant, emphasize large size classes	Present with large brooms	Shrubs in gaps	10 to 20 percent open, 10 to 20 percent single, 60 to 80 percent multi
Nesting, roosting capable—long[c]	Develop medium and large trees	PSME, PIPO							
Nesting, roosting capable—short[d]	Develop second canopy layer	PSME, PIPO							
Foraging capable—long[c]	Develop medium and/or large trees	PSME, PIPO							
Foraging capable—short[d]	Retain medium and/or large trees	PSME, PIPO							

[a] Information was derived from habitat studies conducted in the eastern Cascades and augmented with direct field experience of the workshop attendees.

[b] Nesting, roosting habitat functions: These forest conditions provide the primary constituent elements for nesting, roosting, and foraging functions for northern spotted owls. Forest conditions include high canopy closure (>70%), multiple canopy layers (two or more), presence of large diameter trees, mistletoe, snags, and downed wood.

[c] Habitat capable—long: Forest is in such a condition that with treatment it could reach the targeted habitat goal (nesting, roosting, or foraging) but will take >50 years. For example a forested patch that experienced a stand-replacing fire or regeneration harvest with overstory removal.

[d] Habitat capable—short: forest is in such a condition that with treatment it could reach the targeted habitat function (nesting, roosting, or foraging) in <50 years. For example a commercially thinned forested patch that has remnant overstory trees could become functional habitat by developing or managing the understory to promote structural complexity.

[e] Foraging habitat function: a range of conditions from nesting and roosting to somewhat more structurally complex than dispersal. Habitat conditions are dependent upon the prey base (e.g., flying squirrels or woodrats). Some key habitat elements for prey species include: within-patch spatial variability, large trees, mistletoe, snags, and down wood.

[f] Buchanan et al. 1995.

[g] Everett et al. 1997.

[h] Herter et al. 2002.

[i] Gaines et al. 2010.

[j] Loehle et al. 2011.

[k] Singleton 2013.

[l] Lehmkuhl et al. 2006a.

[m] Lehmkuhl et al. 2006b.

[n] Irwin et al. 2007.

In addition, these objectives serve as working hypotheses that reflect our current understanding of how stand structure influences habitat function for spotted owls and can be tested through an adaptive management approach (chapter 5). Thus, objectives for key habitat elements (large trees, canopy closure, etc.) were developed through an interdisciplinary process that was based on the collective knowledge of spotted owl biologists with extensive field and research experience within the eastern Cascades of Oregon and Washington (table 3-1). For reference, the values presented in table 3-1 represent average conditions within a patch of about 20 ha in size and could be extrapolated to larger patches. The objectives are presented by habitat function: (a) spotted owl nesting/roosting habitat, and (b) spotted owl foraging habitat.

Nesting/Roosting Habitat Objectives

Experimental studies have not investigated the effects that restoration treatments, even light treatments, have on northern spotted owl roosting and nesting habitat in the eastern Cascades. In one study of California spotted owls, alteration of 20 ha or more of nesting and roosting habitat within territories was negatively associated with territory colonization and positively related to breeding dispersal probability (Seamans and Gutierrez 2007). Thus, the structural complexity within a patch that provides for nesting and roosting functions (see previous discussion) may limit opportunities for treatments to occur within nesting and roosting habitat without affecting habitat function. Consequently, the habitat objectives in table 3-1 can be used to guide treatment prescriptions that would develop future habitat. We separated future spotted owl habitat into different management-time periods based on whether the medium- and large-tree element of nesting and roosting habitat is present within the stand. Thus, table 3-1 contains information on two classes of habitat: "habitat capable—long," representing areas that do not have medium and large trees and will take a comparatively long time (>50 years) to develop into nesting and roosting habitat with management, and "habitat capable—short," representing areas that do have medium and large trees and conversely will take a comparatively short time (<50 years) to develop into nesting and roosting habitat with management. Medium and large trees are important components of spotted owl habitat and can take considerable time to develop if missing. Thus, an important objective of restoration treatments within habitat-capable areas is the development or retention of the medium- and large-tree component.

Key habitat components to consider in the development of treatment prescriptions for future nesting/roosting habitat include:

- Retention or development of large trees, preferably Douglas-fir when appropriate to the forest type.

- High canopy closure (>70 percent) and two or more canopy layers.
- Presence of mistletoe brooms.
- Snags and downed wood in variable abundance and a diversity of size classes, including large sizes.
- Within stand spatial variability: ≤10 percent open, ≤20 percent single story, ≥70 to 80 percent multistory.

Foraging Habitat Objectives

The overall desired conditions for foraging habitat are provided in table 3-1. Because the primary function of foraging habitat is to provide for adequate food resources, and habitat structure is quite variable, it may be appropriate to develop restoration prescriptions based on the primary prey of northern spotted owls.

Flying squirrels—

It may be possible in some dry forests and stands to achieve an adequate reduction in fire risk without changing the canopy structure (Agee and Skinner 2005), which would appear best for flying squirrels. If canopy reduction is needed, then maintaining close to 50 percent cover seems to be a threshold between high and low abundance of flying squirrels (Lehmkuhl et al. 2006b). However, stand-level fuel reduction treatments might be modified in several ways to maintain or possibly enhance flying squirrel habitat, including habitats for fungal and lichen communities that support flying squirrels. Similar to recommendations by Carey (2000) for flying squirrels in wet coastal forests in the Pacific Northwest, some form of variable-retention thinning for fuel reduction, or a prescription that leaves canopy "skips" (leave patches) and gaps (Harrington et al 2005), may create heterogeneous, or patchy, stand conditions that maintain or create key habitat elements for flying squirrels (Lehmkuhl et al. 2006b). Open canopy gaps might favor the growth of fruit- and mast-producing shrubs that are important for flying squirrel recruitment and survival. Retention of down wood and cool-moist microenvironments in closed-canopy skip patches within treated areas likely would maintain diversity and production of truffle foods (Lehmkuhl et al. 2004) that are associated with high recruitment and survival of flying squirrels (Lehmkuhl et al. 2006b). Gap sizes to maintain within-patch connectivity should be no more than 100 m across and mostly <30 m across, which is the average glide distance of northern flying squirrels, and irregular in shape (Smith et al. 2013). It is unknown how spotted owls may react to these gaps. More than 50 percent of the patch or landscape should remain in good habitat to maintain connectivity (Reunanen et al. 2000). Retention of large old trees in those same closed-canopy patches might retain the high forage lichen (*Bryoria*, *Alectoria*) biomass associated with old forests (Lehmkuhl 2004).

Woodrats—

The two species of woodrats are found in both open and closed-canopy forests. This diversity of habitat use may provide many positive options for designing forest restoration treatments (Carey et al. 1999). Retention of large snags, mistletoe-infected trees, and large down logs throughout the treated area might provide the structures associated with high-density bushy-tailed woodrat populations in both open pine and mixed-conifer forests (Lehmkuhl et al. 2006a). Carey et al. (1999) hypothesized that the abundance of dusky-footed woodrats over a landscape could be increased by landscape-level management that created open shrubby patches designed to mimic historical, patchy spatial patterns (Carey and Curtis 1996).

Forest management that reduces downed wood, large snags, and eliminates mistletoe would likely reduce bushy-tailed woodrat populations (Lehmkuhl et al. 2006a). As a result of these findings, some forest managers have modified stand-level restoration prescriptions to include clumps, gaps, and complex patches (USFS 2012). Complex patches are areas within stands where these key habitat components for woodrats are retained.

Snowshoe hares and gophers—

Dry forest treatments may actually be beneficial for snowshoe hares and gophers by opening the canopy in gaps and allowing for greater understory development. A mix of open and closed patches (skips and gaps) might benefit snowshoe hares by providing cover in skips and high food production in gaps, especially where woody species benefit (e.g., moist lower slopes and near riparian areas). Likewise, the creation of gaps, especially where deep and moist upland soils are present, might foster the development of herbaceous vegetation for gophers.

Other small mammals—

Thinning and burning treatments appeared to have mostly positive, if weak, short-term effects on community composition of small mammals in dry forests (Fontaine and Kennedy 2012). Lehmkuhl (2009) predicted that treatments would open the canopy and increase solar radiation on the forest floor, resulting in drier and less-productive understory habitat for small mammals, with consequent disappearance of typical west-Cascades species associated with mesic or closed-canopy conditions. Short-term data in the eastern Washington Cascades[7] did not support that hypothesis. Deer mice and yellow-pine chipmunks remained the dominant species, but other open-forest species like vagrant shrews and long-tailed voles appeared

[7] Unpublished data. On file with: J. Lehmkuhl, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 1133 N. Western Ave., Wenatchee, WA 98801.

to increase slightly in the small mammal community, probably as a result of slight increases of otherwise depauperate understory vegetation (Dodson et al. 2008).

Most of the other small mammal species typically found in these forests appeared to remain infrequent and in low abundance immediately after treatment. Little is known about their ecology and effects of treatments in dry forests; therefore, we drew from other areas. Among those species, the northwestern deermouse (*Peromyscus keeni*) and southern red-backed voles (both occur only in Washington) are two closed-canopy species that are expected to decline with canopy reduction. A few studies (Carey and Wilson 2001) found no impact of thinning on the northwestern deermouse west of the Cascades. The southern red-backed vole is well known to generally decrease with clearcutting (Gliwicz and Glowacka 2000, Klenner and Sullivan 2003, Medin 1986, Sullivan et al. 1999, Walters 1991), unless there is abundant woody debris (Simon et al. 2002); so, it was predicted to decline with thinning. Thinning or patch cutting, however, appear to have little impact on southern red-backed vole abundance (Carey and Wilson 2001, Gitzen et al. 2007, Klenner and Sullivan 2009, Zwolak 2009); but abundance may be correlated with residual tree basal area in thinned areas (Sullivan and Sullivan 2001). Further research is needed to determine if the northwestern deermouse and southern red-backed vole, mostly studied in and associated with mesic forests, respond similarly to thinning in eastern Cascades dry forests on the edge their range.

Key habitat components to consider in the development of treatment prescriptions within current or to develop for future foraging habitat include:

- Retention or development of medium-large trees, preferably Douglas-fir when appropriate to the forest type.
- Moderate canopy closure (>50 percent) and one or more canopy layers but limit the number of trees 5 to 8 inches dbh.
- Presence of mistletoe brooms.
- Snags and downed wood in variable abundance and a diversity of size classes, including large sizes
- Within stand spatial variability: 25 percent open, 25 percent single story, 50 percent multistory.

Summary

The integration of disturbance ecology and spotted owl habitat objectives is a significant issue in the fire-prone forests in eastern Oregon and Washington. To progress in our scientific understanding, we presented a summary of spotted owl habitat use, including interactions with barred owls; reiterated the importance of establishing a landscape context for where and how much habitat to retain, and where and how restoration treatment should occur; and we summarized key stand-level spotted owl habitat objectives to consider in the design of treatments and to use as working hypotheses in adaptive management. This provides a consistent set of habitat objectives so that treatment effects on spotted owl habitat structure and prey species, fuels and fire behavior, and vegetation structure and composition can be compared across ecological provinces. The design of specific monitoring or management studies based on the implementation of these treatments follows in chapter 5.

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Chapter 4: Silvicultural Approaches to Restoring Resilient Landscapes for Northern Spotted Owls

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Introduction

Current habitat conditions deviate from the desired conditions for northern spotted owl (NSO) recovery in most dry-forest landscapes at scales from individual stands to entire landscapes. These conditions include: (1) stands containing occupied or suitable habitat that are uncharacteristically susceptible to stand-replacing fire; (2) adjacency between stands and resultant fuel continuity that has increased the likelihood of fire flow into occupied and suitable habitat from the surrounding area (Ager et al. 2007); and (3) large landscapes (i.e. watersheds/firesheds) that are dominated by fuel amounts, distribution, and continuity that increase the likelihood of widespread habitat loss, potentially at that home-range or larger scale. The specific location of such undesirable conditions moves in time and space, suggesting that our efforts to provide for resilience should not focus on identifying exactly where they are today, or next year, but on broadly developing resilient sustainable forest conditions and dynamics within preferred habitat areas of the eastern Cascades and similar dry-forest landscapes.

Current trajectories for stand development in our dry mixed-conifer forests, and the resultant landscape-level forest condition, are not likely to naturally reduce that growing gap between current conditions and desired future resilient habitat conditions, particularly in light of emerging climatic uncertainties (Hessburg et al. 2007). Over much of the eastern Cascades Range, biomass continues to accumulate, creating additional hazard over much of the region as well as continually adding new areas of concern to the total. In dry-forest landscapes, not only does the entire fuel load hazard increase (and the fire debt grow) with each ensuing year, but the continuity among those fuels is increasing. Risk is thereby compounded (Ager et al. 2012), increasing the likelihood of a wildfire event that produces large-scale and long-term losses in habitat because it has been delayed until fire weather conditions are so extreme that it cannot be regulated.

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Wildland fire under extreme fire weather conditions has the potential to make abrupt, nonequilibrium changes to NSO nesting/roosting/foraging stands and their surrounding landscapes.

Wildland fire under extreme fire weather conditions has the potential to make abrupt, nonequilibrium changes to NSO nesting/roosting/foraging stands and their surrounding landscapes. Substantial amounts of habitat have already been lost or degraded in areas containing a mixture of fire-tolerant and fire-sensitive species and stand structures (USFWS 2011). The risk of such loss is increasing, with increases in fuel accumulations, contagion among stands, and human access. Decreased active forest management and projected increased length and depth of fire seasons add to this risk. Active management or restoration should therefore be considered fundamental for NSO habitat protection and recovery over time, for the current forest situation as well as the growing problem (Lehmkuhl et al. 2007).

The focus of this chapter is to:

- Review silvicultural options for treating stands in and around NSO habitat of various quality in the mixed-conifer forests of the eastern Cascade Range.
- Model the development of stand conditions in the four most common forest types associated with owl occupancy, with and without a range of silvicultural treatments.
- Contrast stand-scale fire hazard and habitat quality over time following treatments, and discuss these within a landscape context.
- Present guidelines for implementing silvicultural treatments in and around NSO habitat.

Active Management Principles

Prescribed fire alone has limited potential to alter dry mixed-conifer forest structure and composition for restoring resilience, but it can play an important role in treating fine surface fuels–litter accumulations and understory herbaceous vegetation (Arno and Fiedler 2005, Schwilk et al. 2009). The introduction of fire into many of these structurally complex, mixed-species stands may not be wise in the absence of pretreatment that helps regulate the effects of the burning on stand conditions, however. The appropriate fire weather window (and smoke management window) is severely limited in areas with existing heavy surface fuel conditions and abundant ladder fuels. Multiple burning entries would be required to progressively reduce fuel accumulations without damaging a core population of larger, older, fire-resistant trees—but this may be the only option in some areas. Alternatively, mechanical pretreatment can help modify and regulate fuel issues and enlarge the subsequent burning window (Agee and Skinner 2005). Much of our future prescribed fire is likely tied to the judicious management of wildland fire; allowing wildfire to burn under appropriate fire weather conditions can save both current and future suppression costs and be coupled with strategic fuel breaks at the landscape scale.

Mechanical density management is consistently the best tool for altering stand conditions within meaningful management time horizons (Arno and Fiedler 2005). Such entries into the existing stand immediately set in place processes toward desired future conditions and dynamics that can be maintained by natural wildland fire. Heterogeneity should be created within and among many stands if it is under-represented in targeted treatment areas, given the natural fire dynamics in these forest types (Agee and Skinner 2005, Noss et al. 2006). Stand heterogeneity (alpha diversity) is easily accomplished within a silvicultural prescription—both even-aged and multi-aged approaches are available (see box 4-1). Not all stands need to be pushed toward lower density and higher heterogeneity, however, particularly where there is little existing timber value with which to work or few market opportunities or incentives—managers can use what the landscapes are easily providing. Assessments and prescriptions for individual stands, including signature features associated with high-quality habitat, must always be considered in the context of adjacent stands within the "neighborhood" (beta-diversity) to achieve the desired pattern and heterogeneity of forest landscape (gamma diversity). Prescribed fire

Box 4-1

Even-Aged and Multi-Aged Terminology and Philosophy

Even-aged approaches, namely "thinning," move a dominant overstory canopy into the future: thinning from below is a method of choice to reduce ladder fuels (particularly from unusual densities of shade-tolerant, fire-sensitive understory saplings) and preferentially removes the smallest trees, typically resulting in a well-spaced residual stand; "free" and/or "variable-density" thinning allows greater flexibility to remove trees across a range of tree sizes, including medium-sized diameter classes and codominant canopy positions in order to create within-stand diversity among tree sizes and residual spacing; variable post-treatment densities can range from gaps or small openings (>0.1 ac) to unharvested high-density patches of trees.

Multi-aged management approaches call for regular, repeated entries into a stand **in perpetuity**, providing permanent forest cover, predictable growth of trees across species and sizes based on growing space availability, and regular regeneration: individual tree selection focuses on removing or safeguarding single trees to minimize gap size and distribute the disturbance more evenly throughout the stand; group selection focuses on harvest/retention of clumps of trees as well as individuals, creating larger openings than those associated with removing single trees, which are often required to regenerate shade-intolerant species within the dry mixed-conifer forest types.

and judicious use of wildland fire are both excellent tools to create and maintain multiple scales of heterogeneity.

Silviculture Within Landscapes

Stands are connected by the most fundamental ecosystem services and human actions: habitat conditions and wildlife movement/home ranges, watershed hydrology, fire spread, plant regeneration processes (e.g., seed dispersal), and roads/trails for human recreation and extraction of products. Actions in one stand directly impact the adjacent stand through edge effects, and to varying depths into those neighboring stands; indirectly, actions in one stand affect the transfer and intensity of disturbance processes such as fire and insects into adjacent stands. The nesting/roosting/foraging behavior of NSOs links dozens of stands into a complex ecosystem that supports their reproductive success (Irwin et al. 2012). Fire also links these stands together, heavily influenced by fuel contiguity but not constrained only by fuels. Northern spotted owl home ranges in dry forests can be thousands of acres. We consider this size to be a significant collection of stands, a neighborhood of stands, which is the appropriate spatial extent to assess habitat and plan treatments. Larger watershed-level analyses are necessary (e.g., Hessburg et al. 2013) and most operations are implemented on single stands, but the focus of silviculture for NSO habitat should be at this neighborhood scale.

Varying the type, intensity and timing of silvicultural treatments can accommodate these realities and interests within a neighborhood of stands; beyond that, well-implemented treatments can enhance many of these interests over the long term. A single stand can meet a limited number of objectives at one time, but neighborhoods of stands and large landscapes can provide a greater array of conditions and services and, over time, meet a greater array of objectives (Franklin and Johnson 2012). Indeed, planned treatments can develop and maintain high-quality habitat for nesting/roosting/foraging in many areas where it is currently absent, and possibly create new areas as replacement habitat when wildland fire inevitably consumes habitat; other treatments can develop and maintain stand conditions that would limit the spread/severity of wildland fire within said landscapes (Gaines et al. 2010a).

A single stand can meet a limited number of objectives at one time, but neighborhoods of stands and large landscapes can provide a greater array of conditions and services and, over time, meet a greater array of objectives.

Modeling Approach

We assembled guidelines and concepts for stand-level fuels and restoration treatments in NSO habitat beginning in 2010 with a series of meetings and conferences involving foresters, biologists and other stakeholders. Consensus has emerged from those discussions that are reflected in many of the above principles as well as the following NSO habitat classifications and silvicultural approaches.

In this chapter, we separate nesting and roosting habitat as defined in chapter 3 into two types: (a) occupied nesting/roosting habitat that represents the highest quality nesting/roosting habitat available, and (b) unoccupied nesting/roosting habitat, which is also high quality, but in our typology suggests a slightly lower level of quality than occupied habitat. We also distinguish two categories of foraging habitat: (c) stands that can easily transition into nesting/roosting habitat with time or management, which were referred to as nesting/roosting capable-short in chapter 3; and (d) broader, lower quality foraging habitat, referred to as nesting/roosting capable-long in chapter 3. We use the term "transitional habitat" to refer to both capable-short and capable-long conditions. All four of these habitat categories and conditions exist in a mosaic of sizes, shapes and relative abundances within any given landscape, and current conditions are important to treatment priority.

Habitat Classifications Relative to Treatment Priority

1. **Existing occupied nesting and roosting NSO habitat** stands are not a high priority for mechanical treatment of any kind given their high landscape value. Prescribed underburning is unlikely given the unpredictable nature of fire behavior in dense multistoried stands, or may be restricted to such a small operational window (given fuel condition, weather, smoke management restrictions and owl breeding activity) as to be impractical. Consideration may be given to management practices around these stands that increase their isolation from landscape-level flow of wildland fire given that their stand-level hazard is high.

2. **Unoccupied nesting and roosting habitat and transitional (habitat capable — short and long) NSO habitat** stands may be considered for hazard reduction treatment in the near term as well as isolation from landscape contagion (per above occupied sites) in order to provide potential future replacement habitat. We realize that the revised NSO recovery plan recommends avoiding treatment of high-quality habitat regardless of whether it is occupied (USFWS 2011); however, we chose to model treatments in unoccupied nesting and roosting habitat to allow us to investigate the potential consequences of such treatments on habitat quality. Because treatment of unoccupied nesting and roosting stands may occasionally be supported in specific cases by landscape assessments that suggest long-term benefits of such treatments outweigh short-term effects, our investigation can inform expectations about post-treatment habitat quality.

Some fire hazard protection may be afforded by a light thinning-from-below treatment in some plant associations and situations, but, such treatments have minor immediate impact and are short lived. Transitional habitat, particularly capable-short habitat (see chapter 3), may be a high priority for restoration treatment that affords a higher level of hazard reduction and for longer time periods. This is achieved by more aggressive treatment throughout much of a stand that removes more trees from across diameter classes, restoring more open stand structure and composition and allowing reintroduction of mixed-severity fire as a natural landscape process. The allocation of lighter versus heavier treatments (see below) is a stand-specific and stand neighborhood decision based on:

a. Spatial proximity to existing occupied habitat (including the actual nest trees), the meta-population of owls, and the status of the landscape relative to the flow of wildland fire;
b. The specific characteristics/qualities of a stand both currently and its development into the future; and
c. The potential for these treatments to protect that stand **and** boost the stand into future suitability as replacement habitat (when the existing stands burn).

Foraging habitat, capable-short and -long or not-capable: The stands we consider under this heading correspond to stands that typically provide little or no habitat value for spotted owls, but may sometimes serve as “dispersal habitat” mentioned in chapter 3. Ponderosa pine-dominated, mixed-conifer stands may be considered for extensive fuel reduction and restoration treatments given that they are low-quality NSO habitat but often serve as the matrix within which quality habitat is distributed and important dispersion corridors among higher quality stands, as well as a sizable proportion of the fireshed. For efficiency, most of these stands may be considered high priority for more aggressive restorative treatments depending on their proximity to occupied and future habitat, their current fuel hazard condition, and their inherent potential as open park-like stands of old growth that function as landscape-level fuel breaks and provide other ecosystem services. Lighter thin-from-below fuel treatments are insignificant in these landscapes.

General Silvicultural Approaches

1. **No treatment** is an option to avoid predictable near-term impacts on the natural progression of stand structure/dynamics and habitat function, but it also has no immediate influence on existing fuel hazard and fire risk. When no action is prevalent in the neighborhood and larger landscape, there will

likely be increasing risk over time of losing the existing stand condition through the proliferation and densification of understory and midstory trees and subsequent high-intensity wildland fire.

2. **Lighter fuel reduction treatment** options are best characterized by "thinning from below" (box 4-1). Most or all trees below 8 to 10 inches diameter are harvested in such treatments even though they have little commercial value, but half or more of basal area (and volume) removed is 10 to 16 inches diameter trees that are merchantable. The residual stand is left near the upper limits of a density management zone (higher density but not actively self-thinning). These lighter treatments focus on the removal of individuals of fire-sensitive species (e.g., true fir) that have invaded/expanded within a stand after a century of fire exclusion, and of overtopped individuals with poor form and vigor. Given their size/age and crown characteristics, their removal typically has limited effect on stand dynamics and canopy cover (key to habitat function), but significant and immediate impact on existing ladder fuel hazards; in some operations, additional treatment of surface fuels is possible, or tree selection can extend into the overstory canopy to slightly alter crown fuels. Overall, the impacts of this treatment on surface and crown fuels are relatively limited and short-lived as crowns regrow and surface fuels reaccumulate within 5 years. Indeed, surface fuel loading can be increased with the activity fuel (i.e., harvest slash) created by the treatment and through the promotion of a vigorous, continuous overstory canopy. Supplemental prescribed underburning treatments may be considered following these treatments to mitigate fire hazard (with likely minor impact on habitat function).

3. **Moderate fuel reduction treatment** options are also characterized by "thinning from below" (box 4-1) but with the removal of additional merchantable 10- to 16-inch diameter trees, or larger if identified as post-settlement, typically still focused on fire-sensitive species and overtopped individuals. Their removal has some additional and modest effect on stand dynamics and canopy cover (habitat function) as the stand density is reduced to the middle or lower part of the density management zone. This moderate treatment has increased immediate impact on ladder fuel hazard (canopy base height) and some minor impact on crown fuels (canopy bulk density) but is still relatively short-lived as crowns regrow and surface fuels reaccumulate with vigorous understory regrowth and potential residual activity fuels within a decade or two.

4. **Heavy restoration treatment** options are best characterized by free thinning more broadly across diameter classes or, more appropriately, by "multi-aged management" (box 4-1), because stands receiving such treatments will not be managed to a rotation age but, rather, entered repeatedly over time mechanically and with fire (prescribed or wildland). Given the typical current condition of these stands, **most** of the trees removed are still less than 8 to 10 inch diameter; however, an appropriate number of these small trees are reserved for current structural objectives and future growth across smaller diameter and age classes. Mid-range diameters (10- to 20-inches) typically are heavily thinned in these treatments to the appropriate number across diameter classes needed to grow into successively larger diameter classes, and at a random spatial pattern for building enhanced regeneration of shade-intolerant species and increased resilience to wildland fire flow. A few larger trees (20 to 24 inches) may also need to be removed from some stands (e.g., when the stand has an abundance of large trees) to provide sufficient growing space for mid-sized and smaller trees. Such a heavy treatment affects stand dynamics by initiating new regeneration and typically reduces canopy cover below that specified for NSO nesting and roosting habitat functions—at least for some time—throughout much of a stand. However, these more aggressive "restorative" treatments have a large impact on ladder fuels **and** crown fuels; surface fuels are then more easily treated either mechanically or with prescribed fire in these lower density stands. Following surface fuel treatment, subsequent wildland fire behavior is very modest under all but the worst fire weather conditions. In this way, the treatment restores the composition, structure, and resiliency functions for multiple decades.

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Selecting Exemplars to Model

We wanted to test the relative impact of these light, moderate, and aggressive approaches on stand dynamics, NSO habitat function, and fire behavior for relevant nesting and roosting habitat. To do this, we modeled stand growth and silvicultural treatment response within the four most common plant associations linked to NSO nesting and roosting, and foraging, habitat based on data generated in December 2012 by Ray Davis for the Pacific Northwest (table 4-1). We did not model the restoration of dry, ponderosa pine–dominated forests given little scientific debate about that topic.

Table 4-1—Percentage of forest within 100 meters around historical northern spotted owl nesting sites (3.1 ha) along the eastern Cascades provinces by dominant tree species within plant associations

Dominant tree species	Washington	Oregon
Abies amabilis (silver fir)	10.1	10.2
Abies concolor (white fir)	6.5	26.8
Abies grandis (grand fir)	35.9	21.8
Abies magnifica (red fir)	0	15.1
Abies lasiocarpa (subalpine fir)	3.9	0
Picea engelmannii (Engelmann spruce)	0	2.7
Pinus ponderosa (ponderosa pine)	0.5	0.6
Pinus contorta (lodgepole pine)	0	3.2
Pseudotsuga menziesii (Douglas-fir)	18.4	5.5
Thuja plicata (western redcedar)	0.2	1.5
Tsuga heterophylla (western hemlock)	11.1	6.4
Tsuga mertensiana (mountain hemlock)	9.2	5.6
Nonforest	4.2	0.6

The four most common dry, mixed-conifer plant associations from this table, two each in Oregon and Washington, include:

- "Oregon grand fir"—ABGR/SYMPH (grand fir/snowberry, CWS331); 7.4 percent of all plant associations in Oregon, and 35 percent of all grand fir types. Described for the east side of Mount Hood (Topik et al. 1988) and revised by Simpson (2007) to ABCO-ABGR/SYMO (CWS361) (*Abies concolor–Abies grandis/Symphoricarpos mollis*), white fir-grand fir/creeping snowberry. This plant association typically occurs at moderate elevation up to 7,000 feet, mostly on north- to northeast-facing mid to upper slopes that lack deep, recent ash or pumice deposits (Simpson 2007). *Symphoricarpos mollis* used in a plant association name is now known as *S. hesperius* (G.N. Jones), trailing snowberry. This is a very productive plant association. In our modal tree lists for this association, small grand fir trees dominate stand conditions, particularly in the older stand (fig. 4.1).

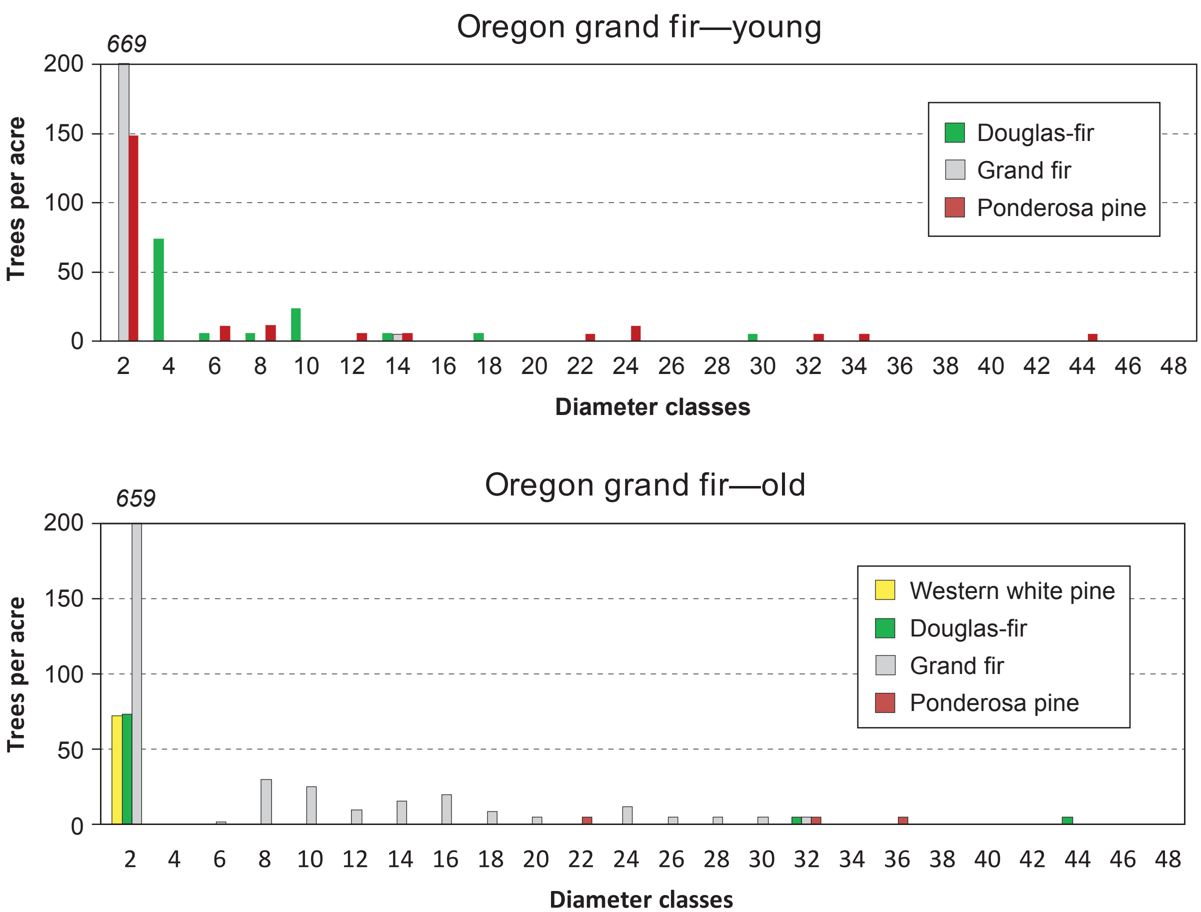
- "Oregon white fir"—ABCO/CACH-PAMY/CHUM (White fir/chinquapin-boxwood/princes pine, CWH112); 10.4 percent of all plant associations in Oregon, and 39 percent of all white fir types. Described as occurring from east of Mount Hood south to Klamath Falls, and revised by Simpson (2007) to ABCO-ABGR/CACH (CWS533) (*Abies concolor–Abies grandis/Castanopsis chrysophylla*), white fir-grand fir/golden chinquapin. This plant association typically occurs at 4,500–6,000 feet in elevation on north- to northeast-facing mid to upper slopes that lack deep, recent ash or pumice deposits (Simpson 2007). *Castanopsis chrysophylla* used in plant association name is now known as *Chrysolepis chrysophylla* (Douglas ex Hook.), giant chinquapin. Productivity is moderate at these elevations; current stand dynamics are heavily regulated by self-thinning in white fir (fig. 4.2).

- "Washington grand fir"—ABGR/SYAL/CARU (grand fir/common snowberry/pinegrass, CWS336); 4.9 percent of all plant associations in Washington, and 13.5 percent of all grand fir types. This plant association occurs up to 3,500 feet in elevation on south- and west-facing slopes (Lillybridge et al. 1995). Productivity is moderate on these slopes and at these elevations. Regeneration and smaller trees are dominated by grand fir creating closed canopies, although there are some large Douglas-fir, grand fir, and ponderosa pine in the overstory (fig. 4.3).
- "Washington Douglas-fir"—PSME/SPBE/CARU (Douglas-fir/shinyleaf spirea/pinegrass, CDS639); 4.5 percent of all plant associations in Washington, and 24.4 percent of all Douglas-fir types. The plant association typically occurs at 2,000 to 4,000 feet in elevation on moderately steep, mid to upper slopes (Lillybridge et al. 1995). Productivity is moderate to low and these stands have the lowest total density across diameter classes, in both shade-intolerant and shade-tolerant species (fig. 4.4).

FVS Modeling

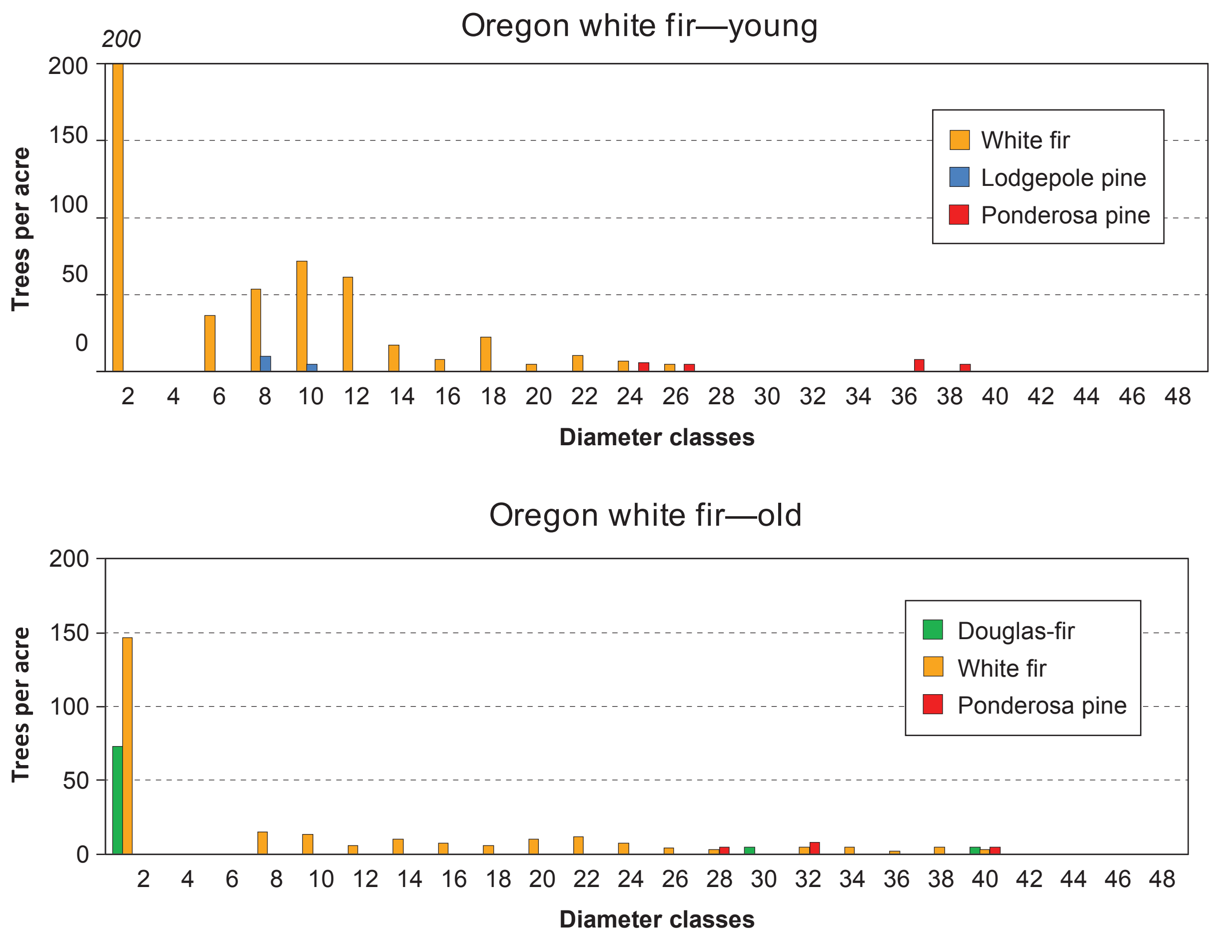
Individual plot data were selected from the national Forest Inventory and Analysis (FIA) database, one modal plot each for a young stand condition (≤100 years) and an old, late-successional old-growth condition belonging to the range of plots and tree lists for each of these four plant associations. "Young" stand conditions approximate what we describe as foraging habitat, and the "old" condition approximate nesting and roosting habitat. Stand age is a field classification reflecting the perceived dominance of the stand and age of those individuals. Old individuals are found in young stands and, often, the composition of the largest diameter classes does not markedly vary between "young" and "old" stands in these plant associations (fig. 4-1). However, these data sufficiently reflect some real-world conditions and opportunities for examining modeled management differences.

We examined a combination of: (1) current conditions and 50-year stand development without management, both with and without wildland fire; and (2) silvicultural treatment responses to light, moderate, and heavy mechanical treatment, both with and without prescribed fire and/or wildland fire (table 4-2) for young and old stands.



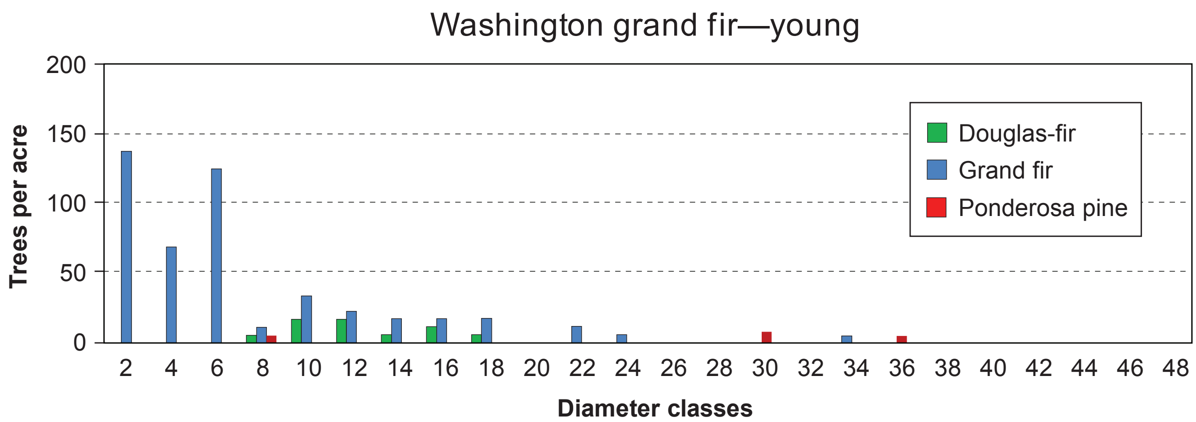
	FIA age	Trees/acre	Total basal area/ acre (ft^2)	SDI	Percentage of basal area in fire-resistant species
Young	60	997	997	326	87
Old	208	935	935	399	15

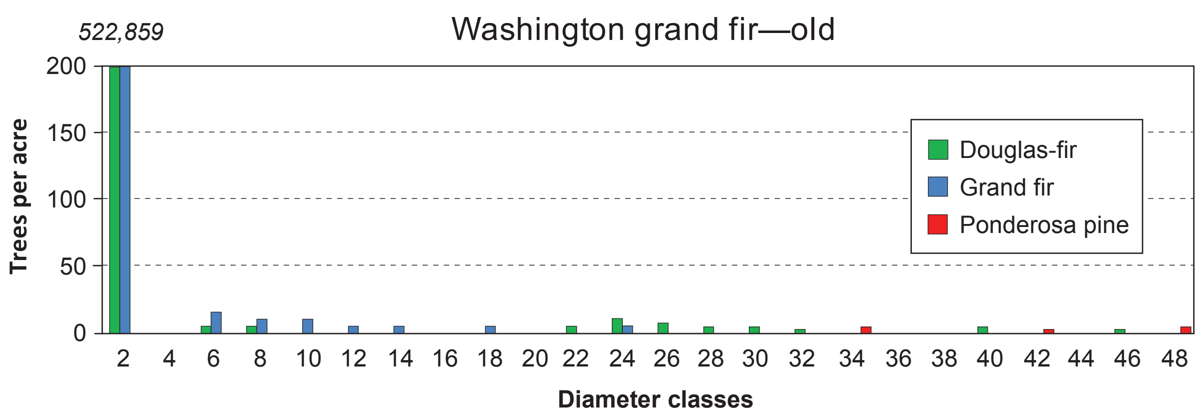
Figure 4-1—Diameter distribution by species for modal Oregon grand fir (GF) plant association stands: (a) young stand, and (b) old late-seral stand. Young shade-tolerant GF regeneration dominates both stand conditions; the old stand has greater numbers of large GF relative to shade-intolerant and fire-resistant Douglas-fir (DF) and ponderosa pine (PP) trees. In this young stand, PP and DF represent 32 percent of the stems but 87 percent of the basal area, implying some combination of a strong history of fire and lack of heavy selective logging of those species. Such young stands are excellent candidates for restoration. This old stand, however, suggests a longer term absence of fire and/or selective logging history. Both stands have a high stand density index (SDI) and are actively self-thinning. Torching and crowning indices are <25 mph and decreasing with time.



	FIA age	Trees/acre	Total basal area/ acre (ft^2)	SDI	Percentage of basal area in fire-resistant species
Young	102	503	277	503	33
Old	186	323	210	380	12

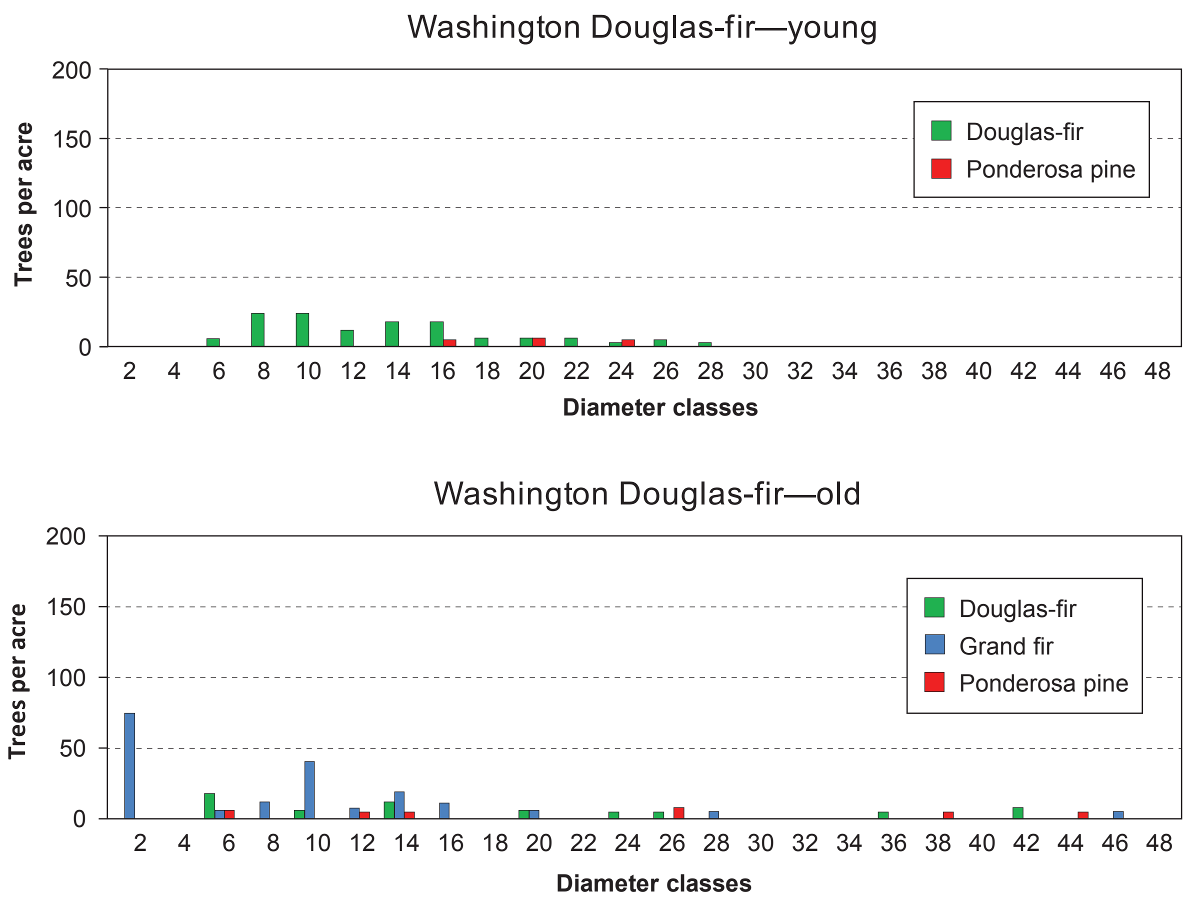
Figure 4-2—Diameter distribution by species for modal Oregon white fir (WF) stands: (a) young stand, and (b) old late-seral stand. Young shade-tolerant WF regeneration dominates both stand conditions; the young stand has greater numbers of larger WF trees relative to shade-intolerant and fire-resistant Douglas-fir (DF) and/or ponderosa pine (PP) trees. Both of these example stands have very low numbers and basal area of pine. Both stands have a high stand density (SDI) index, particularly the young stand, and are actively self-thinning. Torching and crowning indices are currently <20 mph in the young stand; the old stand has a crowning index of <25 mph.





	FIA age	Trees/acre	Total basal area/ acre (ft²)	SDI	Percentage of basal area in fire-resistant species
Young	78	539	276	502	26
Old	349	1,516	229	476	68

Figure 4-3—Diameter distribution by species, for example, Washington grand fir (GF) stands: (a) young stand, and (b) late-seral old stand. Young shade-tolerant GF regeneration is common in both stand conditions; the young stand has greater numbers of larger GF trees relative to shade-intolerant and fire-resistant Douglas-fir (DF) and/or ponderosa pine (PP) trees. Both of these example stands have very low numbers and basal area of pine. SDI = stand density index.



	FIA age	Trees/acre	Total basal area/ acre (ft^2)	SDI	Percentage of basal area in fire-resistant species
Young	99	137	131	231	100
Old	202	239	184	316	54

Figure 4-4—Diameter distribution by species, for example, Washington Douglas-fir (DF) stands: (a) young stand, and (b) late-seral old stand. Shade-tolerant grand fir (GF) is not present in the young stand presumably given past management (e.g., planting) and/or short passage of time or perhaps recent fire; overall productivity and stand densities are much lower in this plant association. Both of these example stands have relatively low total tree densities and basal area of trees, including shade-intolerant ponderosa pine (PP). SDI = stand density index.

Table 4-2—Summary of modeled silvicultural treatment and fire combinations

	No fire	Prescribed fire (2020)	Wildland fire (2030)
No treatment	y		y
Light thinning from below	y		y
Moderate thinning from below	y	y	y
Multi-aged management	y	y	y

Density Management Targets for Dry Mixed-Conifer Stands

Stand density index (SDI) is a measure of stocking or "fullness" defined as the equivalent number of trees per acre that an identically stocked even-aged stand would have when at a quadratic mean diameter of 10 inches (future or past). SDI is a good management guide because it is rooted in the fundamental biology of self-thinning in moderately aged stands. Cochran et al. (1994) established normal values of SDI for fully-stocked, even-aged stands of eastside Pacific Northwest ponderosa pine at 365, and 380 for eastside Douglas-fir stands—given maximum SDI values of 450 and 500, respectively. Stands with a range of tree sizes can support some additional SDI given spatial allocation of growing space in canopies, as can multiple species stands that include shade-tolerant individuals. Indeed, maximum SDI values can approach 750 in these plant associations with increasing site quality and increasing species and structural diversity (Lillybridge et al. 1995).

The upper management zone (UMZ) is defined as 55 percent of the maximum (75 percent of the normal SDI), and represents the density level at which dominant trees consistently suppress smaller trees in a stand. The lower management zone (LMZ) is defined as 35 percent of that same maximum SDI (or 67 percent of the UMZ) and represents the lowest density level at which the stand is fully occupied and individual tree growth/vigor is optimal. Historically, most density management approaches have attempted to maintain stocking levels between the UMZ and the LMZ via thinning to maximize the development of timber value on the site. However, lower densities may be desired to stimulate regeneration in the understory, and higher densities may be desired to provide hiding cover or to suppress understory growth.

Various maximum SDI values for our four example plant associations are available from Lillybridge et al. (1995) and other literature; however, unless purposefully held at such a value the Forest Vegetation Simulator (FVS) model assigns a weighted maximum SDI based on the actual basal area composition of the FIA plot. We used the FVS adjusted values to define the upper and lower management zones (table 4-3). FVS uses SDI to regulate self-thinning by species over time based on random location of the trees. It recalculates SDI at each time step in the model based on growth and any silvicultural treatment. Variable amounts and species of tree regeneration (12 to 137 seedlings per acre randomly) can be triggered at each time step based on stand density and the presence of trees larger than 6 inch diameter across plant associations.

Northern spotted owl behavior and reproductive success cannot be consistently linked to these or any particular metrics of stand density like basal area or SDI (Irwin

Table 4-3—Stand Density Index (SDI) values for the four representative plants associations around NSO nesting sites in the Pacific Northwest

Plant association—Name	FVS maximum SDI	Upper management zone	Lower management zone
Oregon white fir: ABCO-ABGR/SYMO (CWS361)	600	330	210
Oregon grand fir: ABCO-ABGR/CACH (CWS533)	500	275	175
Washington grand fir: ABGR/SYAL/ CARU (CWS336)	500	275	175
Washington Douglas-fir: PSME/SPBE/ CARU (CDS639)	400	220	140

Note: These are relative values for comparison and standardization of treatments; northern spotted owl behavior and reproductive success has not been linked to these or any specific SDI values.

et al. 2012). These guidelines are used here only to consistently span the myriad of stand types within this analysis, to access the FVS model, and to allow unbiased comparison across model runs. Actual stand prescriptions would follow such general targets but ultimately focus on the enhancement of desirable stand attributes known to be associated with northern spotted owl habitat use and function (e.g., large living and dead trees, moderate stand density, canopy layers and spatial heterogeneity) (see chapter 3, table 3.1). The statistics and diameter distributions produced throughout these model runs are absolutely consistent with those kinds of prescription details.

Prescription Themes Across Plant Associations

The simplest management approach is to thin the stand from below to a specified SDI target; we projected such thinning treatments set at both the UMZ ("light thinning") and LMZ ("moderate thinning") for comparison (table 4-2). We also projected a multi-aged management harvest (basal area–diameter maximum–quotient (BDQ), see box 4-1) that selects trees more broadly across diameter classes but to the same LMZ SDI value. This latter prescription removes some medium-diameter trees in lieu of thinning out all smaller trees and restores a closer approximation of historical stand structure in fire-adapted stands (Bailey and Covington 2002). Species preference during all these harvest treatments was to retain the larger, fire-resistant ponderosa pine and Douglas-fir trees. Using the FVS, we modeled a single harvest occurring in the first decade of the projection period, with subsequent growth for 50 years, including a no action stand development scenario.

We introduced a prescribed underburning treatment in 2020 following mechanical harvests using the Fire and Fuels Extension (FFE) in FVS with weather/fuel conditions typically associated with prescribed underburning, including 8 mile/

hour 20-foot wind speeds at 70 °F with 12 percent fine fuel moisture. This treatment option under these conditions allowed us to compare the effects of (potentially) further reducing tree density as well as treating surface fuel accumulations, although more conservative burning conditions might be chosen for a first entry into some of these treatment areas. However, none of our simulations experienced unusual mortality associated with this burning prescription. We then compared the resulting stand structure to mechanical treatment only, and assessed the resiliency to future wildland fire.

In addition to examining projected torching and crowning indices at 10-year intervals as stands developed, before and after mechanical and/or prescribed fire treatment, we introduced ignition under wildland fire weather conditions in the year 2030 to assess treatment effectiveness and longevity. Stand response to wildland fire focused on projected tree mortality and crowning index (CI): the critical wind speed (miles per hour) needed to initiate and sustain a crown fire given the fuel accumulation and arrangement at that time (Scott and Reinhart 2001). This index number is typically higher than the torching index: the critical wind speed (miles per hour) needed to transition from surface fire to crown fire in one given location. Torching index is highly sensitive to the presence of regeneration in our modeled stand dynamics since they can serve as ladder fuels; crowning index is a more stable indicator of overall stand conditions through time. Our simulated extreme fire weather conditions included 20 mile/hour 20-foot wind speeds at 90 °F with 8 percent fine fuel moisture.

We were ultimately interested in inherent tradeoffs between (a) increasing resistance to fire at the stand- and neighborhood scales, and (b) maintaining NSO habitat function with these different treatment approaches. We specifically wanted to see if the heavier thinning and/or uneven-aged management treatments (to the LMZ), with and without prescribed burning, for unoccupied stands within the home-range "fire-shed" would promote fire resiliency in those stands, provide some landscape-level fuel breaks to protect existing nesting and roosting habitat, and provide replacement (habitat capable—long and short) habitat under the whole landscape philosophy (chap. 2).

We were ultimately interested in inherent tradeoffs between (a) increasing resistance to fire at the stand- and neighborhood scales, and (b) maintaining NSO habitat function with these different treatment approaches.

Results

Stand Dynamics

Projected stand development (dynamics) with no-action simulations showed that every stand was actively self-thinning, losing from one-third to over half of its density over 50 years; however, each stand accumulates basal area, often reaching a maximum during the unmanaged simulation, and increases SDI (approaching its theoretical maximum) during the 50 years unless already there at the initiation of the model runs. Such high-density structural conditions, with a temporal pattern of increasing biomass over time, are consistent with denser, multistoried stands reported to support northern spotted owls (with canopy cover well above 40 percent). These conditions are also consistent with wildland fire crowning indices that are initially low (consistently less than a "breezy" 25 mph), and that decrease with time, meaning that the critical wind speed needed to sustain stand-replacing fire is low and gets lower. Such unmanaged fuel hazard and susceptibility to crown fire is consistent with reported stand-replacing fire in northern spotted owl habitat and therefore consistent with a silvicultural rationale to alter these fuel beds as a means to protect owl habitat.

Projected wildland fire in 2030, 10 years after treatment completion, under severe fire weather conditions, reduced five of the eight stands (table 4-4) to ≤ 2 trees/ac and ≤ 7 ft^2/ac of basal area (both young and old stands), stands that were (1) dominated by white/grand fir, and (2) had crowning and torching indices sufficiently low that our introduced wildland fire weather conditions resulted in stand-replacing fire (see above). Consistent with field observations/syntheses of recent wildland fire (Werth et al. 2011), even large fire-resistant trees were killed in such stand-replacing fire when fueled by abundant surface and ladder/crown fuels provided by a mid-story of grand fir or white fir (e.g., old Oregon grand fir stands).

These same modeled fire weather conditions, however, did not completely consume the Oregon white fir or Washington grand fir old stands (fig. 4.5), given their higher torching indices (above the threshold we modeled) and a high percentage of basal area in larger, fire-resistant trees within only a "modest" sea of fir. Similarly, the Washington Douglas-fir young stand survived these introduced wildland fire weather conditions given the lack of white fir in the understory and resultant higher

Table 4-4—Survivability of overstory trees following wildland fire for five representative plants associations-stand conditions around northern spotted owl nesting sites in the Pacific Northwest, showing the influence of thinning with and without prescribed fire 10 years prior to wildland fire

Plant association—stand type	Post-wildfire density unmanaged	If thinned to LMZ before the wildfire…	If thinned to LMZ and prescribed underburned before the wildfire
		Trees/acre	
Oregon grand fir—young	1	8	25
Oregon grand fir—old	2	50	42
Oregon white fir—young	0	50	45
Washington grand fir—young	0	2	44
Washington Douglas-fir—old	0	17	32

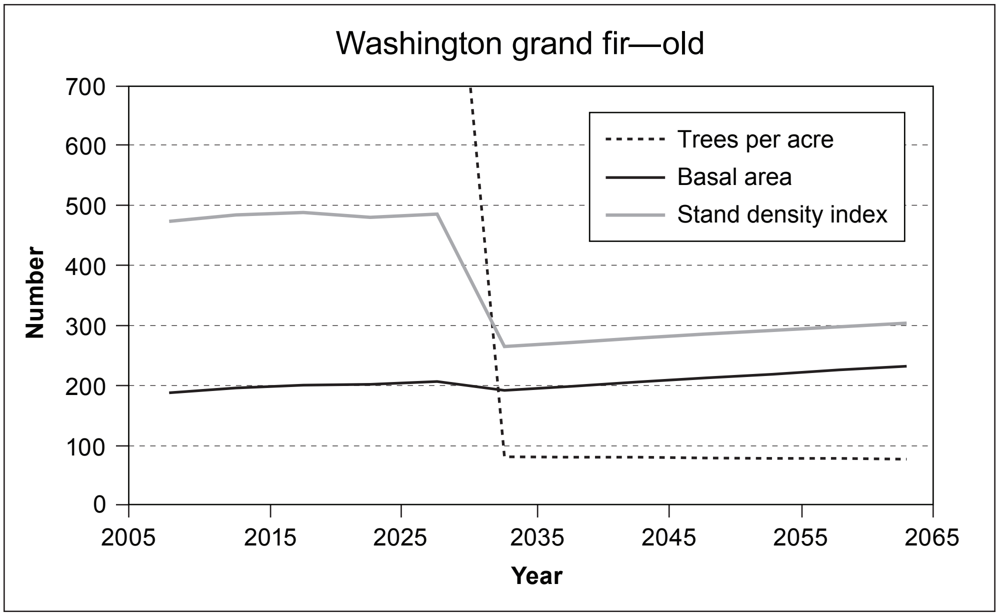


Figure 4-5—Change in stand density (trees per acre), basal area (per acre) and stand density index for an example Washington grand fir late-seral old stand: wildland fire only. Abundant, small, shade-tolerant grand fir is heavily affected by wildland fire, but 82 trees/ac and most of the existing basal area (in larger fire-resistant species) survives these modeled wildland fire conditions.

torching index (fig. 4.6). These model runs emphasize the point that, within any large fire perimeter, the interplay of variability among existing stand conditions (old and young stands) and variability in topography and weather translates into mixed fire behavior within and among these plant associations. This collection of eight stand conditions reflects observations of actual postfire severity patterns within burned landscapes (Hessburg et al. 2007, Hudec and Peterson 2012).

Fuels Management and Restoration Potential

Simulated thinning from below to the upper management zone (UMZ), a light thinning by definition, was effective at creating some stand-level resilience to wildland fire in two of the five fire-susceptible stands summarized in table 4-4. These modeled lighter treatments altered fire behavior in the stand sufficiently so that many trees subsequently survived projected wildland fire. However, in the other three stands, Oregon grand fir young and old, as well as Washington Douglas-fir young, the mechanical treatment did not offer sufficient protection, and survivability of trees was extremely low. Because we cannot forecast what the future wildland fire intensity will be, and therefore what the appropriate thinning threshold should be, we can acknowledge only that each additional unit of treatment enlarges the fire behavior window based on future stand density/fuels.

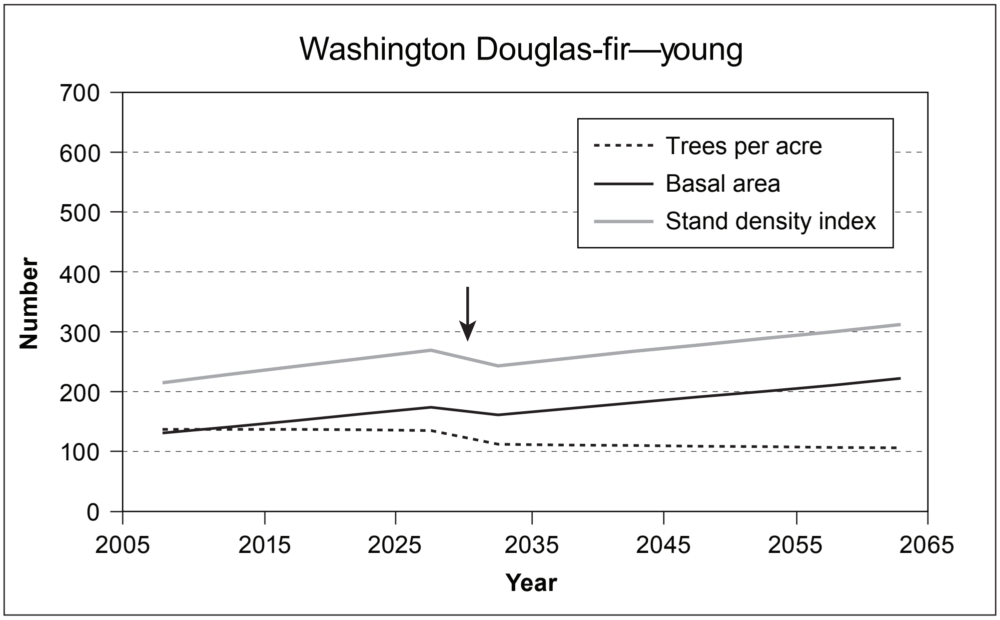


Figure 4-6—Change in stand density (trees per acre), basal area (per acre) and stand density index (SDI) for an example Washington Douglas-fir young stand: wildland fire only in 2030 (arrow). Fire-resistant Douglas-fir (DF) mid-story and overstory trees, without a dense understory, survive these wildland fire conditions similar to a prescribed underburning.

The above simulated light thinning maintains high canopy cover that allows rapid surface fuels recovery, likely within a decade following treatment, so we modeled a moderate thinning from below to the lower management zone (LMZ). Such treatments for these projected conditions increased overstory survival in all five previously fire-vulnerable stands (table 4-4). Three of the five stands are examples of stand structural conditions in which a thorough treatment of ladder fuels and modest treatment of crown fuels are sufficient to create fire resistance and preserve some of the existing habitat functions (e.g., dispersal, habitat capable-short). Canopy cover was consistently reduced below 40 percent by such moderate treatment and prescribed burning, but subsequent wildland fire removes very little additional canopy. Furthermore, the canopies of stands with 25 to 50 surviving trees/ac immediately respond with the production of new leaf area.

Moderate thinning to the LMZ is not always sufficient, however. In two of the five stands, fewer than 10 trees/acre survived the projected 2030 wildland fire—a scattering of only the larger fire-resistant trees in those stands (table 4-4). The fire resistance window was not enlarged sufficiently in these projections, combined with only a limited number of larger individuals that can survive wildland fire. This latter point speaks to the need to protect and grow many of these individuals and in many stands.

Thinning from below followed by prescribed fire (within 5 years) consistently maintained or increased the effectiveness of our simulated thinning treatments (table 4-4); however, this response also can be limited by the lack of larger trees

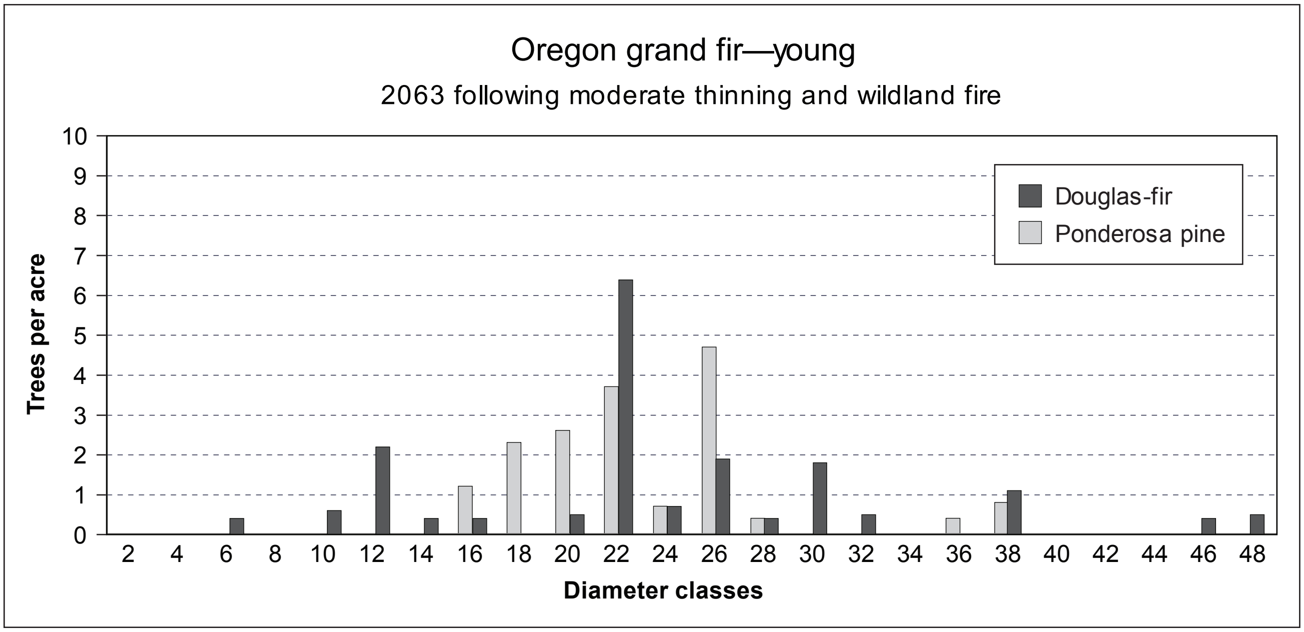


Figure 4-7—Resultant diameter distribution in year 2063—young Oregon grand fir stand thinned from below to the lower management zone (LMZ) and then exposed to wildland fire. Residual tree distribution reflects the limits of the initial stand conditions and the maintenance of a dominantly even-aged stand. This distribution has 32 trees/ac that are >16 inches diameter, equivalent to 112 ft^2/ac of basal area and with canopy cover estimated.

(e.g., Oregon grand fir young; fig. 4.7). Doubling wildland fire survivability with prescribed underburning (fig. 4.8; Washington Douglas-fir old stand) has major implications for future stand development and habitat function. More importantly, stand conditions like Washington grand fir young showed an increase from 2 to 44 trees/ac surviving under these wildland fire conditions, which is a major change in terms of future forest conditions.

Multi-aged restoration treatments consistently doubled the critical wind speed required to sustain crown fire given treatment impact on crown continuity, but the projected regeneration typically following treatment sometimes lowered torching index to hazardous levels for several decades.

Applying a multi-aged management approach to restore a broader range of stand structures (and ecosystem function) left similar amounts of residual basal area in our modeled stands but with more broadly distributed tree diameters/crowns (increased numbers of smaller trees and fewer medium-sized trees) in these stands (fig. 4.9). Multi-aged restoration treatments consistently doubled the critical wind speed required to sustain crown fire given treatment impact on crown continuity, but the projected regeneration typically following treatment sometimes lowered torching index to hazardous levels for several decades. Without subsequent prescribed fire to treat surface and ladder fuels, multi-aged treatments sometimes showed reduced resilience to future wildland fire (e.g., Oregon grand fir) when wildland fire visited the stand soon after treatment.

Such fully restorative multi-aged management regimes consistently created flatter, multi-aged diameter distributions, and, when followed by prescribed underburning, consistently produced stand structures that are resilient to subsequent

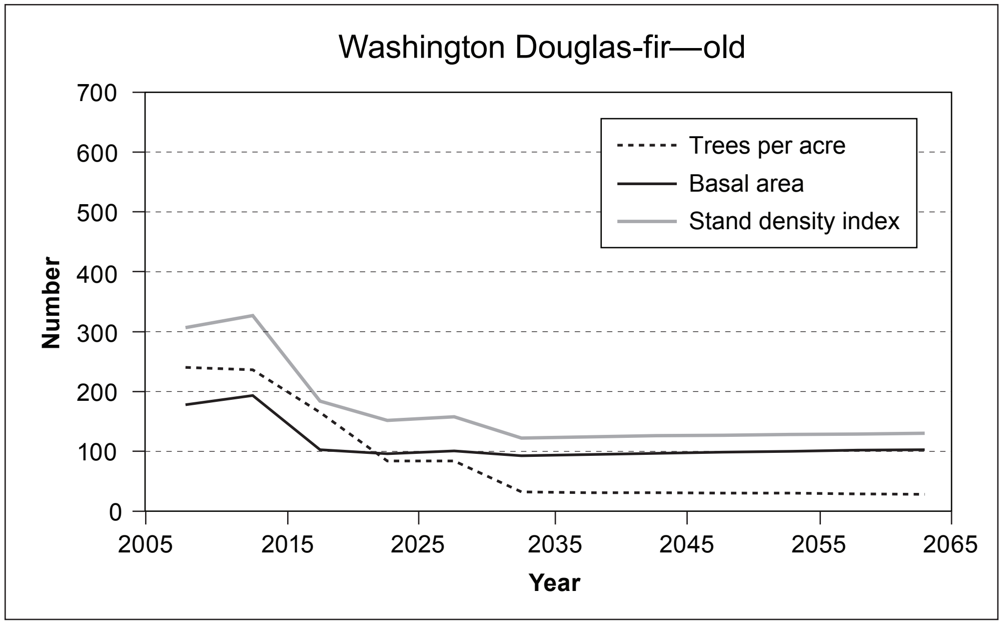


Figure 4-8—Change in stand density (trees per acre), basal area (per acre) and stand density index for an example Washington Douglas-fir old stand following a moderate thinning, prescribed burning and wildland fire (in 2030). Twice as many fire-resistant Douglas-fir and ponderosa pine trees (mid-story and overstory trees) survive 2030 wildland fire conditions (see table 4-4). The distribution similarly has 32 trees/ac in 2063, including a few grand fir, that are >16 inches diameter, equivalent to 100 ft^2/ac of basal area and with canopy cover estimated by FVS at 30 percent.

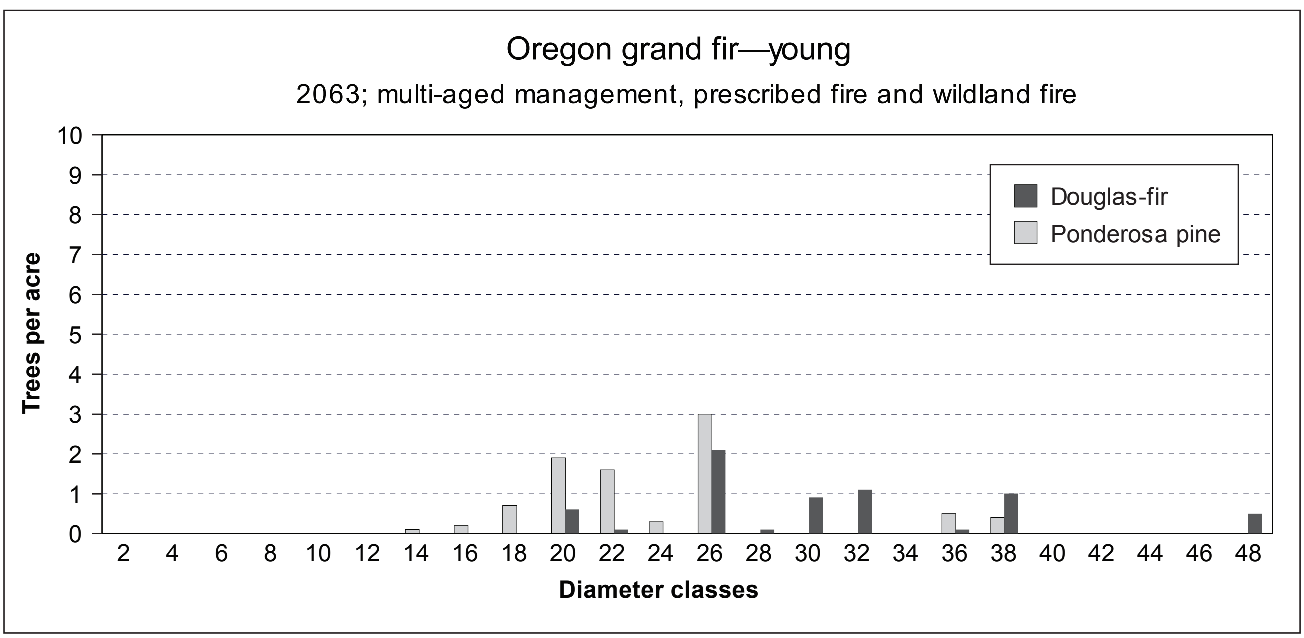


Figure 4-9—Resultant diameter distribution in 2063—young Oregon grand fir with multi-aged management to the lower management zone, prescribed burning treatment, and then exposed to wildland fire. Residual tree distribution and composition reflects more aggressive removal of mid-canopy trees and repeated fire. We did not include subsequent regeneration in this figure, given that it would randomly fill lower diameter classes (up to 10 inches)—but future regeneration can be assumed, and it can be regulated with repeatedly burning and/or weeding as needed. This distribution has 15 trees/ac that are >16 inches equaling 64 ft^2/ac of basal area, with canopy cover estimated by FVS at 15 percent.

Table 4-5—Stand density (trees per acre) for the four representative plant associations, young and old stands, following sequential multi-aged management and prescribed underburning treatments and subsequent wildland fire

Plant association	Age group	Post-BDQ tree density (2018)	Then, post-prescribed -burning density (2023)	Ultimately, post-wildland-fire density (2033)
Oregon grand fir	Young	199	80	76
	Old growth	131	55	53
Oregon white fir	Young	86	53	52
	Old growth	77	44	42
Washington grand fir	Young	150	57	56
	Old growth	189	88	87
Washington Douglas-fir	Young	222	87	86
	Old growth	187	89	87

wildland fire (table 4-5). Stands in which greater numbers of smaller true fir were left to meet the diameter distribution requirement suffered greater subsequent mortality following prescribed fire (e.g., Oregon grand fir young and old; figs. 4-9 and 4-10), but little additional mortality in subsequent wildland fire—the basic idea behind prescribed burning (fig. 4.8). Again, this pattern in the modeled stands accentuates the need to exercise preference for fire-resistant species across all diameter classes, as these individuals are more likely to persist long term.

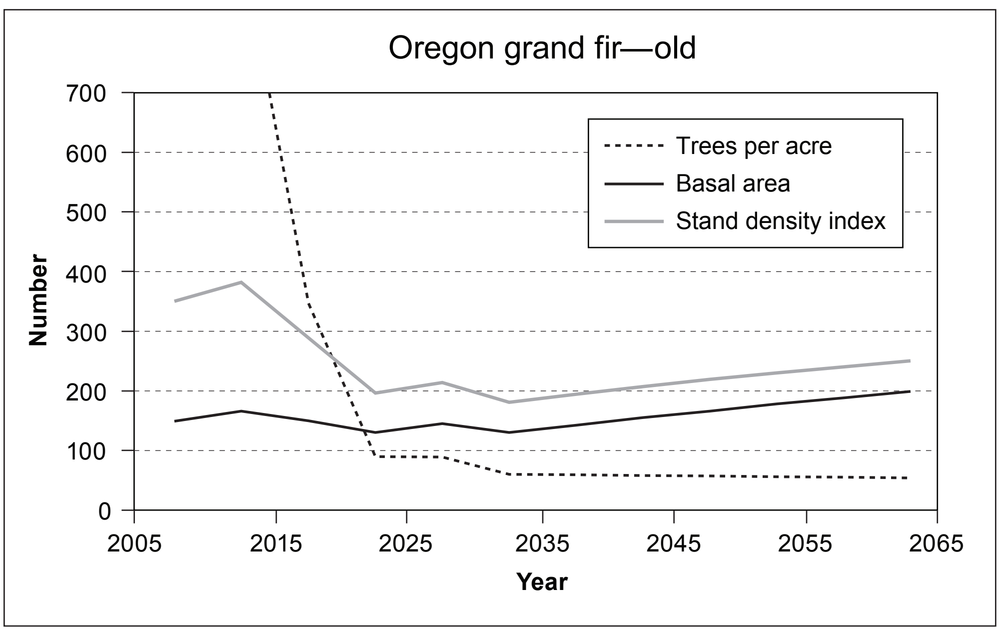


Figure 4-10—Change in stand density (trees per acre), basal area (per acre), and stand density index for an example Oregon grand fir old stand. A partial harvest using a multi-aged management (BDQ) approach in 2015 reduces crown continuity and ladder fuels, followed by a prescribed burning treatment in 2020, which positions the stand to weather wildland fire conditions (in 2030) that would otherwise replace this stand.

Discussion

Our modeling approach provides a comparison of patterns in stand growth, resiliency to wildland fire, and responses for four silvicultural options applicable to stand structures commonly found in NSO home ranges. Our results quantify some of the basic tradeoffs of these different approaches in terms of fire resilience and habitat value. We opted not to add random effects into the models (e.g., RANN-SEED within FVS) and/or run multiple scenarios (e.g., a range of fire weather conditions), as multiple comparisons among silvicultural options and multiple stand types can become difficult given too many "moving parts" to compare. However, managers should be aware that the median numbers presented herein often vary twofold. For example, the median SDI in year 2065 for CWS361 was 91, but ranged from 84 to 132 over 50 model iterations incorporating random effects about regeneration, growth, mortality, tree selection during partial harvest, and fire severity.

Ultimately, managers will make site-specific silvicultural choices to cumulatively build resilient landscapes for an unknown future. When making those treatment choices, they should be fully aware of the following four conclusions about treating and altering habitat functions within NSO home ranges to restore resiliency to wildland fire:

1. Mechanical treatment reduces fuels and changes fire behavior.

Thinning from below to a density within the management zone for these and related plant associations in the Pacific Northwest is typically effective in reducing the impact of subsequent, inevitable wildland fire on stand structure and long-term habitat development. Leaving more trees (UMZ instead of the LMZ) provides more stems post-thinning and into the near future for canopy cover, microclimate moderation, and buffering against further mortality (e.g., windthrow); however, additional trees constitute fuel that potentially pushes the stand across a threshold into stand-replacing fire (depending on unpredictable fire weather conditions and specifics of fine surface fuels and ladder fuels). Density management is a balancing act. Understanding that a threshold is always present **and** that it moves over time (within fire seasons and among years as stands develop) reinforces the need for varying prescriptions among stands and neighborhoods.

Density management is a balancing act. Understanding that a threshold is always present and that it moves over time (within fire seasons and among years as stands develop) reinforces the need for varying prescriptions among stands and neighborhoods.

Stands with higher numbers of stems and percentages of basal area in fire-resistant trees (ponderosa pine and Douglas-fir, predominantly) will fare better during wildland fires—though some or all will be lost under the most severe fire weather conditions and/or with abundant understories and ladder fuels (grand/white fir). Most importantly, survival of some of these larger fire-resistant individuals and clumps is crucial to long-term stand dynamics. These stands are imminently "restorable" and should be our highest priority for restoration treatments. They are likely the most productive stands and, therefore, with the greatest disruption of their historical, natural fire regime, have experienced the greatest infill of grand/white fir. They are likely found throughout a larger landscape that will need future nesting, roosting and foraging habitat for northern spotted owls, given increasing large-scale fire in the Pacific Northwest.

2. Prescribed fire supplements mechanical treatment.

Prescribed underburning following mechanical tree removal frequently creates some mortality in residual trees, particularly in stands containing residual trees of fire-sensitive species. However, the benefit of prescribed underburning in terms of surface/ladder fuel treatment, stand resilience to wildland fire, and long-term ecosystem function is substantial—dramatically so in many cases that we projected for this comparative analysis. The additional mortality in smaller diameter classes, pruning of lower branches, and reduction of surface fuel (living and dead) all combine to enlarge the window of survivability of stands that will face future inevitable wildland fire, often under more extreme weather conditions than managers would typically choose.

Some silvicultural treatments like mowing and chipping/collecting for biomass can mimic some aspects of this prescribed burning effect (e.g., reducing surface fuel loading). These may be a preferred option in areas where risk of fire escape or smoke production is prohibitive. However, they do not fully substitute for surface fuel treatment effect or the ecosystem responses following prescribed burning.

3. Tradeoffs between fire resistance and NSO habitat quality are real.

Our results demonstrate that balancing the goals of increasing fire resilience while maintaining habitat function, especially nesting and roosting, for the NSO in the same individual stand is a difficult, if not an impossible, task. Even lighter thinning treatments typically reduce canopy cover below 40 percent. The reality is that nesting and roosting NSO habitat is by definition very susceptible to high-severity fire; owl habitat value and fire risk are in direct conflict on any given acre. However, we can manage for a mix of conditions within a home range (neighborhood of stands) that allow for coexistence within a landscape. Indeed, this is likely the only way that owls could have historically occupied these forest types. Basically, we have four options for treatment of individual stands to guide the development of a neighborhood:

- **No treatment**: This option has the highest value for NSO populations when the objective is to maintain nesting and roosting functions (occupied or not), but it also has the highest fire hazard and potential risk of fire depending on adjacent fuel conditions.

- **Light treatment**: This option likely reduces NSO habitat function in the near term (although it may still provide foraging or dispersal functions), but stands regrow canopy conditions relatively quickly (within a decade), providing an opportunity to improve stand growth toward conditions that provide nesting and roosting functions via species selection, growth rates, and spatial arrangement. There is an immediate improvement in fire resistance, but it is short lived.
- **Modest treatment**; thin from below to LMZ: This option significantly degrades habitat function (where already present), requiring a longer time to regrow; however, it represents a greater opportunity to mold future stand conditions. There is immediate and significant improvement to fire resistance, particularly with prescribed burning (which is easier to implement) and the treatment effects persist longer—a decade or more.
- **Aggressive treatment**, multi-aged management: This option significantly degrades habitat functions, but stands regrow very quickly following more historical stand dynamics and with a more complete range of tree structures, particularly with prescribed burning. Conditions are best and most consistent across stand types for fire resistance, including in the long term with regular re-entries to treat understory.

Sustaining NSO habitat in fire-prone landscapes therefore requires managing for a mosaic of structural conditions across an area larger than an individual stand—the neighborhood and larger landscape.

4. Creating heterogeneity at multiple scales will be the key.
Sustaining NSO habitat in fire-prone landscapes therefore requires managing for a mosaic of structural conditions across an area larger than an individual stand—the neighborhood and larger landscape. It is possible to maintain owl populations over time in fire-prone landscapes if habitat is embedded within a mosaic that is resistant to large-scale, high-severity fire. Individual stands or patches of nesting and roosting habitat may experience high-severity fire, but other patches should burn at lower severity and be able to quickly regrow into habitat (e.g., habitat capable—short). Such mosaics should contain four basic stand types:

- **Nesting and roosting habitat**: occupied or unoccupied nesting and roosting habitat that remains untreated but is the focus of neighborhood treatment designs that isolate them from the flow of high-severity fire during severe fire weather events, reducing the probability of encounter and increasing the probability of successful fire suppression when possible.
- **Habitat capable—short**: stands that can be made somewhat resistant to wildfire and contain a sufficient number of large trees and medium-size trees to grow into nesting and roosting habitat (may still provide foraging

or dispersal functions) within one or two decades. Light thinning treatments (UMZ) can enhance fire resilience and resilience and often produce/improve these structural conditions via accelerated growth of larger trees and structural development.

- **Habitat capable—long**: stands at can be made highly resistant to high-severity wildfire with moderate thinning or multi-aged management (LMZ). These stands break up the continuity of fuels and can slow or stop the spread of active crown fire across the mosaic. They also have a cohort of large trees and, thus, can develop high-quality habitat conditions, but may take longer (three to five decades) in the absence of sufficient understory and mid-story development. More aggressive treatments can produce these structural conditions. Stands that lack a cohort of large trees will take much longer to develop into nesting and roosting habitat.
- **Non-habitat**: stands in plant associations or vegetation types that likely cannot support NSO habitat (e.g., pure ponderosa pine forests, shrub or grasslands, or other nonforest habitats), not modeled in this comparative analysis but which often occur over substantial acreages within these landscapes. These stands, especially if treated with aggressive treatments, can provide important crown fire breaks, thereby increasing the resistance of the mosaic to severe wildfire, as well as serving broader early-seral ecosystem functions.

Varying these four treatment types and residual density will promote neighborhood and landscape mosaic, which may ultimately be enhanced by a wildland fire event given landscape memory. We can only speculate as to when and how wildland fire will actually visit stands within given neighborhoods, so the distribution of these treatments on particular landscapes should be based on topography and local fuel conditions, among other constraints. Some stands will be better candidates for lighter thinning-from-below treatments (particularly those with emerging, abundant small white fir in the understory), and some will be better candidates for aggressive multi-aged management treatments (particularly those with a range of existing diameter classes, including abundant larger diameters in fire-adapted species).

In general, the heavier a mechanical treatment (particularly if followed by a prescribed underburning treatment to reduce fine surface fuels), the larger the resultant window for low-to-moderate fire behavior and the longer the timeframe to return to or develop conditions that provide nesting and roosting habitat functions. The desired proportion and spatial arrangement of different stand types to create and maintain over time will depend upon existing stand conditions and future stand growth potential (productivity), local NSO habitat needs (e.g., for dispersal), potential wildfire spread patterns within the landscape, implementation constraints (e.g., road access, economics, and other treatment restrictions), and other competing resource objectives.

Managing for within-stand heterogeneity is also important. Nesting, roosting and foraging (NRF) habitat, especially foraging habitat, requires a mix of features including dense thickets, small openings, multistory patches, and large tree clumps (see chap. 3). Large areas of uniform thinning do not provide ideal habitat for NSO prey species (Lehmkuhl et al. 2006) and are also inconsistent with patterns found in frequent-fire forests with intact fire regimes (Churchill et al. 2013a, Fry and Stephens 2010). Multi-aged management approaches, or moderate thinning-from-below with purposeful "clumpiness" and openings, will also enhance wildland fire resilience and other ecosystem services (Franklin and Johnson 2012). The spatial component to actually marking restorative multi-aged management treatments, or clumpy moderate thinning treatments, allows further within-stand enhancements to tree survivability and stand resilience by isolating medium-sized grand/white fir trees from other fire-resistant trees, creating horizontal and vertical separation among vegetation, and thereby manipulating within-stand spread of wildland fire while retaining structure.

Implementation

Implementing treatments that achieve specific targets for spatial heterogeneity at multiple scales is a relatively new challenge in forest management (Lertzman and Fall 1998). To be tractable, multi-scale management requires conceptualizing forest ecosystems as a hierarchy of vegetation patch mosaics (Wu and Loucks 1995). Each level of the hierarchy is a mosaic of patches, and each patch is a mosaic of lower level patches (Kotliar and Wiens 1990). At the highest level are regional landscapes or ecological sub-regions that are differentiated by differences in climate, geomorphology, and vegetation types (Hessburg et al. 2000). The patterns and variability within regions come from local landscapes, typically 5^{th}- or 6^{th}-field watersheds (Seaber et al. 1987), no two of which are the same. Watersheds in turn are mosaics of successional patches or stands (O'Hara et al. 1996). Stands are defined as patches of vegetation with similar composition, structure, and topo-edaphic conditions that contain variable patterns of tree neighborhoods. Tree neighborhoods are the lowest level of the hierarchy and consist of sub-patches within stands that have similar arrangements of tree clumps and openings and thus tree growing environments (Frelich and Reich 1999).

Northern spotted owl recovery requires consideration of habitat quantity, quality, and location at the regional landscape level and also within local landscapes (5^{th}- or 6^{th}-field watersheds) (USFWS 2011). Decisions about where and how much to treat within local landscapes should be guided by a landscape evaluation process (chapter 3) that prioritizes both high-value habitat blocks for retention and areas for treatment (Ager et al. 2007, Franklin et al. 2013, Hessburg et al. 2013). Landscape evaluation will ensure that treatments are integrated with larger scale management goals that seek to sustain a wide range of ecological functions and social objectives over time (Rieman et al. 2010), not just NSO objectives.

For implementation of silvicultural treatments, we suggest consideration of an area about the size of a typical NSO home range in dry forests, 1,500 to 2,500 acres. This is large enough to embed significant blocks of nesting and roosting habitat within more fire resistant areas, but small enough to plan and implement manageable mechanical thinning sales and prescribed burns. These blocks of stands, or stand neighborhoods, typically make up a single catchment, hillside, or ridge system within a local landscape or 6th-field watershed. Selection of stand neighborhoods should arise from a watershed-level landscape evaluation that prioritizes such areas for treatment and provides landscape level guidance for treatments (Hessburg et al. 2013). In many cases, several 1,500- to 2,500-ac stand neighborhoods may be prioritized for treatment within a 6th-field watershed.

Selection of stand neighborhoods should arise from a watershed-level landscape evaluation that prioritizes such areas for treatment and provides landscape level guidance for treatments.

Once stand neighborhoods have been selected, managers can move the neighborhood toward the desired mosaic of forest structure by: (a) varying treatment types across stands, and (b) managing for heterogeneity within stands.

Varying prescription types across individual stands—
Given the benefits of considering areas larger than individual stands, the context discerned from a landscape evaluation can inform prescription approaches for individual stands. Ideally, a landscape evaluation will provide a "landscape prescription" that provides guidance as to the type of stand structures most needed as well as patch size and configuration (Hessburg et al. 2013). An example landscape prescription might be: "(1) create larger patches of large tree, multi-story forest for 20 percent of the watershed, and (2) reduce the patch size and connectivity of small tree, multi-story forest." Fire flow analysis is also very useful to identify areas to target for fuels treatment in order to interrupt crown fire spread.

A next step might typically be to determine where existing occupied and unoccupied nesting and roosting NSO habitat is located and also what areas are inaccessible or have other restrictions for mechanical entry. Stands where treatment is possible can then be identified. Consideration of both current stand conditions (e.g., species composition, size, tree health, structural complexity, potential fire behavior) and the landscape context (e.g., landscape prescription and surrounding stands) is necessary to determine the prescription type, including the no treatment option, for individual stands. Stand-level considerations include:

- A light thinning-from-below treatment, within an even-aged management approach, is most appropriate when the NSO habitat objective is "habitat capable—short" and where there is:
  - A preexisting one- or two-story stand in which mechanical removal of understory trees (e.g., <8 to 10 inches diameter), perhaps followed by prescribed underburning of accumulated surface fuels, will largely treat the issue of high crown fire potential;
  - One or more restrictions to using heavy equipment, such that hand work (cutting and piling of small trees) is required; and/or
  - Interest in developing the overstory fully intact to some future final harvest.
- A moderate thinning (with clumps) or multi-aged management approach is most appropriate when the NSO habitat objective is "habitat capable—long" and where there is:
  - A preexisting multi-story stand within which the mechanical removal of trees can develop an appropriate range of diameters among desired species, and largely treat the issue of high crown fire potential (particularly when followed by prescribed underburning of accumulated surface fuels) while concurrently restoring broader structural conditions and meeting more functional objectives;
  - No restriction to using heavy equipment, and few restrictions on the size or species treated; and/or
  - Interest in developing a complex stand with high horizontal and vertical structural diversity that can be sustained through time with regular fire or mechanical entries.

Heterogeneity within stands—

Once a prescription type has been selected for an individual stand, targets for stand-level variability will need to be developed. Stand-level prescriptions that seek to create spatial heterogeneity can initially seem overly complex, expensive, and infeasible. Yet, operationally practical approaches do exist and are currently being implemented and refined in many places across the West (Bailey and Covington 2002, Churchill et al. 2013a, Franklin et al. 2013, Gaines et al. 2010b, Jain et al. 2008, Knapp et al. 2012). These approaches share a common framework that consists of prescribing three to four different treatment types across a stand: untreated areas or skips, openings, heavy thin, and a thinning area (table 4-6), as well as creating variation in fine-scale patterns of widely spaced individual trees and openings.

Table 4-6—Within-stand silvicultural treatment options: descriptions, functions and implementation guidelines

Type	Description and key characteristics	Ecological and northern spotted owl (NSO) habitat functions	Implementation and prescribed fire
No-thin skips (wildlife retention patch, complex patch)	• Areas left untreated and not entered with equipment. • Often have concentrations of important NSO habitat features such as large snags, dwarf mistletoe, downed logs, etc. • Variable: large (2+ ac) to small: (0.1 to 0.5 ac). • Typically dense forest with canopy cover >60 percent, often has multiple canopy layers and/or unique features or plant species.	• Protect important NSO habitat elements (e.g., vertical structure) and other biological hotspots (e.g., riparian features). • Provide for future snags and downed wood originating from insects, fire, and competitive mortality. • Provide canopy cover and dark, moist habitat areas. • Promote variable understory cover conditions.	• Larger skips should be located, laid out, and GPS located prior to marking or cutting. • Painted center trees or GPS points can be used for small skips (<1/3 ac) • Protection from prescribed fire may be necessary, but cool burns seem acceptable for some skips; however, inadvertent burn mortality creates collections of snags
Openings (gaps)	• Created or existing areas with few or no overstory trees. • Often related to disturbance agents such as root rots, insects, or fire. Can also be caused by shallow soils. • Often contain a few individual or small clumps of overstory trees. • Variable: large (2+ ac) to small: (0.1 to 0.5 ac).	• Regenerate or plant new species. • Promote and develop understory-midstory tree and shrubs/herbaceous layers. • Release hardwoods or understory fire-resistant conifers for rapid growth (within gaps and around edges). • Inhibit spread of fire, insects, and pathogens.	• Larger openings should be located, laid out, and GPS located prior to tree marking or cutting. Flag center line or perimeter. • Smaller openings can be indicated with a center tree or via marking guidelines. • Burn through, with some care for unique saplings of desired species via lighting pattern
Low density areas (multi-aged management and irregular shelter-woods)	• Areas with low residual overstory tree density, typically 5 to 20 percent of maximum SDI. • Widely spaced individual trees and small clumps of trees (2 to 6 trees). • Can be individual tree release (0.1 ac) but typically in patches 0.5 to 5+ ac in size.	• Release and grow large, fire-resistant trees with large crowns and high vigor. • Alter stand-level fire behavior through surface, ladder and crown fuel treatment. • Develop early seral understory-midstory tree and shrubs/herbaceous layers. • Release hardwoods or understory fire-resistant conifers. • Inhibit spread of fire, insects, and pathogens.	• Generally accomplished via marking guidelines. • Special paint color or double band of paint indicating wider spacing can also be used in conjunction with a DxD or DxP prescription. • Burn throughout to stimulate ecosystem processes; these areas likely to burn hotter.
Light and moderate thinning	• The remainder of stand, generally; 50 to 80 percent of the total stand area depending on objectives. • Residual stand left at 25 to 55 percent of max SDI with logistically/topographically appropriate variability. • Thinning from below or multi-aged approach.	• Increase and/or maintain tree growth, crown development, and vigor. • Reduce ladder fuels and decrease crown bulk density modestly. • Stimulate limited understory-midstory trees and shrubs/herbaceous layer.	• Marking with guidelines to create tree-level variability: small clumps, individuals, and range of density. • DxD/DxP with guidelines and/or paint to create tree level variability. • Burn throughout and with likely variability.

The amount and spatial arrangement of these four treatment options (table 4-6) within an individual stand can be set to achieve a full range of treatment types and objectives. In most dry forest restoration treatments, the thinning area will comprise the majority of the treatment unit. Any of the thinning approaches discussed in the preceding sections can be applied in the thinning area. Skips, openings, or heavy thin areas are then added in as necessary. In many cases, two of the types can be blended together to reduce complexity. For example, openings and heavy thin areas can be combined, or heavy thinning can be integrated into the thinning area prescription. This framework can also encompass variable retention or regeneration treatments, where the majority of a stand is given an opening or heavy thin treatment (e.g., irregular shelterwood, or variable retention with a mix of aggregated and dispersed retention).

Determining the amount and spatial arrangement of skips, openings, and heavy thin areas to add to a thinning prescription is one of the most challenging aspects of restoration. Understanding the functional rationale for different sizes and kinds of skips, openings, and heavy thin areas is critical to prescribing ecologically appropriate targets (table 4-6). There are no ideal percentages for skips and openings. For stands being managed for NSO habitat in the short to medium term, the habitat definitions provided in table 3-1 of the previous chapter provide guidance. See Franklin et al. (2013) for a detailed discussion of skip types and their functions.

It is critical to keep in mind that the pattern of forest structure across a neighborhood of stands is what creates the desired mosaic of northern spotted owl habitat and fire resistant conditions, not patterns within individual stands.

It is critical to keep in mind that the pattern of forest structure across a neighborhood of stands is what creates the desired mosaic of NSO habitat and fire resistant conditions, not patterns within individual stands. Rigid skip or openings guidelines for all stands will not ensure a functional mosaic. A treated stand surrounded by untreated stands, for example, will likely need fewer skips than a stand that is part of a large treatment area. Determining and tracking the target proportion of openings, untreated dense patches, heavy thin pockets, and thinned areas is best done across neighborhoods of stands based on functional objectives and biophysical conditions. Box 4-2 lists factors that can be used to inform setting targets for different treatment types across a stand neighborhood and also within stands.

Prescribing and tracking the number treatment types across a neighborhood of stands provides more flexibility to work with topography, stand conditions, and operational needs. Unit boundaries, for example, can be used to exclude areas that are good skip candidates, often by forming “fingers” that extend into the stand and reducing the need to place skips within the unit. However, skips and openings need to be sufficiently distributed within treatment units to meet habitat needs for many species, not packed exclusively into unit edges, riparian buffers, or untreated blocks of the neighborhood. We suggest defining an average and maximum square area of thinning treatment than can occur without a skip or opening/heavy thin area. This can

Box 4-2

Factors to Be Considered When Setting Targets and Guidelines for Skips, Openings, Heavy Thin Areas, and Openings Across Stand Neighborhoods and Within Stands

Landscape context: The desired structure/cover class can be informed by a landscape analysis. In general, stands surrounded by dense forest will require fewer skips, while stands within large blocks of treated area may need more skips. Stands that are located in fire flow corridors will likely require more aggressive restoration treatments with more openings and few skips, while those being managed for NSO habitat in the short or medium term will required more skips.

Biophysical context: Variation in topography and soils can influence the amount and location of skips, openings, and overall treatment type. For example, high density skips are best placed in wetter, cooler microsites, while areas with shallow soils are good places for openings or heavy thinning.

Existing structure, composition, and forest health: The extent to which current species composition needs to be shifted toward fire and drought-resistant species, especially on drier sites, can guide how much thinning versus heavy thin and opening patch types are created. Forest health considerations can also be factored in. Root rot pockets, dwarf mistletoe patches, or pockets of insect mortality provide critical habitat elements, but can also degrade habitat and resistance to fire if they are prevalent over extensive areas.

Biological hotpots: The type and amount of area in required buffers around riparian areas, threatened and endangered species sites, archeology sites, and sensitive soils can be a major factor in determining how many skips and their size are needed. Aspen pockets or old, fire-resistant trees are also biological hotspots that may require heavy thinning or opening treatments.

Habitat needs: Additional skips may be necessary to reduce sighting distances or to provide hiding cover. NSO foraging habitat will generally require skips with downed wood and snags, as well as openings to promote herbaceous layers (table 3-1).

Fire: Plans for prescribed fire can be factored into the number and placement of skips and openings created during mechanical treatments. Fire will often create or enlarge openings over time. Prescribing high numbers of skips where prescribed fire must be excluded will increase the cost and complexity of burning, resulting in fewer overall acres burned.

Access and implementation issues: Logging system and other implementation-related restrictions may create areas in which wood cannot be removed. These can be left as skips or may present opportunities for noncommercial thinning where wood is left on the ground.

be based on maximum desired sighting distances for specific wildlife species or other considerations. An example guideline for stands being managed for short- to medium-term NSO habitat could include restrictions on thinned areas larger than five acres with well-spaced trees and no skips.

The extra time and cost of including skips and openings in treatments is often a concern. A number of strategies have been developed that can increase both the efficiency and effectiveness of these kinds of prescriptions, primarily through increased use of geographic information system (GIS) and global positioning system (GPS) technology. First, remotely sensed GIS information such as LiDAR or high-quality orthophotos can be used in planning to identify potential locations of different treatment types. Tablets can then be used to help locate these features once in the field and to provide an overhead view of the spatial pattern being created. In the field, specialists can GPS center point locations of good skip, heavy thin, or opening candidates; these locations then are then passed onto marking crews or contractors doing the layout. During layout, regular GPS units, tablets, or smart phones can be used to record and track skips and openings to immediately see their location and size, as well as stand totals. Prescribed fire instructions for skips are also recorded. This information is then passed onto operators, sale administrators, and prescribed fire planners and crews for implementation, as well as for future monitoring. Franklin et al. (2013) provided more details on layout of such features.

In addition to skips, openings, and heavy thin areas, it is also important to consider fine-scale, or tree-level variability, particularly in the thinning portion of the stand. Marking guidelines that create a mix of widely spaced individual trees, tree clumps of various sizes, and small openings (Larson and Churchill 2012) will be discussed in the next section.

Marking Guidelines

Marking stands varies slightly between a thinning-from-below or multi-aged management approach, given the above results and discussion about silvicultural prescription choices and their projected relative effectiveness in restoring structure and moderating future wildland fire behavior and habitat value. In general, however, a traditional thinning-from-below follows a spacing guide based on desired residual basal area or SDI, with size, species, and form preferences for residual trees. Spacing varies a little given existing stand conditions; relaxing the requirements for spacing can promote within-stand heterogeneity with little effect on the distribution of residual tree diameter, species, and form.

Instructions for skips, openings, and heavy thin areas are often dealt with first in marking instructions. Guidelines for the thinning area are then included. In many cases, it is more efficient to combine the heavy thin area with opening, or integrate heavy thinning into the thinning guidelines. Marking stands for a multi-aged distribution involves one of several approaches to calculating a target residual tree diameter distribution and total stand stocking level that support continual regeneration and growth while providing diverse habitat and fire resilience (fig. 4-11).

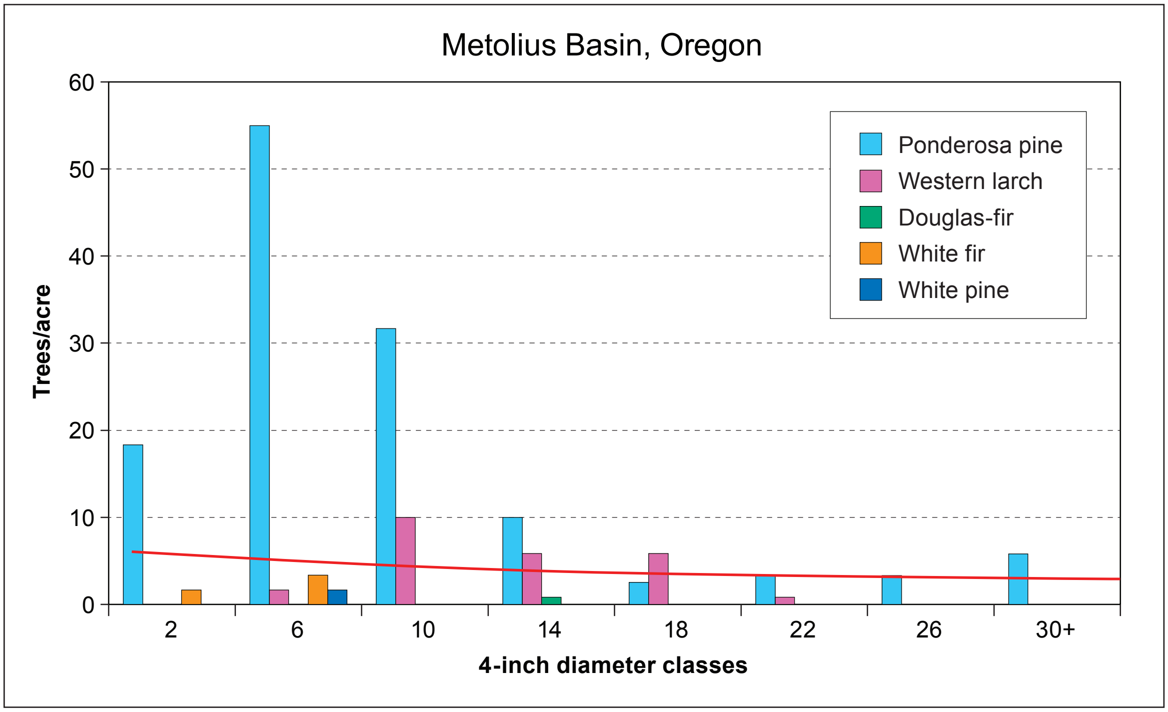


Figure 4-11—Example of a multi-aged management diameter distribution against existing stand conditions. Differential between target (red line) and existing (bars) guides selection of leave trees along with species preferences and considerations of form and spatial location (e.g., given future growth potential and ladder fuel arrangement).

The desired residual distribution is compared to the current condition and guides the (obvious) selection of diameter classes in need of partial harvest. In this example, a few trees between 12 and 20 inches are harvested, but most future growing space and open stand condition is created by removing a large number of (but not all) trees <12 inches. Residual trees in the 2- through 18-inch diameter classes are selected and marked based on form and spatial location, with residual trees purposefully left in clumps of various size and numbers when possible. The largest trees are already typically clumped, and these residual clumps should accent that spatial arrangement to create openings of various size for habitat and fire resilience.

Providing numerical targets for the number of clumps of different sizes to retain will provide greater clarity to marking crews and reduce the subjectivity involved in creating fine scale variability. Churchill et al. (2013a) have developed a methodology termed ICO (individuals, clumps, and openings) to derive clump targets for prescriptions. Ideally, data from reference stands can be used to inform these targets, but this is not essential. Clump targets are not meant to be rigid targets, but instead "guard rails" to ensure that a pattern of clumps, widely spaced individual trees, and openings is created that is within the range of reference stands. See Churchill et al. (2013b) for more information on implementing this method, which can be used in any forest type. It is also possible to add clump targets, especially for medium and large clumps (5 to 20+ trees), to a basal area prescription. This can help clarify when and how often to retain higher levels of basal area than the target average (fig. 4-12).

Large skips (0.5 to 0.75 ac) were marked by painting the perimeters around biological hotspots. Small skips (~1/4 ac) were marked by painting the center tree. They are generally dense overstory skips, with some surrounding large dwarf mistletoe trees. Only two openings (⅓ to ⅔ ac) were placed as the stand already had numerous large openings. A 4-ac square area is shown to indicate the approximate size of area that should contain at least 1 skip. Note how the fingers extending into the stand, as well as the narrow portion in the lower section, add both openings and denser forest patches to stand. The portion of the unit not in skips or openings will be thinned with individual trees, clumps, and openings (ICO) prescription that leaves a mosaic of tree clumps from 2 to 10 trees, isolated individual trees, and small openings (<1/5 ac).

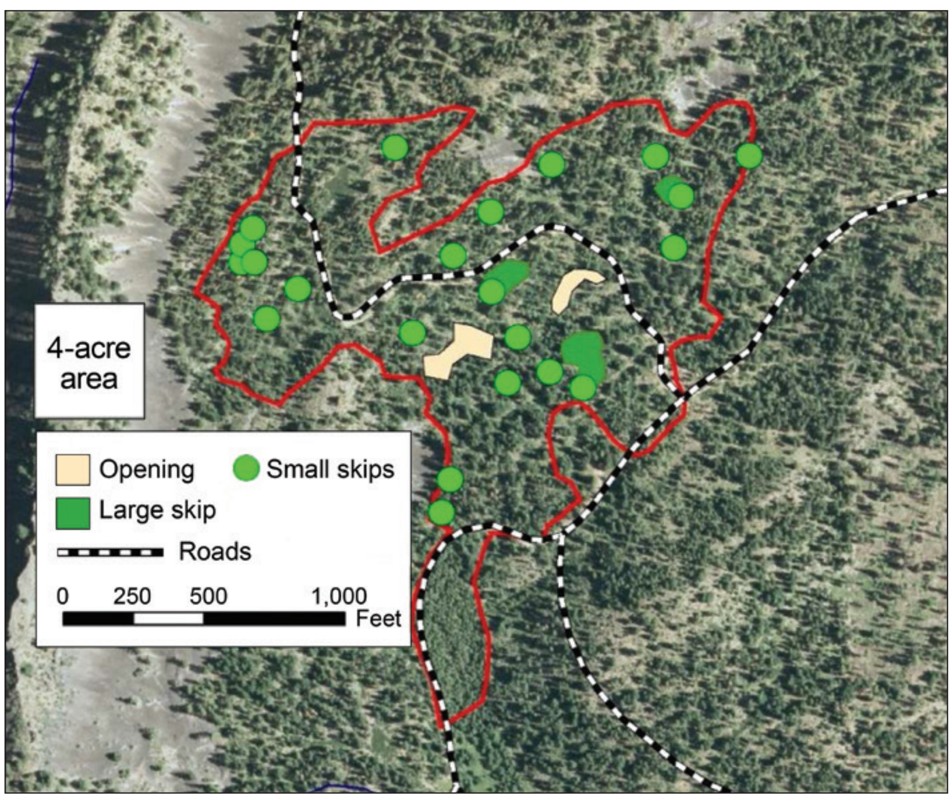


Figure 4-12—Example of a 40-ac pretreatment stand with planned skips and openings, for a typical dry forest plant association (from Franklin et al. 2103).

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Chapter 5: Monitoring, Adaptive Management, and Information Gaps

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Introduction

Since its inception more than two decades ago (Holling 1978, Walters 1986), adaptive management has been elevated to the forefront of ecological science and environmental management for dealing with problems characterized by uncertainty (Gunderson and Holling 2002). However, the track record for successful implementation of adaptive management is weak (Gregory 2006, Walters 1997), and many ecological planning, restoration, and species recovery initiatives that are promoted under the banner of adaptive management exhibit few, if any, of the characteristics generally considered to be essential. Instead, adaptive management has been used as a means of postponing difficult decisions or as a means to advance biological research agendas without careful consideration for other important environmental, social, or economic objectives (Gregory et al. 2006). Thus we intend to determine if adaptive management is feasible for addressing uncertainties associated with recovery of the northern spotted owl—and if so, to consider what specific management problems should be the focus of an adaptive management approach to the recovery of the northern spotted owl. Finally, we provide a framework for adaptive management that could be applied to guide learning about how spotted owl habitat objectives and hypotheses (detailed in chapter 3), implemented by treatment options and prescriptions (described in chapter 4), can be tested through management experiments to enhance learning about the effects of stand-level restoration on spotted owl habitat functions.

Monitoring is integral to an adaptive approach to ecosystem restoration and natural resource conservation (Bormann et al. 2007, Busch and Trexler 2003, Franklin and Johnson 2012, Gregory et al. 2006, Stankey et al. 2005). As such, the recovery plan for the northern spotted owl (USFWS 2011) identifies monitoring and research, as well as active adaptive forest management, as important steps in achieving recovery goals. This need is particularly recognized in Recovery Action 11, which states ,"When vegetation management treatments are proposed to restore or enhance habitat for northern spotted owls (e.g., thinning, restoration treatments, prescribed fire, etc.), consider designing and conducting experiments to better

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understand how these different actions influence the development of northern spotted owl habitat, northern spotted owl prey abundance and distribution, and northern spotted owl demographic performance at local and regional scales." The revised recovery plan for the northern spotted owl also identified essential research and adaptive ecosystem restoration monitoring questions, several of which are directly relevant to the subject of spotted owl and forest restoration:

1. What vegetation restoration treatments best accelerate the development of forest structure associated with northern spotted owl habitat functions while maintaining or restoring natural disturbances and providing greater ecosystem resiliency?
2. What are the effects of wildland and prescribed fire on the structural elements of northern spotted owl habitat?
3. Can strategically placed restoration treatments be used to reduce the risk of northern spotted owl habitat being burned by high severity fire within dry forest ecosystems?
4. What are the effects of epidemic forest insect outbreaks on northern spotted owl occupancy and habitat use? And, what are the effects of forest restoration treatments used to reduce forest insects to endemic levels?

In this chapter, we provide an overview of adaptive management; evaluate the monitoring questions regarding spotted owls and restoration treatments that are appropriate for an adaptive management approach; review monitoring design considerations; provide recommendations for successful management studies; and present an approach to monitoring and adaptive management that could be implemented in the dry and mesic forests of the eastern Cascades.

Adaptive Management—An Overview

Adaptive management is a system of management practices that does three things (fig. 5-1): (1) it clearly identifies desired outcomes, (2) it requires monitoring to determine if management actions are leading to desired outcomes, (3) if outcomes are not being achieved, it facilitates management changes to ensure that outcomes can be met or reevaluated. Adaptive management stems from the recognition that the behavior of natural systems is often difficult to predict (36 CFR 219.16; FSM 1905) thus uncertainty is addressed by testing, learning, and doing simultaneously. Adaptive management is much more than a technical, science-based process. It is a bold approach to management, which requires creativity, curiosity and a long-term commitment to structured learning (Murray and Marmorek 2003). In addition, it is a means of providing "quality control" to determine if restoration is implemented

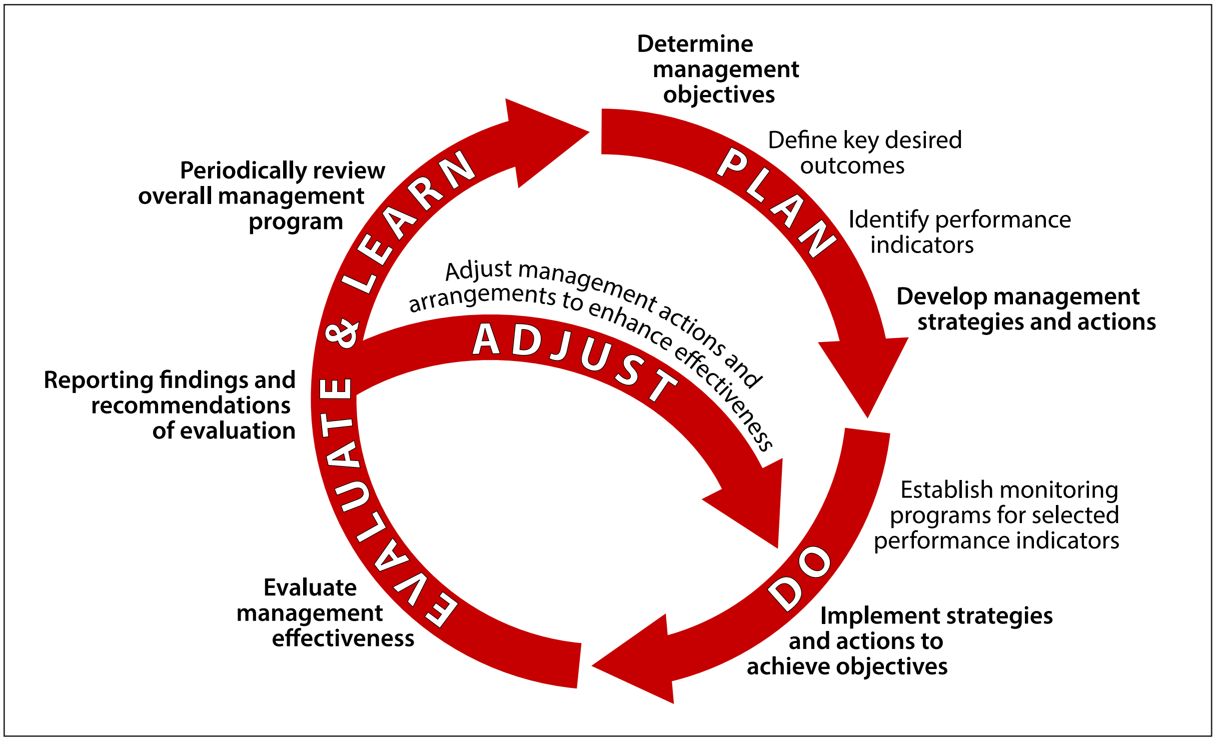


Figure 5-1—The adaptive management cycle based on Walters (1986).

in the desired way. Because of the uncertainty and complexity surrounding the interactions between forest restoration and the recovery of the northern spotted owl, an adaptive management approach has been suggested (USFWS 2012). By coordinating adaptive management and monitoring efforts across the range of the northern spotted owl within fire-prone provinces (fig. 5-2), it is hoped that much can be gained in terms of our ability to learn and adapt restoration prescriptions that accomplish multiple and integrated objectives.

There is a considerable amount of guidance and policy concerning the use of adaptive management within the federal agencies that oversee or carryout forest restoration within the range of the northern spotted owl. For example, at the national level, adaptive management is described in the Land Management Planning Handbook (FSH 1909.12 Chapter 20), is a critical component of the *Forest Service Strategic Framework for Responding to Climate Change* (USDA FS 2008), and the Forest Service manual FSM 2000, Chapter 2020 Ecological Restoration and Resilience) states that "adaptive management, monitoring, and evaluation are essential to ecological restoration." At the regional level, the adaptive management process for the Northwest Forest Plan is described in the Record of Decision (USDA and USDI 1994: E12–15). In addition, adaptive management figures prominently in the final Northern Spotted Owl Recovery Plan and revised Critical Habitat rule,

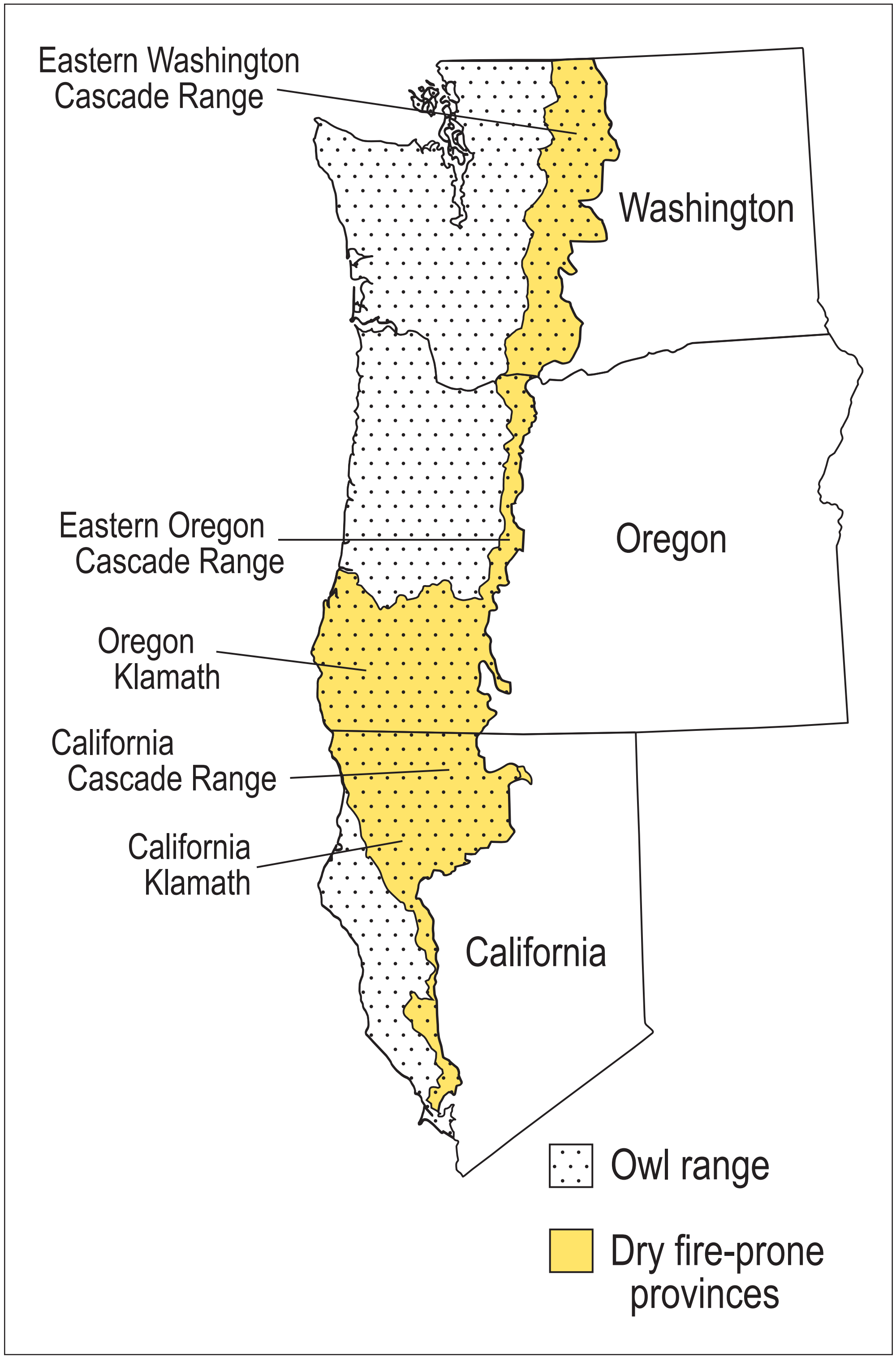


Figure 5-2—The “fire-prone” areas within the range of the northern spotted owl (Rapp 2005) showing the location of studies underway that are focused on the effects of treatments on prey species.

especially as it relates to the fire-prone provinces (USFWS 2011, 2012). However, coordinated efforts to implement adaptive management at the provincial and project levels have been lacking as well as challenging for a wide variety of reasons, from cultural to technical. One effort that attempted to make adaptive management a part of everyday life is the Okanogan-Wenatchee Forest Restoration Strategy (USDA FS 2012), to which the Forest Leadership Team devoted considerable time and resources to learning and adaptation within the context of implementing their restoration strategy.

Scientists can play an important role in adaptive management (Stankey et al. 2005, Walters 1986), but local resource professionals are who must become "adaptive managers" if the promise of the concept is to be realized through its application to natural resource management issues (Nyberg 1998, Stankey et al. 2005). For adaptive management to be effective, individual and organizational behavior must contribute to making it work. For this to occur, we provide a set of operational principles that describe the characteristics of individuals, projects, and organizations that contribute to effective adaptive management. They are based on the document *Adaptive Management: A Tool for Conservation Practitioners* (Salafsky et al. 2005).

Principle 1: Do adaptive management at the district or local level

- One of the most important principles is that the people who design and implement the project must also be involved in performing effective adaptive management.
- Involve regular project staff members in the adaptive management and monitoring plan.
- Help people learn about adaptive management.

Principle 2: Promote institutional curiosity and innovation

- Effective adaptive management fundamentally requires a sense of wonder about how things work and a willingness to try new things to see whether they are more effective.
- Survive in a changing world through innovation.
- Promote curiosity and innovation by starting with top managers.

Principle 3: Value failures

- Effective adaptive management requires that we value failure instead of fearing it. A willingness to fail is thus an indicator that we are pushing ourselves to get better.
- Learn from our mistakes.
- Create a fail-safe environment.

Principle 4: Expect surprise and capitalize on crisis

- Effective adaptive management requires that a project or organization both expect the unexpected and be prepared to act quickly during periods of turmoil. Often, the strange and surprising results are what lead to new insights and understanding, but only if we are willing to look for them.
- Use surprises to point to flaws in understanding.
- Use crises as opportunities for action.

Principle 5: Encourage personal growth

- Effective adaptive management requires individuals who have a commitment to personal growth and learning.
- Encourage employees to be committed to continual learning.
- Invest in helping staff develop skills and experiences.

Principle 6: Create learning organizations and partnerships

- Effective adaptive management requires projects and organizations to capture the learning that individuals develop so that it can be used in the future. Because many projects are implemented through partnerships, it is also important to ensure that knowledge, skills, and information resources are shared.
- Promote organizational learning.
- Build teams of project partners.

Principle 7: Contribute to global learning

- Effective adaptive management requires learning at personal, organizational, and global levels. Practitioners around the world are struggling with similar problems and challenges. The key is for each project team to make the lessons it has learned available to others.
- Encourage use of good science.
- Promote and market work in forest restoration.

Principle 8: Practice the art of adaptive management

- Adaptive management is more than just science; it is also an art. Above all, constantly practice adaptive management.
- Treat adaptive management as a craft.
- Pay attention to intuition.
- Practice, practice, practice.

Adaptive Management and Recovery of the Northern Spotted Owl

Gregory et al. (2006) suggested that a part of the "failure" of adaptive management in environmental management is a lack of screening to determine when and if an adaptive management approach is appropriate. They presented criteria for the selection and design of adaptive management initiatives that can be used to determine if adaptive management is appropriate and, if **passive** or **active** adaptive management is best given the circumstances of a management problem (Gregory et al. 2006). We apply these criteria to one of the questions identified in the workshop and the northern spotted owl recovery plan as a means of exploring if and how adaptive management should be applied (table 5-1): What vegetation restoration treatments best accelerate the development of forest structure associated with northern spotted owl habitat functions (in this case, foraging habitat; see chapter 3) while maintaining or restoring natural disturbances and providing greater ecosystem resiliency?

We distinguish between two approaches to implementing adaptive management. **Passive** adaptive management typically relies on historical data from a specific area to develop a "best guess" hypothesis and to implement a preferred course of action. This makes good sense when there is high confidence in the anticipated ecosystem response. **Active** adaptive management typically involves development of competing hypotheses about the impact of management activities on ecosystem functions and the design of management experiments to test them. Regardless of the approach taken, and given the status of the spotted owl and the continuing effects of fire suppression in dry forests, we think that effective adaptive management is integral to the continuing effort to conserve spotted owl habitat. Adaptive management experiments should directly address key questions and should be done in a manner that is both structured and judicious with respect to results of other efforts that provide guidance about likelihood of success.

Most of the issues that challenge the use of an active adaptive management approach to understand the effects of restoration treatments on spotted owl foraging habitat and prey base, forest structure and composition, and fuels and fire behavior can be mostly overcome with careful study design (see monitoring section below). However, concerns over the loss of spotted owl habitat in areas receiving restoration treatments as part of the study design will need to be addressed. In addition, the institutional capacity of management agencies to carry out treatments and complete the monitoring is of great concern owing to limited budget and available personnel.

Table 5-1—Application of adaptive management (AM) criteria to the address the effects of forest restoration treatments on spotted owl foraging habitat function, forest structure and composition, and fuels and fire behavior

AM criteria	Response	Rating
Temporal and spatial scale:		
Duration	Short-term response variables can be selected to provide a reasonable timeline for results.	1
Spatial extent and complexity	The spatial extent is large (eastern Washington and Oregon) but can establish AM on a subset of the area stratified by provinces and dry forest types.	2
External effects	Response variables can be selected to minimize confounding external influences. Climate change is challenging in longer-term studies.	2
Dimensions of uncertainty:		
Parameter uncertainty	Response variables can be selected and studies designed to allow reasonable statistical power.	1
Structural uncertainty	Previous research will allow hypotheses to be developed and response variables to be selected without too much uncertainty.	2
Stochasticity	This can be addressed in the study design by carefully selecting representative areas and adequate replication.	2
Confidence in assessments	A reasonable degree of confidence in completing useful assessments can be achieved about restoration treatments and foraging habitat at a patch or stand scale.	1
Costs, benefits, risks:		
Specifying costs and benefits		2
Magnitude of effects	Treatments need to be substantially different so as to measure effects. This may conflict with desires to minimize impacts to spotted owl habitat.	2
Multiple objectives	In addition to monitoring effects to spotted owl habitat structure and prey base; measure response of forest structure and composition, and fuels and fire behavior.	1
Perceived risks of failure		2
Institutional support:		
Leadership guidance	This is a high-profile issue that leadership has long recognized. However, additional commitment will be needed for resources to be made available and AM to occur. The Dry-Cascades Work Group could provide important leadership and coordination.	2
Flexibility in decisionmaking	Regulating policies about spotted owl recovery provides flexibility when treatments are focused on ecosystem restoration allowing for AM.	2
Taboo tradeoffs	There will be tradeoffs between conducting restoration treatments and preserving spotted owl habitat. However, the AM approach will allow managers to better define integrated management options.	3
Capacity of institutions	The management agencies have limited capacity owing to budget and personnel reductions.	3

Source: Gregory et al. 2006.
Key:
1 = Not a major barrier to proceeding with an active, experimental AM approach;
2 = Challenge that must be addressed to successfully proceed with an active, , experimental AM approach. Passive approach may be more appropriate;
3 = Significant challenge; active, experimental AM infeasible unless resolved.

Monitoring Design Considerations

Monitoring is continuous and provides feedback about changing conditions over time, the effectiveness of management actions, and testing of relevant assumptions. Monitoring is an essential component of adaptive management. However, current agency monitoring suffers from a lack of coordination and focus across administrative units and agencies. One of the major goals of the workshop on which this report is based was to coordinate better on monitoring questions and methods so that greater learning can occur about the effects of restoration treatments on northern spotted owl habitat functions. Here we review the different kinds of monitoring, important considerations in the design of monitoring studies, the key monitoring questions identified by workshop participants, and methods that can be used to address these questions. For convenience of discussion, monitoring is often described is three phases (Busch and Trexler 2003): implementation monitoring (i.e., did the restoration treatments result in the desired stand structure?); effectiveness monitoring (i.e., how did the restoration treatments affect prey for the northern spotted owl?); and validation monitoring (i.e., does a specified restoration treatment enhance the foraging habitat function for northern spotted owls?). There are several important considerations for managers and researchers to address in the design of an adaptive management monitoring program:

1. **Control sites are necessary to account for background changes** in the environment or the dynamics of the species or habitat elements of interest (i.e., temporal variability). For example, annual changes in weather may produce apparent treatment effects (e.g., drought and tree mortality) independent of the treatment, making it difficult to understand the effects of treatments unless controls are also monitored.
2. **Replication of treatments and control conditions** in several locations is necessary to account for spatial variation. We all know that no two stands are exactly the same, so we cannot expect to treat and measure one stand and be able to say confidently that the treatment will have the same effects everywhere. How many replicates of a treatment in a project are needed? Three is a bare minimum, four better, and six great. The exact number depends on the number of treatment alternatives being evaluated, how many stands are available in the project area, and the resources available to complete the monitoring. In general, it is better to have fewer treatment alternatives and more replicates per treatment than many treatment alternatives and few replicates per treatment. Significant advantages in the ability to detect treatment effects can be gained by replicating the

treatments across different project areas, either on the same national forest or on several national forests. In addition, such coordinated studies in a regional study network can account for a broader range of conditions that better reflect "real world" situations facing managers. Such study networks would be the "holy grail" of adaptive management and provide us with the best information and a faster learning curve. A good example of this is the national Fire and Fire Surrogates Study (McIver et al. 2012), which produced many strong and robust results on the effects of fuel reduction treatments in Western U.S. dry forests (e.g., Schwilk et al. 2009).

3. **Pre- and post-treatment sampling.** Pre-treatment sampling is not always necessary if there are sufficient control sites, but it does help account for high spatial and annual variability, especially when replications are few.
4. **Randomization** of the location of control and treatment units among the available project stands is important for applying the treatments across the full range of management conditions to avoid biasing outcomes by using subjective criteria. For example, we will not get a very good idea of the effectiveness of burn-only treatments vs. thin-and-burn treatments if we always select units with low fuel loads for burn-only treatments and high-load sites for thin-and- burn treatments.
5. **Develop and implement alternate treatments** to hedge bets on the best treatment. Why develop and test alternative treatments? We often have a good idea of what treatment is the "best" for our project; but if we are dealing with multiple or competing resource objectives, including cost and differing social values, and the uncertainty associated with the appropriate application of scientific studies done elsewhere, then it is highly unlikely that our knowledge is so fine-tuned that we know the best option. If we test only one treatment compared to a set of controls and do not get the outcome we wanted, then we must wait a few years and another project to test something different. If we test two or three treatments compared to a set of controls, we can greatly accelerate learning about how to achieve our restoration and habitat objectives.

Management Studies or Experiments—When Science, Planning, and Implementation Meet

Central to the application of adaptive management is the use of management experiments or studies that test assumptions about how management actions or treatments are likely to affect a particular resource such as spotted owl foraging habitat or forest structure that influences fire behavior (Nyberg et al. 2006, Stankey et al. 2005).

Management studies are defined as experimental designs applied to a management project to produce scientifically and operationally valid conclusions about the project and prescriptions used (Bormann et al. 2008). Successful implementation of and learning from management studies requires strong relationships and effective collaboration from researchers and managers (Bormann et al. 2008, Stankey et al. 2005, Swanson et al. 2010).

There are a number of examples of researchers and managers collaborating to design and implement management experiments (Agee and Lehmkuhl 2009, Gaines et al. 2007, McIver et al. 2012, Saab et al. 2007). Here we use the term management experiment or study in the context of integrating experimental research design concepts (see previous section) into project planning and implementation (Bormann et al. 2008). However, the integration of research and planning has not always gone smoothly in past efforts, as there are many challenges that can delay or even preclude these essential learning opportunities if key issues are not anticipated and addressed early in the process. The strength of relationships between managers and researchers reflect two main factors: (1) the level of mutual understanding of various authorities related to management and research programs, and (2) the interest of the involved parties in working together for common goals (Swanson et al. 2010). A key to successful partnership is having a shared commitment to the commons— the common land, a common interest in learning, and a common program of work (Swanson et al. 2010). Here we summarize lessons learned from past efforts that scientists and managers should consider in the design of management experiments that address wildlife habitat and forest restoration issues.

- **Early collaboration in project design.** It is essential that managers and researchers collaborate very early in project planning to ensure that mutual objectives can be met and experimental design concepts are integrated with project treatment design.
- **Identify a boundary spanner** (Stankey et al. 2005). A boundary spanner is someone, preferably from the management side, who has in-depth knowledge of both the basic research concepts and the agency planning process. Our experience has shown this position to be essential. In addition, communication skills are critical to an effective boundary spanner and should be foremost in the selection of the right person for this important role.
- **Educate about basic study design.** The entire interdisciplinary planning team, including the deciding official, should be educated about basic study design concepts including randomization, replication, and the need for no-treatment areas.

- **Collaborate on clearly articulated monitoring questions and objectives.** It is imperative that the study questions that are addressed matter to managers. A meeting early in the process focused on the development of these questions will help engage managers and focus research, setting a constructive tone for the remainder of the collaborative effort.
- **Document and continually revisit timelines.** Our experience has shown that timelines will inevitably slip and regularly need to be adjusted. Thus it is very important that frequent communication occurs so that everyone has clear expectations about timelines and commitments to meet timelines.
- **Be flexible, as planning is inherently uncertain.** Management direction may change, public comments may result in design changes, or change in leadership may alter the emphasis of a project. These can best be dealt with through communication between researchers and managers at key check points in the planning process. These include (1) initial project purpose and need discussion, (2) identification of issues, (3) development of a range of alternatives, (4) selection of a preferred alternative, and (5) final decision. What is important to track is how the experimental design concepts get integrated into the project design. This is an important role of the boundary spanner. They communicate to researchers how the process is going and bring researchers and managers together when important topics or changes need to be discussed.
- **Do not forget the implementers.** Be certain that those responsible for implementing the project (often these are not the same people as those planning the project) clearly understand the objectives, can review the design, and know the importance of communication if changes need to be made.
- **Use co-authorship to create ownership.** Publications that include both researchers and managers are a great way to get ownership in monitoring results and assure that results get implemented in future planning efforts.
- **Communicate results.** Include a strategy for how results will be shared with planners, implementers, decisionmakers, and the public.
- **Document adaptive management decisions.** Managers should clearly document how research results are integrated into future decision-making. Clearly articulated and judiciously documented management adaptations show critics that adaptive management can work.

By addressing these “lessons learned,” management actions as experiments can eventually become more integrated into the culture of land management agencies (Bormann et al. 2008, Stankey et al. 2005, Swanson et al. 2010). Clearly there is a need to learn as we go, made even more necessary by the uncertainties associated with a rapidly changing climate. In the next section of this chapter, we propose an adaptive management and monitoring approach to address spotted owl recovery and ecosystem restoration in eastern Cascades dry and mesic forests.

Adaptive Ecosystem Restoration and Monitoring for Northern Spotted Owl Recovery

There is a crucial need to approach adaptive ecosystem restoration and monitoring within the fire-prone provinces in the range of the northern spotted owl in a coordinated fashion to promote the rapid accumulation and dissemination of monitoring results, promote learning, and provide implementers with the latest information about how to design and implement projects that can accomplish multiple objectives at stand and landscape scales. There is a sense of urgency to this as the occurrence of large, uncharacteristic fires have already altered many landscapes, reducing the options for spotted owl recovery and forest restoration. In addition, there is a need to restore forest ecosystem resiliency in the face of climate change (Lenihan et al. 2008, Littell et al. 2010, Shafer et al. 2010, Spies et al. 2010). Fortunately, there is a group identified within the final northern spotted owl recovery plan (USFWS 2011) whose role would be ideal for coordination of active adaptive ecosystem restoration efforts.

Recovery Action 7 in the final northern spotted owl recovery plan calls for the creation of the interagency Dry Cascades Work Group that would be available to assist land managers in developing and evaluating landscape-level recovery strategies for the eastern Washington, eastern Oregon, and California Cascades Provinces, including monitoring and adaptive management actions (USFWS 2011). Some of the specific tasks that have been identified in the recovery plan for this group include:

- Recommending relevant research.
- Standardizing, to the extent possible, new recommendations for prescriptions and treatments for fuel reduction and other dry forest management (such as restoration treatments) to facilitate regional comparisons by meta-analysis and to maximize the scientific and management value of studies.
- Standardizing, to the extent possible, experimental (and monitoring) designs to assist with comparability across the region and to ensure statistically valid results.
- Assisting in the development or evaluation of plans that include landscape specific habitat objectives, treatment strategies, and projected outcomes.

- Developing monitoring techniques and coordinating effort. Given the uncertainties concerning sustaining spotted owl habitat in dry forest landscapes, monitoring is imperative.

Ideally, adaptive management and monitoring would occur through a network of management studies located within representative physiographic provinces (table 5-2). Within each physiographic province, at least two management studies would occur, spatially located to account for variation across the province. At each management study, four replicates of the following treatment objectives would be implemented to test spotted owl habitat function objectives and hypotheses described in chapter 3: no treatment, retention of key foraging habitat elements, and standard fuels reduction with retention of large trees. Response variables would include (see "Effectiveness Monitoring" in table 5-3): (1) population response of primary spotted owl prey species, (2) fuels modeling to determine if treatments altered short- and long-term fire behavior, and (3) levels of insects and disease risks, as well as presence or abundance of invasive species.

Once management study sites are selected, the process for designing and implementing adaptive management and monitoring to address the effects of restoration treatments on spotted owl habitat involves seven steps (Elzinga et al. 1998, Gaines et al. 2003): (1) complete background tasks, (2) develop objectives, (3) design and implement management, (4) design the monitoring methods, (5) implement monitoring, (6) report and use results, and (7) adapt management in light of monitoring results. We use these seven steps to illustrate how an adaptive management approach can be applied to spotted owl recovery within the context of ecosystem restoration.

Step 1: background tasks—
This step involves compiling and reviewing existing information, including relevant management direction. A major contribution of this report is to provide researchers and managers with the information needed for this step, including summaries of current science and relevant spotted owl recovery actions.

Step 2: develop clear, well-defined objectives—
At this step, general management goals and objectives are defined, and monitoring indicators are selected. The desired conditions for spotted owl habitat functions provided in chapter 3, table 3-1, reflect the best available information about spotted owl habitat and were developed to allow managers to develop measurable objectives and testable hypotheses for different habitat functions. In addition, the monitoring indicators provided in this chapter, table 5-3, provide a set of indicators that can be

Table 5-2—Potential network of adaptive management study sites by physiographic province in the eastern Cascade Range

	Number of management study sites		
Physiographic province	Ongoing	Additional	Management study site location
Washington eastern Cascade Range	1	1	Ongoing Swauk Study located on the Okanogan-Wenatchee National Forest. Additional site needed in southern part of the province.
Oregon eastern Cascade Range	2	0	Ongoing Pelican Butte Study located on the Winema National Forest.
California Cascade Range	0	2	Additional sites needed in south and north of province.

Table 5-3—Monitoring questions, indicators, and protocols identified by resource specialists at the workshop

Monitoring phases	Key monitoring questions	Resource area	Monitoring indicators and protocols
Implementation monitoring	Did the treatments achieve or move toward the desired conditions?	Wildlife	Vegetation plots to measure key habitat variables (see table 3-1).
		Fuels/Fire	Vegetation plots to measure surface and ladder fuels, and crown bulk density.
		Vegetation	Vegetation plots to measure species composition, structural attributes, and spatial arrangement of large trees.
Effectiveness monitoring	Where treatments effective at: Restoring or maintaining foraging habitat structure? Reducing fire hazard? Increasing stand sustainability?	Wildlife	Population response of primary prey species to the treatments using mark-recapture methods.
		Fuels/Fire	Fuel modeling to determine if treatments altered long- and short-term fire behavior.
		Vegetation	Determine if insect and disease risks were reduced. Determine if invasive species increased.
Validation monitoring	Was the assumption that treatments could be used to restore or maintain foraging habitat function while reducing fire, and insect and disease risks correct?	Wildlife	Foraging by northern spotted owls in treated versus untreated stands using radiotelemetry. Relationships between prey abundance and vegetation, down wood and other habitats.
		Fuels/fire	Postfire monitoring to determine if treatments altered stand-level fire behavior.
		Vegetation	Short- and long-term monitoring in treated and untreated stands of insects, diseases, and invasive species.

selected and to provide consistency across different monitoring areas. It is recommended that implementation and effectiveness monitoring be carried out at each of the management study sites. Validation monitoring (shown in table 5-3) may be too complex or long-term to be an effective adaptive management study and is better conducted as part of a research program.

Step 3: design and implement management—
It is important that monitoring be considered an integral part of the project design based on design considerations described in this chapter. Early collaboration between researchers and managers is imperative. In chapter 3, we provided stand-level spotted owl habitat objectives to move stands of varying initial conditions toward stand structures that provide for different spotted owl habitat functions. These should be useful in the design of the management treatments and development of testable hypotheses to be monitored.

Step 4: design the monitoring method—
This chapter provides a set of recommended monitoring indicators (e.g., habitat structure, prey population response) and protocols that can be used to design the monitoring and provide consistency across monitoring studies.

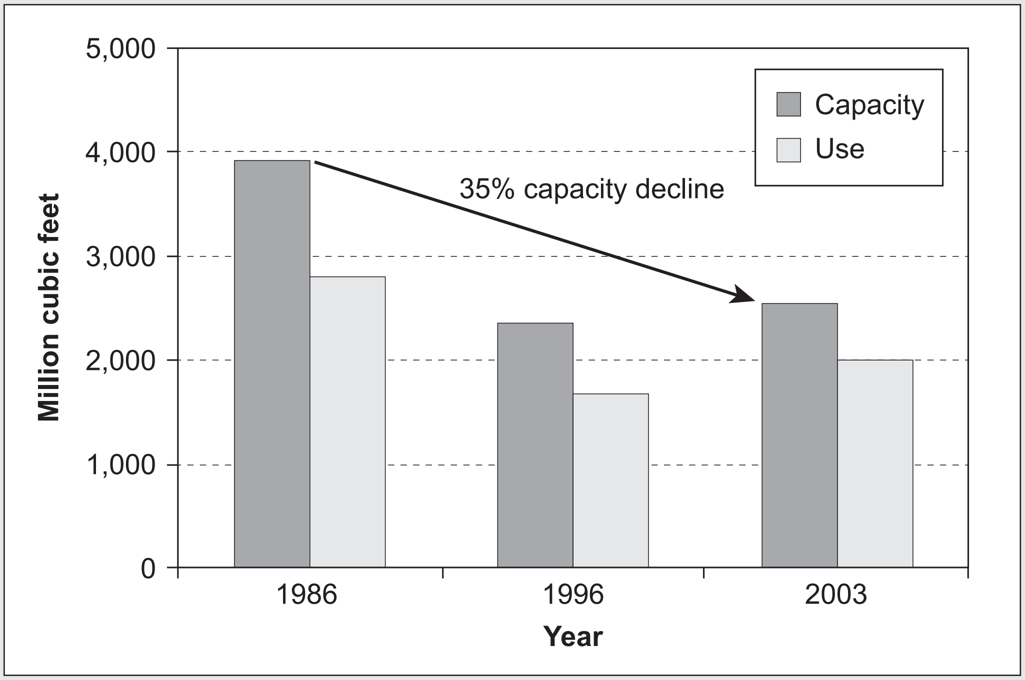
Step 5: implement monitoring—
This step includes the collection of field data, analysis of data after each measurement cycle (e.g., pretreatment, posttreatment), and evaluation of monitoring results. The Dry Cascades Work Group (described above) could provide an important role in coordination across monitoring studies to assure consistent data collection and analysis, and facilitate adjustments to monitoring efforts that might arise as methods are adjusted.

Step 6: report and use results—
For monitoring and adaptive management to be successful, the results, and their applications, must be displayed to managers, interested parties, and decisionmakers. In addition, it is important to leave tracks for successors, as some monitoring may be long term. Seeking peer review of the analysis methods and results is very important and should be an integral part of this step. The Dry Cascades Work Group could provide several key roles at this step: (1) coordinating analysis methods across monitoring studies, (2) establishing and implementing a peer review process, and (3) conducting meta-analyses across multiple monitoring studies.

Step 7: adapt management approaches given the monitoring results—
If monitoring is carried out in a way that views management approaches as experimental, is designed into projects at their inception, and is done in a scientifically rigorous manner, then it can be used to guide management of natural resources.

Box 5-1

Ongoing Monitoring: Swauk Management Study, Okanogan-Wenatchee National Forest; Pringle Falls Management Study, Deschutes National Forest; and Westside Management Study, Fremont-Winema National Forest.



Pacific Coast timber-processing capacity and timber use (excluding pulpwood and industrial fuel wood), from Keegan et al. 2006.

Project overviews: All projects evaluate experimental treatments within spotted owl habitat outside of an activity center. Treatments are designed to maintain some foraging habitat function for spotted owls. Each study is an independent effort by local management staff to address the issues; i.e., these three projects are not integrated into a larger meta-study.

Monitoring objectives: Wildlife monitoring objectives are to determine the effects of treatments on spotted owl prey species, primarily flying squirrels and woodrats, and spotted owl habitat structure.

Treatment design: The **Swauk** study will apply two silvicultural prescriptions that vary tree thinning levels ("light" vs. "heavy") and tree spatial distribution. The **Pringle Falls** study is measuring the impacts of five levels of thinning-from-below as a percentage of the Upper Management Zone based on the stand density index for ponderosa pine. The **Westside** Project has a single thinning prescription that attempts to reduce tree density

Continued on next page

Box 5-1 (continued)

by thinning-from-below to about 40 percent canopy cover while maintaining owl habitat value and within-stand patchiness with 2.5-ac uncut remnant patches over 15 percent of the treatment unit.

Monitoring methods: The experimental design includes monitoring before and after treatments, with replication of treatment and control units. The allocation of treatments to units (stands) was randomized, subject to operational feasibility. The occurrence and abundance of spotted owl prey species are being monitored by standard live-trapping methods on 40-m grids. Animals are trapped and marked during a 2-week trapping period during September or October. Prey occupancy and abundance will be estimated with multiscale occupancy and mark-recapture statistical methods. Vegetation (i.e., habitat) overstory and understory vegetation composition and structure and dead wood are being quantified by sampling 400-m^2 circular plots. Down dead wood is being quantified using a combination of line-intersect transect and log tallies on belt transects.

Progress to date: The Swauk project pretreatment prey and vegetation data collection occurred in 2013 and treatments will be implemented in 2016. The Pringle Falls study pretreatment data were collected during 2011 and treatments were implemented from 2011 through 2013. The Westside Project pretreatment data were collected in 2011 and treatments were implemented in 2013.

Project Leaders: Swauk: John Agar, silviculturist, Cle Elum Ranger District, Okanogan-Wenatchee National Forest; and Peter Singleton, ecologist, Pacific Northwest Research Station, Wenatchee, Washington. Pringle Falls Project: Paul Anderson, research forester, Pacific Northwest Research Station, Corvallis, Oregon; and Peter Singleton. Westside Project: Amy Markus, forest wildlife biologist, Fremont-Winema National Forest; and Peter Singleton.

Specifically, if monitoring is carried out in a consistent and rigorous manner across multiple representative sites within fire-prone provinces, important learning about how restoration treatments influence spotted owl habitat functions will take place. Again, the Dry Cascades Work Group can provide important roles at this step: (1) from the monitoring results, determine what warrants management adaptation, (2) determine the best source where these adaptations need to be made (e.g., recovery plans, land management plans, project planning, etc.), (3) coordinate how adaptations are made, and (4) provide a venue for supporting information.

Summary

The controversy and scientific uncertainty regarding how to implement spotted owl recovery within the context of ecosystem restoration provides an opportunity to implement short- and long-term adaptive management to improve the scientific basis for decisionmaking. A representative network of monitoring study sites within the fire-prone provinces of the eastern Cascades would ensure (1) consistent application of scientific principles, (2) robust statistical design and analysis, (3) central management of data to ensure quality and security, and (4) rapid learning and dissemination of results. Adaptive management and monitoring to address the effects of restoration treatments on spotted owl habitat remain an important proposal in recovery actions for the northern spotted owl. However, limited progress has been made in initiating and implementing these important actions on a scale needed to address the social and ecological diversity that occurs across the range of the spotted owl in the eastern Cascades. We propose a network of management study sites, each with a similar set of treatment objectives, that can be used to further our scientific understanding of spotted owl recovery within the context of ecosystem restoration. Work across this network would be implemented through research-management collaborations and coordinated by the interagency Dry Cascades Work Group. Additionally, this group could assure that information generated from the network of management studies be used to adapt recovery and management plans as necessary. With spotted owl populations continuing to decline across much of their range, and projections for considerable increases in the amount of wildfire as a result of changing climates, time is of the essence. Our limited knowledge about how best to design treatments to restore the resiliency of landscapes while providing for spotted owl habitat could greatly hinder our ability to act unless we learn as we go.

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Chapter 6: Social Trends Affecting Successful Implementation of Forest Restoration Guidelines

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What are the current and long-term prospects for implementing silvicultural and monitoring guidelines to restore dry mixed-conifer forests in Oregon and Washington across the range of the northern spotted owl (*Strix occidentalis caurina*)? We examine the human sources of support for their successful implementation and barriers to their success. We consider people within the context of institutions and markets, as individuals, and as members or critics of organizations. Our interest is in policy, economic, public, and organizational trends of the past decade important for forest management because the outlook for silviculture and monitoring in the eastern Cascade Range is derived from them. In our view, the current prospect for successful guideline implementation is limited. Long-term success depends on near-term actions.

The current prospect for successful guideline implementation is limited.

Policy Trends Affecting Guideline Implementation

Policy support for implementing silvicultural and monitoring guidelines to restore dry forest types is expanding (USDA FS 2012a, USFWS 2011). For example, a critical habitat designation for the northern spotted owl (NSO) was revised in 2008 and has recently been revised again (USFWS 2012). Likewise, a 2008 recovery plan issued by the U.S. Fish and Wildlife Service for the NSO was revised in 2011 (USFWS 2011). The newest plans seek to address two threats now considered key to the continued survival of the owl, namely habitat loss and intra-species competition. It does so by including recommendations that include protecting nesting and roosting habitat and occupied NSO habitat, restoring forests through active management, and managing the barred owl (*Strix varia*). Policy recommendations for a program of landscape-scale, science-based adaptive restoration treatments have been years in the making; in the coming sections we summarize trends in their evolution and continued limitations.

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The decade after the 1990 listing of the NSO as an endangered species was marked by policies and activities focused at the species-level. In particular: (1) learning what habitat was; (2) identifying population demographics; and (3) relating habitat to population dynamics. Large-scale, landscape and regional monitoring (i.e., understanding what existed and how it changed) was emphasized more than smaller-scale, stand-level silvicultural treatments and monitoring (i.e., changing what existed and observing effects). The first "critical habitat" designation noted that even-aged silvicultural practices such as clearcutting and short rotations eliminated or prevented the development of suitable NSO habitat but that uneven-aged silvicultural practices like selection systems could potentially maintain it (USFWS 1992). To protect existing owl habitat on federal land, the Northwest Forest Plan (NWFP) conservation strategy zoned 24.4 million acres into different management allocations (USDA FS and USDI BLM 1994). The NWFP was explicit about the role of active management in some land allocations, but ambiguous about it in others (Hummel et al. 2001).

Late-successional reserves and managed late-successional areas (collectively referred to as LSRs) were the NWFP land allocations intended to provide nesting, roosting, and foraging habitat (NRF) over the long term (USDA FS and USDI BLM 1994). In concept, silvicultural activities were permitted to protect or develop habitat in LSRs but, in reality, few treatments occurred. The lack of activity likely stemmed from a lack of clarity in the NWFP to the geographic scale of silvicultural implementation or evaluation (Hummel et al. 2001) in combination with aversion to risk exhibited by federal land managers and their stakeholders (Lee and Irwin 2005). Silvicultural treatments that did occur were more to protect existing habitat (e.g., fuel reduction to change fire behavior) than to develop new habitat (Lee and Irwin 2005). Moreover, some people believed that traditional silvicultural systems were inadequate for any objective other than wood production and thus proposed new ones (e.g., Debell et al. 1997). The lack of empirical evidence about the new systems hampered their being implemented and provided impetus for simulation models being used instead to estimate their effects.

Beginning around 2000, the species-level, habitat focus of the 1990s expanded to a broader scope: namely, managing ecosystems and landscapes. At least three things drove this expansion. First, the increasing severity and size of wildfires in the Western United States (such as the 2002 Biscuit Fire) (Bormann et al. 2007) led to new legislation (HFRA 2003) and to increased funding levels for fire-related research (e.g., Cleland et al. 2005). Second, advancements in the use of remote sensing and geographic information systems (GIS) in ecology increased the geographic scale at which forest structural and compositional dynamics were studied and disturbance dynamics were understood (Cohen and Goward 2004), and third, the development and use of landscape models accelerated as part of a focus on new methods by the USDA Forest Service Pacific Northwest Research Station (fig. 6-1).

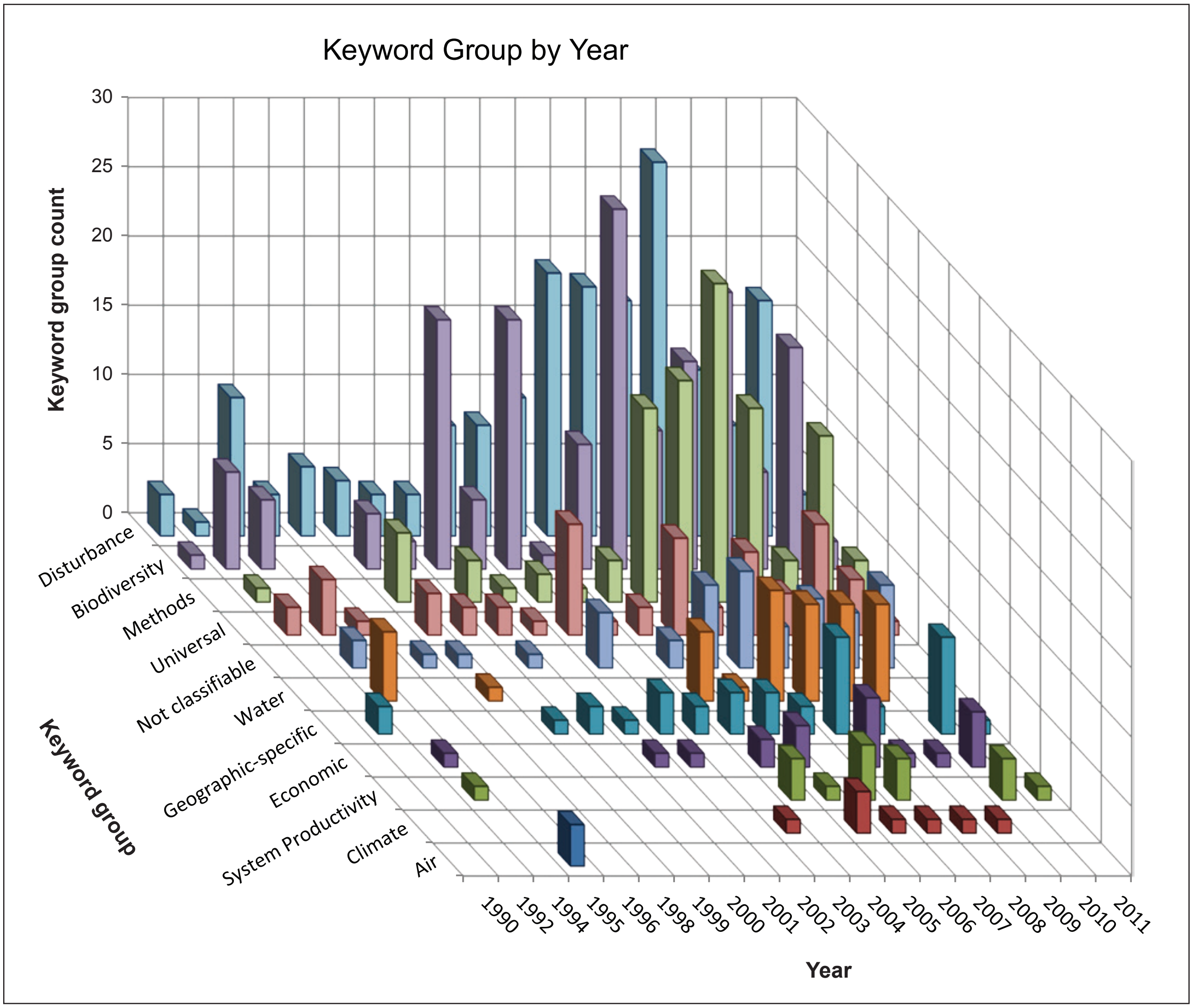

Figure 6-1—Annual landscape science publications by year and keyword topic published by USDA Forest Service Pacific Northwest Research Station scientists.

Since the listing of the NSO, knowledge about wildfire effects and landscape ecology has been advanced by better spatial information and analytical capacity. The advances have been translated into better modeling of both owl habitat and fire "habitat," and—according to the 15-year review of the NWFP—"wildfire remains the leading cause of owl habitat loss" (Davis et al. 2011).

As awareness of wildfire effects on owl habitat grew after 2000, so too did recognition of size differences between landscape disturbance effects, owl home ranges, and silvicultural treatment units ("stands"). Taken together, the spatial mismatch raised questions about the appropriate spatial unit for prescription design and evaluation (e.g., Hummel and Calkin 2005). Because certainty was lacking (especially on relations between habitat and fitness), it was rare to find specific silvicultural guidelines for creating or protecting NSO habitat with respect to fire (but see, e.g., Mendez-Treneman 2002). Silviculturists asserted that their discipline was relevant (DeBell et al. 1997), but did not have many opportunities to demonstrate it. Even in the NWFP land allocation created specifically for innovative silviculture (adaptive management areas or AMAs), "precaution trumped experimentation," and little activity occurred (Bormann et al. 2007). Some long-term silvicultural demonstrations were initiated or continued, but they lacked variables considered important for evaluating effects on the NSO (Poage and Anderson 2007). Moreover, there was scant organizational or financial support from federal agencies for adaptive management (Bormann et al. 2007, Stankey et al. 2003, 2006). As a direct result of limited agency and public support for implementing innovative silvicultural systems and then monitoring them, empirical evidence remains scarce about treatment effects on the NSO at multiple spatial scales.

As a direct result of limited agency and public support for implementing and monitoring innovative silvicultural systems, empirical evidence remains scarce about treatment effects on the northern spotted owl at multiple spatial scales.

Previous inaction to develop NRF habitat continues to limit silvicultural options when empirical evidence is required before treatments can occur. That is the case for the current reserve-based management strategy of the NWFP and for a whole-landscape strategy proposed under the Northern Spotted Owl Recovery Plan (USFWS 2011). A whole-landscape approach refers to eliminating zoning as currently applied in reserve and matrix conservation designs and instead managing ecosystems under direction similar to the east-side reserve standards and guidelines of the Northwest Forest Plan, which emphasize ecosystem restoration. The ecological and social implications of a whole-landscape strategy that includes spotted owl recovery remain unknown, however. The proposed forest plan revisions for the Okanogan-Wenatchee and Colville National Forests in eastern Washington address the need for a new approach and new information. They are based on the current Forest Restoration Strategy of the Okanogan-Wenatchee (USDA FS 2012b). Yet, the crux of the issue is not planning and analysis, but policies that implement evidence-based management in a way that constantly improves our knowledge through adaptive learning, i.e., monitoring and research.

The ability of land managers to plan and implement forest restoration activities depends on supportive policies about renewable resources in addition to those that support habitat management. For forest products associated with restoration actions, policy trends are also expanding. For example, many national policies have emerged as a result of the nation's desire to reduce its use of fossil fuels through investments in renewable energy sources, including biomass and wood energy (Aguilar et al.

2011). The issue is addressed in the publication *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: the Technical Feasibility of a Billion-Ton Annual Supply* (Perlack et al. 2005). This so-called “billion ton study” has since been updated to determine if a sustainable amount of biomass is available to displace petroleum consumption in the United States (USDOE 2011). Too, states have begun adopting renewable portfolio standards to fulfill national regulations. In areas with an abundance of biomass in Western states, such standards provide opportunities to use the woody byproducts of forest restoration and fire risk reduction activities (e.g., Nicholls et al. 2008). However, large-scale (from 20 to 75 megawatts [Bain and Overend 2002]) stand-alone projects face numerous challenges. These include sustainability, access to, and cost of supply; fluctuations in the price of competing fuel sources such as oil and natural gas; and, if generating electricity, securing long-term power purchase agreements from utilities. Moreover, the availability and dominance of hydropower in the Northwest makes it difficult to sell excess power generated from other sources back to the grid. Although there is evident interest in expanding the feasible options for resources associated with forest restoration, their current availability is limited.

Economic Trends Affecting Guideline Implementation

Economic trends are in flux for implementing silvicultural and monitoring guidelines in the eastern Cascade Range. Changes in land ownership patterns, decreases in community economic stability and subsequent erosion of infrastructure, and fluctuation in wood product and energy markets create levels of uncertainty that thwart planning. The prescriptions and tree marking guidelines identified in chapter 4 will remain unused if incentives to implement them are lacking or are weaker than barriers to their implementation. Some barriers are economic, meaning how resources like labor, capital, and land are allocated within society for production, distribution, and consumption of goods and services. For example, do processing facilities exist and is there a cadre of people with appropriate technology who will harvest and deliver forest resources to them? Is there a demand for these products? Who owns forest land and within what incentive and regulation structure do the owners operate? These questions are not trivial, given the trend in mill closures and loss of timber processing capacity (fig. 6-2), ongoing changes in the ownership of private forest land in the Pacific Northwest, and fluctuating energy policies.

The prescriptions and tree marking guidelines identified in chapter 4 will remain unused if incentives to implement them are lacking or are weaker than barriers to their implementation.

The direct relationship between the number of processing facilities for forest products, the volume of resources harvested, the price of timber and economic indicators like employment holds both domestically and abroad. Over the years 1996 to 2003, three periods of high mill closures occurred: 1995–1996 (cutbacks in U.S. Forest Service timber sales increased timber prices to mills); 1998–1999

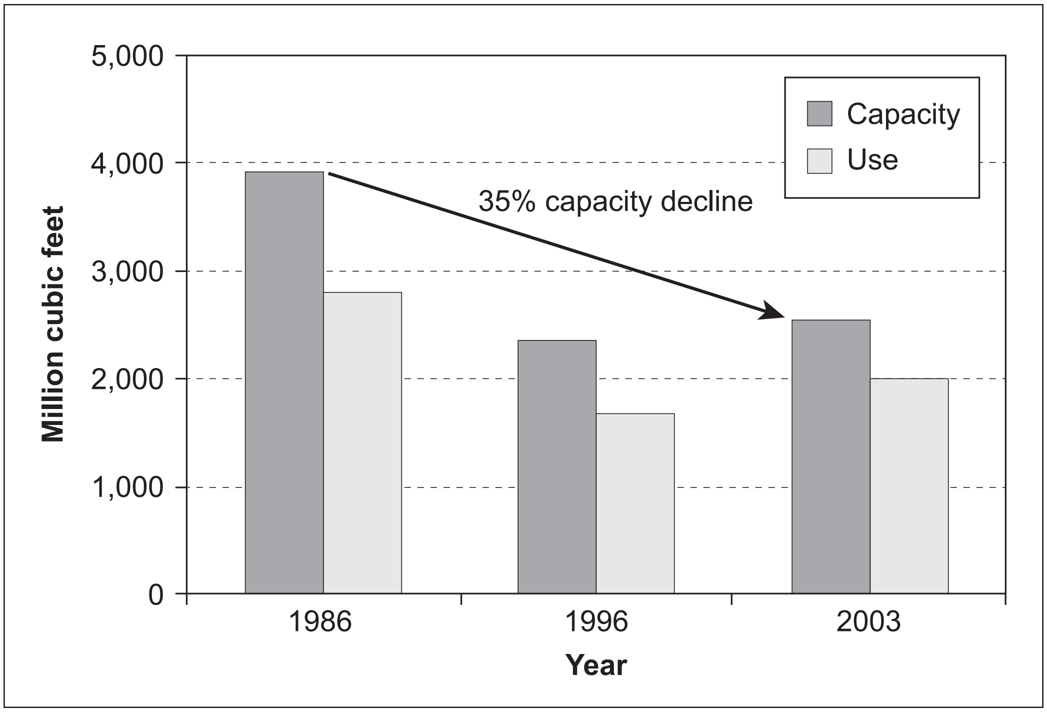

Figure 6-2—Pacific Coast timber-processing capacity and timber use (excluding pulpwood and industrial fuel wood), from Keegan et al. 2006.

(partially due to a major recession in Japan); and 2001–2002 (the result of a recession in the U.S. economy, spurred by reduced housing starts and rising interest rates) (Spelter 2002). Between 1990 and 2010, Oregon lost 93 sawmills and Washington 70 sawmills (Ehinger 2010). The volume of timber harvested on federal lands in the Western United States dropped coincident with the decline in wood processing facilities. Both declines are a reflection of shifting social preferences for Northwestern forests. In addition to the federal listing of species like the NSO there was a move to protect ecosystem services such as water quality and habitat (Weber and Chen 2012), and the combined effects on timber harvest were significant. Federal lands accounted for about 40 percent of timber harvested in the Western United States in the late 1980s; by 2003 this figure was less than 10 percent (Keegan et al. 2006). Most of the negative effects of the NWFP on harvesting infrastructure and production capability (fig. 6-3) occurred by 2000 (Weber and Chen 2012). The Western United States was hardest hit by closure of federal lands to timber harvest that began in the early 1990s (Spelter 2002), but by the mid-1990s in Oregon and Washington timber processing capacity began to be rebuilt by using timber from private and nonfederal public lands (Keegan et al. 2006).

A transition is underway in the amount and type of forest products that are associated with silvicultural activities in the Western United States and, as in any

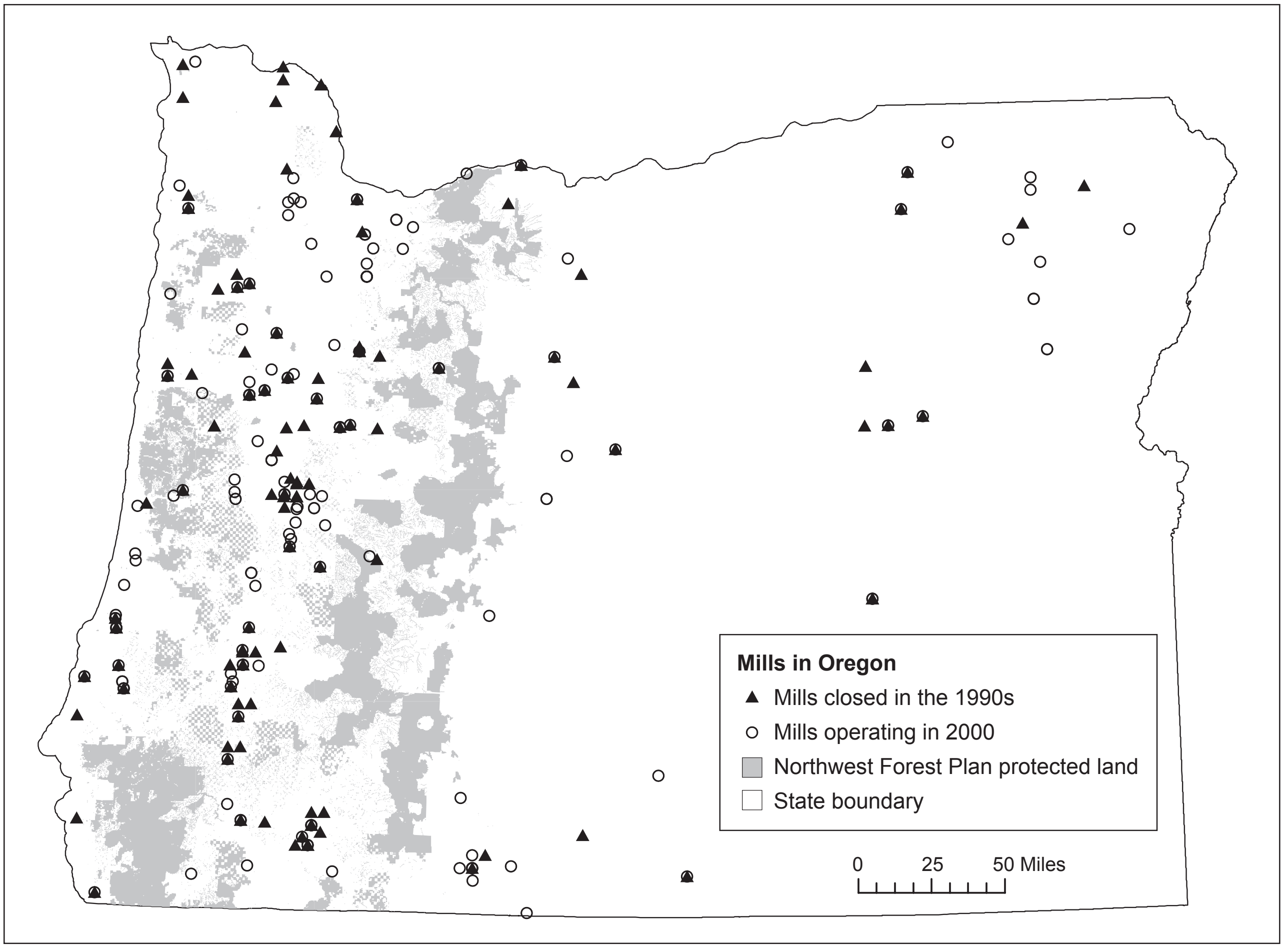

Figure 6-3—Lumber mills and Northwest Forest Plan protected forest land in Oregon (from Weber and Chen 2012). Permission to use secured from author.

transition, uncertainty is high about the feasibility of new approaches that create those products. Priorities for land management on federal lands have evolved to include more than just the removal of sawtimber (volume focus) to restoration prescriptions (forest structure/health focus) in the effort to alter fire severity, reduce insect and disease susceptibility, restore wildlife habitats, and create more resilient forests. In the interior West, this has resulted in a shift from harvesting trees used in traditional solid wood products (sawlog-size trees), to the removal of smaller trees. Keegan et al. (2006) found that in 2003, 80 percent of the milling capacity was unable to process trees <10-inches diameter at breast height (d.b.h.) and there was virtually no capacity to use trees smaller than 7 inches d.b.h. Trees of less than 10 inches d.b.h. were only marginal to process and those under 7.5 inches d.b.h. not profitable at all (Wagner et al. 2000). Dramm (1999) reported that much of the manufacturing infrastructure that could have used this material no longer exists in many forest-based rural communities.

In response to ongoing changes in the size and quality of wood being harvested, exploratory efforts are underway to identify increased utilization opportunities and technological advancements. New technology often comes at a high price, however, and some smaller mills do not have resources for the necessary capital investment. Companies survive that are able to invest in new technology that allow for high-speed processing of small-diameter logs or portable sawmills. Wagner et al. (2000) found that high-speed, small-log sawmills could process the smaller diameter trees more profitably than conventional sawmills. Other companies were hesitant to make the investment given an unreliable feedstock supply. These advances in processing small-diameter trees can be a double-edged sword. Although the capability provides opportunities, improvements often lead to a reduced number of employees.

Other influential elements during the ongoing transition period for wood products include demand for housing and the price of fuel. The housing price decline that began in late 2006 (Gale et al. 2012) and subsequent decreases in new housing starts strongly affected the construction sector and demand for forest products. The effect on communities east of the Cascade Range that had been experiencing rapid growth (e.g., Bend, Oregon) was profound. In 2007, eastern Oregon had 10 mills left in operation (Doussard 2007). By the next year only eight lumber mills remained in central Oregon (fig. 6-3) (Gale et al. 2012). Mill closures in rural communities proportionally represent a much greater loss in employment (Chen and Weber 2012, Eichman et al. 2010) and the forest sector is of much more importance there (OFRI 2013). One result is that formerly timber-dependent communities have begun to examine a wider array of opportunities to use small-diameter logs (LeVan-Green and Livingston 2001) (fig. 6-4).

It remains a struggle for investors and communities to identify appropriate-scale biomass utilization industries and to secure a reliable, long-term supply of raw materials. The latter is particularly true for businesses that rely on supplies from federal land. One reason is that the costs involved—first in implementing restoration treatments and then in hauling away woody material—are often greater than the value of the biomass (Adams and Latta 2005, Han et al. 2004). The best ways to reduce costs are to shorten haul distance or co-locate processing facilities (Becker et al. 2009b), advance development of biorefineries and liquid biofuels (Amidon et al. 2008, Winandy et al. 2008), and find other biobased products (e.g., wood pellets; torrefied wood) to co-fire with coal, thereby offsetting fossil fuel consumption and reducing greenhouse gas emissions. Smaller-scale projects, such as thermal heating projects in public buildings, have gained traction. The Fuels for Schools program (McElroy 2007) is an example that started in the Eastern United States in the 1980s and has since moved to the intermountain West. In recent years, wood pellets have become a popular feedstock in residential heating in Europe and the United States as

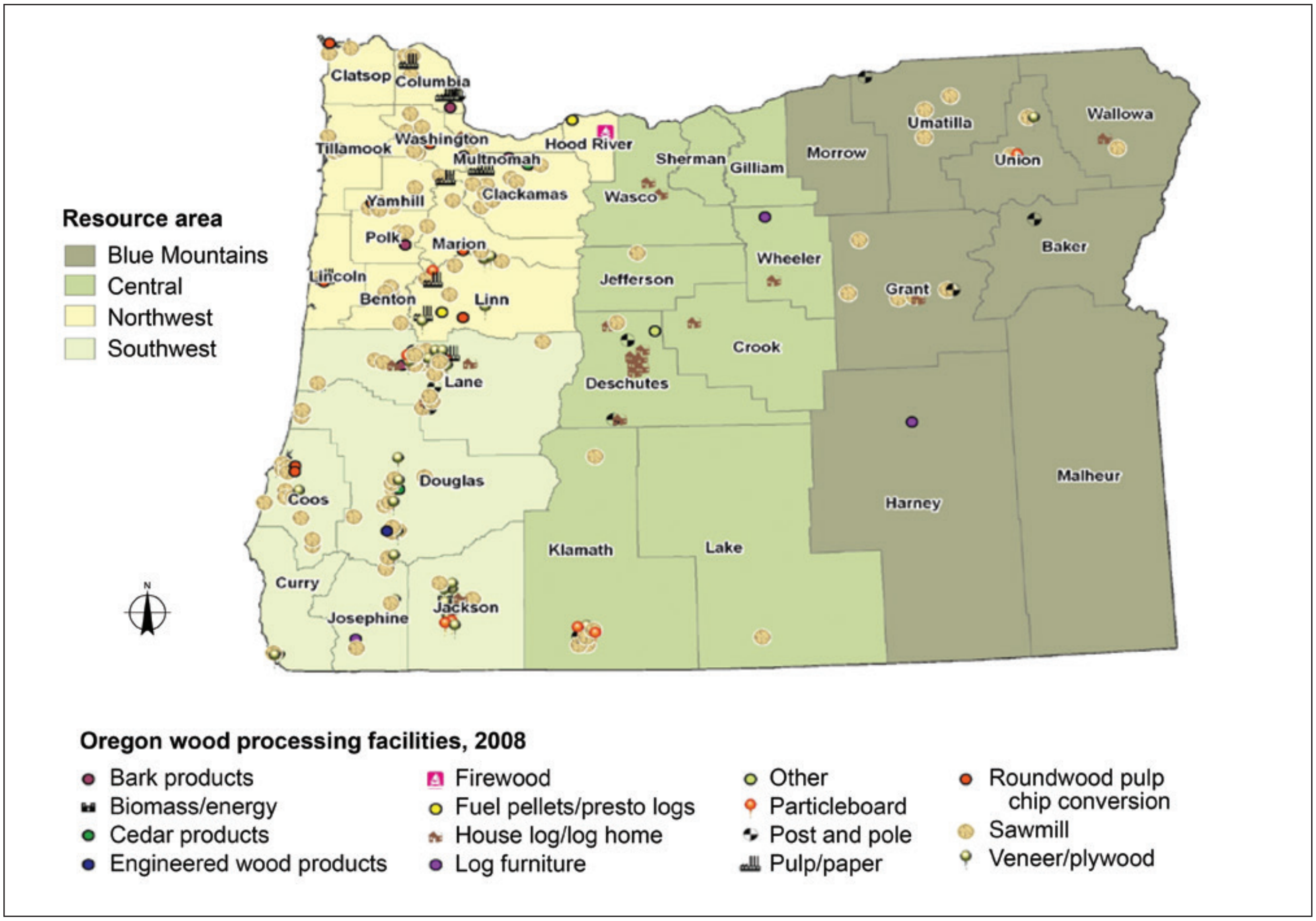

Figure 6-4—Oregon resource areas and active primary forest product manufacturers, 2008 (from Gale et al. 2012).

well as an alternative to wood chips for fueling heat projects. Some of these smaller facilities generate both heat and power (CHP or combined heat and power system). Other small-scale industries were boosted by grants via the National Fire Plan Economic Action Program (2001–2003), which were designed to provide assistance in technology implementation and enhance financial assistance to local projects that emphasize market development and increased value. Becker et al. (2009a) found that success and more importantly continued progress required more than just the individual grant. The Woody Biomass Utilization grant program (2007–present) was implemented to address the nationwide challenge of using low-value woody biomass material. For most wood-energy projects to move forward, a guaranteed long-term feedstock supply is required. In response to this need, the Forest Service began offering long-term (10-year) stewardship contracts in 2004. Partnerships were formed among communities, agencies, nonprofits, and industry to make available and stabilize supply. In their summary of the first 5 years of the White Mountain Stewardship Project in Arizona, Sitko and Hurteau (2010) reported that although treatment costs have not changed, resulting multiplier effects that businesses generated in investments, expenditures, and tax revenue exceeded contract costs. Recognition of the effectiveness of partnerships and collaboration resulted in the establishment of the Collaborative Forest Landscape Restoration Program (CFLRP 2009), which has been described as "one of the most innovative and significant forest policy experiments to take place in recent decades" (Schultz et al. 2012).

Federal forest land may dominate east of the Cascade Range, but cooperation by other landowners and community groups is essential for implementing guidelines that rely on an ecosystem perspective. In the Northwest, the trend has been toward less industrial timberland with a corresponding increase in institutional investors. In contrast to timberland owners, investors are unlikely to have trained foresters on staff and more likely to have short-term financial goals. Land perceived to limit quarterly profitability (like forest with suitable owl habitat) is, therefore, subject to trade, which could increase the likelihood of guideline implementation. This trend gathered steam in the late 1990s, when there was a net loss of industrial timberland in the United States (Sampson Group 2000). Ongoing consolidation among corporate investors continues. One transaction that included land in eastern Washington is illustrative: in 2012 nearly 2 million acres of timberland owned by Forest Capital Partners LLC (an institutional investor) was acquired by Hancock Timber Resource Group (a division of an operating company of a Toronto-based multinational corporation) and Molphus Woodlands Group (a registered investment advisor). According to a press release that accompanied the transaction, "Molphus acquires, manages, and sells timberland as an investment vehicle for pension funds, college endowments, foundations, insurance companies, and high-net worth individual investors." In light of this trend, it is not surprising that some land acquired by institutions was subsequently sold to organizations or land trusts interested in conservation. Such land may be comparatively unproductive, socially contentious, or otherwise appropriate for divestiture. The transfer of land from industrial to institutional to conservation owners is being accompanied by new sales agreements and new organizations that develop to implement them. For example, the Nisqually Land Trust is an organization which purchased 520 acres of "environmentally sensitive land" from the Hancock Timber Resource Group to complete, in 2012, a 2,500-acre, $10.5-million-dollar project known as the Mount Rainier Gateway Initiative. The Nisqually Land Trust made the purchase with help from a federal land-acquisition grant via the Washington State Department of Natural Resources (DNR). According to the press release, "the DNR will hold a conservation easement on the property in perpetuity, ensuring its use as habitat." The areas connected by the corridor, between the Gifford Pinchot National Forest and the Elbe Hills State Forest, include species like the NSO. The Nisqually

Indian Tribe helped provide project funding and will provide management assistance. A partnership of public and private organizations is not unique to this transaction. The increasing trend for land that could be managed as habitat to be transferred to amenable nonprofit or private owners is positive for guideline implementation. Details on who bears the cost of monitoring will depend on the form and content of a land transfer agreement (e.g., deed, conservation easement, partnership, etc.).

Success in restoring and managing forests in the eastern Cascade Range will be measured in more than dollars and depends on more than economic indicators. The scope of the geographic area potentially suitable for restoration silviculture and any associated forest products requires creative solutions that begin in the woods and follow through the product value chain. A large-scale solution may be able to handle the quantity of biomass available, but is the local capacity and infrastructure available? Is it sustainable? Does the community welcome its presence? Solutions more attractive at a smaller scale (low capital investment) might be enterprises like firewood (e.g., traditional, briquettes, pressed logs), post and pole, animal bedding, and log home building or new products under development. Many rural communities in the region are still struggling to build industries that can effectively use materials removed in forest restoration and fire risk reduction activities. They have invested time, money, and resources pursuing feasibility studies on biomass projects that never come to fruition. Yet they know that by establishing a bioenergy or biobased products industry, they will directly benefit through increased jobs, wealth retention and multiplier effects that ripple through their communities (Hibbard and Lurie 2006). Support and success has been realized in projects such as Fuels-for-Schools and other public wood energy applications (Resource Innovation Group 2013) that realize cost benefits in addition to making communities feel less at risk and more resilient. Working together from the start helps make such ventures successful, but requires people willing to invest time and resources.

Public Trends Affecting Guideline Implementation

The beliefs, values and attitudes that people have about land management and the trust they place in land management agencies have great bearing on whether there is public support for forestry. The need for a “social license” in forest management is particularly important in places like Oregon and Washington where a majority of land remains in federal ownership. Over the past decade, public awareness about a role for actively managing habitat has grown and federal agency efforts to consult and involve stakeholders in planning have increased. Nonetheless, public trends in acceptance and trust of agency plans for experimentation in, and management of, public forest land fluctuates.

Awareness among the American public about endangered plant and animal species has increased as has knowledge about the need for conserving their habitat

(Carey 2003, Czech and Krausman 1999, Kempton et al. 1996) Numerous studies, including some in the eastern Cascade Range, document public support for managing forests to reduce the risk of wildfire (Absher and Vaske 2006, Brunson and Shindler 2004, Shindler and Toman 2003) and to improve forest health (Bowker et al. 2008, Burns and Cheng 2007, Paveglio et al. 2010, Vining and Merrick 2008). In some cases, people are willing to give public agencies more discretion in implementing fuels management projects (Absher and Vaske 2006, Brunson and Shindler 2004, Shindler and Toman 2003). Moreover, studies have documented willingness among homeowners and private forest owners to invest in fuels management and restoration activities on their own lands and through cooperation with public agencies, both in the eastern Cascades (Carroll et al. 2004, Fischer 2011, Fischer and Charnley 2012) and the United States more broadly (Bowker et al. 2008, Brenkert-Smith et al. 2012, Jakes 2003). Understanding the interaction of fire behavior, forest structural dynamics, and owl habitat in the eastern Cascades is a topic with increasing policy support (USFWS 2011, USDA FS 2012b) which may be interpreted as a reflection of increasing social support.

Efforts by public land management agencies to raise awareness and engage the public in discussion about forest health and wildfire issues are increasing, which may explain some of the public support for management activities. Indeed, citizens recognize that the Forest Service solicits public input on forestry activities in the eastern Cascades in Oregon more frequently now than it did in the past (Shindler and Toman 2003). The Forest Service also engages stakeholders in forest planning through such mechanisms as Resource Advisory Committees, the Collaborative Forest Landscape Restoration Program, the Fire Learning Network, and, increasingly, local collaborative groups.

Although information about ecological benefits of ecosystem management can improve public acceptance of agency management practices (Brunson and Reiter 1996), much research indicates that information is not sufficient to influence whether people have positive or negative attitudes toward natural resource management practices (Bright and Manfredo 1997). An individual's support for specific natural resource management practices also derives from attitudes, beliefs, and social norms. People support land management strategies that they believe will have a positive outcome for items of personal importance or that they believe have intrinsic value, which depends on their environmental values (Dunlap and Van Liere 1978) and situational relationships to land (e.g., economic reliance, recreational use, proximity of residence) (Vogt et al. 2005; Winter et al. 2002, 2004).

People's perceptions of risk also play into their attitudes about ecosystem management. The "social amplification of risk" framework (Kasperson et al. 1988) asserts that the way people understand risk is influenced by science but also "the cultural, social, and individual response structures that shape the public experience of risk." When individuals hold different perceptions of risk and different levels of risk aversion, it is not surprising that they disagree about the nature of a problem and the solution to it. In the absence of public policy about how to translate risk assessments into management, the likelihood for (continued) stalemate and inaction is high. Lee and Irwin (2005) observed this behavior surrounding proposals for reducing fire severity in habitat occupied by spotted owls. It illustrates risk aversion in biodiversity conservation: a bigger loss now (site-specific habitat loss and potential death of individual birds) is preferred over an uncertain but potentially smaller loss to a greater area of habitat or to a population.

The trust that people have in a land management agency is an important factor in how they perceive risks associated with land management strategies and whether they support such strategies: to place trust in an agency's decision regarding land management, people must not only believe that agencies are competent and legitimate managers; they must also assume that agencies will manage forests in the interests of the public or local citizens (Toman et al. 2011, Vogt et al. 2005, Winter et al. 2004). Trust is conditioned on shared norms and values (Bouas and Komorita 1996, Swaab et al. 2007) and perceived legitimacy (i.e., when people or organizations are viewed as fair and capable and are empowered by others) (Tyler 2006) and perceived efficacy (Lijeblad et al. 2009).

Trust can develop out of social processes that build common understanding. Types of citizen-agency interactions that are thought to build trust are those that go beyond traditional meeting formats such as the public hearings commonly used to comply with the National Environmental Policy Act (NEPA) (Cortner et al. 1998, Shindler et al. 2002). Interactive formats are thought to be more effective than such unidirectional methods (Toman et al. 2006), especially formats in which public involvement is early and continuous and that are open and inclusive, built on skilled leadership, include innovative and flexible methods that integrate local and scientific knowledge and goals, and result in shared decisionmaking that leads to action (Lawrence et al. 1997, Reed 2008, Schuett et al. 2001, Shindler and Cheek 1999). In addition to increasing common understanding of natural resource problems, public-agency interaction and collaborative planning is thought to help overcome policy gridlock and facilitate more effective and equitable solutions to natural resource conflicts (Carr et al. 1997, Daniels and Walker 1996, Wondolleck and Yaffee 2000). However, although collaboration has been linked to positive social outcomes (e.g., increased trust) (Leach and Sabatier 2005), and some argue that litigation has declined in national forest contexts where successful collaborative forest management issues are occurring (Sustainable Northwest 2013), systematic investigations of environmental outcomes of collaboration have not been conducted (Koontz and Thomas

2006). Moreover, Shindler and Toman (2003) found that the public increasingly relies on information from sources other than public agencies, perhaps indicating that they consider other sources more trustworthy. In the same study, citizens in the eastern Cascades region were less confident that the Forest Service in particular uses public input to inform land management decisions A study of homeowners in areas with fire-prone forests found that they gain information not only "vertically"—that is, from experts—but also "horizontally" or from informal interactions (Brenkert-Smith et al. 2013). Thus, in order to improve mutual understanding about, and garner public support for, implementation of any silvicultural and monitoring guidelines to restore forests and sustain NSO habitat, forums for learning among citizens and organizations other than natural resources agencies will likely need to be leveraged.

The experimentation necessary to improve management practices will benefit from strategies that build alliances among people from different disciplines and functional roles and that assuage their concerns about innovation. Evidence to support this perspective is imbedded, for example, in a recent decision by the National Oceanic and Atmospheric Administration (NOAA) to declare a population of steelhead (*Oncorhynchus mykiss*) as nonessential and experimental (NEP) under the 1973 Endangered Species Act (ESA 1973). The NOAA decision directly changes the calculations of risk and liability among individuals and organizations involved with decisions about the ongoing management of the Deschutes River. One response could be for individuals who hold similar perceptions of a problem and degrees of risk aversion to form alliances. Such behavior is observable in current shifts in land ownership from institutional investors to nonprofits and in community "firewise" protection efforts.

Federal agencies involved in forest management possess extensive knowledge and experience from which to draw, but trends in these organizations will limit successful implementation of any silvicultural and monitoring guidelines.

Organizational Trends Affecting Guideline Implementation

The federal agencies involved in forest management possess extensive knowledge and experience from which to draw, but trends in these organizations will limit successful implementation of any silvicultural and monitoring guidelines. One presumption for monitoring and adaptive management is that learning fosters change (see chapter 5). Some evidence suggests, however, that current patterns of communication and cooperation among researchers and managers in federal agencies across the range of the NSO are not consistent with learning (Fischer et al. 2014). Rather, such agencies have historically followed unidirectional approaches to science communication; namely, scientists identify what knowledge is lacking, which knowledge gaps to fill by what methods, and how to transfer new knowledge to land managers. When questions and problems are complex, however, as in forest ecology and management, criticism of the unidirectional model is sharp (Roux et al. 2006); current conditions in forests of the eastern Cascade Range imply that it also is inadequate. Unless meaningful organizational changes can promote a bidirectional model of knowledge generation, the prospect for implementing new silvicultural and monitoring guidelines is limited.

Simulation models, new methods, and large datasets for landscape analyses now exist that can help focus locations for stand-level treatments in support of forest restoration and NSO habitat development (e.g., Ager 2007, Gaines et al. 2010, Kennedy et al. 2008). Indeed, between 2000 and 2010 the USDA Forest Service Pacific Northwest Research Station produced an average of 10 publications per year about landscape science. A spike in the development and use of models (fig. 6-5) is a key reason that “methods” ranked among the three most productive research themes since 2005 (fig. 6-2).

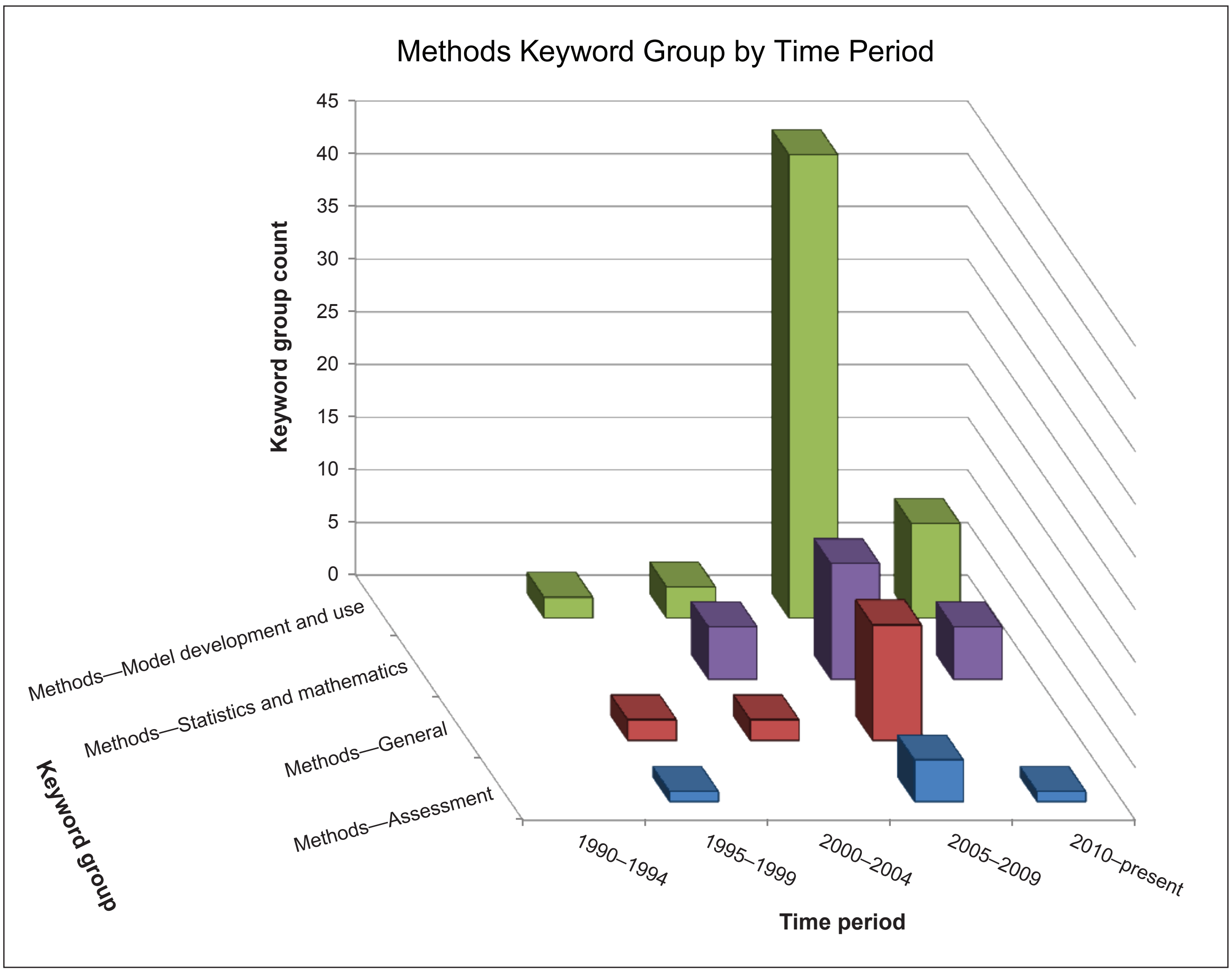

Figure 6-5—USDA Forest Service Pacific Northwest Research Station publications on landscape science (1990–2011) that included model development and use.

The abundance of model development and application is perhaps not surprising because, compared to field testing of silvicultural treatments and their effects, simulation models are relatively easy to develop in the short-term (<5 years). Model performance evaluation lags model development because of the time necessary to collect data on landscape change and to collect data (e.g., from adaptive management experiments) for validation and parameterization of process models, so questions remain about the accuracy of their predictions (Hummel et al. 2013; McElhany et al. 2010). Moreover, developing and refining predictive models will assist but not assure successful implementation of silvicultural and monitoring guidelines because the problems to which they are being applied are complex.

Moreover, complex problems, which are characterized by conflicting and often contested information, theories, and social values, cannot be solved simply with more technical knowledge (Holling 1995, Ludwig 2001). Rather, problems like these require redefinition. The process of problem redefinition is a social one that requires scientists and managers to exchange ideas and information. Thus, instead of being unidirectional, the "social learning" process is collective and iterative, itself generating knowledge (Mackinson and Nottestad 1998, Roux 2006). Accordingly, the process of social learning implies cultural and structural change. For example, changes occur in the culture of applied science, because scientists no longer are the sole initiators and arbiters of knowledge discovery and delivery. Furthermore, changes occur in relationships among agency scientists and the users of knowledge, such as land managers and private citizens. The resulting social structure is one in which scientists, managers, and other individuals evolve new ways to communicate among themselves and also with each other. This is important because organizational cultures differ within and among public agencies like the Forest Service, the Fish and Wildlife Service, and state departments of forestry and wildlife.

Organizational differences among the three different branches of the Forest Service and between regulatory agencies (e.g., the Fish and Wildlife Service) and management ones (the Forest Service) both support and impede guideline implementation. A promotion system for managers in federal agencies like the Forest Service, Bureau of Land Management, and Fish and Wildlife Service that keeps staff on the move can undermine trust in communities that value personal persistence and intergenerational loyalty. In addition, the managers of field units have few or poor incentives to work with agency or other researchers and to risk trying new or experimental practices. Managers are often rewarded not by ecological outcomes but by targets, e.g., acres treated; there are few performance incentives associated with systematically learning and improving management practices. National forests and their ranger districts have no one in charge of monitoring as a long-term job; design protocols, record keeping, and analysis are not supported either in the organization or financially. Scientists are generally interested and have performance incentives to experiment and publish results; but short-term or shifting funding and performance goals do not favor development of relatively complex, expensive, and long-term management experiments. The Forest Service's management and research and development programs are not integrated in terms of program development and funding.

The 2012 planning rule for national forests may address the organizational and programmatic issues about monitoring and adaptive management. It remains to be seen if it facilitates the necessary communication of existing knowledge and the generation of new, collective knowledge (Holling 1978; Rogers 1983; Roux et al. 2006; Walters 1986 1998;). Such a "bidirectional" model of knowledge generation draws from organizational learning theory, which postulates that learning in organizational settings is a social process in which individuals collectively acquire, create, and transfer knowledge and develop new organizational approaches based on this new knowledge (Argyris and Schon 1978, Garvin 1993, Nonaka 1994, Senge 2006). In the context of natural resource management, the organizational learning model would have managers and scientists interacting at the outset in the problem definition stage, in the design, implementation, and interpretation of scientific research, and when managers test scientific principles in practical application. Although little research has been conducted about scientist-manager interaction, studies suggest that attitudes and behaviors that indicate organizational learning (Garvin 1993) are not widely found in federal agencies such as the Forest Service and Bureau of Land Management (Brown and Squirrell 2010, Wright 2010).

Thus, while the necessary organizational structure and programs for monitoring are discussed in adaptive management and planning documents, they have not been well designed or implemented (e.g., Stankey et al. 2003, 2006). Hence, the public remains unsure whether these new practices work as hypothesized and developed. There is also skepticism as to whether land managers can match the scale of implementation with the scale of evaluation and monitoring. One reason is that stand-level treatments remain the convention in silviculture despite landscape-scale objectives. Owing to the logistics of infrastructure (haul routes, mills), harvest practices (marking, equipment), and log marketing (contract preparation and sale), a stand is often sized according to human convenience rather than ecological significance. Given such logistics, the scale at which treatments are implemented is unlikely to change significantly even as the scale at which they are evaluated is expanding. What this means in practice is a need to identify how multiple, stand-level treatments relate to objectives for the larger geographic area of which they are a part and to develop a silviculture of complexity (Puettmann et al. 2008). Expressed another way, this implies the need to distill landscape-scale objectives into manageable treatment units.

Concern for issues related to geographic scale exists both in the general public and within government agencies. The latter are regulated by NEPA. Whether an environmental assessment or an environmental impact statement is developed relates in part to the anticipated scale of effects (MacGregor and Seesholtz 2008). Regardless of the NEPA planning document pursued, proposed agency actions require a statement of "purpose and need." In many instances, the federal agencies involved have stepped up their efforts to solicit public input at this stage of planning but still lack a national framework for managing risk, so weighing tradeoffs is left up to local units. The decentralized approach to risk management currently used by federal agencies is inconsistent with phenomena like wildfire and NSO home ranges that occur at spatial scales larger than the administrative boundaries of individual landowners.

Efforts to apply concepts of risk to biodiversity conservation (Hummel et al. 2009), forest management (Hanewinkel et al. 2011) and wildfire management (Miller and Ager 2012) are underway but not yet widely adopted. No agreement yet exists on what taxonomic level of biodiversity loss is most significant, how to measure it, or what weight to give different levels in different ecosystems. The species level predominates, in part because operational definitions of components above the species level—e.g., communities and ecosystems—are poorly defined, are not static, are open to flows of species and to disturbances, and vary with location and spatial scale (Orians 1993). Unless knowledge gained from risk assessments is put into a framework that links the probabilities of outcomes with a way to evaluate and rank them, it will remain difficult to manage risk thoughtfully and proactively to conserve biodiversity in managed landscapes. In forests of the eastern Cascade Range, for example, a landscape of continuous structure and composition may be at a higher risk from fire or disease than a patchier landscape (Spies et al. 2006).

Summary

Policies are expanding, both the economy and public awareness and trust are in flux, and organizational capacity is limited.

Our overview of trends in social support for implementing silvicultural and monitoring guidelines to aid in forest restoration and spotted owl recovery indicates that the outlook is mixed. Specifically, policies are expanding, both the economy and public awareness and trust are in flux, and organizational capacity is limited. Many factors act to enable or constrain specific silvicultural practices and monitoring activities; some key ones are listed in table 6-1.

Agency managers and scientists can design and implement silvicultural and monitoring guidelines, but organizational capacity is currently lacking to know or discover if indeed the right activities are being undertaken. Hence, the public is not assured that any goals set for restoration and owl conservation will be attained. Our suggestions include:

Table 6-1—Factors affecting implementation of silvicultural practices and monitoring activities in support of forest restoration and spotted owl recovery in the eastern Cascade Range

Silvicultural practice	Enabling factor	Constraining factor	Citations
Tree density reduction		Limited mill capacity Hauling costs/distances Size of trees removed Limited utilization opportunities	Adams and Latta 2005; Gale et al. 2012; Keegan et al. 2006; LeVan-Green and Livingston 2001; Spelter 2002; USDA FS 2012a, 2012b; Wagner et al. 2000
Deadwood management		Rate of deterioration	Lowell et al. 2010, Prestemon et al. 2006
Wildfire risk reduction and habitat restoration	Public knowledge and awareness of local ecology activities	Lack of public knowledge and awareness about local ecology	Brunson and Reiter 1996, Brunson and Shindler 2010,Carey 2003, McCaffrey and Olsen 2012
	Positive attitudes about natural resource management and public agencies		Bright and Manfredo 1997, Dunlap and Van Liere 1978
	Trust in public agencies	Lack of trust in public agencies Lack of perceived legitimacy or competency	Brunson and Shindler 2010, Toman et al. 2011, Vogt et al. 2005, Winter et al. 2004
	Participation by public in forest planning; collaboration	Belief that agencies will not use public input	Lawrence et al. 1997, Reed 2008, Shindler and Cheek 1999, Shindler and Toman 2003, Toman et al. 2006
	Likelihood of being positively affected by management (e.g., reduced vulnerability to fire, increased economic or recreational opportunities or scenic value)	Likelihood of being negatively affected by management (e.g., decreased economic or recreational opportunities or scenic value)	Brunson and Shindler 2004, Hibbard and Karle 2002, Moseley and Toth 2004, Winter et al. 2004
Federal sales	Stewardship activities Collaborative Forest Landscape Restoration Program Policy incentives		

We suggest that better organizational and financial structures be built to support long-term silvicultural innovation, experimentation, and research.

- Make adaptive management with a small "a", not formal Adaptive Management Areas, an operational norm.
- Create better incentives for managers and researchers to work together to create a learning environment.
- Build better organizational and financial structures to support long-term silvicultural innovation, experimentation, and research. The Fire and Fire Surrogate Study (McIver et al. 2013) and the Burns and Burns Study (Saab et al. 2007) provide good examples of close National Forest System and Forest Service Research and Development coordination in large-scale regional and national "meta-studies."
- Build on the new Forest Service emphasis for collaborative management with stakeholders and integrate them in the prescription development and adaptive management processes to gain public trust and support.

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Metric Equivalents

When you know:	Multiply by:	To get:
Inches (in)	25.4	Millimeters
Inches (in)	2.54	Centimeters
Feet (ft)	.3048	Meters
Acres (ac)	.405	Hectares
Miles (mi)	1.609	Kilometers
Square feet per acre (ft^2/ac)	.229	Square meters per hectare
Square miles (mi^2)	2.59	Square kilometers
Degrees Fahrenheit	0.556 (°F – 32)	Degrees Celsius

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