Restoration of Dry Forests in Eastern Oregon

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Restoration of Dry Forests in Eastern Oregon

A FIELD GUIDE

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This guide represents the authors' best current thinking about dry forest restoration; however, it should be viewed as a "work in progress" with additions and revisions to come from additional scientific study and, especially, practical field experience in its application. The authors welcome comments, suggestions, and experiences that can be used in its evaluation.

Contents

Introduction

Dry Forest landscapes dominated by pine and mixed-conifer forests composed of ponderosa pine and associated coniferous species, such as Douglas-fir and white or grand fir, are extensive in western North America, including the Pacific Northwest (Franklin and Dyrness, 1988). These forests typically occupy landscapes that are moisture limited and historically experienced disturbance regimes that included frequent wildfire. On many sites fires were predominantly low severity but mixed-severity and, occasionally, even high-severity wildfire occurred, the latter primarily in areas at higher elevations and on sites with higher productivity (Perry et al. 2011).

These Dry Forest landscapes have been dramatically modified by human activities during the last 150 years throughout their extent (Franklin and Agee 2003, Noss et al., 2006), including eastern Oregon. These changes have significantly altered the composition and structure of these forests and, most importantly, their potential responses to disturbances, such as wildfire, drought, and insects. There is an emerging consensus among a broad array of stakeholders, scientists, and managers that restoration of these forests to more resilient conditions would have many environmental and social benefits.

Purpose of this Field Guide

This field guide has been prepared to provide a practical, science-based framework for activities intended to restore characteristic functionality, "resistance", and "resilience" (see Box 1) of Dry

Forest landscapes. Dry Forests are defined as those growing on sites that are characterized by ponderosa pine and mixed-conifer plant association groups, as explained below. Specific restoration goals include reducing the vulnerability of Dry Forests to wildfire, drought, and insect epidemics and improving their ability to accommodate future environmental change while continuing to provide desired ecosystem services and biological diversity.

This guide provides users with information relevant to management of the ponderosa pine and mixed-conifer forests found east of the crest of the Cascade Range in Oregon including:

- Basic principles for restoring Dry Forest stands and landscapes, including non-forest components, such as meadows and aspen groves;
- Examples of on-the-ground application of the principles;
- Silvicultural prescriptions for different forest types; and
- Strategies for learning and adaptive management.

This guide focuses primarily upon restoration of upland forests as well as incorporated meadows and small drainages with their populations of aspen. It does not cover, in depth, other aspects of restoration that will be needed such as improving the road system (e.g., relocation, removal, and improvement of roads), addressing pressures from large ungulates including cattle, and recovering conditions in major streams and rivers, such as by restoring stream banks and near-stream vegetation and adding large wood.

Forest restoration of public lands must involve a broad range of stakeholders in setting goals for restoration and in planning, implementing, and monitoring restoration activities. This guide is intended to provide information and guidance for these stakeholders as well as natural resource professionals and technical personnel directly engaged in these activities (Figure 1). If you have more than just a passing interest in the management of eastside forests, this guide is for you.

Figure 1. Stakeholder groups and classes will find this field guide useful in understanding issues and potential approaches to Dry Forest restoration.

Box 1: **Resistance, Resilience, and Restoration**[1]

For the purpose of this Guide, we define these terms as follows.

Resistance refers to the capacity for an ecosystem to resist the impacts of disturbances without undergoing significant change. For example, wildfire can burn through a resistant forest without significantly altering its structure, composition, or function. The structure and composition of a low-density forest dominated by fire-tolerant trees is perpetuated by frequent, low- to moderate-severity fire as it repeatedly and patchily consumes fuels and regeneration.

Resilience is the capacity of an ecosystem to recover to essentially the same community composition and ecosystem structure and function after being impacted or modified by a disturbance. For example, a resilient forest can recover to an approximation of its pre-disturbance state following a wildfire that was severe enough to significantly alter its structure, composition, or function. Resistance is often considered to be one aspect of ecosystem resilience, and we will assume this inclusion in our further use of the term resilience.

Restoration includes activities that assist ecosystems in the recovery of resilience when they have been degraded, damaged, or destroyed and that enhance the capacity of an ecosystem to adapt to change. Ecological restoration focuses on re-establishing ecosystem functions by modifying or managing the composition, structure, spatial arrangement, and processes necessary to make terrestrial and aquatic ecosystems ecologically functional and resilient to disturbances expected under current and future conditions.

Restoration emphases in this guide include:

- Advocating active management for restoring and maintaining resistance and resilience in Dry Forests;
- Conserving functionality (e.g., productivity, conservation of nutrients and soil, and provision of habitat for biodiversity) under current and future conditions, using information from a broad array of sources, including historical, empirical, and modeling studies, and expert opinion;
- Emphasizing ecosystems and the array of goods and services they provide rather than focusing exclusively on singular objectives, such as fuels reduction, timber production, or provision of habitat

1 These definitions draw heavily on similar definitions in the draft and final planning rules for implementing the National Forest Management Act (USDA, 2011, 2012).

for a single species. Restoration designed to incorporate multiple landscape and ecosystem values will address such singular objectives;

- Giving priority to sites where past human activities have: 1) greatly increased the potential for high-severity disturbances and high risk of accelerated loss of important ecological values or 2) created significant deficiencies in key organisms, structures, or processes;
- Recognizing that different ecosystems (such as Dry Forests and Moist Forests) require different goals and approaches appropriate to their disturbance regimes and that attempts to use a "one-size-fits-all" approach are bound to fail; and,
- Recognizing the need for continued management to maintain restored conditions.

Restoration Focus: Dry Forests of Eastern Oregon

This guide is written for the Dry Forests of central and eastern Oregon[1] (Figure 2). Dry Forest sites, which are the focus of this field guide, are identified here by their plant associations and differentiated from Moist Forests, which are not addressed by this guide.

Tree species found on Dry Forest sites are listed in Table 1 along with some of their important ecological attributes. Understanding the ecological roles and susceptibilities of these species will help the reader in selecting tree species to achieve specific objectives.

Dry Forests and Moist Forests are distinguished by the plant associations that are characteristic of the site or landscape under consideration. Comprehensive classifications of plant associations have been developed and are available for all federal forest lands (Hopkins, 1979a, 1979b, Simpson, 2007, Volland 1985, Johnson and Clausnitzer,1992). These classifications are based upon plant community composition *and emphasize those plants that have high environmental indicator value*, which are generally those characteristic of later successional stages. Plant associations are generally named for the major predicted climax tree species and one or more understory species—for example, Ponderosa Pine/ Bitterbrush. Climax species predictions are based on what would happen if there were no intervening disturbances even in systems characterized by frequent disturbance. Thus, although the indicator species are present they may not be dominant where sites have been frequently or recently disturbed. Hence, the historical forests on many Dry Mixed-Conifer sites and some

1. This guide can also be relevant to Dry Forests in eastern Washington and in southwestern Oregon, but forest conditions and restoration goals may differ in significant details. For example, pure ponderosa pine stands (i.e., climax ponderosa pine habitats) are much less common in eastern Washington than in eastern Oregon (Franklin et al., 2008). In southwestern Oregon many Dry Forest sites are occupied by maturing Douglas-fir forests that have few if any residual old (>150 year) trees and appear to be the first generation of closed-canopy conifer forests. Recommendations in this guide would need adjustment for these differing ecological conditions.

Figure 2. Dry Forests in eastern Oregon, the focus of this guide, lie primarily in the areas indicated—the Eastern Cascades Slopes and Foothills and the Blue Mountains ecoregions.

Moist Mixed-Conifer sites were typically dominated by large ponderosa pine or western larch. Closely related plant associations are grouped into Plant Association Groups (PAGs) given an expected or observed similarity in site potential or response to disturbance.

This guide addresses restoration of Ponderosa Pine and Mixed-Conifer forest sites, with the mixed-conifer sites broken into Dry Mixed Conifer and Moist Mixed Conifer. The generalized distribution of these types is shown in Figures 3 and 4, which do differ, particularly in the division of mixed-conifer sites between Dry Mixed Conifer and Moist Mixed Conifer in the Blue Mountains. Identification of plant associations always needs to be done in the field when planning or conducting restoration projects or other management activities (Appendix 2, Table A1); maps cannot provide sufficiently accurate site-specific

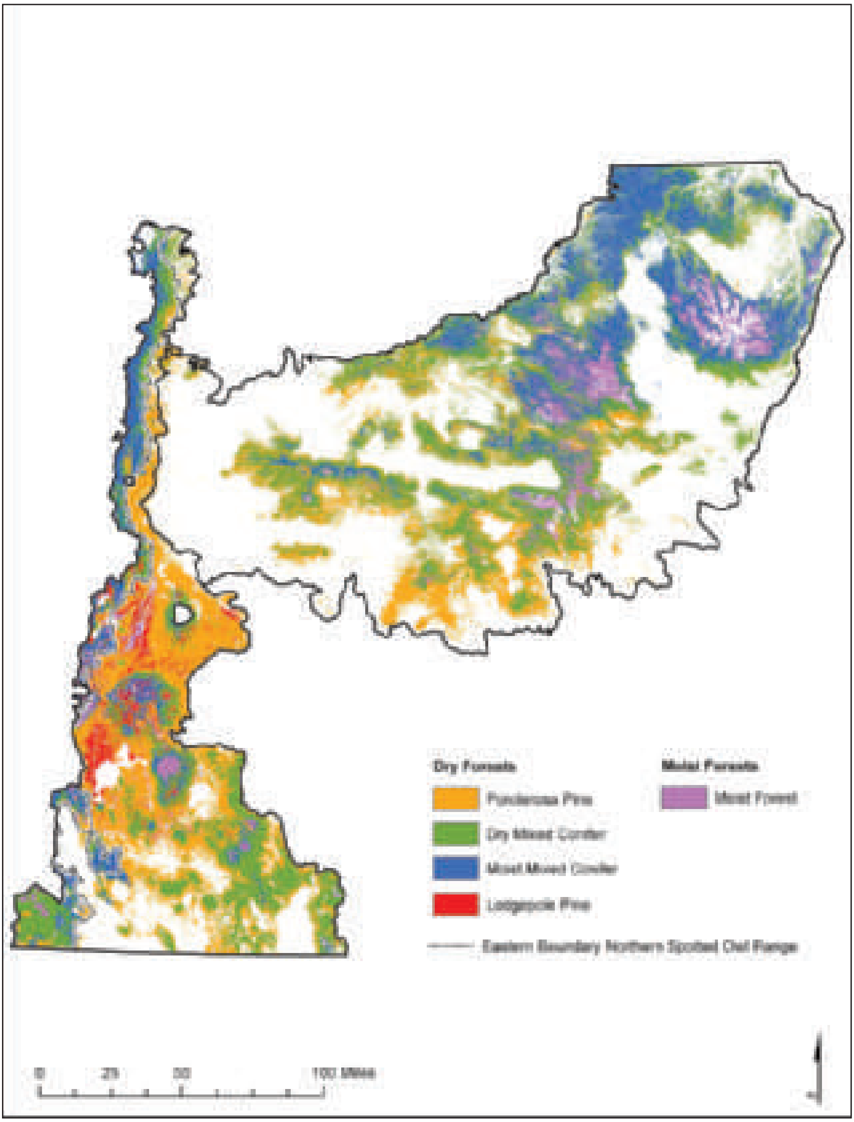


Figure 3. Representation of the Dry Forests that are a focus of this Guide (Ponderosa Pine, Dry Mixed-Conifer, and Moist Mixed-Conifer plant association groups) along with other plant associations in eastern Oregon (Lodgepole Pine and Moist Forest). Source: Integrated Landscape Assessment Project (ILAP), 2012.

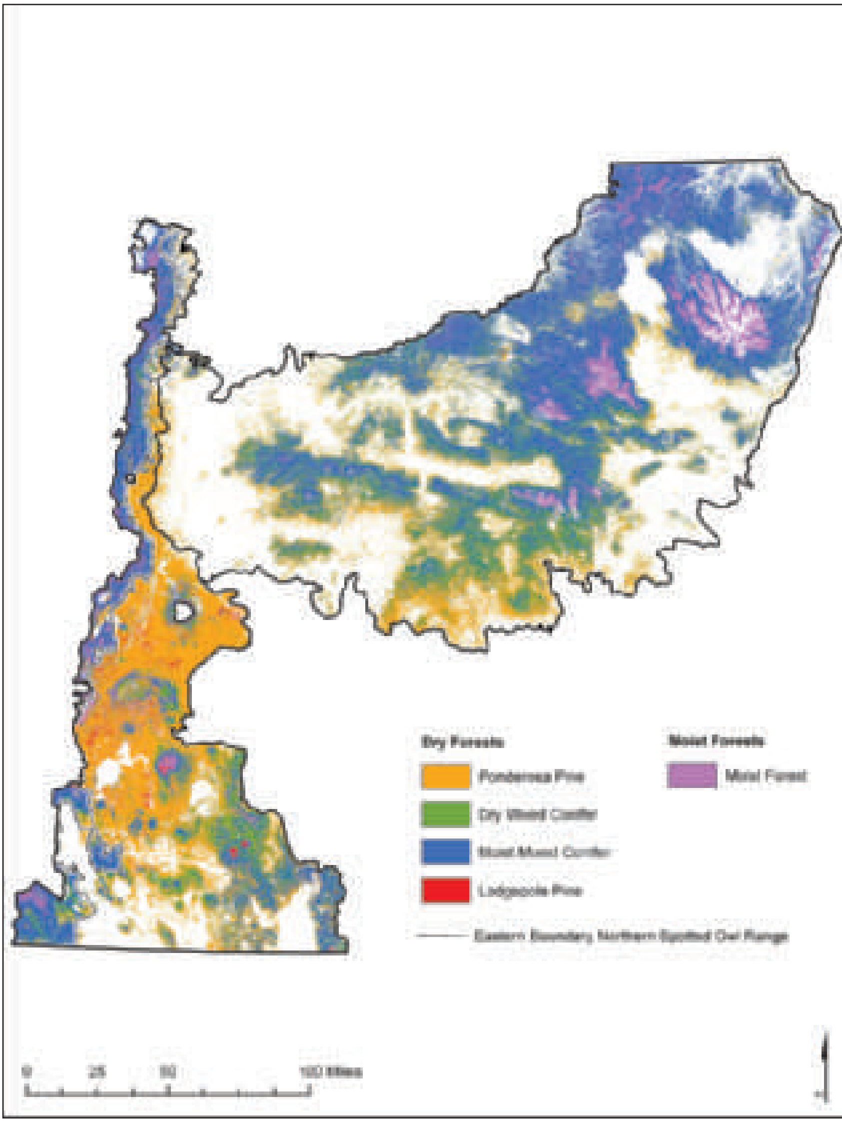


Figure 4. Representation of the Dry Forests that are a focus of this Guide (Ponderosa Pine, Dry Mixed-Conifer, and Moist Mixed-Conifer plant association groups) along with other plant associations in eastern Oregon (Lodgepole Pine and Moist Forest). Source: Simpson, 2011.

Table 1. Tree species found on Dry Forest sites in eastern Oregon with relative ranking of ecological attributes.

Species	Longevity	Drought Resistance	Wildfire Resistance	Defoliator Risk	Bark Beetle Risk	Heart/Root Rot Risk/ other disease	Mistletoe	Climate Adapted?	Shade tolerance
Ponderosa pine	500+	High	High	Low	Medium	Low	Medium	Yes	Low
Western larch	500+	Medium	High	Low	Low	Medium	High	Yes	Low
Incense cedar	500+	Medium	High	Low	Low	Medium	Low	Yes	Medium
Douglas-fir	400+	Medium	Medium	Medium	Medium	Medium	High	Depends	Medium
Sugar pine	400+	Medium	Medium	Low	Medium	Medium	Low	Yes	Medium
Grand fir/ white fir	200-	Low	Low	High	Medium	High	Medium	No	High
Lodgepole pine	150-	Medium	Low	Medium	High	Low	Low	No	Low
Oregon white oak	300+	Medium	Medium	Low	Low	Medium	Low	Yes	Low
Quaking aspen	100+ as individual[1]	Medium as clone	High as clone	Medium as clone	Low	Medium as individual	None	Medium as clone	Low as individual

1 For individual stems, quaking aspen is a clonal species that readily reproduces vegetatively through suckers which makes it resilient (as a clone) to many disturbances, whereas individual stems may be quite susceptible to rots, defoliators, and drought.

information, particularly where landscapes are complex environmental mosaics, as in mountainous regions.

Collectively **Ponderosa Pine forest sites** are those characterized by ponderosa pine plant associations (Appendix 2, Table A1); ponderosa pine is usually the major tree species present in all age and size classes and, hence, the climax species. These sites often can be recognized by the absence or rare occurrence of other conifers such as Douglas-fir, grand fir, and white fir. Lodgepole pine will often be found in these forest sites where there are deep deposits of coarse Mazama pumice, such as in many locations between Bend and Klamath Falls. Other associates that may occur on Ponderosa Pine sites are western juniper and

Figure 5. Ponderosa Pine forest sites characterized by ponderosa pine plant associations are widely distributed on drier forested areas (e.g., at lower forested elevations) throughout eastern Oregon. Ponderosa pine is typically the only significant tree species and therefore the climax species on these sites. Western juniper may be present and lodgepole pine sometimes invades these sites where they are located close to cold basins where lodgepole pine is abundant

Oregon white oak, the latter occurring on the eastern slopes of the northern Oregon Cascade Range.

Dry Mixed-Conifer forest sites collectively include the sites characterized by Douglas-fir PAGs and dry phases of the Grand and White Fir (hereafter Grand/White Fir) PAGs (Appendix 2 Table A1). Dry Mixed-Conifer forest sites are moister than ponderosa pine sites and, consequently, have greater potential productivity and diversity in tree species (Figure 6). This potential may not be expressed where frequent low- to moderate-severity disturbance favored fire-tolerant species, age/size classes, or spatial patterns. Sites characterized by Douglas-fir plant associations are uncommon in much of the area affected by thick

Figure 6. Dry Mixed-Conifer forest sites characterized by Douglas-fir plant associations are widely distributed in eastern Oregon except where deep coarse-textured Mazama tephra deposits are present. Historically ponderosa pine was a dominant tree species on most Dry Mixed-Conifer sites but with fire suppression Douglas-fir has become much more abundant and typically dominates current stands.

Figure 7. Dry Mixed-Conifer forest sites characterized by Grand Fir or White Fir plant associations are widely distributed in eastern Oregon. Historically ponderosa pine dominated many of these sites, which are typically recognizable today by an abundance of grand fir or white fir regeneration as well as mid- and large-size trees of these species and, often, Douglas-fir.

deposits of Mazama tephra but are otherwise well distributed in eastern Oregon. Sites characterized by dry Grand/White Fir plant associations (Figure 7) are also widely distributed throughout eastern Oregon.

Moist Mixed-Conifer forest sites (*as the term is used here*) are characterized by moister phases of the Grand/White Fir PAGs (Figure 8) than those identified with the Dry Mixed-Conifer forest sites (Appendix 2 Table A1). Historically, some of the Moist Mixed-Conifer forest sites had denser forests and less frequent but more severe fire regimes (mixed and high severity) than Dry Mixed-Conifer forest sites. However, Moist Mixed-Conifer sites often had low-density stands of fire-tolerant trees, such as ponderosa pine, Douglas-fir, and western larch, due to frequent low- to moderate-severity fire based on recently completed fire

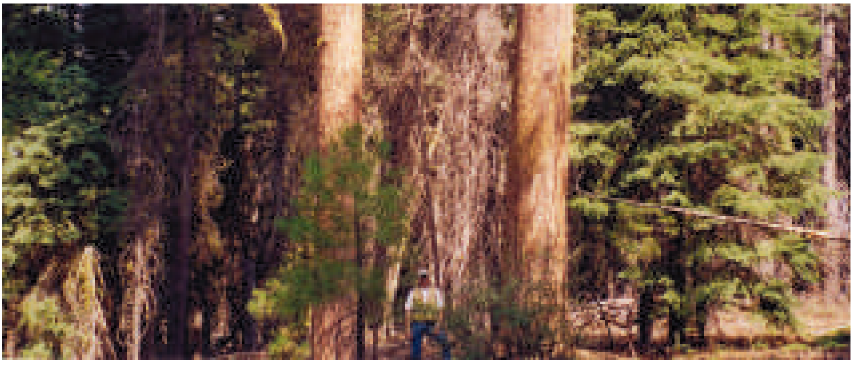


Figure 8. Moist Mixed-Conifer forest sites are characterized by the moistest and coolest Grand or White Fir plant associations, which are often recognizable by an abundance of broad-leaved herbaceous plants, an abundance of grand or white fir in all size classes, and abundant grand or white fir regeneration. Moist Mixed-Conifer sites may be particularly appropriate for retention as denser forest patches within a restored landscape. On the other hand, aggressive restoration treatments will generally be needed where a significant number of large old pine or larch trees were historically present or are currently at risk.

history reconstructions[1], descriptions of remnant old growth trees (Merschel, 2012), and analysis of historical records[2] .

Decisions regarding appropriate restoration approaches for Moist Mixed-Conifer forest sites must consider the landscape context; this is true of all forests considered for restoration but context is a more important issue in the case of Moist Mixed-Conifer forests than in the other types considered in this guide. Historically, we would expect these sites to have a higher proportion of dense stands than the other Dry Forest sites; fire exclusion has accentuated this condition. Currently, some of these dense stands may be important for wildlife species, such as the northern spotted owl and northern goshawk. Thus landscape analyses may result in maintaining dense patches of these stands across the landscape. On the other hand, climate change is predicted to increase drought, insect attacks, and the intensity and frequency of wildfire on such sites (Spies et al., 2011; USFWS, 2011) making them obvious candidates for treatments to increase resilience (USFWS, 2011). Restoration of Moist Mixed-Conifer sites are an especially high priority where large populations of old pine or larch are at risk, or where these trees were historically abundant.

Moist Forest sites[3], as more broadly referenced in this guide, are forest sites that typically experienced infrequent disturbance

1. Emily H. Heyerdahl (personal communication), December, 2012.

2. K. Hagmann (personal communication) found similarity in the historical structure of Dry Mixed-Conifer and Moist Mixed-Conifer PAGs using Simpson (2007) PAG map. Her data comes from cruises of thousands of acres in the early 1900s by the BIA on the Warm Springs Reservation and former Klamath Reservation in the eastern Cascades of Oregon. Both PAGs averaged low numbers of trees per acre (less than 30 per acre over 6 inches dbh), more than 75% of the basal area in trees over 21 inches dbh, and most of that basal area in ponderosa pine. The Moist Mixed-Conifer PAGS did, however, show higher average levels of other conifers especially white fir (see Table 4).

3. We realize that having a group of plant associations called "Moist Mixed Conifer" as a subsection of the "Dry Forests" at the same time that we have a group of plant associations called "Moist Forests", which are distinct from the Dry Forests, can be confusing. We sympathize, but feel the need to use terminology that connects to our classifications of Dry Forests in previous work (Johnson, et al. 2008) and to our broader classification of Dry Forests and Moist Forests (Franklin and Johnson 2012). We urge you to look at the list of plant associations in Appendix 2 to better understand the distinctions.

events that usually included significant areas of stand-replacement severity (Appendix 2 Table A1).This guide is not useful, as an example, for subalpine forests characterized by Engelmann spruce and subalpine fir plant associations, which occur on moister and colder sites, particularly at higher elevations throughout eastern Oregon (Figure 9). Higher-elevation lodgepole pine-dominated forests that are typically seral on these subalpine sites we also place in the Moist Forest category. Other Moist Forest sites, such as those characterized by Western Hemlock, Pacific Silver Fir, and Mountain Hemlock PAGs, represent eastern extensions of forests found along the crest of the Cascade Range.

PHOTO: DAVID POWELL

Figure 9. This restoration guide is not appropriate for use on Moist Forest sites, such as the subalpine forest sites characterized by Subalpine Fir-Engelmann Spruce plant associations. High-severity, stand-replacing fire is characteristic of these forest sites.

We do not consider it appropriate to use this restoration guide in these subalpine or other Moist Forest sites (Appendix 2 Table A1).

Users should be aware that there are other classifications of potential vegetation types that are in use in eastern Oregon, particularly the system developed as a part of the Interior Columbia Basin Ecosystem Management Project (ICBEMP) (Powell et al. 2007). This system is based on a 16-cell environmental matrix of temperature (cold, cool, warm, and hot) and moisture (wet, very moist, moist, and dry). Our Ponderosa Pine and Dry Mixed-Conifer forest sites generally fall within the "Dry Upland Forest" PVG of this classification. Our Moist Mixed-Conifer forest sites fall mainly within the "Moist Upland Forest" PVG, which is, however, much broader and includes many plant associations characterized by subalpine fir (Powell et al. 2007).

Why Forest Restoration is Needed

Most Ponderosa Pine and Mixed-Conifer forests and landscapes in eastern Oregon (hereafter referred to as the Dry Forests) have been significantly modified from their historical structure, composition, and function and would benefit ecologically from restoration. This statement is supported by the vast majority of scientific research that has been carried out during the last several decades as illustrated by (Brown et al., 2004; Hemstrom, 2001; Hessburg et al., 2005; Littell et al., 2010; Noss et al., 2006; Reinhardt et al., 2008; USFWS 2011).

Important changes in the Dry Forests that increase the risk of high-severity disturbance and loss of valued resources and functions include:

- **Much higher densities** due to widespread and intensive grazing by domestic livestock, fire suppression, forest harvest, stand-replacement wildfire, and tree planting, resulting in greatly increased fuel loadings, inter-tree competition, and greater landscape-level continuity in dense stands (Franklin and Agee 2003). These conditions dramatically increase the potential for large stand-replacing events and consequent losses of important forest values, such as wildlife habitat and watershed protection, as well as threats to local communities (Ager et al., 2010, 2007b; Hessburg et al., 2005; Miller et al., 2009; Spies et al., 2006) (Figure 10). These high density forests are also at increased susceptibility to drought and related insect disturbances (Hemstrom, 2001; Littell et al., 2011).

- **Decline and even complete loss of populations of old-growth ponderosa pines, especially large, old-growth pines**—the structural backbone and key contributor to resistance and resilience in Dry Forests (Bolsinger and Waddell, 1993; Henjum et al., 1994; Wisdom et al., 2000; Johnson, et al. 2008).
- **Loss of spatial heterogeneity** characteristic of Dry Forests—an uneven-aged mosaic of isolated individual trees, clumps of trees, and openings (Franklin and Van Pelt, 2004; Larson and Churchill, 2012) including heterogeneous spatial arrangements as well as a diversity of individual structures. Two aspects of this spatial complexity are discussed and illustrated; this spatial heterogeneity contributes significantly to the forest's functional capabilities, including resistance to wildfire and insect attack and provision of diverse habitats for biodiversity (see Part III).
- **Loss of relatively open, old-tree-dominated forests**, which has altered key ecosystem processes and eliminated or greatly degraded habitats for native biota (Hessburg et al.,2000; Kennedy and Wimberly, 2009).
- **Greatly increased risk of mortality of old trees as a result of higher probability of high-severity wildfire, insect outbreaks, and competition from increased density of young trees**. Increased competitive stresses reduces the ability of old trees to resist bark beetle attacks and accelerates mortality, resulting in losses of old trees faster than they can be replaced (Lutz et al., 2009; van Mantgem et al., 2009; Stephenson et al., 2011) (Figure 11).
- **High vulnerability of trees, stands, and landscapes to effects of climate change**. Predicted changes include increased

Figure 10. The effects of high severity wildfire associated with the buildup of fuels in a ponderosa pine forest.

Figure 11. Old trees, like this ponderosa pine, are at risk of mortality from fire, insects, and competition because of the increased density of surrounding young trees.

moisture stress and a longer fire season as a result of higher temperatures with or without additional precipitation. Increased potential for stand-replacement wildfire, drought stress, and insect epidemics are related likely outcomes (Coops and Waring, 2011; Franklin et al., 1991; Hemstrom et al., 2007; Littell et al., 2010; Luce et al., 2012; McKenzie et al., 2009;Spies et al., 2011).

- **Reduced biodiversity and degraded capacity to support important natural processes and functions as a result of the establishment of invasive, non-native and native species**. Western juniper is an example of an invasive native species.

Obviously, there is much that needs to be done in these Dry Forests and landscapes!

Restoration Goals

Ecologically-oriented forest restoration goals, as adopted here, are intended to address many of the changes that have occurred in the Dry Forest stands and landscapes by:

- Restoring resilient forest structures, patterns, and disturbance regimes;
- Protecting and nurturing existing old-growth trees and restoring their populations;
- Protecting and enhancing wildlife habitat for the full array of species;
- Increasing under-represented forest conditions; and
- Slowing or reversing the spread of invasive species of both native and non-native origin.

Social—economic and cultural—goals for restoration include:

- Sustaining the local workforce and infrastructure needed to accomplish forest stewardship, including the restoration activities by:
  - Providing employment and income to local communities,
  - Maintaining wood processing infrastructure, and

- Creating enough value though harvested products to help pay for restoration and other management activities.
- Protecting communities or key resources like municipal watersheds by decreasing the likelihood of extensive high-intensity wildfires and insect outbreaks; and
- Conserving and restoring culturally valuable places, resources, and systems, including plants important as sources of food and medicine and culturally-modified trees.

PHOTO: ANDREW LARSON

Figure 12. Example of a culturally modified ponderosa pine.

Part I

Principles in Restoring Dry Forests

This booklet is a guide to forest restoration activities intended to increase the resistance and resilience of Dry Forests and the landscapes in which they are located. Specifically, our goal is to provide guidance on: 1) Reducing the potential for forests and landscapes to be severely impacted by wildfire, drought, and uncharacteristic levels of attack by insects and diseases; and 2) Increasing the ability of Dry Forests to rapidly recover to desired levels of ecosystem function when they are impacted by severe disturbances. ***Most importantly, restoration, as we define it, is holistic, focusing on all aspects of ecosystem structure and function and on entire landscapes. This holistic approach contrasts with silvicultural treatments focused on singular objectives—such as treatment of fuels or preservation of a single species to the exclusion of others, or on limited locations in landscapes—such as strategic fuel breaks.*** Key elements of our restoration approach are identified below.

Plan and Implement at the Landscape Level

All of our resource objectives—restoring desired ecological conditions in terrestrial and aquatic ecosystems, provision of habitat for wildlife and other biota, and achievement of economic and cultural objectives—require integration of goals at landscape scales. Restoration objectives can, at times, be either complementary or conflicting (Rieman et al., 2010). Landscape perspectives allow managers to plan for diversity of varying forest conditions to meet multiple objectives (Reilly, 2012; USFS, 2012).

Provide for Heterogeneity at all Spatial Scales

Heterogeneity provides the diversity of conditions that allows for a full range of ecosystem processes and habitat for biological diversity (Churchill et al. 2013, Lindenmayer and Franklin, 2002). While homogeneity is often sought where goals involve singular outcomes, such as maximizing timber production, the goal on federal, tribal, and private lands owned by conservation-based organizations is generally to maintain the full array of ecological services and biota. The goals of maintaining natural services and biota, as well as protecting these resources, require recognition and incorporation of heterogeneity across the full range of spatial scales-from logs to landscapes! Much of the responsibility for creating heterogeneity during restoration lies with the silviculturists and marking crews engaged in stand-level prescriptions, which are a primary subject of this field guide.

Retain and Restore Old Tree Populations and Other Foundational Elements

Specific structures and conditions in forest stands have great importance as ecological keystones. As already noted, old-growth trees, especially large old-growth trees of all species, definitely qualify as keystones given their central roles in ecosystem function, wildlife habitat, resilience as live trees and as large persistent snags and logs after death (Franklin and Johnson, 2012; Lindenmayer et al., 2012). Large hardwood trees also play multiple unique roles in forests otherwise dominated by conifers, such as providing ideal cavity habitat. Unique conditions in forest stands, such as wet areas, rock outcrops, and concentrations of woody

Figure 13. Old trees are the structural backbone and key contributor to resistance and resilience in Dry Forests. In general, we recommend retaining trees of all species older than about 150 years of age as part of Dry Forest restoration projects – even if they are within the crown of an old ponderosa pine tree.

debris, also have unique ecological value. Restoration prescriptions for Dry Forests should retain, protect, and restore keystone structures and conditions.

Learn from the Past but Look to the Future

We learn from historical data the stand- and landscape-level conditions that have generated sustainable Dry Forests in the past and use this knowledge to restore current forests to ecologically functional and sustainable states. However, these restored forests will reflect what is possible and desirable given the current environmental and social context, rather than attempting to simply restore the past. Furthermore, our restoration goals must anticipate and prepare Dry Forests for future changes in such fundamentals as climatic conditions and disturbance regimes (Franklin and Agee 2003). **Fortunately, as discussed below, restoration treatments appropriate to restore resilient Dry Forests under current conditions are consistent with treatments that pre-adapt these forests to expected changes in climate and disturbance regimes.**

Restore Fire

Fire is a critical element in Dry Forest landscapes. It can never be eliminated from these landscapes, no matter how much we invest in fuel reduction and fire suppression. Nor would we want to do so, because fire is an agent that stimulates ecological processes and elements of biological diversity in unique ways that cannot be duplicated with mechanical treatments. The roles that prescribed or natural fires can be allowed to play will probably vary widely depending upon many ecological and social variables. These potential roles need to be addressed during restoration planning. Also, the additional fuels generated by restoration activities need to be addressed, preferably by prescribed fire.

Consider Operational and Economic Issues at all Stages of Planning

Many elements influence the level and type of restoration that is economically feasible including: the current road system, logging system accessibility, prescribed fire potential, potential costs/revenues of different stands, available contractors, available mills, resources available for layout, and agency contractual mechanisms (e.g., stewardship). Using funds from high-income treatments to subsidize those with low or no income is fundamental to achieving landscape-level restoration goals. Understanding the opportunities and constraints of these elements is essential to maximize the extent and success of projects. Wood products are the primary economic value that can be marketed so break-even points on projects are often dependent upon market conditions. **There are also tensions related to questions about the degree to which treatments should be modified to increase their economic viability; fortunately, there is often flexibility for adjusting marking guides while still achieving the overall ecological goals of the restoration.**

Engage

Stakeholder participation is essential in all phases of restoration projects from conception through planning, implementation, monitoring and evaluation of outcomes (including interpreting monitoring data and adaptive adjustments in subsequent management activities). Stakeholder participation can take many different forms including formal collaboration groups as well as collaborations between Tribes and management agencies. Ideally, it should involve a continuing engagement of diverse stakeholders in projects from beginning to end, and not be confined to the planning and approval of projects.

Learn, Innovate, and Adapt

***This guide is a work in progress* as we all learn how to restore the Dry Forests of eastern Oregon and safeguard the multitude of values they provide.** Using adaptive management principles and third-party assessments of restoration projects is critical. There can be a high degree of skepticism regarding the motives and approaches used in Dry Forest restoration as well as uncertainty about their effectiveness. Ongoing monitoring and systematic learning from restoration projects is a key part of addressing that skepticism and improving the effectiveness of forest restoration.

Part II

Landscape Planning for Forest Restoration

Restoring resilient forests in Eastern Oregon requires a landscape approach. Forest management has traditionally been focused on stands as the basic unit of organization in forests (Puettmann et al., 2009), with treatments based primarily on stand level conditions (e.g. stand density, insect and disease issues, etc.). Restoring landscapes stand by stand, however, is not a landscape approach.

Critical ecological processes such as fire spread, insect dispersal, and wildlife movement are controlled by patterns of forest structure at multiple scales (Spies and Turner, 1999). At the scale of individual forest stands (10s to 100s of acres) spatial pattern includes the size of clumps, openings, and the spacing of trees. At landscape scales (1,000s to 10,000s of acres), spatial patterns includes the size, shape and configuration of individual forest patches or stands. Stands in this context are patches up to 1000+ acres which also contain smaller-scale sub-patches of tree clumps and openings.

Understanding how stands fit together to form landscape patterns and how these patterns influence key ecological processes and management objectives is one of the most challenging aspects of landscape planning. Many frameworks and tools have been developed to assist managers and stakeholders with this challenge and to prioritize treatments to move landscapes towards desired conditions (Hessburg et al., 2004, 2013; Sisk et al., 2006; Bahro et al., 2007; Finney et al., 2007; Ager et al., 2007; USFS, 2012). For a detailed discussion of landscape planning, see Hessburg et al., 2013.

Increasingly, federal forest managers divide their national forests into large landscapes for treatments, with restoration unit sizes varying from a few thousand acres to hundreds of thousands of acres. The divisions are based on many ecological, economic, and social considerations such as keying on a watershed that contains threatened fish stocks, selecting an entire mountain that contains wildlife populations of particular interest, designing a boundary for a stewardship contract that includes projects that need investment with projects that will produce income, and honoring an area of special interest to a collaborative group or tribe. Many different criteria often need to be balanced when restoration unit boundaries are drawn.

Managers, with the help of interdisciplinary teams, then set an order of unit treatment and develop a landscape plan for the selected landscape units that will be treated first. Based on our experience, we outline below seven important components of landscape planning for restoration units along with examples of landscape planning from Oregon's Dry Forests.

Elements of Landscape Planning

Identify Areas of Special Significance

Landscapes include areas that have special ecological and cultural significance, which need to be identified for special management consideration (Lindenmayer and Franklin, 2002). These will include:

- Streams, rivers, ponds, and other aquatic features;
- Specialized habitats, such as meadows and rocky outcrops;
- Biological hotspots, such as calving and spawning habitat; and cultural sites.

Aquatic or semi-aquatic ecosystems always merit focused attention when they are present because of their ecological significance (Figure 14) (see Stine et al. 2013). Although great care needs to be taken to see that such ecosystems are not damaged during restoration, aquatic or semi-aquatic ecosystems may themselves be a high priority for intensive restoration efforts, such as where wet meadows and associated quaking aspen groves have been heavily invaded by lodgepole pine (Figure 15).

Many specialized habitats are easily recognized such as meadows, scablands, rock outcrops and associated cliffs, and caves. Some biological hotspots, such as elk calving locations and high-productivity salmon spawning habitat, may not be as obvious except to specialists.

Create Landscape Heterogeneity

It is necessary to define and plan the distribution of forest conditions in the desired future landscape, in addition to recognizing the special ecological and cultural features. One coarse-filter perspective on the sustainability and resilience of the landscape can be the distribution and abundance of different cover types and structural conditions or classes relative to historical conditions. This perspective can assist in identifying which cover and structure types are over-represented and the proportion of each that needs to be treated. The same assessment can be done against projected future conditions as well (Hessburg et al., 2013).

It is also important to assess patch size distributions and the overall pattern of cover and structure types, as they underpin the basic landscape function (Perry et al., 2011). Many landscapes in eastern Oregon have larger patch sizes and greater connectivity of dense forest structural types compared with historical conditions, which facilitates spread of high severity fires and insect outbreaks. In contrast, there is evidence that many areas of Dry Forest in eastern Oregon historically consisted of low contrast, fine-scale

Figure 14. Aquatic ecosystems require great care during restoration efforts.

Figure 15. Wet meadows and associated quaking aspen groves have been heavily invaded by lodgepole pine. These ecosystems are high priorities for intensive restoration efforts.

mosaics of individual trees, clumps and openings, which were continuous over large areas to form large landscape units or patches (1000+acres) (Hagmann et al., 2013). A major activity in landscape restoration is often stitching these large patch, low contrast, fine-scale forest mosaics back together.

It will often be necessary to retain dense, mid- to large-size forest patches (e.g., 10 to 500 acres) within Dry Forest landscapes otherwise restored to large continuous patches of low density forest to provide for the habitat needs of specific wildlife species. Examples include hiding cover for ungulates, and nesting and foraging habitat for northern goshawk and northern spotted owl. Fur bearers, such as American marten and fisher may also require special habitats. Wildlife biologists can provide guidance regarding desirable locations, conditions, and sizes for these denser forest patches and the degree to which any restoration activities can be undertaken in them. For example, the northern spotted owl recovery plan (USFWS 2011) provides general guidance regarding the size, condition, and distribution of patches needed for that species; consultation with agency biologists, including on-the-ground review, is essential in development of specific plans for Dry Forest treatments within the range of the northern spotted owl.

Landscape-level denser forest patches can be preferentially located in less fire-prone areas, such as steep north-facing slopes, riparian habitats, and sites protected by natural barriers, like lakes and lava flows. These will often be moister sites characterized as Mixed-Conifer forest sites. Restoring more fire-resilient conditions in the surrounding landscape matrix should increase the persistence or “hang time” of these denser forest patches (Ager et al., 2007a; Gaines et al., 2010). Note that these retained denser forest patches are not permanent reserves but, rather, are intended to be retained for as long as they remain intact and functional as dense forest patches. Losses of denser forest patches will be inevitable given their fuel loadings and at that time they will need to be replaced by growing new dense forest patches. However, since the surrounding restored matrix still is forested with significant populations of larger and older trees, it should be possible to grow replacement dense forest patches within a few decades.

Retaining larger (e.g., 10+ acres) dense forest patches may not be an ecological necessity in all Dry Forests tracts. Historically, landscapes dominated primarily by Ponderosa Pine forest sites probably had very few patches of denser forest and, like many forests on frequent-fire landscapes, extended over many miles as a fine-scale structural mosaic. Even in such cases retaining some denser patches may be desirable to meet wildlife goals, such as big game hiding cover.

In conclusion, examining larger planning areas is generally necessary with the goal of identifying areas that need modified management approaches, including areas to be left in a dense condition. This does not mean, however, that every landscape needs to retain significant larger dense forest patches. Rather, this should be one consideration in the landscape-level assessment, along with many others.

Strategically Place Treatments across the Landscape

In locating treatment areas within the landscape there should be careful consideration of the values that are at stake. Treatments can be located so as to:

- Focus treatments where they will help protect key resources such as concentrations of old trees;
- Maintain cover for big game;
- Help protect areas that will be left in a denser condition;
- Influence important landscape functions and processes, such as wildlife connectivity and fire behavior; and,
- Provide fuel breaks that will aid fire fighters in suppression efforts.

The work of Hessburg (2004, 2013), Finney (2007), Ager, et al (2007b), Gaines, et al. (2010a) illustrate useful analytical approaches that might be taken. In the end, though, much judgment will still be needed!

Identify High Priority Areas for Immediate Treatment

Priority setting for treatments should be done at the landscape level and there are many factors that will influence priority setting, which have to include forest-wide considerations. ***From an ecological perspective the highest priorities for treatment in landscapes should be areas where the greatest values—including those that are most difficult to replace—are at risk.*** Surprisingly, these may not necessarily be the sites and forests that are most "out of sync" with their historical fire return intervals (Franklin and Agee 2003). The most "out of sync" sites are likely to be the driest and least productive of the forest sites—i.e., the climax pine sites. Similarly, the highest priority sites ecologically are not sites where forests already have been homogenized by past forest management practices, such as by clearcutting, overstory removal, and establishment of plantations. ***Rather, a common example of where irreplaceable values are at risk are sites where residual populations of old trees are embedded in fuel-loaded stands dense with strongly competitive young grand/white fir and/or Douglas-fir*** (Figure 16). The much higher site productivity of the Dry and Moist Mixed-Conifer forest sites and the presence of ideal fuel ladders—shade-tolerant firs—are responsible for this condition in which old pines are at high risk of both stand-replacement wildfire and competitively-induced bark beetle mortality.

Develop Prescriptions as Part of Landscape Planning

Much of the landscape-level planning will be done by interdisciplinary teams as a part of larger planning efforts (e.g., during development of Environmental Analyses) on tracts of thousands to tens of thousands of acres. It is important to develop the general prescriptions for different treatment types and intensities at the same time, in collaboration with the

Figure 16. The sites where residual populations of old trees are embedded in fuel-loaded stands dense with strongly competitive young grand/white fir and/or Douglas-fir are going to provide the most common example of where high, essentially irreplaceable values are at risk in eastern Oregon—old pine trees on overgrown Mixed-Conifer Forest sites.

interdisciplinary team; otherwise the planning teams may not have a realistic notion of what can be accomplished and also will have difficulty doing their "effects" analysis. In addition, the treatments available for use can influence the landscape design.

Package Treatments of Different Economic Viability

Some forest restoration projects will pay for themselves through the value of harvested products and some will not (Adams and Latta, 2005; Franklin and Johnson, 2012). Monies generated from revenue-positive stands can be used to pay for or offset treatments that can't pay for themselves under authorities such as "stewardship contracts." Integrating areas that will generate products that can help pay for restoration treatments with those that require treatment but cannot generate significant financial returns is a key to successful landscape restoration.

Integrate Access, Logging Systems, and Economics

Road access and logging system limitations will often constrain what is possible to treat mechanically, and help define what areas are left untreated. A basic idea of which stands are accessible, what type of logging systems are required, and the cost and potential revenue of treating stands can help ensure that projects are economically viable.

Reduce the Impacts of Roads

Most areas where treatments can occur in Dry Forests already have an abundance of roads. Therefore, evaluating the desirability and usefulness of the existing road system is an essential part of landscape planning, especially analyzing the potential for closure and decommissioning parts of the road system.

In addition, with their negative ecological and hydrological impacts, proposals for added roads are often controversial and can derail restoration efforts. While each situation is unique, we offer some overall guidelines:

- Any additional roads, even temporary roads, must be clearly justified in the context of overall restoration goals.
- In most cases, building new permanent roads is neither necessary nor worth the negative ecological impacts and social distress.
- Reconstructing completely re-vegetated closed roads can be especially controversial and needs careful thought and justification.
- Some short temporary roads may be needed but they should be proposed only where essential to achieve project goals and

where they will be effectively decommissioned after the project is completed.

Set Aggregate Treatment Goals

Guidelines for the extent of treatments at the landscape level, including both mechanical treatments and prescribed fires, will vary substantially with the management goals and current condition of the landscape. For example, within the range of the northern spotted owl we expect that roughly a third of the landscape will be retained in patches with little or no restoration treatment in order to be consistent with the recovery plan for the owl (USFWS 2011). Denser patches may occupy a lower percentage of the landscape in other parts of eastern Oregon depending upon wildlife requirements or historical conditions. Conversely, **we expect that one-half to two-thirds of many (but certainly not all) Dry Forest landscapes will require some type of active management, given that restoration goals include creating landscapes that are more resilient in the face of wildfire, drought, and insects.** These will include treatments that can pay for their operational costs as well as those that cannot.

Examples of Landscape Planning

Three examples of our past and current efforts in landscape planning for Dry Forest restoration are provided here: 1) Pilot Joe Project on the Ashland Resource Area of the Medford District, BLM in southwest Oregon, 2) Soda Bear Project of the Prairie City District of the Malheur National Forest; and 3) the proposed Red Knight Project on the Chemult District of the Fremont-Winema National Forest.

Pilot Joe: Increasing Resilience of Dry Forest Landscapes while Contributing to Recovery of Northern Spotted Owls

Pilot Joe in the Middle Applegate Watershed, southeast of Grants Pass (Figure 17) was a Secretarial Pilot Project (developed at the direction of Secretary of Interior Salazar) on BLM forests (USDI BLM, 2011; Johnson and Franklin, 2012; Reilly, 2012). The objective of the project was to demonstrate the nature and the feasibility of active management to reduce stand densities and increase heterogeneity and resilience in Dry Forests, while retaining dense forest patches for the northern spotted owl (NSO) within the Dry Forest landscape.

Although there was general support for restoration forestry in the area, there were many concerns among stakeholders. For example, some were concerned about new road construction and skeptical that commercial harvest could be done while protecting residual stand characteristics such as large oak trees. Others felt restoration forestry does not provide a high enough economic return. Developing partnerships outside of the agencies helped considerably (Reilly 2012).

In the case of the Pilot Joe Project, the Applegate Partnership and the Southern Oregon Forest Restoration Collaborative were strong participants. These local groups, with membership from industry, environmental, and other community interests, were instrumental to the success of the project development and public review process—e.g., the Partnership and Collaborative organized and facilitated meetings side-by-side with the BLM. Having local community members make presentations and facilitate meetings provided a different tone to the proceedings than the usual meetings run solely by federal agencies (Reilly 2012).

In Pilot Joe, the BLM, with the assistance and advice of the stakeholders, applied the Franklin and Johnson (2012) restoration strategy to Dry Forest stands south of the Applegate River (Figure 18). The forests are relatively dense stands of maturing Douglas-fir

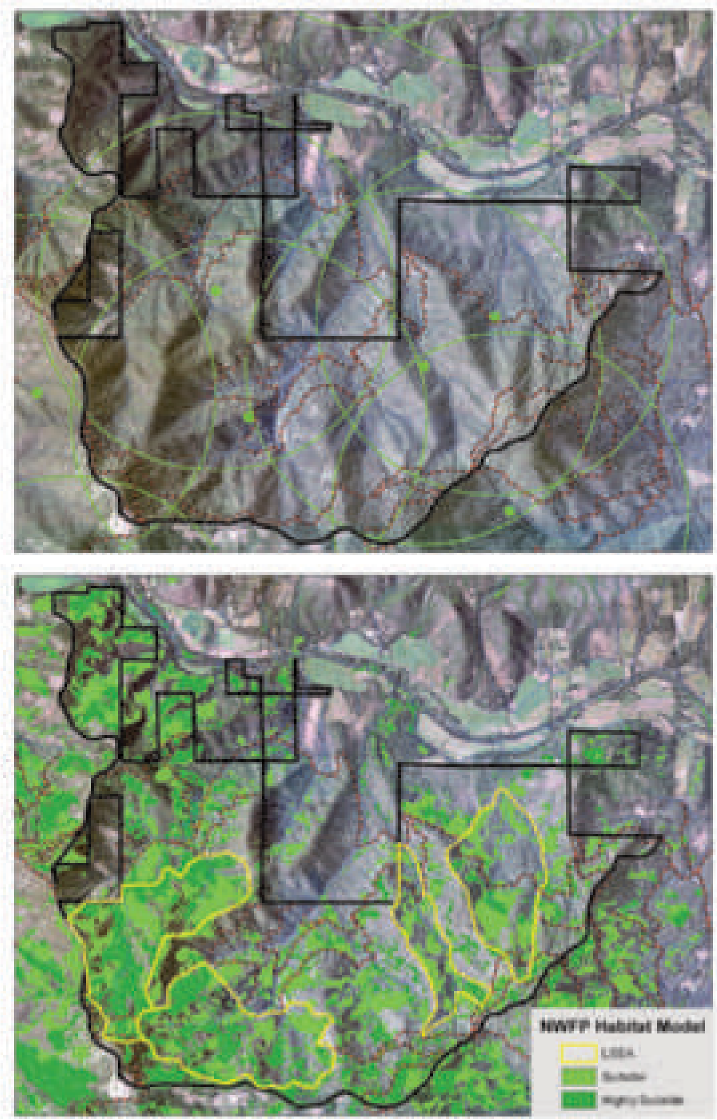


Figure 17. Consideration of the Northern Spotted Owl in the Applegate River Drainage, Medford District, BLM. Spotted owls have historically occupied the Pilot Joe area—home range circles and sightings (green dots), but few have been found lately. Preferred habitat for the Northern Spotted Owl was estimated in the range-wide analysis of Davis et al. (2011). Late Successional Emphasis Areas (LSEAs) were placed to capture suitable habitat, using both sources of habitat information, and reflect past owl use and relatively low fire probability.

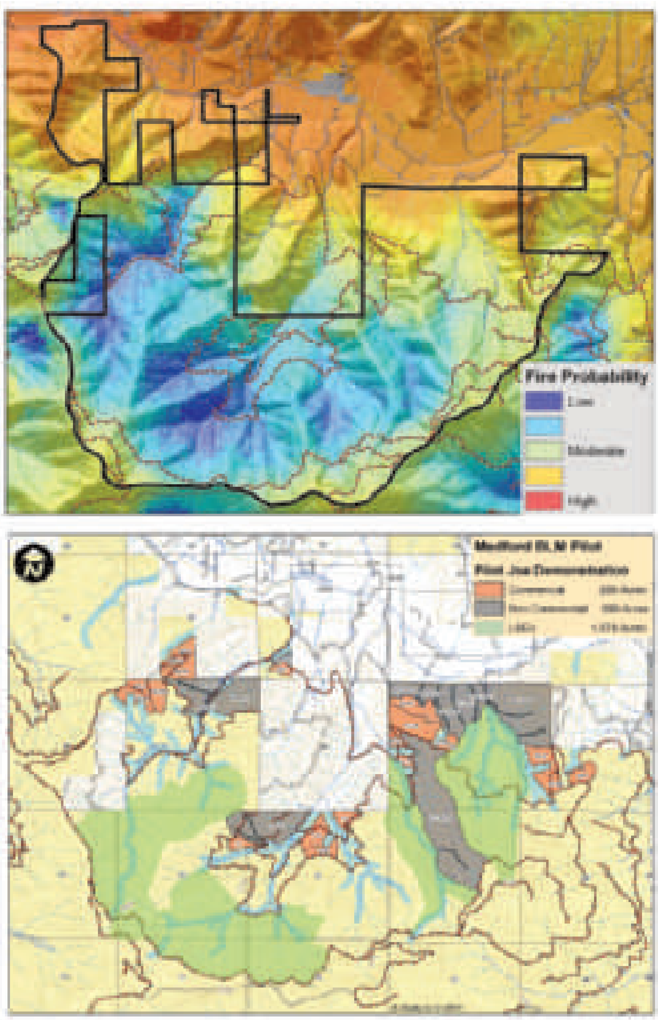


Figure 18.Top: Fire probability In Pilot Joe varies from relatively high in the valley bottom to relatively low in higher elevations. The Pilot Joe area regularly experiences both lightning strikes and human-caused ignitions; most of the fires start in the valley bottom. Bottom: Integration of forest restoration with conservation of the Northern Spotted Owl in Dry Forests of the Applegate River Drainage. Colored areas are BLM lands; white areas are private lands; blue linear features are Riparian Reserves; green areas are Late Successional Emphasis Areas (LSEAS) located around nest sites of the Northern Spotted Owl; orange areas are commercial restoration treatments that will provide economically viable timber sales; grey areas are non-commercial restoration treatments that will require investment.

with a mid-story of hardwoods (oaks and Pacific madrone). Ponderosa and sugar pines are present in small numbers. Generally, the few pines present are crowded by the dominant Douglas-fir and the remnant hardwoods are overtopped and in declining vigor or already dead. The heavily shaded understory is sparse.

Identification of approximately one-third of the drainage to retain as dense forest patches was the first step in applying the Dry Forest restoration principles. These landscape-level areas were intended to provide nesting, roosting and foraging habitat for the NSO, some of its prey species, and other species and processes dependent upon dense forests. BLM and USFWS professionals identified and delineated an appropriate set of dense patches based on maps of NSO habitat quality and historical owl use patterns (Figure 17).

Selection of areas for restoration treatments were based partially on their potential to help buffer the dense forest patches from the threat of wildfire. These were areas located between the Applegate River and the retained dense patches, since the valley bottom with its settlements and major highway have higher fire probability (Figure 18). Some of the areas selected for treatment were commercial units (i.e., they could more than pay for their treatment costs through removal of wood products) and some were non-commercial units (Figure 18).

Soda Bear: Dry Forest Restoration, Wildlife Protection, and Collaboration in a Timber Dependent Community

In March 2010, the Blue Mountains Forest Partners (BMFP)—a collaborative group based in John Day, Oregon—began work on the USDA Forest Service's Soda Bear Project on the Malheur National Forest in Grant County, Oregon (Brown 2012). The BMFP selected the Soda Bear planning area to propose forest restoration treatments on 20,000 acres to reduce the risk of uncharacteristic wildfire and lessen the effects of a pine beetle epidemic in the Soda Valley and Lower and Middle Bear sub-watersheds on the Prairie City and Emigrant Creek Ranger Districts. The BMFP and the USFS had previously identified these watersheds as high priorities for restoration through two prioritization processes (Brown 2012).

The Soda Bear Project is one of several projects that are part of a successful 2012 grant through the US Department of Agriculture's Collaborative Forest Landscape Restoration Program to promote ecosystem restoration and job creation in rural America (Brown 2012). Potential job creation through timber harvest and processing is especially important in Grant County because of high unemployment levels and limited employment alternatives.

Over the course of several months, diverse stakeholders representing county government, USFS, timber industry, conservation community, grazing permittees, recreational groups, and contractor interests visited the Soda Bear planning area in the field and discussed values and desired outcomes. Those discussions highlighted the importance of retaining mature and old-growth forest structure, maintaining and restoring aquatic communities, reducing the risk of uncharacteristic wildfire and insect damage, protecting sensitive wildlife species, and producing a merchantable by-product (sawlogs, biomass, etc.) from the restoration activities. This public interaction was critical to building public support for the project and improving project design (Brown 2012).

Use of the best available science was of central importance to the BMFP. Therefore they hosted many scientific experts and worked with Franklin and Johnson (2012) to mark a demonstration stand according to their restoration principles. Of particular importance to the BMFP was the treatment and retention of mature and old-growth tree species; on the Malheur National Forest, harvest rules prohibit the removal of living trees 21 inches in diameter at breast height (dbh) or greater (Brown 2012). This requirement restricts the removal of young, but large, tree species such as grand fir, and did not prohibit the removal of small, but old trees. These rules could reduce the amount of timber volume harvested in an ecologically sensitive way, a significant issue in the economically depressed community. To

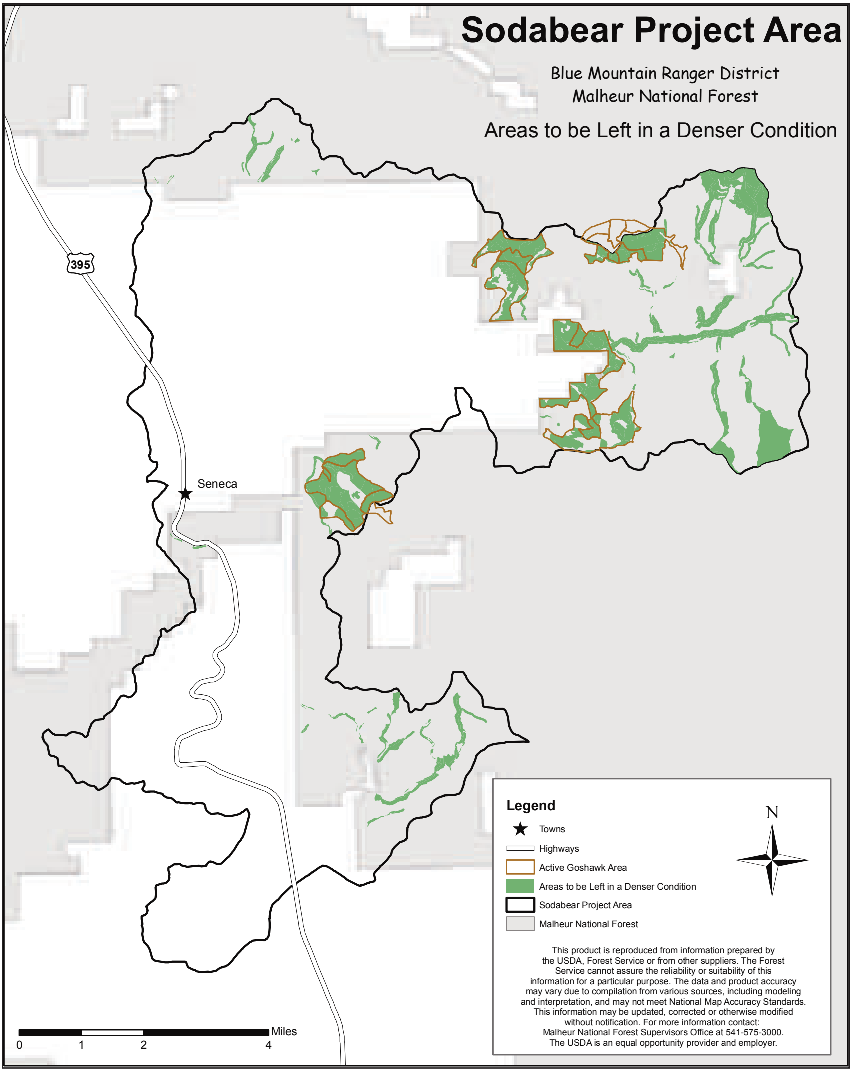


Figure 19. Proposed denser patches in the Soda Bear Project on the Malheur National Forest.

address these rule-based shortcomings, Franklin and Johnson recommended adapting a set of guidelines designed to distinguish old from large trees. This guide (Van Pelt 2008) uses environmental conditions and external characteristics to estimate tree age classes.

The landscape plan for Soda Bear had two major components:

1. Across the landscape about 25% of the area was selected for retention as dense patches, which generally had higher stem densities and canopy closure (Figure 19). These were to provide habitat for dense forest-related wildlife species, such as northern goshawk, pileated woodpecker, and sharp-shinned hawk as well as hiding cover for deer and elk. Many patches overlapped with known northern goshawk nesting and roosting sites. Limited understory thinning was allowed within dense forest patches to enhance or maintain old forest structures and break up the continuity of ladder fuels while maintaining a denser canopy structure.
2. The remainder of the project area would be thinned to increase the ecological resiliency of the forest to fire and insects by reducing stand densities, shifting species composition toward more drought and fire tolerant species (ponderosa pine and western larch), treating ladder and canopy fuels, and increasing spatial heterogeneity. Older trees (>150 years as identified using Van Pelt (2008) keys) would be retained and their survival improved by removing surface and ladder fuels and competing younger trees in an area around each older tree, including large young trees.

Red Knight: Comprehensive Landscape Restoration on the Fremont-Winema National Forest

Planning is underway on the Red Knight project (USFS, 2013) to restore more resilient conditions on approximately 30,000 acres of the Fremont-Winema National Forest that was within the historical Klamath Reservation (Figure 20).The national forest and Klamath Tribes are collaborating on this project, which has the goal of increasing the resilience of forest stands and landscapes by reducing stand densities and ladder fuels and increasing spatial heterogeneity, using the characteristic structure and composition of fire-adapted dry forests as a guide. Trees with old-growth characteristics (generally >150 years) will be maintained and their survival enhanced by removing fuels and competing younger trees around them.

Retention Patches at Different Scales

Two different spatial scales of retention areas have been selected:

1. Approximately 30% of the project area is identified as larger landscape-level retention patches to achieve three objectives (Figure 20): 1) Retain an area around Little Yamsay Mountain that is culturally important to some Klamath Tribal members; 2) Provide habitat for northern goshawk and great grey owls; and 3) Meet the cover portion of the big game cover-to-forage ratio (30:70) required by the Winema Land and Resource Management Plan (USFS, 1990). Although these areas are to be left largely untreated, limited treatments can occur in the big-game cover areas to reduce the densities of younger trees for two drip lines (approximately 20–30 feet) around remnant older trees. Log yarding and under-burning is permitted in the retention patches if necessary, as long as it is done in a way that does not adversely affect the integrity of the retention patch.
2. Within the 17,000 acres of stands selected for forest restoration treatments approximately 10 to 15 percent of the area will be retained in small (<1 to 5 acre) retention patches. These patches will provide habitat diversity within the stand by retaining snag and log patches, protecting spiritual, cultural, and places of worship, promoting desirable visual quality (e.g., reduced sighting distances), and implementing the Klamath Tribes Retention Patch Strategy for providing adequate hiding cover for big game.

Restoration Areas

The Red Knight project has several restoration goals (Figure 20):

1. **Understory Density Reduction in Recreation Areas:** Reduce conifer densities (<7" dbh) to lessen competition near large trees and hardwoods in wetter areas;

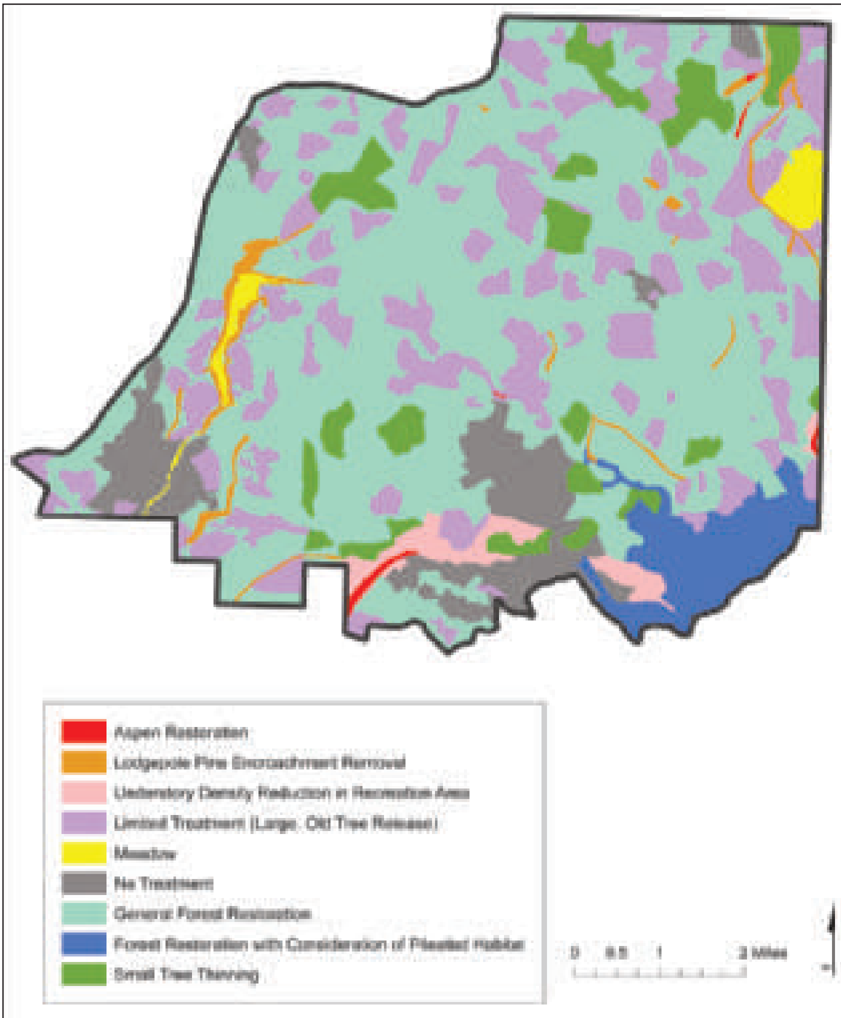


Figure 20. A landscape design for the Red Knight Project on the Fremont-Winema National Forest.

2. **Lodgepole Pine Encroachment Removal:** Improve vegetation diversity, provide wildlife habitat, release native riparian plant species from competition with conifers, and increase hardwood vigor and ability to regenerate along the edge of meadows;
3. **Aspen Restoration:** Reduce conifer competition and encourage aspen using aspen restoration recommendations;
4. **Small Tree Thinning**: Improve vigor, reduce competition, and increase heterogeneity in ponderosa pine plantations;
5. **General Forest Restoration**: Maintain old trees and reduce competitive stresses on them, increase heterogeneity, reduce stand density to maintain large tree overstory structure. Thinning densities vary by plant association and retain the natural clusters of ponderosa pine. Harvesting white fir greater than 21" dbh and younger than 150 years old is permitted. Lodgepole pine is targeted in areas where it has invaded ponderosa pine sites;
6. **Forest Restoration with Consideration of Pileated Habitat**: Maintain old trees and reduce competitive stresses on them, increase heterogeneity, reduce stand density to maintain large tree overstory structure, and provide structures and species of use to pileated woodpeckers. These acres are a high priority for immediate treatment, as they contain a large number of old-growth **ponderosa pine that are threatened by white fir encroachment**. Young white fir threatening old pines will be removed; however, white fir will be maintained over the larger area since large, decadent white fir are preferred foraging habitat for pileated woodpeckers.

The Red Knight Project is currently in the NEPA process and is subject to changes based on public comments and other input. A final decision is anticipated in the fall of 2013.

Part III
Stand Prescriptions for Forest Restoration

What are Stands?

Stands are traditionally defined as a "contiguous group of trees sufficiently uniform in species composition, size and age class distribution, and growing on a site of sufficiently uniform quality, to be a distinguishable unit" (Helms, 1998). This definition of stands works well in natural forests that originate following a stand-replacement disturbance, such as with many Moist Forests, or where even-aged forest management, such as clearcutting, creates forests of uniform age, structure, composition, and spatial arrangement.

This traditional definition of a stand does not work well in Dry Forests that retain much of their natural structure, which typically is highly heterogeneous and composed of intricate mosaics of numerous small (e.g., one-tenth to one-half acre) structural patches (Franklin and Van Pelt 2004). These patches vary from openings dominated by shrubs and tree reproduction to open groves dominated by large old trees and every condition in between. Objectively defining boundaries within this structural patchwork is typically very difficult (Franklin and Fites-Kaufmann, 1996); historically such forests often occurred as continuous heterogeneous units over thousands of acres, which lacked obvious "stand" subdivisions. Most of the "stands" observed today in Dry Forest landscapes are a product of modern management activities.

Hence, an alternative definition of stands is needed for the Dry Forests incorporating three major considerations:

1. Stands are part of a landscape, not independent units. Stands are the "patches" that make up watersheds and landscapes;
2. Stands incorporate smaller-scale structural patches of tree clumps, openings, and individual trees that make them "landscapes within landscapes" (Hessburg, pers. com); and
3. Dry Forest "stands" need to encompass the diversity of structural conditions found within the mosaic to be complete ecologically, from the open patches of reproduction to the groves of old trees (Franklin and Van Pelt 2004).

In this guidebook we define stands as areas from 10 to 1000+ acres with similar topography and soils and comparable overall structure and composition but incorporating significant internal spatial heterogeneity in the form of small patches differing in structure, tree age, and sometimes composition. Stands may or may not be the same as management or treatment units.

Structural Conditions of Stands

Stand conditions vary dramatically in Dry Forest landscapes depending upon the management and disturbance history that they have experienced as well as with environmental conditions. In this guide we highlight two important structural conditions, knowing that many stands combine elements of both:

Complex forest stands are those that still retain a significant amount of their historical structure, including residual populations of older (>150 year old) trees (Figure 21). Some Dry Forest stands on federal lands have experienced only relatively light selective logging based on the Keen bark beetle risk rating system and so still retain significant old tree and snag populations (Johnson, et al. 2008). Many of these stands also retain much of their historic spatial heterogeneity—the fine-scale, patchy

Figure 21. A structurally complex Dry Forest stand, which has a diversity of individual structures (including some large trees, snags, and logs), and a non-uniform (heterogeneous) spatial distribution of these structures. Removing fuels and competitive vegetation around old-growth trees will typically contribute to the desired spatially heterogeneous restoration outcome.

mosaic—that was characteristic of the historic stands, even though stand densities have generally increased with exclusion of wildfire.

Simplified forest stands are typically relatively homogeneous in structure, usually as a result of their management history (Figure 22). Examples include uniform stands of small and medium-sized trees that have resulted from clearcutting followed by replanting or natural regeneration, or from removal of all old trees by treatments referred to as "overstory removal." Such stands typically have few or no residual old structures that can be used to anchor restoration prescriptions.

Figure 22. A typical simplified Ponderosa Pine stand (top) and Mixed-Conifer stand (bottom). Both are dominated by one tree size and condition and a homogeneous spatial distribution of these trees. Such stands have often arisen as a result of "overstory removal" treatments, where the old trees were removed, or as a result of clearcutting followed by tree planting.

Desired Forest Structures

Defining forest structural goals is the first step in restoration. Structural conditions in historical Ponderosa Pine, Dry Mixed-Conifer forests, and some Moist Mixed-Conifer Forests were often characterized by an uneven-aged mosaic of widely spaced individual trees, tree clumps, and openings that was sustained through fine-scale, gap-phase replacement processes (Figure 23, 24, & Box 2) (Larson and Churchill, 2012). These forest mosaics

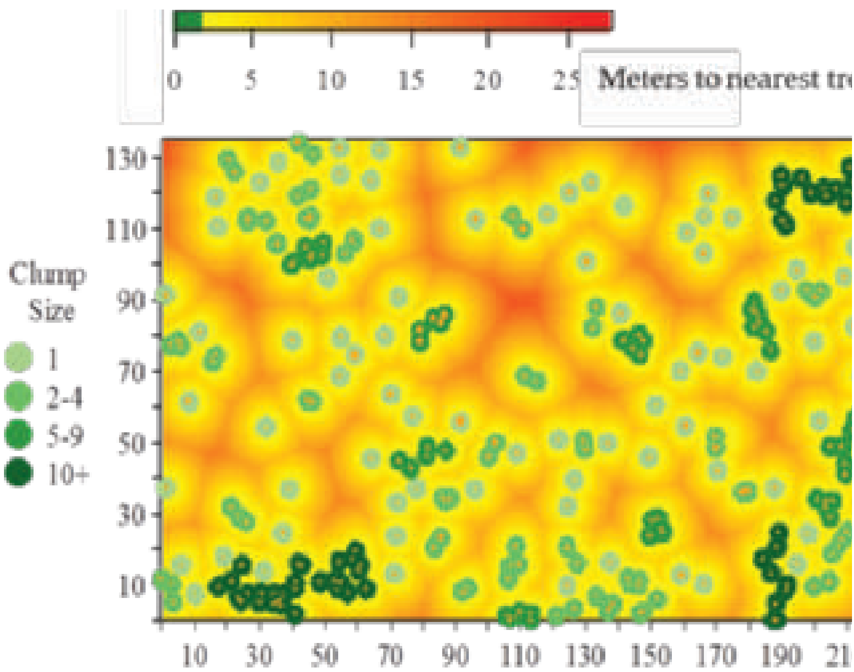


Figure 23. Stem map of reconstructed forest (circa 1900) in the Black Hills of the Fremont-Winema National Forest that displays the spatial pattern of individual trees, clumps, and openings. Stem map is approximately seven acres. Orange dots are tree boles scaled to dbh. All trees are ponderosa pine. Green circles are a fixed 3m (10') crown radius around each tree, and show interlocking crowns and clump formation. Larger clump sizes are shown in darker green colors. Clump size is the number of trees in the clump. Color ramp and background coloration in plot indicate the distance to nearest tree or gap edge. For example, the areas colored dark red are areas that are approximately 25 m (85') from the nearest tree or gap edge.

Figure 24. Mosaic spatial pattern of a contemporary reference site for pine plant associations: a restored area of the Metolius Research Natural Area. This site was not harvested historically and fire has been re-introduced over the last 20 years.

were highly variable with a wide range of tree clump and opening sizes, including thickets of regeneration (Kaufmann et al., 2007), and lacking in traditional stand units. Hardwood pockets, shrub dominated patches, riparian areas, meadows, and rock outcrops were also part of many stands.

Large, old fire-resistant trees made up the majority of the basal area and average tree densities across forest tracts were generally well below site carrying capacity (see Box 2). Basal areas typically varied widely (0–200+ ft^2/ac) at fine scales (approximately one-quarter ac) within forest tracts although the average basal area was relatively low (Hagmann, Franklin, and Johnson 2013). Contemporary Dry Forests with minimally altered or restored frequent-fire regimes are similar (Stephens et al., 2008) as are other highly productive frequent-fire forests, such as those of longleaf pine (Mitchell et al., 2006).

Restoration treatments on these sites are intended to restore forest conditions that will be more resilient to drought and fire as well as providing diverse ecosystem functions by reducing tree densities and shifting forest composition and structure—including a more heterogeneous structural pattern. Understanding and restoring the processes and forest dynamics that sustain frequent-fire forests is also critical (see Box 2). **It is always essential to keep in mind that variability within and among stands is the critical goal—not some single model structure or pattern, however!**

Landscape analyses will provide general guidance about how different treatments need to be arranged at larger spatial scales. For example, a major landscape goal may be to increase the overall area and patch size of low-density forests dominated by old trees by stitching together multiple small patches into larger patches. In contrast, other areas, such as those on cooler, wetter sites, may be managed for dense, multi-storied forest habitat.

A restoration goal in all stands is to retain and nurture important structural complexity including older trees (Figure 25), large diameter snags (even if short) (Figure 26), large down logs, and any significant hardwood trees (Figure 27). As will be seen, important structural elements are not only retained during restoration but also receive special consideration in restoration silviculture, such as by removing fuels and younger competing trees.

Figure 25. Keystone structures, such as old trees and tree clusters, are retained in Dry Forest restoration treatments and their survival is enhanced by removing surrounding fuels and competing younger trees for twice the distance of their crown drip line.

Figure 26. Large snags should be retained even when they are short because of their importance for cavity-creating and cavity-dwelling birds and mammals. For example, snags of this type are high valued as habitat for white-headed woodpeckers.

Figure 27. Hardwood trees, such as Oregon white oaks, provide valuable diversity in Dry Forest stands when they are present, including habitat and forage. Such structures should generally be retained when present in stands undergoing restoration.

Box 2: **Forest Dynamics in Frequent Fire Forests**

Ponderosa Pine and Dry Mixed-Conifer sites that experience frequent fire (5–20 years) are typically a fine-grained mosaic of individual trees, clumps, and openings (Figure 2-1). This condition was created and maintained by fires, insects, pathogens, and other disturbances, which caused periodic mortality of larger trees thereby freeing up light, water, and nutrients for regeneration (Figure 2-2).

Regeneration typically established in dense thickets that were thinned by fire, insects, and competition. Over time, these thickets ended up as clumps of 2–20+ overstory trees. Clumps were often uneven-aged as regeneration established close to existing trees as well as in openings. Large, isolated, individual trees were also present.

Understory shrubs and grasses, along with conifer needles and cones, provided the fine fuels to carry low-severity fires on frequent return intervals. Moderate to high-severity disturbances did occasionally reset these patterns, but some large old trees typically survived (Hessburg et al., 2007). Moist Mixed-Conifer forests generally had somewhat longer fire return intervals with more mixed-severity fire.

Figure 2-1. 150 m x 20 m canopy profile drawn by Dr. Robert Van Pelt in complex forest at Bluejay Springs on the Fremont-Winema National Forest that shows the mosaic of individual trees, clumps and openings.

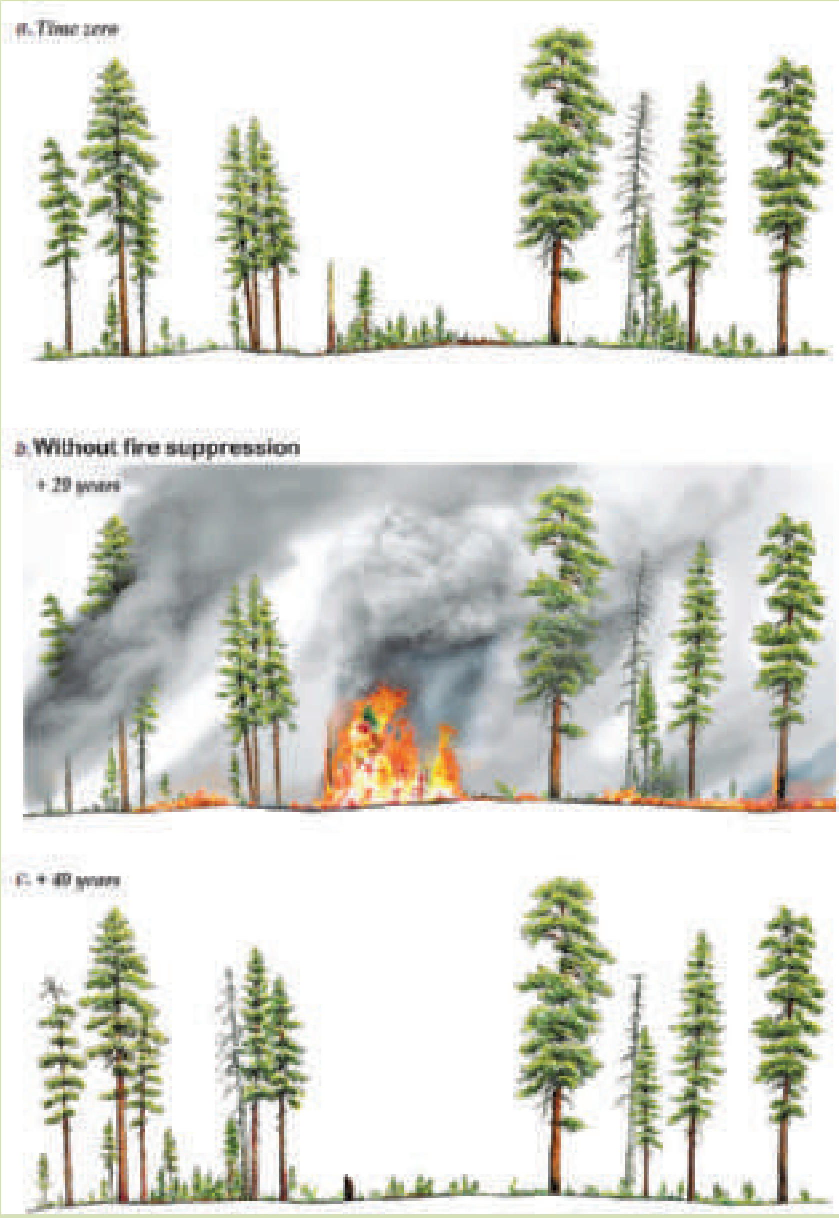


Figure 2-2. Historically, low to mixed severity ground fires would occur every 5 to 20 years freeing up light, water and nutrients for regeneration (Van Pelt, 2008).

Elements of Silvicultural Prescriptions

Much has been learned about fuel reduction and restoration treatments in dry forests over the last 20 years (Reinhardt et al., 2008). The scientific underpinnings and basic principles for mechanical thinning and prescribed-fire treatments have been well established (Allen et al., 2002; Franklin and Agee 2003; Hessburg and Agee, 2003; Peterson et al., 2005; Franklin et al., 2008; Jain et al., 2012, Martinson and Omi 2013, Schwilk et al., 2009). Learning is continuing as more experience and science become available. An important example is in our understanding of how to define and implement spatial heterogeneity in treatments (North et al., 2009; Churchill et al., 2013).

Dry Forest restoration treatments can be broken down into six important elements:

- Retain and release old trees;
- Shift composition towards more fire- and drought-tolerant species;
- Restore a heterogeneous fine-scale spatial mosaic;
- Reduce stand densities while increasing mean diameter;
- Protect and restore understory plant communities; and,
- Do appropriate “finish work,” including treatment of activity fuels.

Each element is described in the following sections.

Retain and Release Old Trees

Old trees are the structural backbone of Dry Forests. Old trees have thick, fire-resistant bark, deep root systems, complex crown architecture, high heartwood to sapwood ratios, and they provide unique wildlife habitats (Kolb et al., 2007). Protecting trees based on age rather than size is recommended because old and mature fire- and drought-tolerant trees are rare on the landscape relative to historic reference conditions and perform unique services and functions. **In general, we recommend retaining trees of all**

species older than about 150 years of age as part of Dry Forest restoration projects. Further, we recommend using breast-height age in this determination to avoid complications caused by trees that have undergone significant suppression as seedlings or saplings.

Determining tree ages is more difficult than measuring their size. However, the approximate age of fire-resistant early seral species, such as ponderosa pine, sugar pine and western larch, can generally be determined from bark, crown form, and branching pattern characteristics (Van Pelt, 2008; Box 3). Identifying old white or grand firs is more challenging, but possible (See: Box 3); a visual guide to grand/white fir tree age is currently under development by James Johnston (Johnston, 2013).

Two caveats are relevant in using age as the first screen in selecting trees for retention:

1. Stakeholders and agency personnel must agree on some allowance for errors in age estimation. Despite the best of intentions, some older trees will occasionally be taken. We do not intend that every old-looking tree be cored to determine its age. Rather, after some training, we suggest a visual-inspection approach after some training paired with post-project monitoring to assess the accuracy of the calls. When stump counts are part of post-logging assessment, all parties need to remember that age counts are always higher at stump height than at breast height; sometimes, as in the case of trees that have been suppressed as seedlings or saplings, they are significantly higher. Hence, appropriate adjustments of stump age to breast-height age will be necessary.
2. Size is important for many wildlife species, such as cavity nesters, and should also be considered when developing silvicultural prescriptions.

Younger trees and other competing vegetation should be removed from the vicinity of older trees for approximately twice the canopy drip line of the old tree to reduce competition for

Box 3: **Identifying Old Trees**

It is possible to learn to gauge the age of ponderosa pines based on appearance. Ponderosa pines less than 100 years old have dark brown or black bark with narrow, shallow fissures that begin to widen and show a lighter reddish color between 90–140 years of age. At around 140–180 years of age, the dark brown or black ridges begin to flatten and turn an orange-red color. Ponderosa pine develops distinctive orange bark plates divided by dark fissures by 200 years of age. Pines 250+ year-old have wide orange or tan bark plates that are substantially wider than the fissures that divide them.

Robert Van Pelt has developed a rating system that can be used to quickly determine the general age for Ponderosa pine (Figure 3-1), western larch and Douglas-fir (Van Pelt 2008). His system is easy to learn and can be calibrated to fit different areas. Even with calibration, though, 100% accuracy should not be expected.

As shown in Figure 3-2, diameter at breast height (dbh) provides an imperfect estimate of the age of a tree. In general, late seral species like grand/white fir and Douglas-fir are younger than early seral species of the same size. Even within a single species, e.g., ponderosa pine, dbh can be a misleading

Rating system for determining the general age of ponderosa pine trees

(Choose one score from each category and sum scores to determine developmental stage)

Lower trunk bark condition	Score
Dark bark with small fissures	0
Outermost bark ridge flakes reddish, fissures small	1
Colorful plates, width about equal to fissure widths	2
Maximum fissure to fissure plate width ≥ 15 cm (6 in) and <25cm (10 in)	3
Maximum fissure to fissure plate width ≥ 25 cm (10 in)	5

Knot indicators on main trunk below crown	
Dead branches below main crown, whorl indicators extending nearly to tree base	0
Old knot/whorl indicators visible below main crown	1
No knot/whorl indicators visible	3

Crown form (refer to figure 49)	
Similar to a tree in top row	0
Similar to a tree in middle row	3
Similar to a tree in bottom row	5

Scoring Key

< 2	Young tree
2–5	Mature tree < 150 years
6–10	Mature tree ≥ 150 years
> 10	Old tree ≥ 250 years

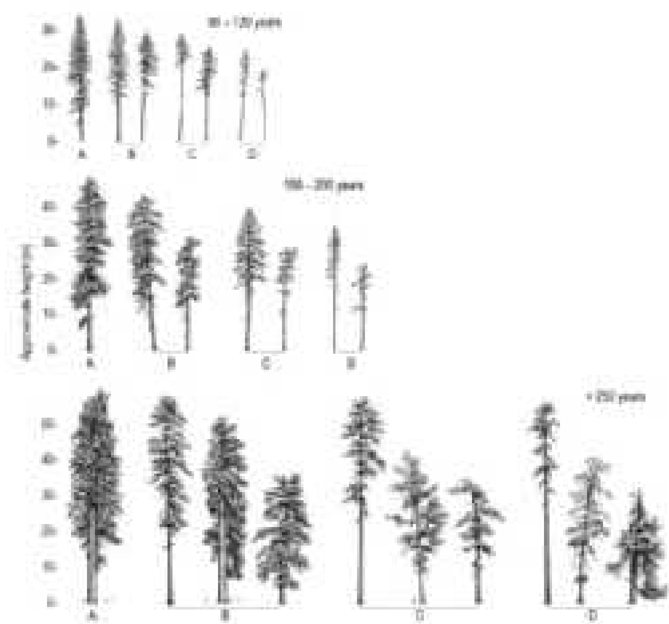


Figure 3-1. This rating system combines bark surface characteristics with crown form and tree vigor to approximate the general age of ponderosa pine trees (Van Pelt 2008). Download the complete guide at www.dnr.wa.gov/ResearchScience/Topics/ForestResearch/Pages/lm_oldgrowth_guides.aspx

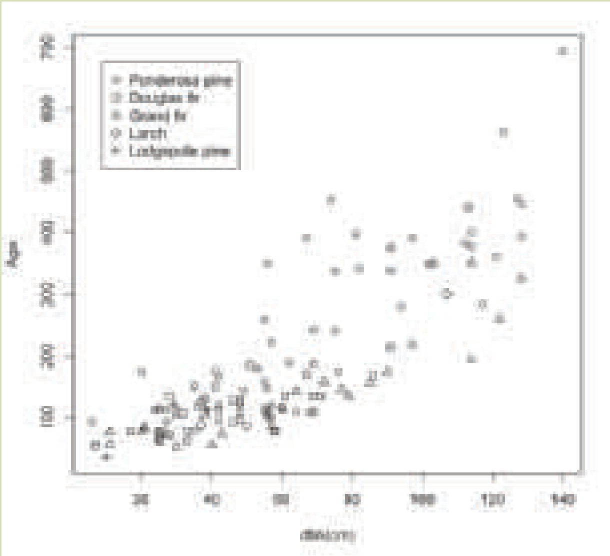
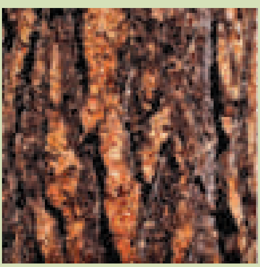
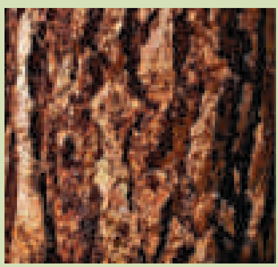


Figure 3-2. Tree diameter does not always correlate well with tree age.


134 years


164 years


227 years


271 years


304 years

Figure 3-3. Bark patterns on mature and old (> 250 years) pronderosa pine. The colofrul bark plates on old trees are generally more than three time wider than the darker fissures that separate them. (Images reproduced from Van Pelt 2008)

Figure 3-4 and 3-5. The white fir on the left is 303 years old and 40 inches dbh. It has no fine branches (or any other branches) near the ground and deep bark fissures. The white fir on the right is 78 years old and 24 inches dbh. It has many fine branches and foliage to the ground with moderately deep (approximately 1.5 inch) fissures.

indicator of age (See Box 8). Maximum bark plate width, however, is well correlated with age and is used in Van Pelt's rating system (Figure 3-1) to determine approximate age.

The three most important morphological clues for aging grand/white fir are the depth of bark fissures, presence of fine branches, and condition of the upper canopy. Grand/white fir with bark fissures that are more than 2 inches deep from the outer portion of the bark are typically older than 150 years (Figure 3-4). The presence of numerous broom-like fine branches less than a 1/16 of an inch in diameter near the ground are generally an indication of a tree that is less than 150 years of age (Figure 3-5). Upper canopies that display multiple tops and extensive mortality usually indicate trees >150 years of age.

water and ladder fuels, which could spread fire into the canopy of older trees. Other old trees may occur within twice the canopy of the drip line but this overlap is OK—all old trees should be left, including the smaller (<21") old trees. The tree marker may leave some younger trees within twice the canopy drip line if they find some tree that they view as desirable old-tree replacement candidates. If groups of trees older than 150 years are found clumped together with slightly younger trees (approximately 125–150 years) that have thick, orange-red bark, we generally recommend retaining the entire clump (Box 4).

Shift Tree Composition towards More Fire- and Drought-Tolerant Species

Restoring the dominance of fire- and drought-tolerant species in Dry Forests is fundamental to increasing resilience. Ponderosa pine, western larch, sugar pine, and incense-cedar are species with significant fire- and drought-tolerance. Douglas-fir also has some drought and fire tolerance, but takes longer to develop thick, fire resistant bark than ponderosa pine (Keane et al., 1990); historically it was also much less common than it is today.

The desired proportion of fire-tolerant to fire-intolerant species will vary by PAG. On sites historically dominated by ponderosa pine, meeting wildlife, fire and fuels, and resilience objectives may involve leaving almost 100% of a stand's post-treatment basal area in pines. In the more productive Dry Mixed-Conifer stands, some Douglas-fir or grand/white fir may need to be left to achieve residual basal area objectives.

Restoring species composition towards historical levels can often mean removing large but younger (<150 year) grand/white fir and Douglas-fir to favor pines and western larch. Hard diameter limits, such as a 21-inch dbh limit, can make it difficult or impossible to achieve desired composition in many Mixed-Conifer Forests, which would compromise their future resilience. At the same time, large, young fir trees provide important wildlife habitat in their live, standing dead and down states, so some often should be retained (Box 5).

Restore a Mosaic Spatial Pattern

Creating spatial variability within a stand is a key aspect of restoring dry forests (Box 6). *While it is useful to have a general stand-level density target, having extensive uniformly thinned areas within a stand is generally inconsistent with ecological goals*; for example, it may have unintended negative impacts on wildlife and/or negatively influence the behavior of disturbances (North et al., 2009).

Figure 28. Upper photo displays evenly spaced thinning treatments that are inconsistent with conditions in historical frequent-fire forests. The lower photo is an example of a treatment designed to create a mosaic of individual trees, clumps, and openings.

Box 4: **Retain Clumps of Old Trees; Don't Thin Them Out**

When clumps of old trees are encountered (which is frequently!) there is often a debate about what to do in restoration treatments. There are concerns that competitive stresses and associated insect mortality will be a problem within clumps of old trees. However, no published evidence of higher rates of mortality of old trees in large clumps exists to our knowledge. We can infer from the existence of the clump that the trees in the clump have developed stable and possibly even mutually supportive relationships with each other over decades or even centuries. By and large, we lack scientific studies of the benefits and risks of these clumps, although some wildlife do benefit from these structural aggregates. Research is underway to determine whether mortality of old trees is indeed higher in large clumps vs. widely spaced individuals. This will provide a greater empirical basis for assessing the actual mortality risk of leaving large clumps.

Concern over future mortality generally does not justify removing old trees from clumps. In historical forests, high proportions of basal area occurred in large clumps of trees resulting in localized areas that could exceed 200 ft^2/ac of basal area (e.g. Churchill 2013). The fact that old trees persisted for centuries in clumps with adjacent openings suggests that competitive stresses experienced by smaller, weaker trees within clumps may be ameliorated by sharing water and nutrients through root grafting. Large, old trees have extensive root systems that can extend laterally into adjacent openings and also vertically into deep sources of below-ground water. While old trees are certainly affected by competition and respond to thinning treatments (Kolb et al., 2007), mortality of old trees results from a number of factors and cannot be explained by competition alone (e.g. Das et al., 2011).

Bark beetles do kill clumps of old trees as well as individuals, but large scale mortality events are rare (Fettig et al., 2007). This is not necessarily undesirable; however, some cavity nesters appear to favor trees in clumps over isolated trees (Saab and Dudley 1998; Haggard and Gaines 2001). Periodic mortality facilitates future regeneration by creating openings. Tree death also results in large and persistent snags and downed logs that are important wildlife habitat; mortality of clumps creates small snag patches. Finally, remember that, in any case, under our restoration strategy old trees are dedicated to the ecosystem both in the living and dead states.

Mortality that exceeds replacement rates of older trees is, of course, a concern. These rates need to be monitored and, if excess mortality occurs, treatment strategies may need to be reconsidered.

Figure 4-1. Top: Intact clumps of Ponderosa Pine—do not thin these out. Bottom: A clump that has been thinned to create a more uniform distance between leave trees—this is a good example of what not to do.

Box 5: **Deciding Which Larger Grand/White Fir to Retain or Remove During Restoration**

Deciding how many and which larger grand or white fir to retain and which to remove can be a challenging question for managers, stakeholders, and marking crews, particularly when there are no diameter limits (e.g., trees >21" dbh) or where diameter limits have been suspended. Large grand/white firs are often abundant on sites where they are poorly adapted or unwanted as potential fuel or a continuing source of grand/white fir seed. On the other hand, larger grand/white firs often make up a large percentage of the basal area and provide important wildlife habitat. So, what to do? Let's begin by looking at some attributes of grand/white firs and then examine factors favoring retention or removal. Do remember that all older (e.g., greater than approximately 150 year old) grand/white firs should generally be retained along with older trees of other species.

Grand/white firs have the potential to grow fast and to larger sizes relatively quickly on sites that are environmentally favorable, such as Moist Mixed-Conifer sites. They are aggressive regenerators, producing large seed crops at frequent intervals. Grand/white firs are highly shade tolerant and typically retain lower branches as they grow into saplings and poles, creating potential fuel ladders. While growth during the first century is often rapid, grand/white firs are relatively short-lived species with low resistance to trunk, butt, and root rots, insect defoliators (especially spruce budworm), and bark beetles, among other afflictions (Table 1). Hence, mature (e.g., approximately 100 year old) stands dominated by white or grand fir can be expected to fall apart during their second century because of high levels of tree mortality, although individual trees may survive for 200 years or more. Grand/white firs are decay prone in the dead as well as the live state, so persistence as a snag or down log is short. Grand/white firs are also highly vulnerable to damage or death by wildfire or drought.

Why would we retain larger young grand/white firs in restoration treatments, given their vulnerability to disease, insects, fire, and drought? One major reason might be the desire to retain some larger diameter trees as part of the residual stand, and a second may be that retaining grand/white fir could help achieve the target residual stand structure (e.g., basal area or tpa) where this species is a major component. Grand/white firs may be a good choice for retention where rapid growth in wood volume is a major objective in the restored stand, however wildlife habitat is more likely to be a reason for retaining larger grand/white firs. Larger grand/white firs often have decadent features, like cavities, decay pockets, and brooms, which are useful to wildlife. Furthermore, many of these trees are important sources of snags and logs, since most will die in the near future (e.g., 50 years). For example, grand/white firs hollowed by Indian paint fungus may be opened up by pileated woodpeckers and later used by Vaux swifts. Finally, grand/white firs produce seed crops that are valuable to some wildlife, including Douglas squirrels.

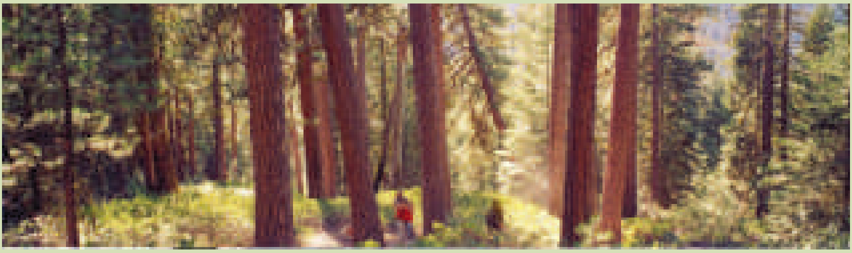
Why should many or most of the larger grand/white firs be removed during restoration treatments? First, they compete aggressively with ponderosa pine and other fire- and drought-resistant species and may provide significant fuel ladders. Hence, the location of larger grand/white firs relative to pines and larches or even Douglas-fir may be an important factor in deciding which ones to retain. Grand/white firs are also relatively short-lived and highly susceptible to fires and defoliators; they are not likely to make a long-term contribution to the live basal area of the stand or to contribute to its resilience. There are many examples where larger grand/white firs were retained to maintain the basal area of restored stands but died within the next decade. Of course, this is fine if an objective is to generate short-lived snags and down logs for wildlife. Finally, removal of larger grand/white fir will substantially reduce the amount of grand/white fir seed source present on the site and, potentially, its abundance in regeneration.

So, what are the most appropriate larger grand/white firs to retain in restoration treatments? First, retain any grand/white fir older than approximately150 years of age. Guides for visual identification of these older trees are under development and initial results are reported above. With larger grand/white firs that are less than150 years of age, consider retaining individuals that are not threatening older pines or western larches either as fuel ladders or competitors, especially in Moist Mixed-Conifer Stands. Further, where a choice is between trees with significant defects, such as cavities and stem rots, and sound trees of comparable size, ***retaining defective trees is generally the better choice ecologically and economically.*** Trees with defects generally will have the greatest wildlife value both in the short- and long-term.

Box 6: **Why Spatial Pattern in Forest Structure Matters**

The structural mosaic of widely spaced individual trees, tree clumps, and openings characteristic of Dry Forests is important because it:

1. Inhibits the spread of crown fires due to openings that force crown fires back to the ground (Beaty and Taylor, 2007; Parisien et al., 2010; Pimont et al., 2011; Stephens et al., 2010; Thaxton and Platt, 2006);
2. Impedes the buildup of epidemic insect outbreaks by disrupting pheromone plumes while sustaining the low levels of bark beetle attack, which are necessary to maintain structural and species diversity (Fettig et al., 2007);
3. Creates barriers to the spread of dwarf mistletoes and fungal pathogens (Goheen and Hansen, 1993; Hawksworth et al., 1996);
4. Provides wildlife habitat for many species of birds and small mammals that require a mixture of tree clumps and openings (Buchanan et al., 2003; Dodd et al., 2006; Long and Smith, 2000);
5. Facilitates frequent and patchy regeneration that creates a multi-aged tree structure and a continuing flow of replacement trees. Frequent pulses of regeneration may contribute to high levels of within-stand genetic diversity of trees found in Dry Forests (Hamrick et al., 1989; Linhart et al., 1981);
6. Increases understory plant abundance and diversity by providing large openings and variability in light, moisture, and soil nutrient environments (Dodson et al., 2008; Gundale et al., 2006; North et al., 2005); and,
7. Increases snow retention, which is highest in stands with canopy openings that are large enough to have reduced canopy interception, but small enough to be shaded and protected from wind (Varhola et al., 2010). Snow retention strongly influences soil water levels, plant growth and vigor, and fuel moisture.



Mechanical and prescribed fire treatments can be used individually or in combination to create variability in within-stand density. Treatments should be planned collaboratively by specialists to balance fuel reduction, wildlife, and other objectives. Marking guidelines can be broken down into three categories when attempting to restore a mosaic pattern of individual trees, tree clumps, openings, and special habitat areas characteristic of frequent-fire forests:

1. Skips, which are areas of stands that are left untreated;
2. Openings, which are areas where most overstory trees are removed; and
3. General thinning areas which is the remainder of the stand where individual trees and clumps or clumps of 2–20+ trees are retained.

Skips

Skips are portions of the restoration unit that are not treated mechanically and may also be protected from prescribed fire. Leaving untreated areas is necessary to:

- Protect important physical and biological features within stands critical to maintaining biological diversity and key processes;
- Retain hiding cover for wildlife species and reduce visual sighting distances;
- Provide for heavily shaded, cool micro-habitats;
- Ensure the retention and ongoing creation of snags, downed wood, and regeneration; and
- Provide for diversity of tree species (e.g., good representation of shade tolerant species or hardwoods).

Incorporating skips into silvicultural prescriptions is sometimes challenged by professional foresters, since skips create more complexity in stand marking, logging, and prescribed burning activities. ***However, identifying and protecting important ecological features and functions is fundamental in managing***

forest ecosystems. It is a complexity that needs to be accommodated to achieve the desired ecological outcomes. Methods to efficiently layout skips are discussed in the implementation section.

Types of skips

We identify different categories of skips based on their functional roles. In practice, an individual skip will often fulfill more than one functional role. When provided with a choice, try to place skips so as to avoid including significant numbers of old-growth ponderosa, sugar pine, or western larch within them, since this would make it impossible to treat the fuels and competing vegetation surrounding these included trees.

1. **Biological Hotspot Skips**
   These skips are intended to protect biologically important features within a stand, such as wet microsites (e.g., seeps), rocky outcrops, and large snags (Figure 29). Skip size and shape will depend upon the nature of the specific feature(s) but typically they will vary from 1/10th acre for a skip focused on a large snag up to an acre or more around rocky outcrops or wet seeps. In general, prescribed burns should not be allowed to burn through these skips. Biological hotspot skips will also function as shade skips (#3) and visual skips (#5). Note: Snags being retained as white-headed woodpecker habitat should not be protected as a skip, since this woodpecker prefers an open condition around snags that it uses.
2. **Regeneration Skips**
   Thickets of seedlings and saplings (1 to 20' in height) are characteristic components of Dry Forests (Figure 30). These areas, which typically are open or have few overstory trees, provide specialized habitat for certain mammal and bird species and hiding cover for big game; they are also primary areas for successful establishment and development of shade-intolerant plant species, including ponderosa pine. These patches generally range from 0.2 to 1 acre in size but

Figure 29. Examples of biological hotspot skips include snags and rock outcrops.

Figure 30. Regeneration skip.

occasionally may be up to several acres. These skips are often compact or circular in shape. Regeneration skips should not have high cover of overstory trees but often will incorporate some larger mid-story or overstory trees. Prescribed fire can be used to burn through regeneration skips and thin the regeneration but at low to moderate severity so that significant tree survival occurs. Some skips will need to be protected from fire to insure that structures required by wildlife are not burned up. Regeneration skips can also serve as deadwood (#4) and visual (#5) skips.

3. **Shade Skips**
   These skips provide shaded cooler and moister habitats required by some ecological processes and organisms, including many decomposer organisms (e.g., fungi and invertebrates) and saprophytic plants. They also provide shaded and protected hiding, resting, and roosting areas for selected wildlife species (Figure 31). These skips should

Figure 31. Shade skip.

generally be compact in shape and large enough to provide moderated microclimatic conditions (>0.20 acre). Shade skips generally have high density and canopy cover of overstory trees, which distinguishes them from regeneration skips. They can have a single story structure, or can be multi-storied, especially when needed for species such as marten or fisher. They are useful on north facing slopes and in draws where they were historically more likely to occur. Prescribed fire can be allowed to burn through these skips if the likelihood of maintaining the shaded environment is high. In some cases, prescribed fire should be kept out to maintain duff layers and dense conditions. Denser shade skips may also function as deadwood skips (#4) and visual skips (#5).

4. **Deadwood or Decadence Skips**
   Retaining areas where fire, root rots, mistletoes, and insects, along with competition, have created pockets of decadence, tree mortality, snags and coarse down wood is part of

restoration (Figure 32). These areas provide critical habitat for many wildlife species. They also provide for ongoing, "time release" mortality of overstory trees and subsequent establishment of regeneration. Decadence skips may be patches with dense overstories where disturbance processes are just beginning or relatively open areas with lots of downed wood and significant ongoing mortality. These skips can vary substantially in size (e.g., 0.1 to 2+acres) depending on the processes operating there. The balance between leaving decadent areas versus treating them should be based on stand and landscape conditions and management objectives. Allowing prescribed fire to burn through decadence patches and create new snags is often desired. In skips with high levels of downed logs, ensuring that prescribed fires don't consume all of the dead wood is important.

Figure 32. Coarse wood or decadence skip.

5. **Visual Skips**
   Visual skips are intended to break up the viewing distances within restored stands. Restored stands that are very open—i.e., where viewing distances of hundreds of feet are typical—are not ideal for many wildlife species, such as those that require hiding cover or avoid large open areas. Visual skips are created to reduce sighting distances in restored stands for big game, predators, and bird and mammal species sensitive to exposure.
   Visual skips will often be relatively narrow and elongated to more effectively breakup stand visuals and incorporate populations of small and intermediate-sized trees that result in dense multi-layered canopy profiles (Figure 33). Other types of skips (#1–3) will also contribute to visual objectives.

Figure 33. Visual skip.

Openings

Openings are localized areas within the stand that are not dominated by a forest overstory and provide suitable conditions for the reproduction of shade-intolerant tree species and the development of sun-loving shrubs, grasses, and herbs (Figure 34). These are a characteristic element of healthy Dry Forest patch mosaics.

Openings in low density forests are challenging to delineate and quantify. The large amount of area in-between tree canopies creates many small, irregularly shaped open areas. Here we define openings as contiguous areas generally larger than 0.25 acre. They are areas that arise as a result of heavy mortality in the overstory due to wildfire, insects, or disease. Such openings typically retain some mature or old live trees and often significant amounts of snags and down wood. Openings can also be a consequence of local conditions that limit tree establishment such as severe soil limitations or frost pockets.

Most current Dry Forest stands have existing natural openings. Many of these natural openings have well-established thickets of seedlings, saplings, and large shrubs and may need to be identified and protected as no-entry areas. To avoid confusion, these types of overstory canopy openings should be considered "regeneration skips" and treated as such.

Openings should be sufficiently well distributed so that one or more openings will be encountered in an area of 8–10 acres. Again, we are defining openings as areas at least one-quarter acre; smaller open areas and space between trees should not count as openings. Openings in frequent-fire forests are rarely circular "gaps", but most often sinuous, amorphous shapes with the widest areas being 50–100' across. The exact area of individual openings is often difficult to quantify due to their irregular shapes, but usually does not exceed 2 acres. Creating such elongated openings will generally provide sufficient area for regeneration and recruitment of shade-intolerant species (Bigelow et al., 2011) while also

Figure 34. Top: natural opening. Bottom: long, sinuous gap.

providing barriers to the spread of disturbances, such as wildfire. Large (>2 acre), circular group-selection type openings within stands are not consistent with most openings found in historical dry forests.

Overall, we recommend a conservative approach to opening creation during the initial restoration treatment, given the probability that the initial restoration treatment will result in some unplanned openings. In assessing the need for creating openings beyond what will be created by the general thinning prescription, it is important to consider the following factors:

- The amount of area already in existing natural openings;
- The amount of opening that will be created by the general thinning prescription. Often, sufficient open area will be created without the need to intentionally create openings. Prescriptions that remove white fir or lodgepole pine, for example, often result in large openings. Landings should also be factored in; and,
- The potential for prescribed fire to result in additional tree mortality and the creation of openings. Mortality of overstory trees when large slash piles are burned can also expand openings.

In general, any actively created opening of significant size (>0.25 acre) should retain some large-tree structures in the form of live trees, snags, and/or down logs. Some live trees can also be retained for eventual conversion to snags, such as with a prescribed burn. As always, older trees should be retained.

How Many Skips and Openings?

Determining the amount and pattern of variability to create in a treatment is one of the most challenging aspects of restoration. Understanding the functional rationale for different sizes and kinds of skips and openings is critical to prescribing ecologically appropriate targets. Thinking through the rationale for different forest types and project areas is critical. The following factors should be considered when prescribing targets:

- Landscape context: conditions surrounding the stand;
- Number and type of biological hotspots and microsites;
- Habitat requirements, including maximum desired sighting distances;
- Desired effects and mortality levels from prescribed and/or wildland fire;
- Number of old trees;
- Need to shift species composition to shade intolerant species;
- Forest health issues and need for treatment;
- Logging system access constraints; and,
- Resources available for layout.

In terms of how many skips and openings to create, we have found the following guidelines useful in our work in eastern Oregon. Always, however, the staff specialists, such as those in silviculture, wildlife and fire, should assess what is needed and feasible in a particular project area:

1. **Units <4 acres:** no skips or openings unless needed to protect a biological hotspot;
2. **Units 4–10 acres:** A general rule of thumb is to place a skip in every 2–4 acre square within a portion of a unit and to limit visual sighting distances to no more than 350–500'. First place skips or openings around biological hotspots. Place additional shade skips as necessary to provide cooler microsites and hiding cover. Regeneration skips that are relatively tall (dominantly pole sized) can often work for some of this kind of habitat. Elongated visual skips can be added to further break up sighting distances if needed. One or two openings 0.2–1 acre in size should be considered;
3. **Units >10 acres:** Follow the guidelines for the 4–10 acre areas. Regeneration and deadwood skips should be added to the mix. One to two openings, 0.2–1 acre in size, should be considered every 8–10 acres or so. Larger openings (1–2 acres) may be

appropriate in some cases, but if large, they should be linear and sinuous.

For units >10 acres, we often begin with a broad target of 10–20% of the area left as skips and 5–15% for openings. Percentages may be lower or higher for some stands due to site-specific conditions, such as whether the PAG is Ponderosa Pine or Moist Mixed-Conifer. Calculated percentages include portions of any reserved areas (e.g., riparian buffers) that extend into the treated stand. Whether untreated areas on the edges of stands should count as skips or openings often arises. Many of the features provided in skips and openings exist along the edges of stands (e.g. dense areas in riparian buffers). These areas can be flagged out of units during boundary layout and factored into the total area prescribed for skips and openings. However, skips and openings also need to be well distributed within harvested or treated areas and should not be located primarily along the edges of the treatments. For example, we generally find that at least 10% of a unit should be skips that are located within the unit to achieve our heterogeneity goals, including riparian buffers or other "fingers" that extend into the unit.

It is important to remember that the goal is not to achieve a particular percentage of skips or openings, but rather, to create a variable pattern of forest structure that will be resilient and ecologically functional over time. We have often found it easier to prescribe numbers of skips and openings, along with a size range, than to prescribe a percentage. Area is much more difficult to track during implementation than the number of skips.

Reduce Stand Densities and Increase Mean Diameter

The majority of the stand will be neither skips nor openings and thus generally available for thinning treatments. Old trees within the thinning area should be retained and treated with the twice the canopy drip line treatment described above. Young trees are then removed to achieve basal area or other density targets. It is important to mark in a way that will leave a mosaic of individual trees, tree clumps of 2–20+ trees, and small to medium openings. This should result in a wide range of leave-tree basal area across the stand. A variety of marking approaches can be used to accomplish this and are discussed in the implementation section.

Reducing stand densities to more historical and resilient levels is a major goal in restoration treatments. By lowering the fuel loadings and the competitive stresses in stands, the potential for both severe wildfire and insect outbreaks are reduced. **Stand average targets for post-treatment densities are often derived from two sources: 1) reference conditions and 2) density management tools.**

Reference conditions as a guide to desired stand densities

Studies of historical composition, structure, and pattern provide us with important insights regarding forest and landscape conditions. These historical forests persisted through centuries of frequent disturbances and climatic fluctuations all the while sustaining a wide array of ecological functions. Hence, they provide structural models that are often useful in designing our restoration goals.

Extensive surveys from the late 1800s describe dry ponderosa pine and mixed-conifer forests in eastern Oregon as predominantly open and extensively marked by the effects of low- and mixed-severity fire with infrequent and typically small-scale high-severity fire effects (Langille, 1903; Leiburg, 1900). Managers and scientists early in the 20th century extended these general descriptions to provide more detailed, site-specific records of forest conditions, fire regimes, and drought-related stressors. We use three major sources of information here to help us understand historical structures in the Dry Forests of eastern Oregon:

1. Munger (1912) provides a record of forest structure in selected ponderosa pine-dominated stands in both ponderosa pine and mixed-conifer sites (by our definition). He describes his record

as selective (in his words "high and should not be considered as being estimates of the yield over large areas in the locality") and designed to meet his principal objective of estimating future yield that he describes as "fully" stocked. Thus we would expect them to have higher densities than the average stands;

2. A recently recovered Bureau of Indian Affairs (BIA) timber inventory collected from 1914–1925 on the Klamath and Warm Springs Indian Reservations provides a systematically compiled, landscape-level record of the historical density by size (dbh) and species distribution of conifers > 6 in dbh on > 50,000 acres of dry forests in south-central Oregon (Hagmann, et al. 2013; Hagmann unpublished data[1]). This 90-year-old strip cruise data represent a roughly 20% sample of over 200,000 acres of forest currently classified as Ponderosa Pine and Dry or Moist Mixed-Conifer forest sites;
3. Recently compiled timber survey data from strip cruises conducted between 1916 and 1932 by the USFS for the Malheur, Minam, Umatilla, Wallowa, and Whitman National Forests provides reference conditions for Blue Mountain forests (data made available by Roy Schwenke and Dave Powell, Umatilla NF from surveys by Griffen (1916, 1918), Griffen and Conover (1917) and Matz (1928, 1929, 1930, 1932,1934).

These data sets (Table 2 and Figure 35) generally show:

- Predominantly low-density forests;
- Most of the basal area over 21" dbh;
- Early seral species (ponderosa pine and larch) dominating the basal area, especially large-diameter ponderosa pine, except for areas identified in the inventory as "fir-larch" in the Blue Mountains;
- Wide range in number of trees and basal area but predominantly clustered around the mean;
- Ponderosa pine and mixed-conifer forests exhibiting similar basal areas and diameter distributions; and

1. Hagmann, K. Dec. 2012 Presented at Fire Ecology (AFE) 5th International Fire Ecology and Management Congress in Portland, OR.

Table 2. Exemplary data on historical stand conditions in eastern Oregon. Data are based on measurements of actual stands—not on reconstructions from the General Land Office (GLO) surveys or other types of data.

Source	Acres	Density (trees/acre)						Basal Area (sq ft/acre)						% pine + larch > 21[ab]	Location	Major Species	PAG
		mean	*%pine*[a]	*%larch*[b]	*<21*	*>21*	*% >21*	*mean*	*%pine*[a]	*%larch*[b]	*<21*	*>21*	*% >21*				
Munger 1912[c]	40	13	100		2	11	81	59	100		3	56	95	100	EC	PP	PP
Munger 1912[c]	189	51	67		30	21	41	125	76		26	99	79	78	EC	PP	MC
BIA 1914-22	9,722	26	82		15	10	40	57	96		11	46	81	99	EC (KR)	PP	PP
BIA 1914-22	2,943	26	90		12	14	55	74	95		9	65	88	95	EC (KR)	PP/LP/WF	DMC
BIA 1914-22	5,348	32	47		17	14	45	81	62		14	68	83	67	EC (KR)	PP/WF	MMC
BIA 1922-25	94	38	89		28	10	27	60	90		26	34	56	90	EC (WR)	PP/IC	PP
BIA 1922-25	6,318	25	72		15	10	41	56	71		17	39	70	71	EC (WR)	PP/DF/IC	DMC
BIA 1922-25	27,719	28	56	3	16	12	42	63	62	2	16	47	74	62	EC (WR)	PP/DF/WF	MMC
Munger 1912[c]	20	35	100		28	7	21	48	100		20	28	59	100	OC /BLUE	PP	PP
Munger 1912[c]	350	45	76		27	17	39	105	84		27	78	74	87	OC /BLUE	PP	MC
USFS 1916-1932	24	36	78		28	8	22	59	94	0	28	31	52	94	BLUE	PP	PP
USFS 1916-1932	1,724	34	57	6	22	12	36	75	68	4	22	53	71	73	BLUE	PP/DF	MC
USFS 1916-1932	222	59	2	12	52	7	12	71	4	15	45	26	36	19	BLUE	L/DF/WF	MC

[a]Pine includes ponderosa pine and sugar pine where present.
[b]Species other than ponderosa pine not identified in Munger data.
[c]Munger selected, in his own words, "well stocked" or "fully stocked" sample areas

Note: Min dbh = 6″ except for Blue Mt cruises where it was 7″. Reducing the minimum dbh to 2″ would increase BA/acre by 1–2 sq ft using Munger's data.
EC= East Cascades, KR= Klamath Reservation, WR=Warm Springs Reservation, OC= Ochocos, BLUE = Blue Mountains
PP= ponderosa pine, LP = lodgepole pine, L= larch, WF=white fir or grand fir, IC =incense cedar, DF= Douglas-fir
MC= Mixed Conifer, DMC = Dry Mixed Conifer, MMC = Moist Mixed Conifer

- Moist mixed-conifer forests having a higher component of shade-tolerant conifers and being more variable, but with large, old fire- and drought-tolerant species generally still dominating.

The only exception to these historical stand density ranges for eastern Oregon is a reconstruction that utilizes a series of assumptions and calculations based on land survey records to generate a regional estimated density of 101 tpa > 4 inches dbh (Baker, 2012). The calculated densities are much higher than those recorded in the BIA inventories and almost twice the mean density in Munger's (1912) record of trees > 2 inches dbh on 599 acres of stands, even though those stands were intentionally selected to represent dense (well stocked) forest.

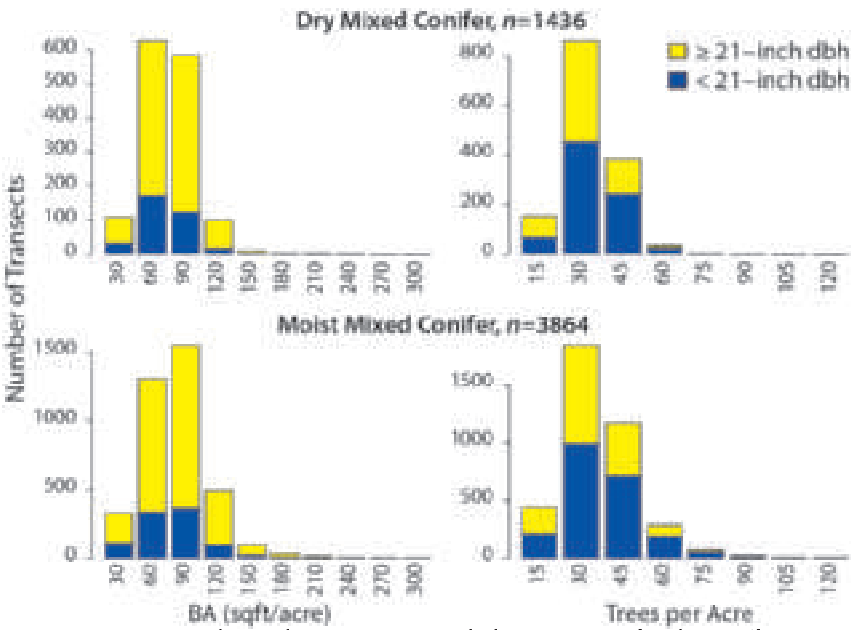


Figure 35. Historical tree densities as recorded in Bureau of Indian Affairs (BIA) timber inventories collected from 1914–1925 on the Klamath and Warm Springs Indian Reservations. Histograms show the distribution of transect means along the range of density as measured by trees per acre and basal area (BA) for more than 26,000 acres of dry and moist mixed conifer habitat. Color breaks indicate mean proportion of trees 6-21 inches or >21 inches dbh.

PHOTO: HAROLD WEAVER

Figure 36. Many accounts of historical stands describe them as open pine forests that a person could easily ride through in a horse or wagon; such conditions were common but not universal (historical photo).

Management tools as a guide to desired stand densities

General density guidelines in basal area, density indexes or trees per acre are available for many eastside forest types (e.g. Powell, 1999). These guidelines typically come from density management diagrams or recommendations from studies of insect mortality. Density management tools generally recommend that density should be reduced to around 35% of the maximum carrying capacity of a site.

Stand Density Index (SDI) is the most commonly used metric and permits a direct, size adjusted, comparison of density across sites. SDI quantifies density in terms of the amount of growing space (light, water, nutrients) that is being occupied by trees. Its advantage over basal area is that it accounts for the fact that larger trees have less leaf area per unit of basal area, and thus occupy proportionally less growing space than small trees (Waring, et al., 1982). SDI works by expressing density as the equivalent number of 10" trees per acre. Table 3 shows how SDI varies for three different stands with the same basal area but different mean diameters. Stand A has an SDI of 183 as its mean diameter is 10". Stands B & C have larger tree diameters and SDI levels 162 and 149. These SDI levels mean that the trees in stands B & C occupy growing space equivalent to 162 and 149 tpa of 10" trees.

For a detailed explanation of SDI and its application to restoration see Appendix 3.

Table 3: Comparison of density metrics of stands with the same basal area.

Stand	BA (ft^2/ac)	Mean Diameter (inches)	Trees per Acre	SDI
A	100	10	183	183
B	100	15	81	162
C	100	20	46	149

This difference in the relative use of growing space by tree size means that stands with larger trees can support higher basal areas. Table 4 shows how using SDI as the primary target results in different basal areas for stands with different mean diameters. Using the same basal area target for these three stands, as in table 3, would result in a different amount of growing space being occupied and thus would have different ecological effects in terms of canopy cover, tree competition, understory development, etc.

Table 4: Comparison of density metrics of stands with the same SDI.

Stand	SDI	Mean Diameter (inches)	Trees per Acre	BA (ft^2/ac)
D	150	10	150	82
E	150	15	75	92
F	150	20	46	101

Another advantage of SDI is that density levels can be directly related to the carrying capacity of the site and resulting ecological implications. SDI is based on the law of self-thinning (Reineke, 1933), which states that plant populations have a density threshold above which mortality occurs. This threshold is typically around 60% of the biological maximum carrying capacity of a site. SDI is often expressed as a percent relative to this maximum: relative density. Determining the maximum SDI for a site is necessary to use SDI. More productive sites (e.g. wetter plant associations) have higher maximum SDI levels. Also, maximum SDI is lowest for shade intolerant species (ponderosa pine) and highest for very shade tolerant species (grand/white fir, red fir). Maximum SDI (SDI-max) is very rare in nature. Full or "normal" stocking is thus sometimes used instead to report upper density levels (SDI-full). SDI-full is the upper end of SDI observed in field plots and is 80% of SDI-max.

Thinning to different proportions of maximum SDI will result in different growth rates, crown development, levels of canopy closure, and competitive mortality over time. These in turn affect understory development, deadwood levels, and disturbance processes such as fire and insects fires (Cochran 1994, Fettig et al., 2007; Long and Shaw, 2005; Powell, 2010). Powell (1999) provides SDI-full levels for plant associations in NE Oregon forests, conversions to BA and TPA, and an excellent overall summary of its use. For other areas in Eastern Oregon, contact the nearest Forest Silviculturist or Area Ecologist. It is critical to determine whether SDI-max or SDI-full values are being obtained! In addition, SDI-max or SDI-full values will vary by tree species for a site. In general, we recommend using the value for dominant tree species to be left, which is typically the most shade intolerant and has the lowest SDI level (e.g. ponderosa pine).

It is important to recognize the limitations of SDI as well as its advantages. SDI was originally developed for wood production silviculture in even-age, spatially uniform, young stands (Reineke, 1933). When used for restoration oriented treatments, three key issues should be considered.

1. **SDI thresholds should not be used to justify removal of old trees.** The extent to which maximum SDI mortality or insect risk thresholds, which are typically derived from young stands, apply to predicting mortality of old ponderosa pines is not known. Old trees are often found in large clumps that exceed these SDI thresholds. Yet these clumps have persisted for centuries. While old trees are certainly affected by competition, no actual evidence of higher mortality levels in large clumps of old trees vs. open grown trees or small clumps has been published to our knowledge. Simply put, a solid empirical basis to justify thinning out clumps of old trees to prevent future mortality does not exist (see Box 4).
2. **Avoid uniform SDI targets**: Thinning to a single SDI target across entire stands is inconsistent with ecological restoration. Natural stands that developed under frequent fire regimes contained large variation in SDI levels (e.g. Churchill et al. 2013). Also, the notion that all parts of a stand should be thinned below insect mortality thresholds to restore forest health is in conflict with historical stand conditions. Maintaining some parts of stands at higher densities where mortality may occur is generally part of an ecologically healthy forest.
3. **Uncertainty with use in heterogeneous stands:** Stand-average SDI levels provide only a general picture of site occupancy in heterogeneous stands. The empirical basis for use of SDI in spatially heterogeneous, multi-species, structurally complex stands is complicated and far from settled (Woodall et al., 2003; Zeide, 2005). We have found that while SDI derived targets can provide a useful starting point, they should be applied with flexibility and recognition of the underlying uncertainty.

These limitations do not mean that SDI is not relevant to restoration. While imperfect, SDI is a useful density management tool. SDI and other stocking control concepts have been adapted for uneven-age, multi-cohort stands (Long, 1995; O'Hara and Gersonde, 2004; Shaw, 2000) and offer useful empirical knowledge that can be applied to ecological restoration (e.g. Arno et al., 1997; Bailey and Covington, 2002; Shepperd, 2007). In a restoration context, SDI can be used to set variation in density across a stand and inform how patches of different densities are likely to achieve different ecological objectives such as growing large trees, promoting forage species, providing for future snags, and managing susceptibility to insect and crown fires in different parts of the stand. For a detailed explanation of SDI and its application to restoration see Appendix 3.

Selecting density targets for prescriptions

Both historical reference conditions and density management tools have their strengths and limitations in setting density targets for restoration treatments. Setting an average density target for a stand requires both science and judgment regarding which tools, or combination of tools, are most appropriate. Average density targets for most Eastside forest restoration projects typically range from 40–120 ft^2/ac of basal area, or 25–40% of maximum SDI. BA targets should be higher for stands with old or large trees and lower for stands of small trees. BA targets for stands with more shade-tolerant species can be higher. For example, a stand on a productive site with a stand average of 80 ft^2/ac of basal area in old trees could likely support an additional 30 ft^2/ac of young trees for a total stand average basal area of 110 ft^2/ac. If BA targets were derived from SDI, adjustments for size and species differences are already factored in. In mixed-conifer stands where most white fir or lodgepole pine will be removed to shift species composition toward fire tolerant species, post treatment densities may end up lower than typical thinning targets.

Always keep in mind that stand targets are an average. A wide range of densities should be the goal over the whole stand. After treatment, density levels within a stand can often vary from

200 ft^2/ac in clumps of large trees to 10 ft^2/ac in openings. The average density should not necessarily be the dominant density in the stand.

In setting stand-average density targets, we consider these steps:

1. **Derive initial average density target.** As described above, targets from historical conditions (Table 2), SDI based density management tools, or a combination of both can be used (Box 7). Landscape planning will often inform density targets for specific stands (e.g. the need to maintain sufficient canopy cover for certain wildlife).
2. **Inventory or estimate the BA and average diameter of old trees.** The BA of old trees will determine how much basal area remains available for young trees. Use the average diameter to calculate the SDI of old tees if you are using SDI.
3. **Determine density target for young trees**: Subtracting the density of old trees from the stand target will provide an initial target for young trees. This can be done using SDI or basal area. We recommend leaving a minimum of 10 ft^2/ac in younger trees.
4. **Convert all targets to basal area or trees per acre for implementation**. There is no quick way to determine the SDI in the field, similar to swinging a variable radius plot for basal area or measuring a fixed area plot for tpa with a laser range finder. Thus converting SDI targets to basal area or trees per acre is generally needed for marking or cutting guidelines, monitoring, and contract compliance. Figures and equations to convert SDI to basal area are provided in Appendix 3. You will need to calculate or estimate the post-treatment average diameter of young trees to convert between SDI, basal area, and/or trees per acre for implementation.
5. **Anticipate mortality.** Ideally, prescribed fire will kill some trees and create snags and downed wood. Natural disturbances such as post-treatment wind-throw or post-fire beetle

mortality should also be factored in. We often increase targets by 5–20% for these allowances.

6. **Consider future mechanical thinning entries.** Reducing densities all the way to historical levels in one entry makes sense in large landscapes with low treatment rates or where roads will be closed. Multiple entries, on the other hand, allow for greater flexibility to work with natural disturbances over time, as well as providing for future revenues to pay for maintenance work. Higher density targets (e.g. +10–30%) are advised if future entries are anticipated within 2–4 decades.
7. **Think about climate change.** Current maximum density thresholds are likely to shift in the future, and thinning heavier to prepare for climate change is often debated. Because the major effects of climate change are several decades away and post-treatment mortality is unpredictable, setting targets below historical levels should be approached carefully using an adaptive management strategy over time.

Reducing stand density to the desired target should be accomplished by generally removing smaller trees, thereby increasing the mean diameter of the stand. Larger trees are typically more resistant to fire, insects, and drought by virtue of thicker bark, more robust physiological defenses, and well developed root systems. "Thinning from below" increases the resources available for the larger and older trees. It also reduces fuel ladders and increases canopy base height, which will lower the risk of crown fire. However, as mentioned above, removing larger trees of fire-intolerant species (e.g., grand/white fir) is often necessary in restoration treatments. In addition, removing larger but young trees of fire-resistant species is sometimes necessary to create openings, release hardwoods, or create the desired spatial pattern (Abella et al., 2006). Finally, retaining sufficient trees in smaller diameter classes for future recruitment of large and old trees is also necessary. Uneven-age management tools can be used to calculate target densities for smaller diameter classes (Bailey

Box 7. **Comparison of Desired Condition to Current Condition—the Klamath Plan Example**

Johnson, et al. (2008) set average target densities for the forests of the former Klamath Reservation after considering historical reference information that was available to them.[1] Targets were set both for trees < 21" and trees > 21" (Table 7-1). Current densities were also estimated based on USFS Current Vegetation Survey (CVS) plots from the mid 1990s (Table 7-1). As with much of eastern Oregon, the stands currently have too many trees <21" and too few >21" compared to both historical and desired future target densities. Consequently prescriptions generally focused on removing smaller, younger trees to achieve desired densities, although white fir over 21" dbh that were less than 150 years of age were also prescribed for removal where they occupied sites formerly occupied by pines. As part of their prescriptions, Johnson et al. (2008) recommended leaving 10–15% of the stand in skips and 10–15% in openings as well as retention of larger dense patches in Mixed-Conifer plant associations. Applying their guidelines, we would expect that total basal area in many stands after treatment would be less than the targets expressed here, due to the lack of large trees.

Table 7-1. Comparison of desired average density, derived from analysis of historical structures, to current density by plant association group and diameter class. Source: Johnson, et al. (2008), page 75.

Plant association group		**Basal area/acre**		
		Total	**<21"**	**>21"**
Ponderosa pine/bitterbrush	Desired	75–95	20–30	55–65
	Current	88	66	23
Dry mixed conifer	Desired	100–120	30–40	70–80
	Current	120	80	40
Moist mixed conifer	Desired	120–140	30–40	90–100
	Current	122	81	41

1. This report includes more robust information on historical conditions (Table 2) than available to Johnson, et al. 2008. Given this information, it can be argued that their target basal areas may be somewhat high, but it is clear that basal area < 21" should be significantly reduced.

and Covington, 2002; Long, 1996; O'Hara et al., 2003). Post treatment diameter distributions can be relatively flat, however, and steep reverse-j distributions are generally inappropriate. As a general rule, we recommend leaving a minimum of 5–10 ft^2/ac in smaller diameter classes (generally < 12" in dbh).

Protect and Restore Understory Plant Communities

Understory communities of herbs and shrubs need to receive careful consideration during restoration of Dry Forests for many reasons, including their important roles as forage for wildlife and as surface fuels. Restoration activities of particular concern are the potential effects of silvicultural prescriptions on light and moisture regimes in the understory, mechanical effects of logging operations, and, particularly, prescribed burning conducted at the end of the restoration process. Individuals who understand the ecology of important understory plants should be consulted during the planning phase of restoration projects to insure that these species are given appropriate attention.

Bitterbrush is a major understory plant in much of eastern Oregon's Dry Forests, particularly in areas with pumice soils. It is important as a source of browse for elk and deer and as a surface fuel. Bitterbrush is sensitive to fire and can be dramatically reduced in cover by intense prescribed burns, as it has limited sprouting capability; bitterbrush reproduces primarily from seed, which is often dispersed by small mammals (Figure 37). On the other hand, bitterbrush populations in stands unburned for extended periods of time are often senescent and produce little high-quality forage. Moderate burning or mechanical disruption of existing bitterbrush stands, such as by mowing, can stimulate bitterbrush reproduction and improve forage production on older plants.

Restoration prescriptions need to set objectives regarding bitterbrush and adjust activities accordingly. Where maintenance of a bitterbrush understory is an important goal, prescribed burns

Figure 37. Bitterbrush successfully regenerating from seed after fire.

should be carried out to retain substantial existing bitterbrush and stimulate regeneration of new plants. Cooler fires that produce patchy burns often produce this outcome. Bitterbrush can be temporarily eliminated from understories with uniform, intense fires.

Understories dominated by rhizomatous grasses, such as pinegrass or elk sedge, may also require care when prescribed burning is reinitiated after a long period of fire absence. Intense wildfires can consume all or most of the litter layer, which is where grass roots and rhizomes have often become concentrated after long periods without fire. Seek advice from local plant ecologists to understand the use of fire and the desirable light conditions for maintaining these grassy plant communities.

Development of dense shrubby understories can be an important consideration on either Dry or Moist Mixed-Conifer forest sites. They can create problems by providing abundant surface fuels and by competing with trees. However, these shrubs may be a source of browse for ungulates and may provide habitat (e.g., herbage, fruits, and nectar) for a broad variety of vertebrate and invertebrate (e.g., butterflies and moths) animals. Reproduction of many shrubs is strongly stimulated by fire either from seed (snowbrush and other species of ceanothus) or by sprouting (e.g., manzanitas). Significant attention needs to be paid to both existing and potential shrub understories in silvicultural prescription development, including the use of fire.

Also, since understories of herbaceous plants are important contributors to surface fuels needed to sustain prescribed fires, sustaining these ground fuels is an important consideration in determining appropriate levels of grazing by domestic livestock.

Readers should consider the preceding to be only a small down-payment on the challenging topic of understory species. Creating and maintaining desirable conditions in restored Dry Forest understories is going to be a major area for adaptive learning. It has received relatively little attention compared to other aspects of Dry Forest restoration. Further, it involves significant challenges in balancing restoration outcomes between goals related to fire behavior and ecosystem resilience, on the one hand, and wildlife habitat, biodiversity, and ecosystem function, on the other. Hence, understories will be a rich topic for learning.

Do the "Finish Work", Including Treating Activity Fuels

We refer to the activities that are undertaken following completion of commercial logging activities as the "finish work." Finish work includes all post-logging activities, such as felling undesirable non-commercial trees (e.g., small trees that are potential surface and ladder fuels), treatment of activity and other fuels (including any concentration or piling of fuels and application of prescribed fire), understory treatments (such as mowing), tree planting, treatment of invasive species, and creation of dead wood (such as by topping, girdling, or felling live trees). ***The quality of the finish work is very important in determining whether the objectives of***

the restoration project will be fulfilled or significantly compromised.

Coordination among resource specialists and between managers and stakeholder groups regarding finish work is critically important to fully achieving the restoration goals. Ideally, the finish work will be integrated into the project design from the beginning. Decisions should not be made unilaterally by individuals representing a single discipline, such as fuel treatment specialists or wildlife biologists, but be done by interdisciplinary groups, including joint site inspections following completion of the commercial logging activity, but before the finish work is undertaken.

A second important element is clear communication of the purposes and procedures to be used in implementing the finish work to the crews that are going to be carrying it out. While this seems obvious, there are cases where directions have not been clearly communicated and desired leave trees have been damaged or killed and important wildlife habitat have been lost because the crews doing the work did not fully understand the restoration objectives:

- In Dry Forest restoration, the most critical post-treatment activity is re-introduction of fire, which often has multiple objectives that include, but are not limited to, fuel reduction. Clearly, one goal is to minimize damage to, and mortality of, residual old trees.
- Mechanical thinning is often part of the finish work to reduce tree densities in regeneration patches and remove non-commercial trees that are potential fire ladders for retained old trees and other structures. Simplistic directions to crews doing such activities—e.g., remove all saplings and poles < 8 inches dbh—can lead to undesirable outcomes, including thinning areas intended as skips. Thorough instruction, training, and crew supervision is necessary.

Retention of sufficient downed wood for wildlife needs and soil health must be factored into activity fuel treatments. Guidelines are available for different forest types and ecosystems (e.g. Brown et al., 2003 and Marcot et al., 2002).

Mechanical thinning operations usually involve an extensive transportation system that includes system (permanent) roads, landings, skid trails (in the case of ground-based logging), and, often, temporary roads. For system roads, finish work should include maintenance activities, such as roadbed obliteration or stabilization, culvert replacement (if needed), and other actions required to mitigate impacts to aquatic systems and wildlife.

The Role of Economics in Stand Prescriptions

As we have discussed earlier in this guide, it is important to consider operational and economic issues at all stages of planning in order to resolve tensions related to questions about the balance between economic viability and ecological objectives. Whether to modify prescriptions to increase their financial attractiveness will be an issue on many restoration projects. This issue will probably be magnified in the future for two reasons: 1) Retention of small (less than 21") mature and old growth trees. Cutting these trees out of old growth clumps or cutting them when mixed with younger trees has fueled the viability of restoration projects in the past. As proposed in this field guide, those actions will largely stop. 2) The need to create revenue to underwrite actions within the project area that do not pay for themselves. As restoration moves to large landscapes, as opposed to individual stands, revenue will be needed for meadow and stream restoration and other good works. We discuss below some of the key elements in decisions about whether and how to modify prescriptions so as to increase their economic performance.

First and foremost, it is important to realize that guidance here is not intended to be a cookbook; choices remain for the user who applies this guide. **Raising or lowering densities a few square feet**

of basal area compared to your original targets or taking a few more or less trees generally will not destroy the ecological effects of your restoration effort as long as you do not take large old-growth trees.

Key choices include:

- *What stand density target to set.* There is not one magic average target for each stand you encounter; rather a range of average targets can be justified. This decision will most affect the small and medium-sized trees that are left. As shown in Table 2, historical information for the Dry Forests of eastern Oregon suggest low historical levels for trees from, 6–21" dbh compared to the stands of today. How far should the prescription push the residual stand toward those densities is a central question in Dry Forest restoration. That will involve many considerations, including how the residual basal area target influences the economic feasibility of the treatment.
- *Whether to take large younger trees greater than 21" dbh (trees less than 150 years of age but greater than 21" dbh).* The "east-side screens," put in place in the mid-1990s generally protect trees over 21" from harvest. And, as we discussed above, the Dry Forests of eastern Oregon appear generally to be deficit in large trees compared to history. Yet the larger, younger trees that remain generally have more economic value than the smaller, younger trees; taking one or two of the larger trees per acre may make a significant difference in the economic viability of the sale. In addition, younger (less than 150 years of age) grand/white fir and Douglas-fir of this size may threaten old-growth ponderosa pine and other desirable old-growth species, or be more numerous than in historical stands and occupy space we seek for early seral species. Finally, even if we want the space to recruit other species, these trees can provide key biological resources for species, such as the pileated woodpecker.
- *Whether to harvest small, old ponderosa pine (Box 8).*

In summary, this guide is grounded in an ecological approach to forest restoration. It is a mistake, though, to attempt to justify all restoration efforts in ecological terms when, in fact, you are taking actions to improve the economic viability of the project. The most important goal is to restore Dry Forests, and their associated meadows and seeps, over large areas. If that means slightly modifying your prescription to improve the economic viability of the sale, such modest changes (i.e., within limits as described above) are likely to be worth the ecological cost.

Effect of Wildfire on Recommended Prescriptions

Occurrence of severe wildfires in areas planned for restoration significantly alters the ecological circumstances and introduces questions about salvage logging and its potential effects on ecological restoration. We recommend that the issue of appropriate actions following stand-replacement disturbances, such as wildfire, be addressed as part of the overall management plan for Dry Forests in each management unit; we think that this is an important element of any management plan and the appropriate place to develop a general policy about salvage and other responses to disturbances.

In general, salvage is carried out primarily to recover economic values and makes little direct contribution to ecological recovery. The burned forest retains significant ecological values, including the structural and functional legacies of snags and down logs; many decades will pass before the forest begins to again generate large dead wood. The burned forest provides habitat for a variety of animal species, such as black-backed woodpeckers. Salvage can eliminate much of this legacy, disrupt vegetative recovery, and cause damage to soils and waters (Lindenmayer et al. 2008).

On the other hand, wildfires in densely stocked stands on Dry Forest sites typically generate substantially more dead woody fuels than would have existed historically following a stand-replacement fire event, which were probably uncommon in the

Box 8: **Removal of Small Old Ponderosa Pine Trees in Dry Forest Restoration Projects**

Removal of small (<21" dbh), older (>150 yr) ponderosa pine trees is sometimes proposed as a part of Dry Forest restoration projects. These older trees are important ecological components of Dry Forests, despite their smaller size, which is why we recommend their retention along with larger old trees. Ponderosa pine >150 years include older mature pines (150 to 200 years) that are beginning to develop old-growth attributes and will become fully developed old-growth trees after about 200 years.

Small old trees fulfill many of the functions that larger old trees provide. These trees have:

1. A significant percentage of heartwood, which exhibits different patterns of decay than sapwood (in live trees, snags, and logs). Young ponderosa pine have relatively little and poorly developed heartwood. Snags from old trees persist for a longer time than snags from younger trees of comparable (or even larger) diameter, and down wood (either bole or branches) decays differently than that of young trees.
2. Distinctive complex crowns and large branches that differ from those found on younger pines and that often have developed various defects (e.g., forks, brooms, and cavities) not present in younger ponderosa pine.
3. Greater value for wildlife than young trees of comparable or even larger diameter as a consequence of the preceding points – complex and distinctive crowns and significant heartwood content, which is reflected in quality wildlife habitat in both living and dead trees.
4. Bark that is thicker and fire resistant relative to the tree's diameter, making the trees more resistant to fire than younger trees of comparable diameter. Since these smaller old trees exhibit many of the attributes of larger old trees, albeit it on a smaller scale, their retention is part of ecologically-focused restoration treatments.

When clusters of old ponderosa pine trees that include small old trees are encountered, silviculturists sometimes assume that significant competition must be taking place within these clusters, particularly if they observe mortality of individual trees. This inference of significant competition is unwarranted, however, and may reflect the silviculturist's projection of the competitive processes of tightly spaced young trees. The old trees in these clusters have not only survived that period of

Figure 8-1. Left: Cluster of four old-growth (>200 years old) ponderosa pine in which the two trees on the extreme right and left are <21" dbh. Right: Cluster of four mature (~170 years old) ponderosa pine all of which are <21" dbh. Under our ecologically-based guidelines all of these trees would be retained; the mature trees represent eventual old-growth replacement trees. However, if a planning decision was made to remove some older (>150 year old) and smaller (<21" dbh) trees for economic or other reasons, then we strongly recommend that the <21" dbh trees selected for removal should come from mature (150 to 200 year old) cohorts (e.g., trees like those in the right photograph) and not from the old-growth trees with well-developed old growth attributes (i.e., the two smaller trees in the figure on the left).

youthful competition but almost certainly have established mutual relationships with each other, such as significant root grafting and shared mycorrhizal masses. Thus, these clusters of old trees are more likely to be mutually supportive than competitive.

Nevertheless, proposals for removal of removal of small older pine trees will arise and the following points should be considered:

1. An ecological justification for the removal of small (<21" dbh), old (>150 yr) ponderosa pine trees has not been established.

2. Proposals for removal of small old ponderosa pine trees would need to be based on economic necessity—that removal of some or all of these trees is necessary to create an economically viable or an economically more valuable restoration project.
3. If a project is calculated to be non-viable economically, we recommend consideration of the following adjustments prior to planning removal of small old ponderosa pine trees:
   - Adjustment of the boundaries of the project area so as to include additional areas that will generate larger volumes of wood during restoration;
   - Increase in the amount of wood marked for removal in trees <150 years even if this requires modification of target restored stand basal areas or trees/acre;
   - Elimination of restoration activities included as costs in the calculation of sale economics that are not essential to accomplishing the stand-level restoration goal; and,
   - Consider the potential for collaborators and partners to find funds.
4. If the restoration project remains non-viable after making the above adjustments, consider the alternative of whether or not to remove some small older ponderosa pine trees, including an assessment of how many such trees would have to be removed in order to achieve economic viability.
5. Calculation of economic viability should be based on the appraisal or other formal analysis that includes actual cruise or inventory data.
6. If a decision is made to proceed with cutting sufficient small older ponderosa pine trees to achieve viability, select only a sufficient number of such trees to achieve the economic break-even point.
7. The older trees selected for removal should come from the mature (150 to 200 year) age class; removal of fully developed (>200 year old) ponderosa pine should be avoided.
8. The decision process should be transparent, well documented to ensure that stakeholders and collaborative groups understand the basis for removing old trees.

Dry Forests; i.e., it would be a "novel" circumstance, one with little historical precedent. The fine fuels will disappear relatively quickly but some of the medium and larger fuels will persist for decades and can make it difficult to conduct subsequent prescribed burns. Hence, some removal of fire-generated fuels may be ecologically justified (Franklin and Agee 2003). There may also be economic or other social benefits from salvage. Large ponderosa pine, western larch, and Douglas-fir snags generally should always be retained because of their persistence and long-term value as wildlife habitat, as well as any other standing structural features that normally have been retained as part of a restoration treatment of a green forest.

From a restoration perspective, if a decision is made to salvage dead wood we recommend that it be conducted so as to minimize impacts on ecological values. The same quantity and type of dead wood should be retained on site as would have existed there if a stand-replacement wildfire had occurred in a historical or restored stand—i.e., retaining the larger and more decay resistant trees. Material removed in the salvage should be small and medium-sized stems of more decay-prone species (e.g., grand/white fir). Salvage needs to occur promptly to capture such material, which emphasizes the importance of having a policy in place on post-disturbance activities in the management plan. Of course, any salvage operations need to minimize negative impacts on soil and aquatic values.

Finally, landscape-level perspectives are essential in salvage planning. Larger spatial-area considerations include provisions for habitat requirements for snag-dependent species, such as black-backed woodpeckers. These are likely to necessitate retaining significant un-salvaged areas. It is also critical to assess the distribution of various types of legacies, such as large snags and dense snag patches, across the burned landscape. Salvage can easily end up being focused on limited areas within the landscapes that have high levels of dead wood legacies—often because those end up being the locations that can carry the cost of salvage! This can result in the burned landscape being "cherry picked" for big wood. From an ecological perspective, "high-grading" the burned landscape for its best wood legacies should be avoided.

Effect of Climate Change on Recommended Prescriptions

Impacts of climate change on eastern Oregon forests are likely to be most profoundly and immediately experienced in the form of altered disturbance regimes, particularly since fire and stress-related insect mortality are the most important agents in these forests (Breshears et al., 2009; Franklin et al., 1991; McKenzie et al., 2009; National Climate Assessment and Development Advisory Committee 2013). Longer hot dry summers will mean longer fire seasons and more extreme weather conditions that fuel larger fires (Littell et al., 2010). Extensive tracts of trees weakened by drought will increase the potential for insect outbreaks that may cause more mortality than fire (Coops et al., 2009; Safranyik et al., 2006)

Historical forests were both resistant and resilient to frequent fire. Fire maintained historical forests far below maximum carrying capacities. Treatments based on historical conditions will thus go a long way towards increasing resilience to higher levels of fire and moisture stress. The treatments proposed in this guide are largely consistent with treatments recommended to adapt to shifting climate and disturbance regimes (Chmura et al., 2011; Franklin et al., 1991; Peterson et al., 2011; Spies et al., 2010; Stephens et al., 2010).

Predicted climate changes may encourage managers to think about developing prescriptions that go significantly beyond restoring Dry Forests in the context of historical or current conditions—i.e., anticipating a much hotter, drier and burnier future. Such anticipatory prescriptions might reduce stands to lower densities than those based on expected near-term conditions as well as more aggressively reduce representation of drought-susceptible species, such as grand/white fir. Quantitative approaches to assessing future environmental conditions and adjusting desired future conditions are being developed (e.g. Churchill et al. 2013). At this time we generally favor more conservative restoration approaches that restore large areas to a more resilient state but maintain more options for future treatments.

In summary, the forest restoration strategies described in this field guide—including protecting old trees, shifting species composition to fire and drought-tolerant species, restoring heterogeneous spatial patterns, and reducing stand densities—are explicitly designed to make forests more resistant and resilient both under current climatic conditions and future stresses from shifts in climate. They are best considered as the first step of many that may be undertaken in our attempt to maintain Dry Forest ecosystems in the face of continuing climate change.

PHOTO: KEN HAVARD

Figure 38. White-headed woodpecker

Part IV
Field Implementation

Marking and Layout Guidelines

Developing and laying out restoration prescriptions initially appears complicated and time consuming but it can be done efficiently once silviculturists and field crews become familiar with the new concepts and approaches (Churchill et al., 2013; North et al., 2012). Several innovative and successful approaches have been developed, which fortunately follow the same basic steps as outlined below.

Clarify Objectives

Basic objectives should have been defined during earlier planning; these objectives should be clearly described in terms applicable to specific stands and understandable by layout crews. Layout crews and operators can respond better to stand conditions when they clearly understand treatment objectives.

Walk the Project Area

Silviculturists and other specialists need to reconnoiter stands to assess current conditions and potential opportunities. Examining the number and spatial pattern of live old trees, as well as pre-fire suppression era logs, snags, and stumps can provide insight into historical conditions as well as opportunities and limitations for placing skips and openings. Remotely sensed data can assist in better understanding stand conditions and locating biological hotspots (e.g. Google Earth, BING or NAIP imagery, GNN data, or LiDAR).

Identify Foundational Elements

Locate biological hotspots and determine whether they need a skip or opening/release treatment before general marking begins. This is best done by silviculturists, wildlife biologists, or experienced layout personnel. The more sensitive the feature, the more important that it be well marked and protected from logging or prescribed burning. Using a GPS to record the location of these features during recon will make implementation more effective and efficient.

Add Additional Skips and Openings as Needed

These are typically dense overstory, regeneration patches, or visual skips. As they are generally well represented in the stand, their exact location is not as critical and complete protection from prescribed fire is also generally less important. These skips can be laid out prior to general marking or built into the marking guidelines. For example, dense overstory skips can be laid out separately or included as large clumps during the marking.

Apply Marking Guidelines

- **Retention of all older trees:** in addition to retaining older trees we recommend removing fuels and competing vegetation from an area around the trees extending out about 2x the dripline of the old tree canopies; highly desirable structures within the dripline, such as an outstanding younger pine, can be marked for retention.
- **An average density target** in basal area or TPA. Both old and young trees are combined in calculating this target, which

applies in the portion of the stand outside of skips and openings. See Part III for a detailed discussion of setting density targets.

- Leave tree criteria for younger trees: Criteria for leave trees typically includes:
  - Favoring specific species—on most sites, ponderosa pine, western larch, and sugar pine will be favored;
  - Retaining larger trees with healthy crowns;
  - Leaving appropriate numbers of green wildlife trees (live trees with cavities, broken tops, branch platforms, forks, brooms, etc);
  - Leaving smaller trees when necessary to meet clumping objectives; and
  - Leaving some mid/understory trees from younger age classes with good crowns.
- **Direction for snag retention:** Every effort should be made to retain large, high value snags. They can be left in small skips to retain screening cover or opened up to promote use by white-headed woodpeckers. Input from a wildlife biologist is needed to determine the appropriate actions. Smaller snags should also be retained as much as is operationally feasible.

Ensure a "Clumpy-Gappy" Thinning Approach

There is no single approach to marking that works for all stand conditions. Below are options for different stand conditions.

- **ICO method:** This approach uses patterns from reference stands to develop guidelines for the numbers of individual trees, clumps, and openings (ICO) to retain. A specified inter-tree distance is used to define tree clumps. ICO is most useful in plantation-like stands or pine-dominated stands with a combination of old and young trees. See Box 9 for a full description of this method.
- **Species and age/diameter limit:** In mixed-conifer, lodgepole pine, or lodgepole-aspen stands, shifting species composition towards ponderosa pine or aspen is typically the primary goal.

Box 9: **The ICO Method (Individuals, Clumps, and Openings)**

The ICO approach provides quantitative targets for spatial pattern based on historical or contemporary reference sites. Pattern is expressed in terms of the number of individual trees, and small, medium, and large tree clumps to leave in a stand (Churchill et al., 2013). Instead of marking for a specific range of basal areas, marking crews identify and track the number of clumps they retain while incorporating other leave tree criteria. We have found this to be an intuitive and efficient approach to creating spatial variability as tree clumps are readily visualized. The ICO approach is particularly useful in plantations or naturally regenerated, even-age stands such as the black bark pine stands that are common in central Oregon. It can also be useful for creating heterogeneous patterns of young trees in stands with low to moderate numbers of older trees. A comprehensive guide to this method is available at: *cfc.umt.edu/ForestEcology/files/ICO_Manager_Guide.pdf*

The ICO approach is implemented as follows:

1. **Identify and mark out skips and large openings:** Follow the principles described above. The clumping or ICO approach applies to the remainder of the stand. By focusing on marking clumps, small to medium sized openings (<0.2 acre) generally result automatically. Larger openings often are not created, so prescriptive creation of larger openings is typically necessary if large openings are a treatment objective.
2. **Determine the appropriate inter-tree distance to define clumps:** The definition of a clump is based on the average distance at which mature/old trees of the dominant leave tree species have clearly interlocking crowns and form contiguous patches of canopy. This distance can vary from 15 to 20', depending on site productivity of the stand. We suggest 20' (tree face to tree face) as a default distance. Trees are members of the same clump if they are within this distance of at least one other tree in the clump. Individual trees are those with no neighbors within the distance.
3. **Obtain reference clump targets:** Table 9-1 provides reference clump targets from existing studies in Oregon and Washington. We broke stands into 3 classes based on the level of clumping: low, moderate, and high. This table is based on a limited amount of data, however. Ideally, a set of reference stands from the PAG and area in which you

are working is available. Reference stands can be reconstructions of historical conditions or contemporary stands with active frequent-fire regimes. Reconstruction studies are currently underway in eastern Oregon that will provide a large set of reference stands for different dry forest PAGs. In other areas, reference information is sometimes available from past studies or can be derived using a sampling method to rapidly assess historical spatial patterns in at least a few stands in the treatment area. Professional judgment can also be used to set and adjust targets for forest types where historical information is difficult to obtain. See the ICO guide for more information on reference clump targets and/or contact the authors.

Table 9-1. Summary of clump proportions from ten 5 to12 acre reconstruction plots in ponderosa pine and Douglas-fir plant associations in the eastern Oregon and Washington Cascades. Intertree distance is 20'. The 10–15 and 16–20 clump sizes can be added together into a single clump size, or used separately. This table should not be used in other areas without consulting the authors. At least some local sampling is advised.

	Proportion of Trees in Clumps Clump Size (# of trees)				
Clumping Level	1	2–4	5–9	10–15	16–20
High	0.25	0.30	0.25	0.10	0.10
Moderate	0.35	0.30	0.20	0.10	0.05
Low	0.5	0.40	0.10		

4. **Derive clump percentage targets for specific stand:** To set targets for individual stands, each stand must be matched with a specific reference stand or an average condition from a set of appropriate reference stands, such as in Table 9-1. Consider the following when setting and adjusting clump targets:
   a. Assess the number and clumping levels of live old trees in your stand. The clump percentage targets should accommodate retaining existing old trees. If a high proportion of old trees are in large clumps, choose a higher clumping level.
   b. In stands with few old trees, assess any evidence of historical tree patterns (live old trees, old stumps, old snags & downed logs) to determine what the largest clump size was and the approximate percentage of trees in large clumps. These historical conditions can inform what that site supported.
   c. Assess the extent to which healthy, young trees of the desired species are clumped in your stand. While some inferior trees

should be left to make up larger clumps, higher clumping levels may not be possible in some stands.

d. Assess whether the pattern in surrounding stands has been simplified by past thinning. If so, consider a higher clumping level.

5. **Calculate the stand average TPA target:** Generally, this is the target for trees greater than the merchantability standard (4–6" dbh) and should include old trees. The BA or SDI target for the stand, including old trees, should be used and converted to TPA.
6. **Generate clump targets for the whole unit:** See Table 9-2.
   a. Multiply the target percentages for each clump size by your leave tree TPA target to get the target number of trees per acre for each clump size.
   b. Divide each total by the average number of trees for that clump size to derive the target number of clumps per acre.
   c. Multiply the clump per acre targets by the total stand acreage to get clump targets for the whole stand. For stands over 20 acres, we recommended breaking the stand into 10–30 acre sub-units for marking so that marking crews can track their clump totals within a reasonable amount of area. Use a road, stream, or other barrier to divide stands up.

Table 9-2. Generating clump targets for a whole unit

	Clump Size (# of trees)			
	1	**2–4**	**5–9**	**10–20**
Target Clump Percentages	30%	35%	20%	15%
Trees per acre (Target TPA 34)	10	12	7	5
Clump target per acre	10	4	1	0.3
Clump target per unit (Unit acres = 20)	204	79	19	7

7. **Add leave tree criteria:** These are discussed in the Prescription Elements section in Part IV.
8. **Mark the stand:** When marking, consider these guidelines to decide what to do at each tree group or small area (<1/10th acre). Leave or cut tree marking can be used for this method.
   a. Leave all old trees. Where high numbers of old trees exist, most of the clumping targets will be met with the old trees.
   b. For young trees, assess what the tree group naturally looks like and has the potential to become. For example, many trees already

appear to be clustered in a clump of a certain size. Isolated trees with large crowns often already appear to be individual trees.

c. Look at what you have already marked and check your progress towards clump targets.
d. Look ahead to see what opportunities for clumps of different sizes exist.
e. Always balance leave-tree criteria with clumping targets. For example, don't try to force clumps by leaving excessive numbers of marginal trees (e.g. > 20% of leave trees with crown ratios below 35%).

9. **Track during marking:** One person on the crew should track clumps that are marked and periodically report to the crew what clump sizes are needed (e.g. individual trees, small clumps, moderate clumps, large clumps). A tally of cut or leave trees by diameter class can also be done to inform whether basal area targets are being met. Also, during implementation 1/10th to 1/5th acre fixed area count plots can be put in to track leave tree TPA and ensure that the overall density target is being met, especially when marking crews are learning this method. NOTE: The average target should not be met on most plots due to the high levels of variability created by this method. Instead, the average of 8–10 plots should get close to the target. This can help train the eye of the marking crew to make sure they are getting the overall density right.
10. **Work with the Stand:** The purpose of this method is not to engineer the target pattern on every acre but to promote a mosaic pattern of individual trees, clumps, and openings within the envelope of historical conditions. The clump targets should not be used as rigid targets but instead as approximate averages to be obtained over the entire unit. The final clump tallies may vary somewhat from the targets, especially where large numbers of old trees in clumps result in higher clumping. If final clump tallies are consistently above or below targets, the marking crew will need to determine if bias for or against clumping exists in the crew.

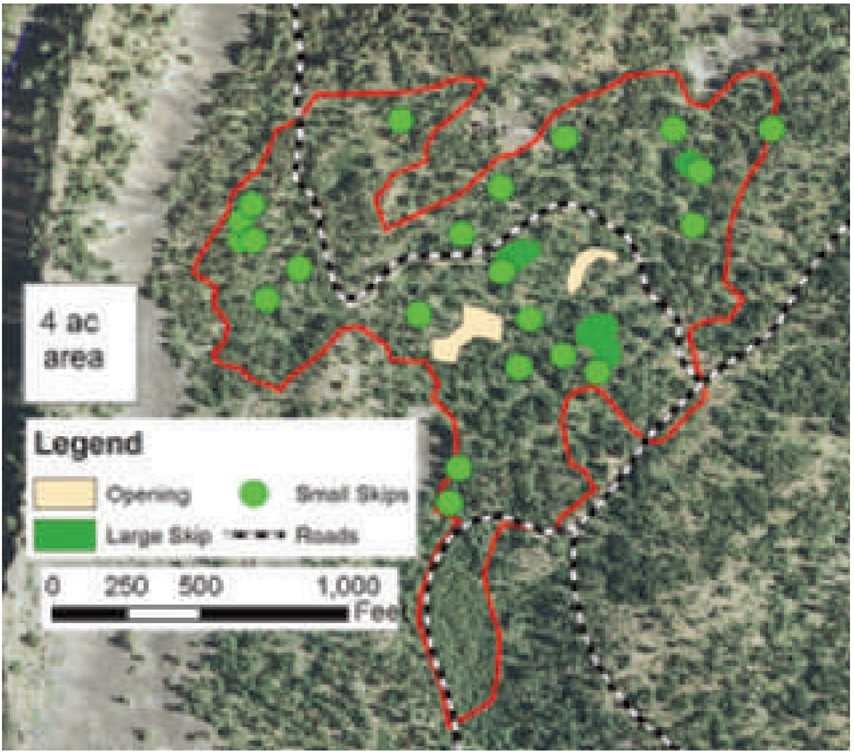


Figure 39. Example 40 ac pre-treatment dry forest stand with skips and openings. Large skips (0.5–0.75 ac) were marked by painting the perimeters around biological hotspots. Small skips (~1/4 ac) were marked by painting the center tree. They are generally dense overstory skips, with some surrounding large dwarf mistletoe trees. Only two openings (1/3rd to 2/3rd acre) were placed as the stand already had numerous large openings. A 4 acre 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 2–10 trees, isolated individual trees, and small openings (<1/5th acre).

In these cases the marking guidelines can be very simple—remove all lodgepole or white fir/grand-fir except for older trees (>150 years) or trees over a specified diameter limit. No explicit guidelines for spatial pattern are needed. This approach can also be used in stands with severe forest health issues, where retaining healthy trees is the main goal and the outcome will generally be a variable post-treatment pattern.

- **Variable Basal Area or TPA:** An average BA and target range of basal area or TPA levels are prescribed for the stand based on reference stands or functional objectives. For example, a prescription may call for thinning to an average of 60 ft^2/ac BA (range of 20–160); with 33% of the area in low density patches (<40BA), 33% in moderate density (40–80), and 33% in high density (80–160). Maximum BA targets should not justify cutting old trees. The Glaze project on this Sisters Ranger District used a version of this approach (Stringer 2008) (see Box 10).
- **Free selection:** This method relies on descriptions and visualizations of the desired spatial distribution of structure (Graham et al., 2007). Quantitative targets are generally included, but they tend to be wide ranges that require marking crews to use a high level of judgment. This method can work well with experienced marking crews.

Track and Monitor

Few marking crews get it right the first time. Feedback and adaptive learning are necessary. Real time tracking (implementation monitoring) during marking is often the most efficient way to provide this feedback. During marking or cutting, skips, openings, large clumps, or other special features can be recorded to ensure that sufficient numbers are left. Tracking adds a little bit of extra time but allows for immediate corrections, accelerates learning, facilitates future monitoring, and builds public trust.

Box 10: **Mosaic Thinning**

This method of creating spatial heterogeneity was designed by Darin Stringer primarily for use in single cohort, black bark pine stands. It was initially used on the Metolius Preserve of the Deschutes Land Trust, near Camp Sherman. It was then implemented on the Glaze Restoration project on the Sisters Ranger District of the Deschutes National Forest (Stringer 2008, Lillebo 2012).

The method seeks to create spatial heterogeneity at two distinct spatial scales (clumps and groups). Resulting structure includes variably sized clumps, individual trees, and openings, all arranged at a larger "group" spatial scale up to an acre in size and variably shaped. The intent beyond encouraging clumpiness, is to restructure tree patterns at this second spatial "group" scale. Basal area targets and total area designated in each group should vary and will be based on whatever range of silvicultural objectives apply (maximizing individual or stand growth, beetle mortality thresholds, new cohort establishment, wildlife habitat, etc.). The grouping method follows the idea that areas with distinct densities will develop along different trajectories as disturbance regimes interact variably within this mosaic and allow desired processes such as new cohort development to occur in a staggered spatial and temporal pattern.

An example prescription directs the tree marker to layout a stand into a mosaic of high, medium, and low density groups each up to an acre in size. In this example the target designates 50% of stand area to a post-thin average basal area of 80 ft^2/ac, 25% to 60 ft^2/ac, 10% to 40 ft^2/ac, 10% in untwined groups, and 5% in openings. Though an average basal area target is met, a range of densities within each group is encouraged and ensured as clump sizes are varied (between 2–20 trees).

Laying Out Skips and Openings

The extra time and cost of including skips and openings in restoration treatments is often a concern. In general, the more sensitive and important the feature, the more effort should be expended on it. To facilitate effective implementation and monitoring, we recommend skips and openings be 1) delineated on the ground with paint or flagging and/or 2) recorded with a GPS unit[1] (inexpensive GPS units can be used and only a center point is necessary for smaller features). Either layout personnel or contractors can delineate and GPS these features at some point in the implementation process. Below are a number of different approaches to laying out skips and openings:

1. **Paint the perimeter.** This is the most straightforward layout method and is recommended, especially for skips around biological hotspots. Painting perimeters is the most time consuming up front, but is easy for loggers and sale administrators.
2. **Paint a center tree.** A radius from painted center trees is provided in the cutting guidelines to specify the perimeter of a skip or opening. Different radial distances can be indicated on the center tree. This works well for smaller openings and skips. With radial distances greater than 40–60', it can be hard to see the center tree. In addition, larger openings and skips (>~1/3rd acre) should generally not be round.
3. **Paint a center line.** A fixed or variable distance off of a center line can be used to create elongated or sinuous skips and

1. We envision that, in the near future, locating and laying out skips and openings can be done with GPS enabled tablets or smart phones. LiDAR and other remote sensing data will also be used to provide an initial assessment of good locations. Here is an example approach: During walkthroughs, specialists will GPS locations of key hotpots. Paper and GIS maps of these locations will be included in marking guidelines, contracts, and prescribed fire plans. Instructions to create additional skips and openings will be added as needed. During implementation, tablets or smart phones will be used to record and track skips and openings so that crews, contractors, and sale administrators can immediately see their location, size, and distribution across the unit. This information will then be available for prescribed fire implementation and future monitoring.

openings. A line around a root rot pocket can also be used to create a "donut" where the center of the pocket is retained for snags but a buffer is cut around it to contain the spread of the pathogen. Lines can also be flagged in by specialists to indicate opening or skips locations for marking crews.

4. **Use unit boundaries.** Unit boundaries, including riparian buffers, can be extended into the unit to create "fingers" that will function as skips. Alternatively, a unit can be split in two to create a long, narrow, wavy skip in the middle. This method should be used for only a portion of the skips.
5. **Distance and compass bearings.** From a known location in the unit (e.g. a corner), a center point or perimeter of a feature can be indicated. A radial distance for a skip or opening is also provided. For example: "Create 5 x 1/3rd acre skips along a 150 degree bearing from the NW corner of the unit; skips should be placed every 200' along this bearing, and have a radius of 68'. Contract markers or logging contractors can then flag or paint and GPS these features prior to cutting.
6. **GPS coordinates or paper map.** These can be used to indicate the approximate perimeter or center location of a skip or opening. Contract markers or logging contractors can then flag or paint these features prior to cutting.
7. **Description.** The desired number, type, and size range of features can be described in a contract, and the operator made responsible for locating, flagging, and GPSing them during implementation. This can work well for more common features (e.g. regeneration skips) where the exact location is not as important. This also provides operators with flexibility to work with logging systems, which is especially important in cable yarding.

Box 11: **Restoration-Oriented, Non-Commercial Thinning**

Non-commercial thinning treatments ("PCT" or pre-commercial thinning) in young stands, typically plantations, are often a significant part of restoration projects, yet they have received far less attention than commercial treatments. Wood production oriented non-commercial treatments that space out trees to a 12, 15, 18, or 20'+ spacing remove tree clumps and homogenize stands. These treatments greatly reduce options to develop the mosaic spatial patterns that are characteristic of historical Dry Forests (Churchill et al. 2013). It is thus desirable to incorporate some level of spatial heterogeneity in such treatments, particularly so as to avoid making it difficult or impossible for later development of clumps of shade intolerant trees. Ideally a clump-based marking or prescriptive approach is desirable to ensure that sufficient numbers of small and medium clumps are retained. Skips and some openings may also be necessary or advisable (e.g. skips for hiding cover or openings for aspen release) and can also help ensure that some larger clumps are retained, especially if thinning is heavy (<150 TPA).

For implementation, we recommend using TPA targets instead of spacing targets. This will allow the focus to be on tree species and tree quality, rather than strict spacing. Contract compliance can be based on the average of fixed area check plots. Additional direction to retain skips and/or small to large clumps is also generally needed. Guidelines from the ICO method can be used to inform these targets. A guiding principal for non-commercial treatments is to avoid preventing development of heterogeneity over time (e.g. thinning out all closely spaced trees and thus precluding the development of clumps and larger skips).

Non-commercial thinning in stands with commercial-sized saw logs is another tool in restoration that should be considered when there is an ecological need to reduce density, but removing wood is too ecologically detrimental or not possible. Dropping young trees around select old trees in inaccessible stands, for example, can increase their odds of surviving drought, insect attack, or fire, and thus help a backbone of old trees persist through major disturbances.

Tree Designation

Three basic designation methods exist for both commercial and non-commercial treatments:

1. **Marking:** Leave or cut trees are painted or flagged by a marking crew. Lump sum (Tree Measurement) sale contracts can be used, as well as a scaled sale contract.
   - **Advantages:** This method provides the most flexibility to achieve the desired objectives and respond to the forest. It allows for the greatest level of complexity in prescriptions and is the easiest to cruise. It is also the most efficient for operators and sale administrators to implement.
   - **Challenges:** *This can be the most expensive option in terms of layout costs, especially in young stands with high densities. Cost for Forest Service tracer paint adds up quickly.* **The quality of the mark depends on the experience and attitude of the crews.** Inconsistencies and miscommunication between crew members can be an issue. Silviculturists or other specialists need to spend some time training and monitoring crews. It is also more time consuming for operators and sale administrators to modify during implementation to meet operational needs, especially if sales are sold lump sum.
   - **Works best in:** *This works best in more complex, variable stands where simple rules won't work in parts of the stand and where more judgment is required. Complex prescriptions are often best done by marking.*
2. **Designation by Description (DxD):** This is a rule-based method of designating the specific trees that will be removed without actually marking. Designation can be based on species, lower and upper diameter limits, or spacing. Two or more rules can be combined (e.g. Leave ponderosa pine >150 years + leave white fir >25" + remove all lodgepole pine). Any person following the prescription will select the same trees. Lump sum (Tree Measurement) sale contracts can be used, as well as a scaled sale contract.

- **Advantages:** It is inexpensive to lay out, although silviculturists writing the prescription need to spend time walking the stand to ensure the DxD rules will produce the desired results. Cruising, implementation, and sale administration are very straightforward and efficient with species rules. There is no judgment required in selecting cut trees for the operator.
- **Challenges**: Fixed rules are inflexible and usually result in unintended consequences in parts of the stand. It can be very difficult to get the desired variability across the stand or respond to specific conditions that require judgment (e.g. placing skips, retaining green wildlife trees, dwarf mistletoe treatments). Combining rules can help, but there is a practical limit to how many rules can be added. Spacing based DxD generally eliminates clumps, even when diameter limits are added. Diameter- and spacing-based rules require a lot of measuring in the field and are time consuming to cruise, implement, and administer. Field modifications are time consuming. Contractors often find it more efficient to mark the stand themselves prior to cutting; this cost is passed onto the landowner.
- **Works best in:** Works best in stands where simple species rules will achieve the desired results, perhaps with a diameter limit rule that rarely occurs (e.g. Remove all white fir, except for trees >30" dbh).

3. **Designation by Prescription (DxP):** The contractor selects which trees are actually removed following clear guidelines that involve some level of subjective judgment, typically spacing or basal area targets. The contractor can be allowed to cut without any actual marking, typically after demonstrating they understand the prescription in a training area. However, the contractor can be required, or chose, to mark trees prior to cutting. DxP is commonly used in PCT treatments and for commercial sales on private lands, and is increasingly being used on public land as well. Only scaled sale contracts can be used with this approach.

- **Advantages:** This approach is inexpensive to layout. It provides lots of options and flexibility to create variability and respond to specific stand conditions, although not as much as with marking. Creative combinations of fixed rules and subjective guidelines can lead to relatively simple prescriptions that create complex stands. GPS coordinates or maps can be used to indicate skips and opening locations. Contractors have more flexibility to incorporate their knowledge and experience into implementation, which can increase efficiency and reduce stand damage. Field modifications are simple.
- **Challenges:** There is a limit to the complexity that can be prescribed. Managers must be somewhat flexible with outcomes, and the potential for major mistakes in implementation is the highest with DxP. It is also the most difficult to cruise and administer as judgment is required in selecting cut trees. Sale administration is more time consuming and requires experienced personnel who can establish strong working relationships with contractors. Estimating production rates and volume removals is more challenging for contractors, and skilled operators are needed.
- **Works best in:** Works best in stands with a moderate to low degree of complexity where a general thinning rule will work (e.g. thin to an average of 80 ft^2/ac BA), with some modifications (e.g. leave 2 large clumps per acre, retain all green wildlife trees, and leave 5 x 1 acre skips).

4. **Combination approaches:** Combining some marking with a DxP or DxD prescription can often provide an efficient approach to achieving desired stand conditions. In general, marking most skips and openings results in better ecological outcomes and lower overall costs, once costs for sale administration, cruising, extra contractor time, etc. are factored in. Marking can also be used for specific situations requiring more judgment, such as retaining large clumps, treating areas infected with root rots or mistletoe, large grand/

white fir retention, etc. Trees that are close to an age threshold can also be marked to avoid the need for the contractor to measure trees while cutting. DxP or DxD can then be used for the rest of the stand. All kinds of combinations are possible to suit specific needs of a project and landowner.

PHOTO: MARET PAJUTEE

Marking Tally Sheet

Stand ID	Date: 10/25/13	Crew: [illegible]
Clump Limit Distance: 5.0'	Unit Area: [illegible]	Note old trees with #

target
5/11/13

Plot	TPA
1	20
2	70
3	30
4	40
5	20
6	30
7	20
8	
9	
10	

Singles

Unit Target: 36

#	dbh	#	dbh
1	10.6	41	
2	11.0	42	
3	15.5	43	
4	13.6	44	
5	10.5	45	
6	12.0	46	
7	18.0	47	
8	12.5	48	
# 9	26.6	49	
# 10	33.0	50	
# 11	36.5	51	
# 12	19.9	52	
# 13	29.0	53	
14	10.0	54	
15	10.0	55	
16	9.0	56	
# 17	31.0	57	
# 18	34.0	58	
19	17.9	59	
20	10.2	60	
21	17.6	61	
22	14.9	62	
23	9.0	63	
24	14.7	64	
25	19.5	65	
# 26	26.0	66	
# 27	29.9	67	
# 28	30.0	68	
# 29	28.8	69	
# 30	27.5	70	
31	10.0	71	
32	13.7	72	
33	24.7	73	
# 34	37.8	74	
35	8.8	75	
36	16.0	76	
# 37	8.8	77	
38	8.2	78	
# 39	23.0	79	
# 40	29.4	80	

Small (2-4 trees)

Unit Target: 24

#	# trees	Avg dbh
# 1	2	32
2	3	16
3	3	17.7
4	2	21.0
5	2	12
6	2	13
7	3	21
8	2	13.5
# 9	2	23.0
# 10	4	28.0
11	4	16.0
# 12	4	23.0
13	2	7.5
# 14	2	22.0
15	2	13.5
16	2	14.0
17	3	12.0
# 18	2	27.0
19	3	11.5
20	2	4.5
21	2	16.0
22	2	7.0
# 23	3	38.0
# 24	4	31.0
25	3	11.0
26	3	11.0
# 27	2	16.0
28	4	14.0
29	4	15.0
30	4	12.0
# 31	3	30.0
32	4	14.0
33		
34		
35		
36		
37		
38		
39		
40		

Mid (5-9 trees)

Unit Target: 6

#	# trees	Avg dbh
# 1	6	17.5
2	5	9.0
# 3	5	16.0
# 4	7	19.0
5	5	8.0
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		

Large Clumps (10-20 trees)

Unit Target: 1

#	# trees	Acres	Avg dbh
# 1	11		27.5
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			

Notes: 1/10 ac density check plots, openings (# and size), etc.

Ethan's Some sugar pine regen
?? Lodgepole clump? in opening? dbh 15 - 18"
18" individual LP
16" individual LP
Also patch of Mahogany

Part V

Putting It All Together: Marking Guides We Use in the Field

Dry Forests are quite diverse but many stands targeted for restoration can be categorized in one of the following groups: 1) structurally simplified ponderosa pine, 2) structurally complex ponderosa pine, 3) structurally simplified mixed conifer, and 4) structurally complex mixed conifer. Exemplary marking guides that we have used for each of these four categories are provided below. In addition, we provide a prescription for aspen/meadow complexes that have been invaded by lodgepole pine—a common issue in Dry Forests. Finally, we include a sample marking guideline using the ICO method which can be integrated, as desired, into the four ponderosa pine and mixed-conifer sample prescriptions. ***Users note: these are examples of prescriptions not general marking guides! Adapt as appropriately to your goals and stand conditions!***

We start with a few comments to the reader about how to interpret these guides:

1. You will notice the guides are somewhat redundant. That should not be surprising since they all apply the same principles that we discussed above, except as needed to adjust to the unique properties of the plant association/habitat type or stand condition.

2. Please remember that these are "guides"—they are not cookbooks. Many choices remain and much interpretation is needed to make them work in our wonderfully diverse forests. We have taken you as far as we can—now comes the art of forest restoration.

Marking Guide for Simplified Ponderosa Pine

Simplified ponderosa pine stands (referred to below as "simplified pine") are homogeneous even-structured stands typically found at low and mid elevations on ponderosa pine sites (Figure 22). They are generally pure or nearly pure ponderosa pine with little representation of other species. They typically have been subjected to silvicultural treatments that removed all or most of the old trees, using such approaches as overstory removal and clearcutting.

Goal: Initial step in creating resilient, multi-aged, structurally diverse stands

1. Retain and facilitate survival of older trees (>150 years) by clearing nearby fuels and competing vegetation, including younger trees;
2. Reduce overall stand density of younger trees to increase resilience of stand to wildfire and insects (target average of 40 to 60 sq ft basal area);
3. Re-introduce spatial complexity by providing skips, openings, isolated individual trees and clumps of trees; and
4. Retain or enhance wildlife habitat.

Steps in marking

1. Reconnoiter the stand to assess its conditions, such as the opportunities that exist for building on existing structural or compositional diversity and preserving or creating habitat value (e.g., potential skips, pockets of insects and disease).
2. Mark older trees, clumps, and other structures (e.g., snags) that are to be retained. Note:

- Significant ground and ladder fuels and competing trees are planned for removal from around all older trees (regardless of species) for 2X the distance of the drip line, excepting where a highly desirable structure (e.g., outstanding younger pines or larches that have the potential to grow into replacement old-growth trees) is marked for retention.
- Overlap of drip lines between older trees is ***OK. All should be marked for retention.***
- Snags or other trees currently experiencing active cavity use should be left as small skips (see below) to retain screening cover unless they are intended as white-headed woodpecker habitat.

3. Mark "skips"—portions of the stand that are not to be entered during harvest activity—by flagging their entire perimeters. Target levels for skips are an average 10 to 20% of the stand in a variety of sizes typically ranging from 0.2 to 2.0 acres. Skips may contain grand/white fir and lodgepole pine. Skips are left to provide one or more of the following:
   - Cool, shaded microhabitats;
   - Visual breaks in the stand (limit sighting distances);
   - Special habitat protection such as rock outcrops and seeps;
   - Concentrations of down wood in an undisturbed condition, including some pockets of tree decline and mortality for future snags & down wood; and
   - Protective cover for snags and live trees with active cavities.
4. Mark leave trees in the remainder of the stand including:
   - Individual dominant and co-dominant healthy ponderosa and sugar pine and western larch trees;
   - Small (2–4 trees) and medium (5–9 trees) sized tree clumps (clumps have trees within 15-20' of other trees in the clumps and include one or more healthy dominant); and
   - Two to 5 green wildlife trees per acre, which are medium or large trees with broken or forked tops, large crooks, mistletoe brooms, insect attack, or cavities.
   - No lodgepole pine and young grand/white fir as leave trees except in skips.

Marking Guide for Complex Ponderosa Pine

Complex ponderosa pine stands (referred to below as "complex pine") are structurally complex stands dominated by ponderosa pine and sometimes sugar pine, which are typically found at low- to mid-elevations on ponderosa pine and Dry Mixed-Conifer forest sites (Figure 5). Other tree species may be present in small amounts include Douglas-fir, western larch, grand/white fir, and lodgepole pine. These stands typically have undergone some selection logging but still retain a significant number of older overstory pines and several different age classes of trees. Considerable spatial heterogeneity may still be present in these forests.

Goal: Restore more resilient conditions (e.g., reduce wildfire and insect risk) in existing complex ponderosa pine forest. Retain and facilitate survival of older tree (>150 years) component by clearing nearby fuels and competing vegetation, including younger trees.

1. Reduce overall stand density of younger trees to increase resilience of stand to wildfire and insects (target 10 to 30 sq ft basal area);
2. Identify and retain replacement trees for existing old pine population;
3. Retain and enhance the existing spatial mosaic by identifying and retaining skips, creating openings, and retaining individual and clumps of younger trees; and
4. Generally remove grand/white fir and lodgepole pine (except for individuals >150 years of age).

Steps in marking

1. Reconnoiter the stand to assess its conditions, such as the opportunities that exist for building on existing structural or compositional diversity and preserving or creating habitat value (e.g., potential skips, pockets of insects and disease).

2. Mark older trees and other structures (e.g., snags) that are to be retained. Note:
   - Significant ground and ladder fuels and competing trees are planned for removal from around older trees for 2X the distance of the drip line, excepting only where a highly desirable structure (e.g., an outstanding younger pine) is marked for retention.
   - Overlap of drip lines between older trees is ***OK. All should be marked for retention.***
   - Snags or other trees currently experiencing active cavity use should be left as small skips (see below) to retain screening cover unless they are intended as white-headed woodpecker habitat.
3. Mark "skips"—portions of the stand that are not to be entered during harvest activity—by flagging their entire perimeters. Target levels for skips are 10 to 20% of the stand in a variety of sizes ranging from 0.2 to 2 acres. Skips are left to provide one or more of the following:
   - Cool, shaded microhabitats;
   - Visual breaks in the stand (limit sighting distances—linear);
   - Special habitat protection such as rock outcrops and seeps;
   - Concentrations of down wood in an undisturbed condition, including some pockets of tree decline and mortality for future snags & down wood; and
   - Protective cover for snags and live trees with active cavities.
4. Mark leave trees in the remainder of the stand favoring
   - Individual healthy dominant and co-dominant ponderosa and sugar pine trees; and
   - Small (2–4 trees) and medium (5–9 trees) sized tree clumps (clumps have trees within 15-20' of other trees in the clumps and include one or more healthy dominant); and
   - Two to 5 green wildlife trees per acre, which are medium or large trees with broken or forked tops, large crooks, mistletoe brooms, insect attack, or cavities.
   - No lodgepole pine and young white fir as leave trees except in skips.

5. Mark larger openings ("gaps") for creation of habitat for regeneration of shade-intolerant species and other sun-favored shrub and herb species by flagging their perimeters. Target levels for openings (created and already existing) are 5 to 15% of the stand in sizes ranging from 0.25 to 2 acres. **Note:** Existing openings may fulfill all or part of this need; **in this case, the opening is marked as a skip since it is an area that is not to be entered during the harvest operation.**

Marking Guide for Simplified Mixed Conifer

Simplified Mixed-Conifer stands (referred to below as "simplified mixed conifer") are homogeneous even-structured stands typically found at mid elevations on Mixed-Conifer sites (Figure 22). They generally are dominated by younger grand/white fir and Douglas-fir with occasional remnant older pines, larches, Douglas-fir and grand/white fir. They typically have been subjected to silvicultural treatments that removed all or most of the old trees, using such approaches as overstory removal and clearcutting.

Goal: Initial step in creating resilient, multi-aged, structurally diverse stands

1. Retain and facilitate survival of older tree (>150 years) component by clearing nearby fuels and competing vegetation, including younger trees;
2. Retain and facilitate survival of younger early seral species, such as ponderosa pine and larch, by clearing nearby fuels and competing vegetation;
3. Create openings for recruitment of early seral species;
4. Reduce overall stand density of younger trees to increase resilience of stand to wildfire and insects (target average of 60 to 80 sq ft basal area);
5. Re-introduce spatial complexity by providing skips, openings, isolated individual and clumps; and
6. Retain or enhance wildlife habitat.

Steps in marking

1. Reconnoiter the stand to assess its conditions, such as the opportunities that exist for building on existing structural or compositional diversity and preserving or creating habitat value (e.g., potential skips, pockets of insects and disease).
2. Mark older trees, clumps, and other structures (e.g., snags) that are to be retained. Note:
   - Significant ground and ladder fuels and competing trees are planned for removal from around older trees for 2X the distance of the drip line, excepting only where a highly desirable structure (e.g., an outstanding younger pine) is marked for retention.
   - Overlap of drip lines between older trees is ***OK. All should be marked for retention.***
   - Snags or other trees currently experiencing active cavity use should be left as small skips (see below) to retain screening cover unless they are intended as white-headed woodpecker habitat.
3. Mark "skips"—portions of the stand that are not to be entered during harvest activity—by flagging their entire perimeters. Target levels for skips are an average 10 to 20% of the stand in a variety of sizes ranging from 0.2 to 2 acres. Skips are left to provide one or more of the following:
   - Cool, shaded microhabitats;
   - Visual breaks in the stand (limit sighting distances);
   - Special habitat protection such as rock outcrops and seeps;
   - Concentrations of down wood in an undisturbed condition, including some pockets of tree decline and mortality for future snags & down wood; and
   - Protective cover for snags and live trees with active cavities.
4. Mark leave trees in the remainder of the stand including:
   - Individual dominant and co-dominant healthy ponderosa pine, western larch, and sugar pine trees. Douglas-fir may also occasionally be left when other species are scarce;

- Small (2–4 trees) and medium (5–9 trees) sized tree clumps (clumps have trees within 15-20' of other trees in the clumps and include one or more healthy dominant); and
- Two to 5 green wildlife trees per acre, which are medium or large trees with broken or forked tops, large crooks, mistletoe brooms, insect attack, or cavities.
- No lodgepole pine are retained as leave trees except in skips; some young grand/white fir may be retained as existing or potential wildlife trees and to meet stand leave targets when other species are scarce.

5. Mark larger openings ("gaps") for creation of habitat for regeneration of shade-intolerant species and other sun-favored shrub and herb species by flagging their perimeters. Target levels for openings (created and already existing) are 5 to 15% of the stand in sizes ranging from 0.2 to 2 acres. **Note:** Existing openings may fulfill all or part of this need; ***in this case, the opening is marked as a skip since it is an area that is not to be entered during the harvest operation.***

Marking Guide for Complex Mixed Conifer

Complex Mixed-Conifer stands (referred to below as "complex mixed-conifer") are usually found at mid elevations and on somewhat moister and more productive sites. These sites are usually dominated by larger and older ponderosa pine and/or sugar pine but often have a significant component of older Douglas-fir, or grand/white fir (Figure 8). The stands have typically undergone some selective logging but are multi-aged, multi-storied and often retain considerable spatial heterogeneity. In some places these are the most productive Dry Forest sites; thus, **they often are the most in need of immediate treatment to reduce threats to old growth trees**

Goal: Restore more resilient conditions (e.g., reduce wildfire and insect risk) and increase pine component in existing complex mixed-conifer forest

1. Retain and facilitate survival of older tree (>150 years) component of all species by clearing nearby fuels and competing vegetation, including younger trees;
2. Reduce overall stand density of young trees to increase resilience of stand to wildfire and insects (target 40 to 60 sq ft basal area in younger trees);
3. Identify and retain replacement trees for existing pine population (both species);
4. Retain and enhance the existing spatial mosaic by identifying and retaining skips, creating openings, and retaining individual and clumps of younger pine trees where they exist; and
5. Reduce grand/white fir and Douglas-fir components of stand (but retain all old grand/white fir and Douglas-fir).

Steps in marking

1. Reconnoiter the stand to assess its conditions, such as the opportunities that exist for building on existing structural or compositional diversity (e.g., potential skips—see below) and potential problems (e.g., pockets of insect or disease damage).
2. Mark older trees and other structures (e.g., snags) that are to be retained. Note:
   - Significant ground and ladder fuels and competing trees are planned for removal from around older trees for 2X the distance of the drip line, excepting only where a highly desirable structure (e.g., an outstanding younger pine) is marked for retention.
   - Overlap of drip lines between older trees is ***OK.*** All should be marked for retention.
   - Snags or other trees currently experiencing active cavity use should be left as small skips (see below) to retain screening cover.
3. Mark "skips"—portions of the stand that are not to be entered during harvest activity—by flagging their entire perimeters. Target levels for skip are 10 to 20% of the stand in a variety of

sizes ranging from 0.2 to 2 acres. Skips are left to provide one or more of the following:
- Cool, shaded microhabitats;
- Visual breaks in the stand (limit sighting distances—linear skips work well);
- Protect special habitats such as rock outcrops and seeps;
- Retain concentrations of down wood in an undisturbed condition, including some pockets of tree decline and mortality for future snags & down wood; and
- Protective cover for snags and live trees with active cavities.

4. Mark leave trees in the remainder of the stand favoring:
   - Individual healthy dominant and co-dominant ponderosa and sugar pine, and western larch trees; and
   - Clumps of trees of variable size (trees within 15'-20' of each other).
5. Mark larger openings ("gaps") for creation of habitat for regeneration of shade-intolerant species and other sun-favored shrub and herb species by flagging their perimeters. Target levels for openings (created and already existing) are 5 to 15% of the stand in sizes ranging from 0.2 to 2 acres. **Note:** Existing openings may fulfill all or part of this need; ***in this case, the opening is marked as a skip since it is an area that is not to be entered during the harvest operation.***

Aspen Restoration

While aspen ecosystems currently occupy only a small proportion of eastside forests, they are biodiversity hotspots. As stated by Seager (2013, page 1), "From mushrooms and insects in the deep, rich soils to the songbirds and woodpeckers in the tree-tops, aspen ecosystems support diverse biota across multiple food webs, including a rich herbaceous understory. Restoring aspen helps restore habitat for diverse wildlife while also helping to restore ecological function and processes to the forest." Yet, aspen ecosystems have been under attack from many forces over the last 100 years including wildfire suppression, grazing by a variety of ungulates, and conifer encroachment. These attacks have taken a heavy toll on aspen ecosystems and restoration is desperately needed.

There is broad agreement in the scientific community on what to do (see Seager 2013) which includes removing competing conifers, controlling grazing by domestic livestock and native ungulates, and reintroducing fire to stimulate sprouting and cohort recruitment processes that are so important to aspen clone survival. Landscape planning will be needed to put aspen restoration energies where they will do the most good, such as on the "core stands"– stands with significant interior habitat (Seager 2013). However, small patches or long linear aspen stands are important too, and often the only aspen stands available.

In this guide, we provide marking guides for the two types of aspen habitat types that are commonly found within landscape restoration projects: 1) aspen-meadow complexes, and 2) upland aspen within conifer forests.

Marking Guide for Aspen-Meadow Complexes and Upland Aspen within Conifer Forests

Aspen-meadow complexes, which wind their way through the eastern Oregon landscapes, are signal ecosystems from both biodiversity and aesthetic perspectives. Many aspen/meadow complexes have been invaded by lodgepole pine following wildfire suppression, often to such a degree that plant association guides sometimes label these ecosystems as "wet lodgepole!" In addition, aspen/meadow complexes are easily impacted by ungulate grazing. These complexes should have a high priority for restoration because of their significance for biodiversity and ecosystem processes (e.g., hydrologic cycling) in eastside forests.

Aspen also grows in isolated patches within a conifer matrix in much of eastern Oregon, whether in pure stands, long stringers, or as an understory in ponderosa pine and mixed-conifer forests. Historical disturbances, seeding events, and social and water resources cause these varying relationships between aspen and conifers. However, in more recent times, various forces--wildfire suppression, livestock and ungulate grazing, and conifer encroachment collectively eliminate or great suppress the aspen in upland conifer forests. Restoring this species would have many benefits and should be a high priority whenever present.

Goal: Restore aspen-meadow complexes and upland aspen stand within Conifer Forests

1. Increase the density, size, and vigor of quaking aspen;
2. Maintain or create a diverse aspen age structure;
3. Provide conditions suitable for development of rich herbaceous understories;
4. Reduce the density of associated young conifers; and
5. Retain and facilitate survival of old conifers.

Steps in Marking:

1. Reconnoiter potential wet meadow complexes to determine the historical spatial extent of the aspen-meadow complex—conifer encroachment may make this difficult. To identify the historical extent of stands look for signs of aspen, willow, or other wet meadow associated species, including aspen logs or snags. Historical photos and aspen fall color can help in this detective work.

   In many instances, it may be difficult to locate aspen within conifer forests. Fall aerial and ground surveys and searches along swales and grassy areas can help locate remnant aspen stands. Marking crews should be directed to shift from conifer guidelines to aspen guidelines when aspen indicators are identified.
2. Mark old conifers (>150 years) for retention within areas of aspen restoration.
3. Target young conifers (especially lodgepole pine) for removal but retain sufficient snags and down logs to provide for wildlife needs. Total conifer representation (both young and old)

should provide <20% canopy closure , unless doing so would cause the removal of old trees.

4. Open a buffer zone around the aspen stand to provide additional light and moisture for the stand by removing young conifers for 1.5-2 tree heights to achieve less than 20% canopy closure unless doing so would cause the removal of old trees.
5. Creation of obstacles to ungulates and domestic livestock should be considered using down trees and slash created in the restoration or by fencing, particularly when significant grazing pressure is expected.
6. Prescribed fire should be seriously considered following reviews by wildlife biologists, fire ecologists, and silviculturists to assess its value in the particular aspen stands being restored.

Example Marking Guide Using the ICO Method

Spacing & clump targets

- Leave an average of 40 TPA over the 200 acre unit. Ignore all trees <5" dbh. Leave trees should be left in the following quantities over the entire unit:
  - 2000 individual trees. These are trees with no neighbors within 20'.
  - 800 small clumps (2–4 trees)
  - 280 medium clumps (5–9 trees)
  - 70 large clumps (10–15 trees)
  - 50 super clumps (16–25 trees). Super clumps should be around large snags or dead wood concentrations where possible.
- Clumps have trees within 20' of at least one other tree in the clump.

Leave Tree Criteria

- Retain all old trees; generally over 150 years.
- Around old ponderosa pine, remove young trees for 2 driplines—OK to keep 1–2 large/vigorous trees occasionally.
- Favor ponderosa pine

- Thin from below removing mostly trees <21" with poor crowns (<35% live crown ratio). Retain occasional mid-story and understory trees as individuals (>45 LCR) or to make up clumps. Some low vigor trees should be left to make up large clumps.
- Retain up to 5 green wildlife trees per acre: trees with forks, broken tops, large branch platforms.

Skips and Openings within 200-acre General Thin Area (All leave trees count toward clump targets)

- Deadwood skips: Leave 15–20 skips around root rot pockets, snags > 20" dbh, or concentrations of downed wood. Size can be 0.1–2 acres.
- Visual and Regeneration skips: Leave 15–20 additional thickets of regeneration and pole size trees in 0.1–2 acre patches to break up sighting distances. These trees should generally be trees <5" dbh and *not counted towards clump targets.*
- Create 12–15 large openings: These should be ~0.75–1 acre and wavy. Retain any old trees within opening and 1–2 larger younger trees. Centerline locations for these openings have been flagged

PHOTO: BRETT COLE

Part VI

Other Major Considerations

Fire

Invasives

Logging systems

Monitoring

Adaptive Management

Fire

Accomplishing restoration goals often will require reintroducing fire either in combination with mechanical thinning treatments or by itself (Fulé et al., 2012). Benefits of fire include, but are not limited to: 1) killing small diameter trees that are not removed by mechanical thinning; 2) removing competition and organic material to create bare patches suitable for early seral conifer regeneration; 3) re-invigorating hardwoods, shrubs, herbs, and grasses; and 4) mineralizing nutrients from organic materials. Removing fine fuels with fire has been shown to significantly increase the effectiveness of fuel-reduction thinning (Raymond and Peterson, 2005; Schwilk et al., 2009; Stephens et al., 2009), although some studies indicate that mechanical thinning alone may achieve fire management objectives (Stephens et al., 2012).

Fire can be reintroduced either through wildland fire use planning or by prescribed fire, or both. It is critical to involve fire and fuel management staff at the outset of restoration project planning so that management objectives related to protecting old trees, augmenting habitat, and enhancing spatial heterogeneity can be integrated with prescribed or natural fire plans. Prescribed fire might treat individual treatment units (1–100 acres), or larger areas (100–20,000 acres) containing treated and untreated forest. In general, prescribed fire can achieve fuel reduction goals at a larger scale and at much lower cost than mechanical (North et al., 2012).

Difficulties in widespread use of prescribed fire are frequently cited as major barriers, including concerns about dangers from fire escapes, particularly in areas with high rural housing density and/or high fuel loading, risk-averse agency cultures, limited availability of personnel skilled in use of fire, and laws and regulations related to air quality concerns (North et al., 2012). Use of fire in restoring and maintaining Dry Forest conditions is probably one of the major ways in which use of historical processes may be constrained by current conditions.

Overcoming these challenges is a complex subject but two points are worth making. First, from the standpoint of risk management, widespread use of prescribed fire will reduce fire risks to communities and air quality degradation (North et al., 2012). Second, with a little strategic creativity, these problems can potentially become solutions. For instance, strategically placed fuel treatments can increase the manageability of fires in large areas, reducing suppression costs and smoke release during fire events.

Prescribed fire frequently involves mortality of a range of tree species and age classes. Mortality associated with prescribed fire is best addressed up-front during the planning process. Planners should be explicit in their definition of a desired condition or treatment objective. For example, an objective to "maintain greater than 50 percent canopy cover in riparian areas" is more workable and meaningful than "do not light within riparian areas." Alternately, instead of aiming for a particular mortality range, a prescribed fire manager can design a burn for "a post-treatment stand structure of X." Of course cost, fuel, topography, and the expertise of the prescribed fire manager may constrain goal-setting.

It must be acknowledged that fire after long periods of fire exclusion has been known to cause significant mortality in older trees (Kolb et al., 2007; Hood 2010). Raking duff from around trees, protecting old trees with shelters, and choosing the appropriate season to burn can mitigate mortality in overstory trees (Kolb et al., 2007; Thies et al., 2006; Hood 2010). Treatment of the duff layer around old trees might be particularly warranted in areas marked by high beetle activity, duff depths > 8 inches, where roots grow into the duff layer, and around high value trees or trees with fire scars (Hood, 2010). Moister spring conditions may allow for easier control of prescribed fire and significantly less mortality to older trees (Thies et al., 2006). Mortality of young trees, on the other hand, is often a goal of prescribed fire. Ideally, fire can do a portion of the "work" of restoring forests by killing trees and creating heterogeneity. Fire is an imprecise tool and flexibility in implementation and outcomes is required, including allowances for the occasional mortality of old trees.

While mechanical treatment has more predictable effects, using prescribed fire alone can often meet restoration/fuel reduction objectives at a fraction of the cost. In some cases, the unpredictability of fire may be the easiest and cheapest way to meet spatial pattern goals. If a fuel bed is so homogenous as to limit variable spatial effects, slashing or thinning to create fuel jackpots or piling slash and then under-burning may be a better tactic.

Burn plans, infrastructure maintenance and environmental mitigation measures should be tightly integrated. For instance, both monetary costs and environmental impacts can be minimized by using existing roads, clearings, ridges, and rocky areas to locate fire control lines. Managers should consider burning different topographic and/or fuel situations at different times. For example, a spring burn in moderate fuel on a south aspect can serve as an excellent burn unit boundary for the more challenging north aspect burn later in the year.

Planning for a diversity of fire effects and maintaining flexibility are the keys to a successful burn. In most cases, the fire that is being planned won't be the last one.

Finally, always remember that repeated fuel treatments are going to be necessary and the more productive site the more frequent the required return treatments whether they are pyric or mechanical! The job of stewardship is never completed in living forests.

Understory Restoration and Invasive Species

A goal of restoration treatments in Dry Forests may be the maintenance and/or enhancement of desired understory species. Enhancement of some desired understory species, such as perennial bunchgrasses, may require planting. Retention of others, such as bitterbrush (a shrub highly palatable to big game), may not reflect historical frequent-fire regimes, but be a socially desirable adaptation to current conditions.

Use of hand crews, heavy equipment, and fire runs the risk of introducing or spreading existing populations of invasive plants, such as cheatgrass (Figure 40). All restoration treatments that risk spread of invasive species should have a monitoring and adaptive management component geared towards controlling their spread within the treatment area. If there is reason to believe that the spread of invasive species cannot be controlled, restoration proposals may need to be shelved while methods are developed and tested to reduce the spread.

Cheatgrass (Bromus tectorum)

Yellow Starthistle (Centaurea solstitialis)

Orange Hawkweed (Hieracium aurantiacum)

Diffuse Knapweed (Centaurea diffusa)

Medusahead (Taeniatherum caput-medusae)

Houndstongue (Cynglossum officianlae)

Figure 40. Invasive plants should be monitored and controlled.

Logging Systems

Restoration planning is constrained by the availability and feasibility of logging systems, which are in turn constrained by restoration objectives, topography and cost. The following are potential logging systems and considerations relevant to restoration work on the Eastside.

Whole Tree Logging (Ground Based)

Whole trees are cut by machine (feller-bunchers), skidded to a landing, and limbed and bucked or chipped on the landing. This is a cost effective and flexible system widely used in Dry Forests. To be cost effective and avoid creating heavily impacted skids trails, average yarding distances should be less than 600', with maximum distances less than 1200'. Costs range from $100 - $150 per mbf at the landing.

Cut to Length (Ground Based)

Cut to length systems are carried out with harvesters that cut, de-limb, buck, and bunch trees in the stand. A forwarder then hauls logs to the landing without skidding the logs on the ground. Stand damage and soil impacts are reduced because the equipment travels over the tree tops and limbs on the trails, and the equipment has good maneuverability in stands. Compared with skidding, forwarders can use significantly smaller landings, provide more flexibility for placing skid trails, and can work on steeper slopes. Average yarding distances can be longer (1000' to 1500'), as well as maximum distances (2000–2500'), which reduces the need for temporary roads. These systems are generally more expensive than whole tree logging ($150–200 per mbf), although costs are falling and can be competitive with whole tree logging. Tops and slash can also be hauled out by forwarders.
They also offer the most options for complex prescriptions.

Skyline or Cable Yarding

These systems are necessary on slopes inaccessible to ground based yarding (>30–45%). Many different cable yarding systems exist, but they all involve full or partial suspension of logs via cables suspended from a yarder and a tailhold tree. Trees are generally felled by hand. Yarding uphill is the preferred approach, but logs can also be yarded downhill. Maximum yarding distance depends on the yarder and the amount of deflection, which is a function of the shape of the slope. Intermediate supports and tail-trees are often needed on convex slopes and with extended yarding distances. Costs range from $180–300/mbf at the landing. Smaller yarders designed for thinning small logs with parallel corridors exist and can be economical if sufficient work can be aggregated in a single project or area. These smaller systems can efficiently yard 1000–1500', can keep corridors narrow (10'—15'), and avoid large landings and fan like patterns. Costs can be significantly lowered if a processor can cut trees and pre-bunch logs. The placement of skips can be challenging as yarding corridors have to be straight. If contractors are given flexibility, skips can be placed in-between corridors.

Helicopter Yarding

Helicopter logging involves felling, often by hand crews, and aerial yarding to a nearby landing with a helicopter. This is the most expensive of all systems ($300+/ mbf) and is generally only possible when log prices are high. It is quite flexible for prescriptions and involves little or no soil impacts. Most snags have to be felled for safety, however, unless they are embedded in large skips. Costs can be significantly lowered if a processor can fall and pre-bunch logs. Helicopter yarding can work well with skips and gaps because the wood is concentrated in openings.

The amount of commercial material that is produced by restoration treatments may affect the feasibility of different logging systems. Ground based systems typically require at least 2,000–3,000 board feet of commercial timber per acre to "pay their way out of the woods." Skyline and helicopter systems require from 5,000–10,000 board feet per acre or more. It is important to consider the limitations of local contract logging equipment and expertise. Bringing new logging systems into an area may require approximately 6 months or more of work for a contractor to justify the move. On-the-ground layout that considers the silvicultural objectives along with the logging system capabilities and limitations leads to successful projects.

Monitoring and Adaptive Management

Forest restoration has many goals such as reducing risk of severe fire, improving habitat for deer, increasing the chances of survival of old trees, and improving and reducing the road system to enhance health of aquatic systems. Not surprisingly, there are many uncertainties associated with restoration efforts ranging from whether the treatments will be faithfully implemented to whether the treatments will have the desired effect. In addition, this field guide calls for a variety of "new" approaches, such as the ICO marking approach, that people, understandably, may be unsure about.

In general, these uncertainties have led to the call for systematic gathering of information to assess performance and for mechanisms to ensure that adjustments will be made as needed. These approaches often go by the names of "Monitoring" and "Adaptive Management."

The increasing importance of monitoring and adaptive management have been recognized in the Collaborative Forest Landscape Restoration Act and resulting program, in the new National Forest Management Act planning rule, and the new US Forest Service handbook in response to that rule. Increasingly, collaborative groups support, advocate for, and wish to be part of monitoring and also want to see evidence that land management organizations can learn and adapt. In the future, monitoring and adaptive management will be an important part of forest restoration.

Types of Monitoring

The Front Range Roundtable (2013) recognizes five types of monitoring (Table 5) through integrating the approaches in a variety of sources (DeLuca et al., 2010, Hutto and Belote, 2013, Lindenmayer and Likens, 2009, Likens and Lindenmayer, 2013). The most recognizable types are implementation monitoring and effectiveness monitoring, which we focus on here. Surveillance monitoring and ecological effects monitoring are important too and an adaptive approach to monitoring is essential. In fact detecting changing baseline conditions that give concern (surveillance monitoring) or detecting unintended consequences of actions (ecological effects monitoring) often lead to the formation of new questions and issues to tackle with monitoring (adaptive monitoring) and changes in policies.

Table 5. Types of monitoring (Adapted from the Front Range Roundtable (2013))

Monitoring Type	Definition
Implementation monitoring	Assesses whether or not a management action has been performed as designed
Effectiveness monitoring	Assesses whether an action has achieved its objective
Surveillance monitoring	Assesses whether any change in a response variable exceeds some pre-determined threshold requiring management action
Ecological effects monitoring	Seeks to uncover unintended ecological consequences of management activity
Adaptive monitoring	Periodically assesses whether the monitoring program needs adjustment, especially relative to new information or new questions

Elements of Monitoring

Adaptive management can be seen as having four key elements (Johnson, et al. 2014):

1. **Acknowledging uncertainty.** Adaptive management starts with an acknowledgement of the uncertainties surrounding proposed management policies. As Gunderson (1993) said: you must keep a ruthless hold on uncertainty. Ideally, management policies are a means to one or more goals. Whether these policies will in fact achieve the goals is uncertain. Usually, some "key bets" were made in developing the policy. Identifying those key bets about which you are uncertain is critical in successful application of adaptive management. They enable forest managers to focus their energies on crucial assumptions made in policy development.

   Further, we suggest grouping key bets into a few major categories: 1) policy implementation (Was the policy followed?), and 2) policy effectiveness (Did the policy achieve the goals?). We use, as our example, an effort to restore the ponderosa pine forests of the Fremont-Winema National Forest using the strategies in this guide. Let's start with a key bet surrounding policy implementation. Our first key bet might be that timber harvest will retain old trees. And let's add one on policy effectiveness. Our second key bet might be that our harvest/prescribed fire prescription revitalizes bitterbrush (for big game forage).
2. **Developing testable hypotheses about policy success.** Given the key bets, we turn them into testable hypotheses by reframing them as testable statements (as needed) and by adding two attributes to each statement: 1) determining what will be measured to assess the validity of the hypothesis, and 2) determining what standard (expectation) will be used to judge whether the hypothesis should be accepted or rejected. As an example, the key bet that timber harvest will retain old trees becomes a testable hypothesis by adding how this supposition

will be measured (number of live trees over 150 years of age at diameter breast height that were cut) and the standard (expectation) by which it will be judged (less than two trees/ac over 150 years will be cut). The key bet about revitalizing bitterbrush could be turned into a testable hypothesis by adding how it might be measured (comparison of distribution and productivity of bitterbrush plants before treatment and a few years after treatment) and expectation by which it would be judged (doubles productivity).

3. **Searching for information to test the hypothesis or hypotheses.** This can range from informal observations of foresters and other specialists, to the study of the latest research results, to formal replicated experimental design, but all approaches require a conscious attempt to assess the validity of the hypothesis or hypotheses in question. As an example, the number of live trees over 150 years of age that were cut could be measured through a post-project survey of the project area. Also, pre- and post-bitterbrush surveys could be done on the project area.

   The development of hypotheses and the search for information to test them can take two forms: 1) "Passive" adaptive management in which information is gathered from the ordinary management activities that occur in pursuit of plan goals and 2) "Active" adaptive management in which alternative approaches to achieve plan goals are systematically compared (an "experiment").

4. **Developing an institutional mechanism that ensures that the hypotheses will undergo periodic, fair-minded review, and management policies can change as a result of that review.** As part of this review, evidence of policy failure must be able to surface and be fairly considered. Bella (1992) noted that it is often difficult for people and organizations to admit that policies, in which they are invested, have not been successful in helping achieve their intended goals. As convincingly described by Bella (1992), people and organizations tend to

selectively produce and sustain information favorable to their management system. Favorable assessments, which do not disrupt organizational systems, thrive in organizations; contrary assessments tend to be systematically filtered out. The cumulative outcome is systematic distortion of information (Bella 1992). It appears human (and organization) nature to invest in particular management strategies, promote them, and be reluctant to believe that they do not work. It is important to have some mechanism to ensure that policy success and failure can be fairly considered and policies can change as a result.

It takes real effort to counter these forces. In most cases, we believe that mechanisms outside the control of the organization in question, such as external review or a strong effort by collaborative group members, will be needed to counter the tendency to bury "bad news" about favored management strategies.

Increasing Your Chance of Success

The difficulties of adaptive management in federal forestry (Stankey et al. 2003) might discourage even an optimistic person. How then might you approach monitoring and adaptive management to increase your chances of success in its application? Here are some suggestions that might prove useful (Johnson, et al 2014):

1. Get started quickly. You can read much on adaptive management that calls for the use of simulation models to set up hypotheses and elaborate and expensive monitoring designs. While that approach can be very helpful in some situations, it is not needed to get started in learning about the effects of management actions. The first three steps listed above (identify key bets, turn them into testable hypotheses, and find information to help evaluate them) can be developed for at least some items of interest at a few staff meetings or a few meetings of a collaborative group. As an example our forest

restoration case above highlighted the key bet that actions will not take old trees and a number of others. It is true that there may be arguments over what to measure, but that should not stop getting started. These arguments, in fact, reveal what is important to people in gauging policy success—a very important ingredient in effective adaptive management.

2. Focus mostly on information that can be gathered at little additional cost. Costly monitoring programs generally will not last unless they have a guaranteed funding source, and few have it. That is just a fact of life. Often key information, such as cost data, is already being gathered by the organization for other purposes but not organized to be useful for monitoring. At other times, you may learn a lot by simply having field staff systematically record observations, such as sightings of large predators. In still other cases, you may get volunteers to record measurements such as bird counts.
3. Get as many people involved as possible. Separate monitoring departments, isolated from the rest of the organization last only until the next budget cuts. Rather, a monitoring program in which people both inside and outside the organization gather information is much more likely to be supported. Also all those people can contribute thoughts about what needs to be gathered.
4. Measure some policy effects that have immediate payoff. Monitoring programs that will not produce results for many years or decades only rarely will be supported until conclusion. You need some hypotheses that you can evaluate, at least partially, in a year or two at most—the hypothesis that old trees will not be cut in timber sales can be tested after the first sale. Hypotheses with a short turnaround are needed to give people hope that their efforts will produce results.
5. Utilize monitoring methods that are useful to the organization in other ways. To the degree that the information you gather is directly useful in forest management and conservation, the greater the likelihood it will be continued. As an example,

think about how the information can help with future forest planning.

6. Be flexible on the standards of proof. Even though, these methods borrow from the scientific method, they are not scientific experiments in which 95% confidence intervals need to be met. A standard based on "preponderance of evidence" seems more useful. In addition, the useful information may come from many different sources and be of many different types. In the case of whether old trees were cut, sampling may miss those few stumps off by themselves that a hiker finds and reports to the paper. That information should be swept into the monitoring results too.
7. Be alert for information beyond your forest that may bear on your hypotheses. Many other people may be studying the same things and new scientific results come out all the time. You should utilize this information too.
8. Find an advocate for the adaptive management program that is respected by those who might be affected by the results. Leadership is important and this person will be, to some degree the messenger of the monitoring results—showing either policy success or policy failure. They need to be respected as someone who can be trusted to follow the truth.
9. Set up a regular, independent review of policy success. As we described above it is very difficult for organizations to admit to policy failure. Even if they allow information to be collected that bear on an issue, they will find a way to bury any "bad news" about policy success. It is essential to set up a mechanism that does not allow this to happen. A commitment to a regular review will help; an independent review is even better. In addition to giving a fair-minded evaluation of how things are going, knowledge of a coming review makes the entire monitoring more real and important.
10. Learn from others. Find useful approaches and study them. As an example, Sharon Hood's approach to monitoring old tree

loss during prescribed fire is very instructive (Hood 2010). Others can be found with a little effort.

As the very first words of this field guide express, our booklet represents our collective knowledge to this point but is not the final word by any means. Therefore we have a great interest in learning from your experience in using this guide. Both implementation and effectiveness monitoring can help improve the guide for future use.

Part VII

References and Other Resources

The restoration concepts and principles presented here are generally consistent with those being developed for other Dry Forest ecosystems (North et al., 2009, USFS 2010, North, 2012) and provide resources for expanding on the information presented here. The review by Hood (2010) is an excellent source of information on approaches to mitigating old tree mortality when reintroducing fire to sites where it has been excluded for long periods of time.

Other Sources of Useful Information on Forest Restoration

Some particularly valuable sources of published information on Dry Forest restoration include the following:

Altman, B., Stephens J. L., 2012. Bird habitat and populations in oak ecosystems of the Pacific Northwest. American Bird Conservancy, Washington, DC. 81 p.

Casey, D., Altman,B., Stringer, D., No date. Snags, bark beetles, and cavity nesting birds: conservation and management in ponderosa pine forests of the Pacific Northwest. American Bird Conservancy, Washington, DC.16 p.

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Appendices

Appendix 1: List of Common and Scientific Names

Common name	*Scientific name*
Trees	
Pacific silver fir	*Abies amabilis*
White fir	*Abies concolor*
Grand fir	*Abies grandis*
Subalpine fir	*Abies lasiocarpa*
California red fir	*Abies magnifica*
Pacific madrone	*Arbutus menziesii*
Incense-cedar	*Calocedrus decurrens*
Western juniper	*Juniperus occidentalis*
Western larch	*Larix occidentalis*
Engelmann spruce	*Picea engelmannii*
Whitebark pine	*Pinus albicaulis*
Lodgepole pine	*Pinus contorta*
Sugar pine	*Pinus lambertiana*
Western white pine	*Pinus monticola*
Longleaf pine	*Pinus palustris*
Ponderosa pine	*Pinus ponderosa*
Quaking aspen	*Populus tremuloides*
Douglas-fir	*Pseudotsuga menziesii*
Oregon white oak	*Quercus garryana*
Western hemlock	*Tsuga heterophylla*
Mountain hemlock	*Tsuga mertensiana*
Shrubs, Forbs, Grasses	
Bitterbrush	*Pershia tridentata*
Elk sedge	*Carex geyeri*
Pinegrass	*Calamagrostis rubescens*
Cheatgrass	*Bromus tectorum*

Snowbrush	*Ceanothus velutinus*
Greenleaf manzanita	*Arctostaphylos patula*

Animals

Northern goshawk	*Accipiter gentilis*
Sharp-shinned hawk	*Accipiter striatus*
Vaux's swift	*Chaetura vauxi*
Mountain pine beetle	*Dendroctonus ponderosae*
Pileated woodpecker	*Dryocopus pileatus*
American marten	*Martes americana*
Fisher	*Martes pennanti*
White-headed woodpecker	*Picoides albolarvatus*
Black-backed woodpecker	*Picoides arcticus*
Great grey owl	*Strix nebulosa*
Northern spotted owl	*Strix occidentalis caurina*
Douglas squirrel	*Tamiasciurus douglasii*

Appendix 2: Plant Associations of Eastern Oregon

Table A1. Dry Forest plant associations in eastern Oregon—the focus of this field guide.

	Code	Reference[1]
Ponderosa Pine		
Ponderosa pine/bitterbrush-sagebrush/fescue	CPS111	V
Ponderosa pine/ bitterbrush-sagebrush/ squirreltail	SPS112	V
Ponderosa pine/mountain mahogany-bitterbrush-big sagebrush/fescue	CPC211	V
Ponderosa pine/big sagebrush	CPS141	S
Ponderosa pine/big sagebrush/fescue-bluebunch wheatgrass	CPS131	J
Ponderosa pine/bitterbrush	CPS210	S
Ponderosa pine/bitterbrush/fescue	CPS211	V
Ponderosa pine/bitterbrush/needlegrass	CPS212	V

	Code	Reference[1]
Ponderosa pine/bitterbrush-manzanita/needlegrass	CPS213	V
Ponderosa pine/bitterbrush-manzanita/long-stolon sedge	CPS214	V
Ponderosa pine/bitterbrush-snowbrush/needlegrass	CPS311	V
Ponderosa pine/bitterbrush-snowbrush/fescue	CPS314	V
Ponderosa pine/bitterbrush-snowbrush/long-stolon sedge	CPS312	V
Ponderosa pine/bitterbrush/long-stolon sedge	CPS215	V
Ponderosa pine/wooly wyethia	CPF111	V
Ponderosa pine/bitterbrush/bluebunch wheatgrass	CPS216	V
Ponderosa pine/bitterbrush-manzanita/fescue	CPS217	V
Ponderosa pine/bitterbrush/squirreltail	CPS218	V
Ponderosa pine-Oregon white oak/bitterbrush	CPH212	S
Ponderosa pine/long-stolon sedge	CPG211	S
Ponderosa pine/manzanita	CPS219	S
Ponderosa pine/needlegrass	CPG125	S
Ponderosa pine/bitterbrush/Ross' sedge	CPS221	J
Ponderosa pine/bitterbrush/elk sedge	CPS222	J
Ponderosa pine/bitterbrush/fescue-bluebunch wheatgrass	CPS226	J
Ponderosa pine/mountain mahogany/elk sedge	CPS232	J
Ponderosa pine/mountain mahogany/Wheeler's bluegrass	CPS233	J
Ponderosa pine/mountain mahogany/fescue-bluebunch wheatgrass	CPS234	J
Ponderosa pine/mountain mahogany	CPS325	S
Ponderosa pine/common snowberry	CPS524	J
Ponderosa pine/mountain snowberry	CPS525	J
Ponderosa pine/mahala mat	CPS341	S
Ponderosa pine/fescue	CPG135	S
Ponderosa pine/fescue	CPG112	J

	Code	Reference[1]
Ponderosa pine/pinegrass	CPG221	J
Ponderosa pine/elk sedge	CPG222	J
Ponderosa pine/bluebunch wheatgrass	CPG111	J
Ponderosa pine/long-stolon sedge-fescue-thickleaf peavine	CPG212	V
Ponderosa pine-Oregon white oak/snowberry	CPH215	S
Ponderosa pine/Douglas spirea	CPS541	S
Ponderosa pine-aspen	CPH312	S
Ponderosa pine/kinnikinnick	CPS641	S
Ponderosa pine/creeping snowberry	CPS542	S
Ponderosa pine/prince's pine	CPF141	S

Wet meadows invaded by lodgepole pine		
Lodgepole pine/sedge-grass wetland	CLM111	V
Lodgepole pine/blueberry/forb wetland	CLM311	V
Lodgepole pine/bearberry	CLM211	V
Lodgepole pine/few-flowered spikerush	CLM912	S
Lodgepole pine/widefruit sedge	CLM113	S
Lodgepole pine/bog blueberry/widefruit sedge	CLM312	S
Lodgepole pine/Douglas spirea/widefruit sedge	CLM314	S
Lodgepole pine/Douglas spirea	CLM313	S
Lodgepole pine-aspen/strawberry	CLH111	H

Dry Mixed Conifer		
Mixed conifer/greenleaf manzanita	CWS111	V
Mixed conifer/snowbrush	CWS114	V
Mixed conifer/snowbrush/long stolon sedge	CWS115	V
Mixed conifer/snowbrush-greenleaf manzanita	CWS112	V
Mixed conifer/manzanita-snowbrush/sedge-penstemon	CWS113	V
Mixed conifer/snowbrush-chinquapin	CWH111	V
Mixed conifer/snowbrush-chinquapin/brackenfern	CSC211	V

	Code	Reference[1]
Mixed conifer/snowbrush-chinquapin/pinegrass	CWC212	V
Mixed conifer/snowbrush/long stolon sedge-brackenfern	CWC213	V
Mixed conifer/snowbrush-bearberry	CWC215	V
Mixed conifer/snowbrush-squawcarpet/strawberry	CWS116	V
Mixed conifer/snowberry/pinegrass	CDS614	V
Mixed conifer/snowberry/forb	CDS613	V
Mixed conifer/snowberry/twinflower	CDS612	V
White fir-grand fir/snowberry	CWS362	S
White fir-grand fir/pinegrass	CWG141	S
White fir-grand fir/pinemat manzanita	CWS363	S
White fir-grand fir/long-stolen sedge	CWG142	S
White fir-grand fir/mahala mat	CWS364	S
White fir-grand fir/woolly wyethia	CWF741	S
White fir-grand fir/greenleaf manzanita	CWS141	S
White fir-grand fir/sticky starwort	CWF362	S
Grand fir/birchleaf spirea	CWS322	J
Grand fir/pinegrass	CWG113	J
Grand fir/elk sedge	CWG111	J
Ponderosa pine-incense cedar/strawberry	CPC731	S
Ponderosa pine-incense cedar/mahala mat	CPC732	S
Ponderosa pine-incense cedar/manzanita	CPC733	S
Ponderosa pine-incense cedar/bitterbrush	CPC734	S
White fir-lodgepole pine/long-stolon sedge-needlegrass	CWC311	H
White fir-ponderosa pine/manzanita-Oregon grape	CWS117	H
White fir-ponderosa pine/snowberry/starwort	CWS313	H
White fir-ponderosa pine-western white pine/sticky currant	CWC411	H
Douglas-fir/common snowberry	CDS633	S
Douglas-fir/mahala mat	CDS645	S

	Code	Reference[1]
Douglas-fir/elk sedge	CDG111	S
Douglas-fir/greenleaf Manzanita	CDS141	S
Douglas-fir/bitterbrush	CDS673	S
Douglas-fir/common snowberry	CDS624	J
Douglas-fir/mountain snowberry	CDS625	J
Douglas-fir/pinegrass	CDG112	J
Douglas-fir/elk sedge	CDG111	J
Douglas-fir/big huckleberry	CDS821	J
Douglas-fir/ninebark	CDS711	J

Moist Mixed Conifer		
White fir/snowberry/strawberry	CWS312	H
White fir/chinquapin-boxwood-prince's pine	CWH112	H
White fir-ponderosa pine-sugar pine/Manzanita	CWC412	H
White fir-ponderosa pine-incense cedar/ serviceberry	CWC111	H
White fir-ponderosa pine-aspen/long-stolon sedge	CWH211	H
White fir-grand fir/western starflower	CWF521	S
White fir-grand fir/chinquapin	CWS533	S
White fir-grand fir/starry false-solomon seal	CWF562	S
White fir-grand fir/creeping snowberry	CWS361	S
White fir-grand fir/prince's pine	CWF241	S
White fir-grand fir/oceanspray	CWS531	S
White fir-grand fir/wild ginger	CWF551	S
White fir-grand fir/queencup beadlily	CWF431	S
White fir-grand fir/vanilla leaf	CWF522	S
White fir-grand fir/twinflower	CWF341	S
Grand fir/queencup beadlily	CWF421	J
Grand fir/twinflower	CSF312	J
Grand fir/Columbia brome	CWG211	J
Grand fir/big huckleberry	CWS212	J
Grand fir/grouse huckleberry-twinflower	CWS812	J

	Code	Reference[1]
Grand fir/grouse huckleberry	CWS811	J
Grand fir/Columbia brome	CWG211	J
Douglas-fir/starflower	CDF341	S
Douglas-fir/chinquapin	CDH525	S
Douglas-fir/creeping snowberry	CDS643	S
Douglas-fir/prince's pine	CDF342	S
Douglas-fir/oceanspray	CDS210	S
Douglas-fir/oceanspray	CDS611	J

Wet Mixed Conifer		
Grand fir/oakfern	CWF611	J
Grand fir/sword fern-ginger	CWF612	J
Grand fir/false bugbane	CWF512	J
Grand fir/Pacific yew/queencup beadlily	CWC811	J
Grand fir/Pacific yew-twinflower	CWC812	J
Grand fir/Rocky Mountain maple	CWS541	J

Table A2. Forest plant associations in eastern Oregon to which this guide does not apply.

	Code	Reference[1]
Lodgepole Pine		
Lodgepole pine/bitterbrush/needlegrass	CLS211	V
Lodgepole pine/bitterbrush/sedge	CLS212	V
Lodgepole pine/bitterbrush/forb	CLS213	V
Lodgepole pine/bitterbrush/fescue	CLS214	V
Lodgepole pine/current-bitterbrush/needlegrass	CLS215	V
Lodgepole pine/fescue	CLG316	S
Lodgepole pine/needlegrass	CLG317	S
Lodgepole pine/beargrass	CLM411	V
Lodgepole pine/snowbrush-manzanita	CLS911	V
Lodgepole pine/sedge-lupine	CLG411	V
Lodgepole pine/sedge-lupine-penstemon	CLG412	V

	Code	Reference[1]
Lodgepole pine/needlegrass-lupine-linanthastrum	CLG313	V
Lodgepole pine/pinegrass	CLS416	J
Lodgepole pine/strawberry-fescue	CLG315	H
Lodgepole pine/squirreltail-long-stolon sedge	CLG415	H

Marginal site and high elevation lodgepole pine		
Lodgepole pine/needlegrass-lupine	CLG314	V
Lodgepole pine/pinemat manzanita	CLS311	V
Whitebark pine-lodgepole pine/pinemat manzanita	CLC113	S
Whitebark pine-lodgepole pine/ long-stolon sedge	CLC114	S
Lodgepole pine/long-stolon sedge	CLG419	S
Lodgepole pine/needlegrass basins	CLG311	V
Lodgepole pine/sedge-needlegrass basins	CLG413	V
Lodgepole pine/grouse huckleberry	CLS412	V
Lodgepole pine/sagebrush	CLS112	V
Lodgepole pine/sagebrush/fescue	CLS111	V
Lodgepole pine/forb	CLF111	H
Lodgepole pine/grouse huckleberry/forb	CLS413	H
Lodgepole pine/grouse huckleberry/long-stolon sedge	CLS414	H

Moist Forest		
Mountain Hemlock Series		
Subalpine Fir Series		
Silver Fir Series		
Western Hemlock Series		
Shasta Red Fir Series		

1. H=Hopkins (1979a and 1979b), J=Johnson and Clausnitzer (1992), S=Simpson (2007), V= Volland (1985).

Appendix 3: Application of Stand Density Index

Stand Density Index (SDI) can be a useful tool to inform or model the effects of restoration treatments for a number of reasons. First, SDI quantifies density in terms of the amount of growing space (light, water, nutrients) that is being occupied by trees. It is a better density metric than basal area because it accounts for the fact that larger trees have less leaf area per unit of basal area, and thus occupy proportionally less growing space than small trees (Waring et al., 1982). SDI works by expressing density as the equivalent number of 10" trees per acre. Table 3-1 shows how SDI varies for three different stands with the same basal area but different mean diameters. Stand A has an SDI of 183 as its mean diameter is 10". Stands B & C have larger tree diameters and SDI levels 162 and 149. These SDI levels mean that the trees in stands B and C occupy growing space equivalent to 162 and 149 tpa of 10-inch trees.

Table 3-1: Comparison of density metrics of stands with the same basal area

Stand	BA (ft^2/ac)	Mean Diameter (inch)	Trees per Acre	SDI
A	100	10	183	183
B	100	15	81	162
C	100	20	46	149

This difference in the relative use of growing space by tree size means that stands with larger trees can support higher basal areas. Table 3-2 shows how using SDI as the primary density metric results in different basal areas for stands with different mean diameters. Using the same basal area target for these three stands would result in a different amount of growing space being occupied and thus would have different ecological effects in terms of canopy cover, tree competition, understory development, etc.

Table 3-2: Comparison of density metrics of stands with the same SDI.

Stand	SDI	Mean Diameter (inch)	Trees per Acre	BA (ft^2/ac)
D	150	10	150	82
E	150	15	75	92
F	150	20	46	101

The other major advantage of SDI is that density levels can be directly related to ecological outcomes. SDI is based on the law of self-thinning (Reineke, 1933), which states that plant populations have a density threshold above which mortality occurs. This threshold is typically around 60% of the biological maximum density of site. SDI is often expressed as a percent relative to this maximum: relative density. Thinning to different proportions of maximum SDI will result in different growth rates, crown development, levels of canopy closure, and competitive mortality over time. These in turn affect understory development, deadwood levels, and disturbance processes such as fire and insects fires (Cochran 1994; Fettig et al., 2007; Long and Shaw, 2005; Powell, 2010).

It is important to recognize the limitations of SDI as well as its advantages. SDI was originally developed for wood production silviculture in even-age, spatially uniform, young stands (Reineke, 1933). When used for restoration oriented treatments, three key issues should be considered.

1. SDI thresholds should not be used to justify removal of old trees. The extent to which maximum SDI mortality or insect risk thresholds, which are typically derived from young stands, apply to predicting mortality of old ponderosa pines is not known. Old trees are often found in large clumps that exceed these SDI thresholds. Yet these clumps have persisted for centuries. While old trees are certainly affected by competition, no actual evidence of higher mortality levels in large clumps of

old trees vs. open grown trees or small clumps has been published to our knowledge. Simply put, a solid empirical basis to justify thinning out clumps of old trees to prevent future mortality does not exist (see Box 4).

2. Avoid uniform SDI targets: Thinning to a single SDI target across entire stands is inconsistent with ecological restoration. Natural stands that developed under frequent fire regimes contained large variation in SDI levels (e.g. Churchill et al., 2013). Also, the notion that all parts of a stand should be thinned below insect mortality thresholds to restore forest health is in conflict with historical stand conditions. Maintaining some parts of stands at higher densities where mortality may occur is generally part of an ecologically healthy forest.
3. Uncertainty with use in heterogeneous stands: Stand-average SDI levels provide only a general picture of site occupancy in heterogeneous stands. The empirical basis for use of SDI in spatially heterogeneous, multi-species, structurally complex stands is complex and far from settled (Woodall et al., 2003; Zeide, 2005). We have found that while SDI derived targets can provide a useful starting point, they should be applied with flexibility and recognition of the underlying uncertainty.

These limitations do not mean that SDI is not relevant to restoration. While imperfect, SDI is a useful density management tool. SDI and other stocking control concepts have been adapted for uneven-age, multi-cohort stands (Long, 1995; O'Hara and Gersonde, 2004; Shaw, 2000) and offer useful empirical knowledge that can be applied to ecological restoration (e.g. Arno et al., 1997; Bailey and Covington, 2002; Shepperd, 2007). In a restoration context, SDI can be used to set variation in density across a stand and inform how patches of different densities are likely to achieve different ecological objectives such as growing large trees, promoting forage species, providing for future snags, and managing susceptibility to insect and crown fires in different parts of the stand. SDI “zones” with distinct ecological implications are described below.

Instead of single SDI target, restoration prescriptions can aim to thin a certain proportion of a stand to each zone, depending on the objectives. For example, a prescription may aim for 15% of a stand’s area in the Open and Open-Tree zones, 20% in Tree-Dominance, 35% in Low Competition, and 30% in Max biomass and Mortality. Data on historical ranges of SDI within stands will be available soon to guide setting of proportions (contact authors for more information). The plot size or basal area factor (BAF) used to measure density of patches within a stand will influence how wide the range is. We suggest plot sizes at which trees are influenced by their neighbors, generally 1/10th to 1/5th acre fixed area plots, or a BAF of around 20.

Determining the maximum SDI for a site is necessary to use SDI and establish thresholds for the different zones. Maximum SDI is based on the productivity of a site and tree species. Maximum SDI is lowest for shade intolerant species (ponderosa pine) and highest for very shade tolerant species (grand/white fir, red fir). Maximum SDI (SDI-max) is very rare in nature. Full or “normal” stocking is thus sometimes used instead to report upper density levels (SDI-full). SDI-full is the upper end of SDI observed in field plots and is 80% of SDI-max. Powell (1999) provides SDI-full levels for plant associations in NE Oregon forests, conversions to BA and TPA, and an excellent overall summary of its use. For other areas in Eastern Oregon, contact the nearest Forest Silviculturist or Area Ecologist. It is critical to determine whether SDI-max or SDI-full values are being obtained! Once the SDI-max (or SDI-Full) has been obtained for a site, SDI values corresponding to the different zones can be calculated based on the descriptions below.

- Open: <10% SDI-max (<15% SDI-full). Most of the site resources are available for non-tree understory plants and tree regeneration. Few trees exist and they are open grown.

- Open-tree: 10–25% SDI-max (15–30% SDI-full). Trees occupy a significant portion of the site resources, but no competition is occurring between them. Most trees are open grown. Understory plant community development and establishment and growth of tree seedlings is rapid, including shade intolerant species.
- Tree dominance: 25–35% SDI-max (30–45% SDI-full). The site is tree dominated. Canopies are touching in many cases, but competition is still quite low and individual tree growth is rapid. Significant resources are available for understory plants and tree regeneration.
- Low competition: 35–50% SDI-max (45–60% SDI-full): Trees occupy most of the site resources. Competition between trees is significant and canopies are lifting, but individual tree vigor is still high. Canopy cover is typically greater between 40%-60%. Shading out of understory species is occurring, although many species can still persist. Growth of shade intolerant tree regeneration species is slow, but shade tolerant species will continue to recruit into the midstory.
- Maximum biomass accumulation: 50–60% SDI-max (60–75% SDI-full): Canopy cover is nearing its maximum, and generally between 60–80%. Competition is high, individual tree growth rates are declining, and crown ratios can drop below 40%. Trees in subordinate crown classes can be susceptible to insect related mortality. However, stand grown, biomass accumulation, and carbon sequestration is at its maximum as almost all site resources are consumed by trees. Many understory species have fallen out or are in decline. Shade tolerant tree regeneration can establish, but growth is slow.
- Mortality: 60–100% SDI-max (75–100% SDI-full). Canopy cover is at or very near its maximum for the site. Self-thinning is occurring with mortality primarily in lower crown classes, but all trees are susceptible to insect related mortality. Crown ratios can drop below 30% and height to diameter ratios can climb above 100. The understory is often bare, with only a few

species able to persist. Tree regeneration establishment and growth are negligible. Crown bulk densities are generally above 0.10 kg/m3, the threshold for high crown fire susceptibility.

As described above, SDI has several advantages over basal area or TPA for setting density targets. However, there is no quick way to determine the SDI in the field, similar to swinging a variable radius plot for basal area or a measuring a fixed area plot for tpa with a laser range finder. Thus converting SDI targets to basal area or trees per acre is generally needed for marking or cutting guidelines, monitoring, and contract compliance. Conversions of SDI to basal area for different zones are shown in Figure 1. All of the relevant equations are also shown below.

Definitions

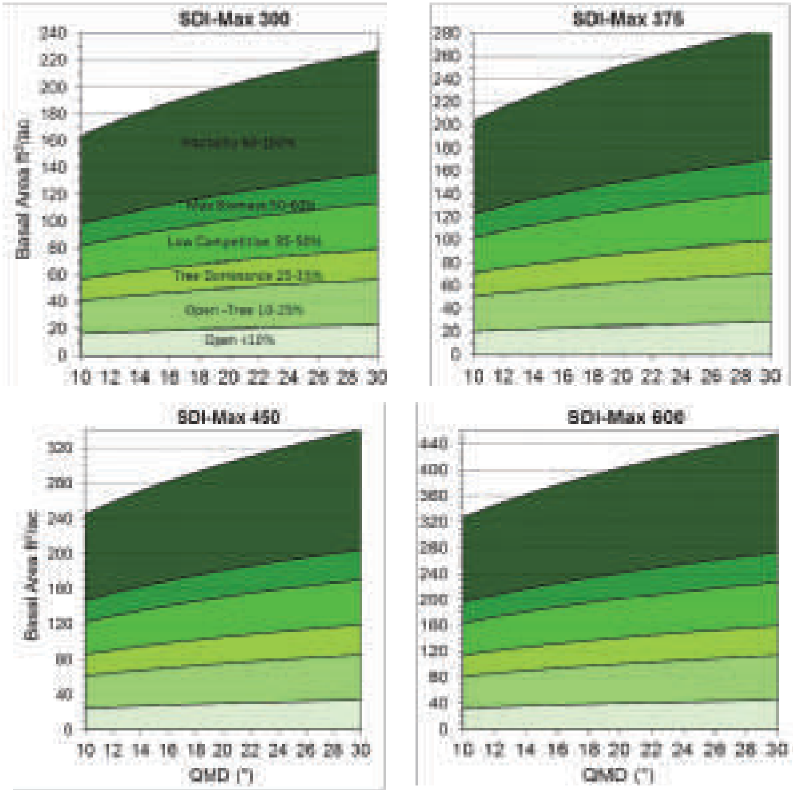
Stand Density Index (SDI): the density of a stand equivalent to the TPA of 10 inch trees. For example, a stand with 100 SDI has a density that is equivalent to 100 TPA of 10" trees in terms of leaf area and water use.

- SDI = TPA * (QMD/10)k where k is a constant that varies by species. Values for ponderosa pine and most other species range from 1.6 to 1.77 (Long and Shaw, 2005). 1.7 is a reasonable default. We recommend using the summation method for calculating SDI for stands that do not approximate bell shaped diameter distributions (Shaw, 2000). To use the summation method, calculate the SDI of each tree in the tree list (TPA is the generally expansion factor for that tree) and add the total up. Alternatively, SDI can be calculated by species and/or diameter class and summed.

Trees per Acre (TPA): the average number of trees per acre in a stand

Basal Area (BA): the two dimensional area of a site occupied by tree boles at breast height expressed as square feet per acre.

- BA of a tree = dbh^2 * 0.005454



Appendix 3, Figure 1. Stand Density Index based ecological management zones expressed in basal area and quadratic mean diameter. Percent values for different zones are proportions of maximum SDI levels. An exponent of 1.7 was used. Four SDI-max levels are shown to provide a range for different plant associations and species. Increases between zones are linear. For example, a basal area value for a QMD of 20" at 35% of 300 SDI-max is 71 ft2/ac and 88 ft2/ac at 35% of 375 SDI-max. The basal area value for 337 SDI-max (halfway between 300 and 375) is the average of 71 and 88 or 80 ft2/ac .

- BAA of a stand per acre = sum of the BA of all the trees in a stand

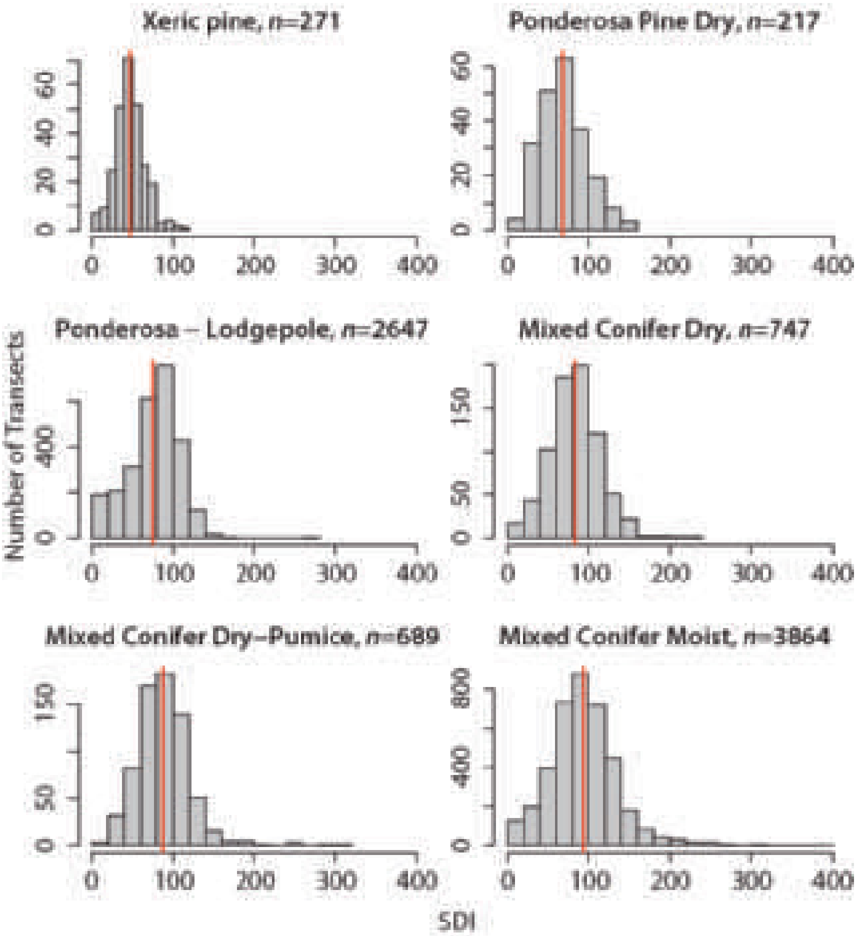
Quadratic Mean Diameter in inches (QMD): the diameter of a tree that has the average basal area of a stand. It is equal or higher than the average diameter of a stand.

- QMD = BAA/ (0.005454 * TPA))

Conversions for stand level metrics:

- BAA = TPA * QMD^2 * 0.005454
- TPA = BAA / (QMD^2 * 0.005454)
- TPA = SDI / (QMD/10)^k

Appendix 4: Historical SDI at Landscape Level



Appendix 4, Figure 1: Distribution of Stand Density Index (SDI) in historical dry forests derived from a roughly 20% sample of >200,000 acres compiled between 1914–1925 on the Klamath and Warm Springs Indian Reservations by the Bureau of Indian Affairs (BIA) (See page 94.). These BIA timber inventories include all conifers > 6" dbh on transects which were typically 20 x 2 chains (1/4 mile x 132 ft) and covered a 4-acre area. Histograms show the distribution of transect means for each habitat type. Average SDI is indicated with a red line. Boundaries for habitat types were derived from the Integrated Landscape Assessment Project potential vegetation type map (Figure 3) (ILAP 2012).

Appendix 5: Achieving Efficiency in Implementation

The combination of declining Forest Service budgets and the ecological need to treat large areas of Dry Forest (North et al. 2012) is increasing pressures on managers to reduce implementation costs. Many large projects (10,000+ acres) are being planned and agencies clearly do not have resources to mark all stands. Use of designation approaches (DxD & DxP) is often proposed as a solution, along with keeping prescriptions very simple and efficient to layout and implement.

Many resource professionals, contractors, and stakeholder groups are developing innovative ways to use DxP or DxD, typically with some marking, to achieve results that adequately meet ecological goals in a cost effective manner. However, there is a limit to how far you can go in pursuing simplicity and efficiency before resilience, habitat goals, and public trust are seriously compromised.

The fundamental challenge is that ecosystems are inherently complex and restoring them is not an operation that can be mass produced by breaking it down into simple tasks. Educated, experienced, and skilled professionals are required who can think critically and adapt to changing environmental and social conditions. The basic steps of landscape planning and prescription development (outlined in the beginning of Part IV), can be made more efficient but cannot be short circuited without a significant loss of quality. Retaining the capacity to have experienced professionals walk each stand and well trained layout crews do at least some marking is paramount.

Tradeoffs involved in shifting work to contractors must also be recognized. DxP or DxD sales have lower layout costs, but some of those costs are shifted onto sale administrators and contractors. Contracting out NEPA analysis can add capacity, but costs are rarely lower and agency specialists are still needed to administer the contracts. We can achieve two of three of the following main goals but not all three: 1) Treating large areas; 2) Low costs; and 3) High quality outcomes.

There are certainly lots of opportunities to find efficiencies, however, while still meeting ecological and social goals. The following are some key examples:

1. *Revamp contracting rules:* Contracting rules are often the biggest impediment to more efficient implementation of restoration prescriptions. Rigid Forest Service accountability standards, which originated when old-growth trees were worth thousands of dollars, can cost far more in staff time than they save in timber values. Other "internal" rules can limit options for layout and drive up. Stewardship authority is a big improvement; the ability to use DxP should be extended to standard timber sale contracts. A benefit/cost approach to contracting rules would significantly increase agency capacity. The desired heterogeneity in ecological restoration provides room for greater flexibility in layout and contract administration.
2. *Boil prescriptions down:* Restoration prescriptions often start out complicated and can become overwhelming. Through field testing and trial and error, as well as input from layout personnel, contracting staff, and operators, they can usually be boiled down to key elements that create most of the desired results. Time consuming and complicated elements can typically be made more efficient, substituted, or eliminated with little sacrifice to ecological outcomes. Flexibility and openness to innovation in layout procedures and contracting rules is essential. Still, in aggregate, most restoration prescriptions will require more time to implement than production forestry thinning prescriptions.
3. *Embrace emerging technologies:* Systems that integrate GIS information with GPS-enabled tablets and smart phones are rapidly improving. Using them to identify, record, and track skips, openings, and other biological hotspot features during planning, implementation, and monitoring will make

restoration prescriptions more effective and efficient. Instead of painting perimeters of skips, for example, operators could work off of a GIS perimeter on a tablet in their cab. The increase in efficiency and acres treated should offset the loss in precision and occasional mistake. Combining these tools with information from remote sensing technologies such as LiDAR, Google Earth, or other imagery products offers even greater possibilities.

4. *Harness the efficiency of fire:* Both wildland and prescribed fire can be very cost effective ways of reducing fuel loads and restoring ecosystems. While there are many barriers to increasing their use, the only way that we are likely to keep up with restoration and maintenance needs is to increase the use of fire (North et al. 2012).

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