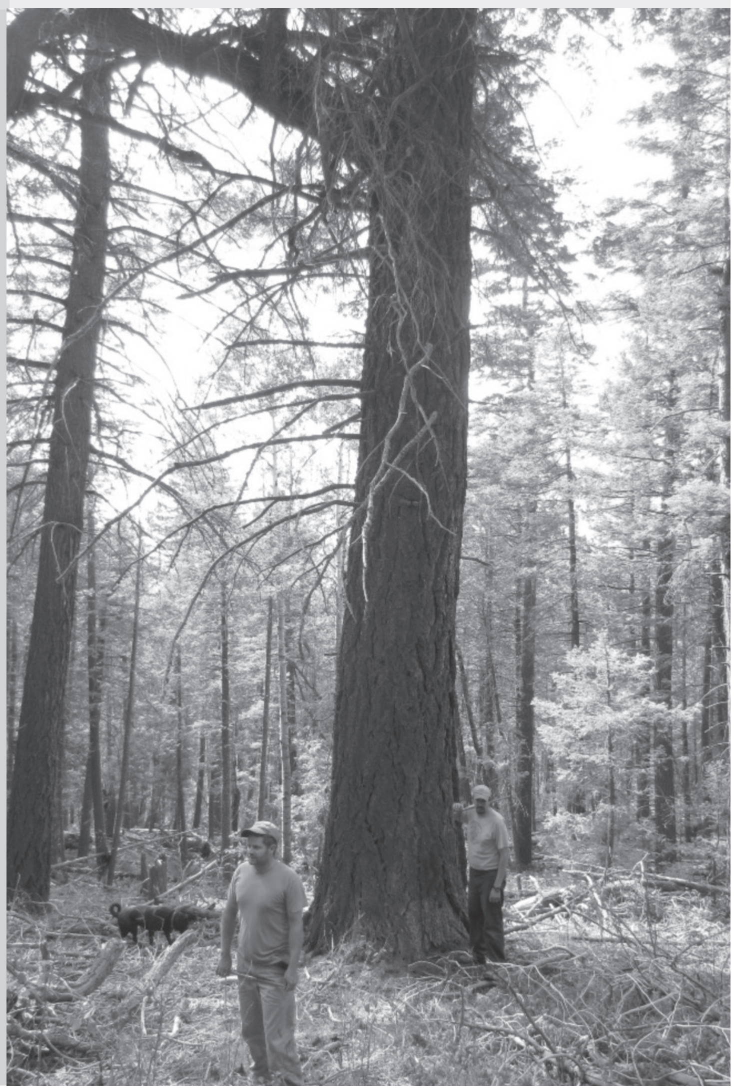
Ecological Restoration Institute
Working Paper No. 28

28

Southwestern Mixed-Conifer Forests: Evaluating Reference Conditions to Guide Ecological Restoration Treatments

October 2013



SOUTHWEST FIRE SCIENCE CONSORTIUM

NORTHERN ARIZONA UNIVERSITY

Ecological Restoration Institute

JOINT FIRE SCIENCE PROGRAM

Working Papers in Intermountain West Frequent-fire Forest Restoration

Ecological restoration is a practice that seeks to heal degraded ecosystems by reestablishing native species, structural characteristics, and ecological processes. The Society for Ecological Restoration International defines ecological restoration as "an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability….Restoration attempts to return an ecosystem to its historic trajectory" (Society for Ecological Restoration International Science & Policy Working Group 2004).

Most frequent-fire forests throughout the Intermountain West have been degraded during the last 150 years. Many of these forests are now dominated by unnaturally dense thickets of small trees, and lack their once diverse understory of grasses, sedges, and forbs. Forests in this condition are highly susceptible to damaging, stand-replacing fires and increased insect and disease epidemics. Restoration of these forests centers on reintroducing frequent, low-severity surface fires—often after thinning dense stands—and reestablishing productive understory plant communities.

The Ecological Restoration Institute at Northern Arizona University is a pioneer in researching, implementing, and monitoring ecological restoration of frequent-fire forests of the Intermountain West. By allowing natural processes, such as low-severity fire, to resume self-sustaining patterns, we hope to reestablish healthy forests that provide ecosystem services, wildlife habitat, and recreational opportunities.

The ERI Working Papers series presents findings and management recommendations from research and observations by the ERI and its partner organizations. While the ERI staff recognizes that every restoration project needs to be site specific, we feel that the information provided in the Working Papers may help restoration practitioners elsewhere.

This publication would not have been possible without funding from the USDA Forest Service and the Southwest Fire Science Consortium. The views and conclusions contained in this document are those of the author(s) and should not be interpreted as representing the opinions or policies of the United States Government. Mention of trade names or commercial products does not constitute their endorsement by the United States Government or the ERI.

Cover Photo: A cool/moist mixed-conifer stand structure indicative of past high-severity fire (Jemez Mountains, NM). The emergent Douglas-fir in the foreground is the only tree that survived the last fire (in 1861). Charred bark, elevated crown, and a growth change in the tree-rings of the Douglas-fir helped confirm the dating of this high-severity fire.
Photo credit: E.Q. Margolis

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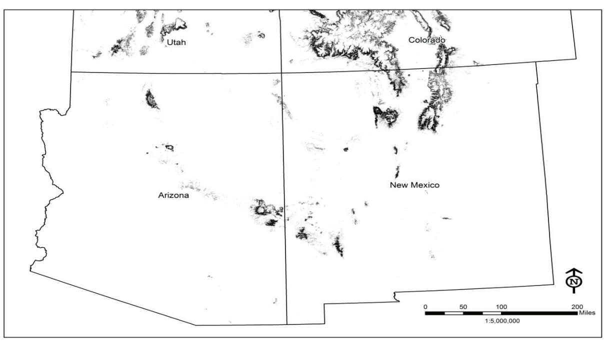
Introduction

Mixed-conifer forests of the Southwest are variable and complex, covering approximately 2.5-million acres scattered across the region (Dieterich 1983, Korb et al. 2013; Figure 1). Mixed-conifer forests contain a diverse mix of tree species (Table 1) and typically occur between, but do not include, the lower-elevation warmer, drier ponderosa pine forests and the highest-elevation cooler, wetter spruce-fir forests. Because mixed-conifer forests have diverse stand structures, forest composition and disturbance regimes, it is often difficult to generalize about reference conditions and historical fire regimes that can be used to guide management for specific locations. In this working paper, we 1) describe the current knowledge of mixed-conifer historical reference conditions for fire regimes, stand structure, and species composition in the Southwest (Arizona, New Mexico and adjacent areas); 2) provide field diagnostics to assess reference conditions; and 3) offer land managers restoration-related guidance to promote resilient mixed-conifer forests in the Southwest.

Figure 1. Distribution of mixed-conifer ecosystems in the Southwest.



We emphasize that mixed-conifer forests are found along a gradient of environmental conditions that results in a wide range of species compositions, fuels characteristics, and natural disturbance regimes. Historical fire regimes in mixed-conifer varied along this gradient from frequent, low-severity fires, to less frequent fires that may be mixed in severity, to infrequent, high-severity fires. However, for the sake of description and to inform restoration-related activities, we feel it is beneficial to divide mixed-conifer into two groups: 1) **warm/dry mixed-conifer,** where ponderosa pine is present and low-severity fire regimes were dominant historically, and 2) **cool/moist mixed-conifer,** where ponderosa pine is generally absent and high-severity fire regimes were typical historically (Romme et al. 2009).

Table 1. Tree species typically found in southwestern mixed-conifer forests.

Common name	Scientific name
Aspen	*Populus tremuloides*
Blue spruce	*Picea pungens*
Douglas-fir	*Pseudotsuga menziesii*
Engelmann spruce	*Picea engelmannii*
Gambel oak	*Quercus gambelii*
Limber pine	*Pinus flexilis*
Ponderosa pine	*Pinus ponderosa*
Southwestern white pine	*Pinus strobiformis*
Subalpine fir	*Abies lasiocarpa*
White fir	*Abies concolor*

Natural Fire Regimes

A fire regime can be defined by the severity, fire (patch) size, seasonality, and frequency of fires through time (Agee 1993). Although other disturbances occur in mixed-conifer forests (e.g., insect outbreaks, drought, fungal pathogens, wind disturbance), fire was historically a major influence on forest structure and composition throughout the region (Romme et al. 2009). Historical fire regime parameters differ between warm/dry (i.e., frequent-fire) and cool/moist (i.e., infrequent-fire) mixed-conifer subtypes. Not only are there differences in fire behavior and effects between the mixed-conifer types, there are also differences in the methodologies available for reconstructing the fire regimes. For example, researchers may analyze dates of fire scars on trees to determine fire-return intervals for low-severity fires, whereas analysis of stand ages and landscape patterns may provide information concerning fire patch size, fire extent, and connectivity for high-severity fire regimes where fire scars are rare or absent. Here we summarize the current state of knowledge concerning fire regime parameters in warm/dry and cool/moist subtypes of mixed-conifer forests in the Southwest.

Warm/Dry Mixed Conifer

Compared with other dry forest types (e.g., ponderosa pine forests), less is known about the historical fire regimes of Southwest mixed conifer. Fire history reconstructions based on dendroecological analysis of fire-scarred trees indicate that prior to the late 1800s, fires in warm/dry mixed-conifer forests of the Southwest were relatively frequent and low severity. For example, Swetnam and Baisan (1996) provided a summary of tree-ring studies conducted at 24 mixed-conifer sites in Arizona and New Mexico, and reported historical mean fire intervals (i.e., of spreading fires that scarred more than 10% of recording trees) that ranged from about 4 to 15 years for mixed-conifer sites dominated by ponderosa pine. Alternatively, they found fire-return intervals from about 8 to 26 years on sites with a more even mix of mixed-conifer tree species, but still containing ponderosa pine. Elevation at the sites ranged from 5,920 to 9,620 feet for pine-dominated mixed-conifer forests, and from 7,546 to 10,080 feet for more mixed forests (Swetnam and Baisan 1996). Longer mean fire-return intervals (19-30 years) were reported by Grissino-Mayer et al. (2004) for three mixed-conifer sites containing ponderosa pine in southern Colorado. Other researchers have documented historical fire-return intervals at sites in New Mexico, northern Arizona, and southern Colorado within this range (4-30 years) (Brown et al. 2001, Heinlein et al. 2005, Fulé et al. 2003, Fulé et al. 2009, Margolis and Balmat 2009, Bigio et al. 2010).

The range of fire intervals in warm/dry mixed conifer exemplifies the diversity of this forest type and likely reflects interactions between climate, fuels, and topography. Longer fire-return intervals can result from a heterogeneous landscape structure that restricts fire spread (Iniguez et al. 2009) or long periods between climate conditions favorable for fire (Margolis and Swetnam 2013). Across the region, fire-return interval has also been shown to increase with increasing elevation. However, more work is needed to develop predictable models to support this concept (Swetnam and Baisan 1996, Wolf and Mast 1998, Brown et al. 2001).

High-severity fires that create large patches of tree mortality can be identified by even-aged stands of trees, patches of sprouting species, such as aspen or oak, and numerous charred snags or logs. Such patches may be intermixed with evidence of low-severity fire and appear to occur more frequently with increasing microsite moisture and cooler temperatures (Fulé et al. 2003). Even in a frequent, low-severity fire regime there certainly will be some amount of tree mortality. The available data for warm/dry mixed conifer in the Southwest indicate that small, high-severity patches occurred on rare occasions. This suggests that large patches of high-severity fire were historically uncommon in this mixed-conifer subtype.

Fire scar records indicate that the frequent, low-severity fire regime in warm/dry mixed-conifer prevailed for more than four centuries prior to 1900 (Swetnam and Baisan 1996, Margolis and Balmat 2009). Conversely, most studies of warm/dry mixed-conifer forests report very few fire scars after 1900. This disruption of the long-term historical regime of frequent surface fires was a result of the onset of intensive land uses, particularly livestock grazing, associated with Euro-American settlement of the region (Swetnam and Baisan 1996, Fulé et al. 2009). Because frequent fire was a key ecological process operating over very long time periods, elimination of fire led to critical changes in ecosystem structure and function that now require restoration. Additionally, tree-ring fire scars indicate that fires in warm/dry mixed-conifer historically occurred in the spring or summer, and were rare in the autumn (e.g., Heinlein et al. 2005, Margolis and Balmat 2009). This is important to consider when determining the timing of prescribed or managed fires.

Cool/Moist Mixed Conifer

Compared to warm/dry mixed-conifer, there is relatively little research on the high-severity fire regimes of cool/moist mixed-conifer forests of the Southwest. We use the term "high severity" to broadly characterize fire regimes that were historically dominated by high-severity patches (i.e., near complete overstory mortality) that left a persistent and identifiable legacy in terms of stand structure or composition on the landscape today (e.g., Figure 2). Existing studies do indicate that cool/moist mixed-conifer forests historically burned with large patches (more than 250 acres) of high-severity fire (Fulé et al. 2003; Margolis et al. 2007, 2011), which differentiate them from the warm/dry mixed-conifer and ponderosa pine forests (Swetnam and Baisan 1996). Similar to the warm/dry mixed-conifer, historical fires predominately occurred in the spring or summer in the Gila Wilderness in southwest New Mexico (e.g., Abolt 1997), whereas on the North Rim of the Grand Canyon, Arizona, historical

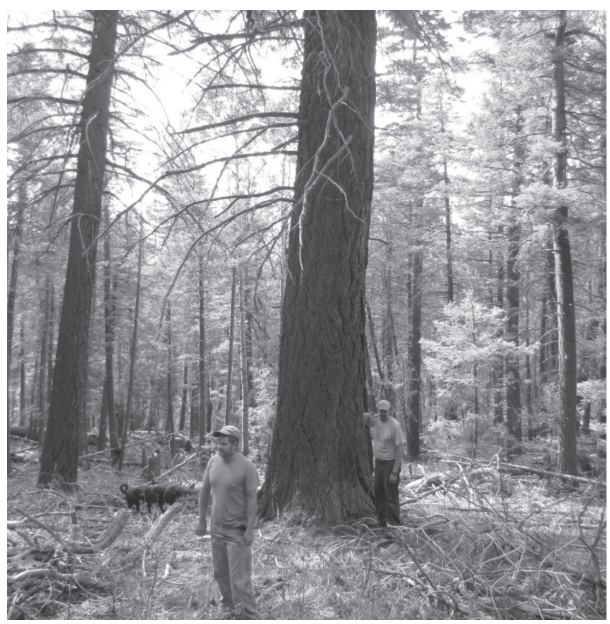


Figure 2. A cool/moist mixed-conifer stand structure indicative of past high-severity fire (Jemez Mountains, NM). The emergent Douglas-fir in the foreground is the only tree that survived the last fire (in 1861). Charred bark, elevated crown, and a growth change in the tree-rings of the Douglas-fir helped confirm the dating of this high-severity fire. High tree density in the surrounding stand is likely part of natural succession following high-severity fire and does not need restoration. *Photo credit: E.Q. Margolis*

high-elevation fire occurrence was later in the summer (i.e., evidenced by middle earlywood to latewood fire scars, July – Sept, Fulé et al. 2003). The differences may reflect sub-regional variability in the timing of snowmelt and the summer monsoon.

The best estimates of fire-return intervals in cool/moist mixed-conifer in the Southwest range from multiple decades to centuries (Abolt 1997, Fulé et al. 2003, Margolis et al. 2007, Romme et al. 2009). The longer fire-return intervals have important implications for fire severity and forest structure. High-elevation, cool/moist mixed-conifer forests are generally thought to have sufficient fuels to carry fire, but require extreme regional drought to dry the fuels so they can burn (Margolis et al. 2007). The rarity of such climatic events is a primary determinant for the long fire intervals in cool/moist mixed-conifer forests. During these long fire-free intervals, shade-tolerant, fire-intolerant tree species (e.g., true firs) naturally establish and high fuels loads accumulate in cool/moist mixed-conifer stands. This results in naturally dense, multi-aged forest structure and high fire severity.

High-Severity Fire Patch Size

High-severity fire patch size is a key determinant of post-fire vegetation composition and structure (Agee 1993). Historical high-severity fire patch size estimates are necessary to determine if current high-severity fire patch sizes are outside the natural range of variability (NRV; Landres et al. 1999) and to guide ecological restoration, if deemed necessary. The only data on high-severity patch sizes in warm/dry mixed conifer is from the Santa Fe Watershed in New Mexico. There, Margolis and Balmat (2009) reconstructed relatively small (less than 250 acres), high-severity fire patches in a Douglas-fir, ponderosa pine, and southwestern white pine warm/dry mixed-conifer forest from nineteenth-century fires using conifer age structure, tree death dates, and fire scars.

There is more evidence of historical high-severity fire patches in cool/moist mixed-conifer forests, which includes patches greater than 2,470 acres in size. In cool/moist mixed-conifer forests on the North Rim of the Grand Canyon, Fulé et al. (2003) identified fire-initiated stands at the plot (0.25-acre) scale, but did not estimate high-severity patch sizes. However, historical observations referencing fire on the North Rim by Lang and Stewart (1910) include, "vast denuded areas, charred stubs, and fallen trunks", confirming the presence of nineteenth-century, high-severity fire reconstructed by Fulé et al. (2003) in these high-elevation forests (some of which were likely cool/moist mixed-conifer). Using quaking aspen patches embedded in cool/moist mixed-conifer forests throughout the Southwest, Margolis et al. (2007, 2011) used tree rings to reconstruct historical high-severity patch sizes ranging from 74 acres to more than 2,471 acres. Comparisons of historical (pre-1905), high-severity patch size estimates with contemporary (1984-2010) patch sizes from mixed-conifer/aspen forests of the Mogollon Plateau and Sky Islands suggest that high-severity fire patches from recent fires may be larger than those created by fires in the past (Margolis et al. 2011).

More research is needed to test these findings and develop local estimates of historical high-severity fire patch sizes as well as finding answers to questions about contemporary high-severity patch size variability, the effects of climate and other variables on patch size, and comparisons of patch sizes of recent wildfires and historic fires.

Historical and Contemporary Forest Composition and Structure

Historical forest structure and composition is important to guide forest restoration (Egan and Howell 2001). To gain the clearest understanding of historical conditions to guide restoration, as many lines of evidence should be gathered as possible, although certain types of evidence and certain combinations of evidence are stronger than others. For example, dendroecological reconstruction using increment cores and models for individual trees can provide precise information concerning stand density, species composition, tree sizes, and spatial patterns (Fulé et al. 1997, Mast et al. 1999, Huffman et al. 2001, Bakker et al. 2008). In addition, historical photographs, written accounts, and other cultural types of evidence may provide general insight concerning stand structure and composition, albeit less precise and possibly prone to greater bias than tree-ring studies. As with reconstructing historical fire regimes, different methodologies lend themselves to assessing forest structure and composition of warm/dry and cool/moist mixed-conifer forests.

Warm/Dry Mixed Conifer

Data from dendroecological stand reconstructions and historical inventories of southwestern warm/dry mixed-conifer forests are limited compared to other forest types. However, studies to date indicate that tree density of warm/dry mixed-conifer forests ranged from about 21 to 99 trees per acre while basal area varied from 34 to 124 ft^2 per acre, prior to Euro-American settlement of the region (Stoddard 2011). Low-severity surface fires, burning at intervals of 4 to 30 years, limited establishment of tree seedlings, and many forests were more open than today. Although information about tree spatial patterns in mixed-conifer is very limited, frequent fire in dry forest types of western North America is thought to promote fine-scale heterogeneity characterized by mosaics of openings, single trees, and groups of trees with interlocking crowns (Larson and Churchill 2012). In the absence of repeated fires, openings fill-in with regenerating trees and stands increase in spatial homogeneity. For example, at a warm/dry mixed-conifer site in southern Colorado, Fulé et al. (2009) found that tree density increased by a factor of nearly five and stand basal area more than doubled from the time of fire regime disruption in 1870 to the time of study in 2003. Similar changes were found by Cocke et al. (2005) in the mixed-conifer zone on the San Francisco Peaks in northern Arizona. Heinlein et al. (2005) studied smaller sites on the San Francisco Peaks and found that tree density and basal area had increased since fire-regime disruption by factors of up to 31 and 4, respectively. Fulé et al. (2003) identified substantial, yet smaller, changes in tree density and basal area following fire-regime disruption at a mixed-conifer site on the North Rim of Grand Canyon National Park.

Although the density of nearly all mixed-conifer tree species has been reported as increasing since fire-regime disruption, proportional increases have been greatest for shade-tolerant and fire-intolerant species, such as white fir (Heinlein et al. 2005, Fulé et al. 2003, Fulé et al. 2009, Iniguez et al. 2009). For example, at a warm/dry mixed-conifer site in southern Colorado, Fule et al. (2009) reported that, prior to fire regime disruption, ponderosa pine trees comprised 42-54% of the tree density and 54-68% of the stand basal area, whereas in 2003 ponderosa pine was reduced to only 4-16% of tree density and 27-46% basal area. At the same site, prior to fire-regime disruption, white fir comprised 14-28% of the tree density and 12-22% of the basal area, whereas in 2003 white fir had increased to 43-75% of the tree density and 29-46% of the stand basal area (Fulé et al. 2009). In contrast, species that are shade intolerant and re-sprout following fire, such as aspen, may have declined (Fulé et al. 2003, Huffman unpublished data) or have a dramatically altered stand structure on some sites (Margolis et al. 2011).

It is also important to note that many forests that today are dominated by warm/dry mixed-conifer species may not have historically been mixed-conifer forests, but have in-filled with fire-intolerant mixed-conifer species (e.g., white fir) following fire exclusion or were altered by harvesting of selected species (e.g., ponderosa pine) (Moore et al. 2004). Increases in stand density and corresponding changes in structure and species composition have altered potential fire behavior on many warm/dry mixed-conifer sites, shifting fire potential from low-severity surface fire toward high-severity crown fire.

Cool/Moist Mixed Conifer

Cool/moist mixed-conifer stand structures and compositions varied in space and time depending on 1) the pre-fire stand composition, 2) the severity of the last fire, and 3) the time since the last fire (Romme et al. 2009). For instance, aspen will often re-sprout following high-severity fire in cool/moist mixed-conifer forests, but shade-tolerant species will regenerate and eventually overtop the aspen, and dominate the stand until the next fire (Jones 1974, Margolis et al. 2007). Hence, while in-filling by shade-tolerant species is considered outside the NRV in warm/dry mixed-conifer forests, such successional trajectories are within the NRV in cool/moist mixed-conifer forests and provide an important distinction between these two mixed-conifer subtypes.

Reconstructing the stand structure and species composition of forests that historically burned with high severity is difficult because the fire-killed forest is often no longer present on the landscape due to high decomposition rates in these mesic locations or subsequent fires that consume the fire-killed trees. Where data exists, the interpretations can be challenging. This is particularly the case when there has been increased tree densities and changing forest composition following the last fire, but no direct evidence of historical fire severity. It is important to remember that change is not inherently negative and must always be considered in the context of the NRV.

Stand Structure

Cool/moist, aspen/mixed-conifer stands can follow a relatively predictable successional pathway after a high-severity fire--starting with aspen regeneration, then to shade-tolerant conifer regeneration and, eventually, forming an aspen/mixed conifer forest. In such a case, historical stand structure could be estimated based on adjacent existing stands with a similar estimated time-since-fire (or stand age). The loss of evidence of historical stand structure through the processes described above is, perhaps, most problematic for stands where some unknown portion of the trees were killed during historical mixed-severity fires (compared to stands that burned with complete mortality). Given these limitations, there is limited data about specific historical stand structures, although the following general statements apply and differentiate cool/moist mixed-conifer from warm/dry mixed-conifer or ponderosa pine (Jones 1974):

- Irregular structures are common (at stand to landscape scales) in cool/moist mixed-conifer stands due to patches of high-severity fire. Even-aged stands may regenerate post-fire, but will deteriorate through time as the oldest cohort dies and subsequent regeneration occurs.
- Stands in cool/moist mixed-conifer forests were likely multi-storied, due to the shade tolerance of mixed-conifer tree species and infrequent, high-severity fires that would not have the effect of "thinning from below."

Species Composition

Species composition is likely to change through time in cool/moist mixed conifer stands due to the subtype's successional tendencies following a high-severity fire and the shade tolerance of many cool/moist mixed-conifer species. At the landscape-scale, there is likely to be a mosaic of stands dominated by a variety of conifer species as well as aspen/conifer-dominated stands (Romme et al. 2009). Multiple tree-ring reconstructions of age structure and species composition in cool/moist mixed-conifer forests dominated by Douglas-fir indicate an increase in density of shade-tolerant and fire-intolerant species during the last century. For example, the high-elevation, mixed-conifer forests on the south slope of the San Francisco Peaks were historically dominated by Douglas-fir and limber pine (with about 10% ponderosa pine) but have exhibited an increase in density of Engelmann spruce, white fir, and corkbark fir since the late 1800s (Cocke et al. 2005). Another example, from the Gila Wilderness, indicates that stands historically dominated by Douglas-fir, and historically subject to both high- and low-severity fires, now have understories dominated by fire-intolerant spruce and fir (Abolt 1997). In this case, where there is evidence of a mixed-severity fire regime, it is likely that some portion of the species composition change and increased density is natural post-fire succession, and that some portion may be an artifact of fire exclusion.

In summary, although there is limited data for cool/moist mixed-conifer forests of the Southwest, historical species composition was likely spatially variable and changed through time in any particular stand. Therefore, unlike ponderosa pine or warm/dry mixed-conifer forests, changes in cool/moist mixed-conifer stand structure and composition may be within the NRV and do not necessarily indicate the need for restoration.

Guidance for Land Managers: Determining Local Mixed-Conifer Subtypes and Natural Range of Variability

Given what forest researchers have discovered about Southwest mixed-conifer forests, land managers can use the structural and composition clues provided in Table 2 to determine the mixed-conifer subtype and coarse-scale disturbance regime of their *local* mixed-conifer forest. We suggest managers use multiple indicators (see also Swetnam et al. 1999, Egan and Howell 2001).

Additional evidence may be used to support field diagnostics and determine the NRV, and could include:

- Historical photos of stand structure or fire
- Written accounts of forest characteristics
- Local knowledge
- Habitat types or ecosystem surveys.

Implications for Ecological Restoration of Southwest Mixed-Conifer Forests

Ecological restoration is the “process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed” (SER 2004). This process makes use of reference conditions to help determine the NRV for ecosystem dynamics, structure, and function. Understanding these reference conditions allows restoration practitioners to measure the degree of degradation (departure), set goals, and measure success. For forest systems, information about natural disturbance regimes, forest structure, and species compositions forms the foundation for developing sound ecological restoration and conservation strategies (Moore et al. 1999).

Warm/Dry Mixed Conifer

Fire managers in the Southwest realize that due to changes in fire regime, forest structure and composition, warm/dry mixed-conifer forest are at high risk of unnaturally large, high-severity fires and have begun ecological restoration efforts using a number of different tools, including mechanical treatments, prescribed fire, and managed natural fire (Evans et al. 2011). This risk of wildfire is especially pronounced and critical for the many mixed-conifer forests in Arizona and New Mexico that are small and isolated (Figure 1). Furthermore, mixed-conifer forests provide unique habitat for rare species, such as the Mexican spotted owl (MSO) and the Jemez Mountains salamander.

At the stand level, restoration approaches for warm/dry mixed-conifer forests should strive to reduce the risk of high-severity fire and re-establish structural characteristics and spatial patterns similar to the site’s NRV. Thinning small and young trees to reduce stand densities and ladder fuels, combined with application of low-intensity fire, is intended to restore structure,

Table 2. Field diagnostics for determining Southwest mixed-conifer forest subtypes.

	Fire-scarred or charred living trees	Presence of ponderosa pine	Surface fuels	Dead and down logs showing char and evidence of past lethal fire	Stand structure	Quaking aspen
Warm, dry mixed-conifer subtype	“Cat-face” fire scars with multiple entries	Ponderosa pine present; old trees, logs, snags, stumps suggesting historical dominance	Abundant tall grass; Loosely compacted, long needle, 1-hr surface fuels	Scattered and not abundant	Low density of pre-settlement trees; No large, dense patches of even-age pre-settlement trees	Multiple pre-settlement age classes mixed with pre-settlement conifers
Cool, moist mixed-conifer subtype	Lack of living trees with charred bark or scars, or scattered trees with single scars and no “cat-face” wounds	Ponderosa pine absent; old tree, snags, logs, stump of fire intolerant species (e.g., true fir or spruce) suggesting long-term presence	Tightly compacted, short needle, 1-hr surface fuels	Abundant in larger patches	Dense stands of pre-settlement trees. Even aged pre-settlement trees (including aspen)	Large, even-age patches embedded within a mixed-conifer forest

species composition, and resilience to near reference conditions (Fulé et al. 2006, Korb et al. 2012). Thinning prescriptions are based on the NRV and ideally on local field assessment of pre-disruption structural conditions, which includes identification of old trees, snags, logs, and cut stumps by species. Mechanical thinning treatments can be expensive, however, and their use may be constrained by other management goals and objectives, such as designated Wilderness management or MSO habitat. Application of low-intensity fire alone is less selective than mechanical thinning and may not immediately reduce stand density to reference levels (Fulé et al. 2006, Korb et al. 2012). Higher-intensity fire may restore approximate structural characteristics and stimulate increases in understory vegetation (Fulé et al. 2004, Huisinga et al. 2005, Fulé and Laughlin 2007, Laughlin et al 2011). However, by allowing fires to burn more actively, land managers incur a higher level of risk that includes escaped fire effects as well as undesirable consequences such as large patches of high-severity fire damage. In remote areas, managing naturally ignited fires may help restore mixed-conifer forests across larger landscapes.

Although the efficacy of some treatments is uncertain and needs to be assessed, ecological restoration is necessary in areas determined to have departed from the NRV and a where a no-action policy can have negative consequences. More work is needed to test long-term restoration alternatives for warm/dry mixed-conifer forests in the Southwest. In particular, studies are needed that examine ecological responses beyond forest structure. For instance, little is known about responses of key wildlife species and invertebrates. Similarly, more research is needed to describe long-term effects of restoration treatments on understory communities, particularly changes in populations of invasive, exotic species.

Cool/Moist Mixed Conifer

Many cool/moist mixed-conifer forest stands may not be outside of their NRV in terms of forest structure, composition or fire regime and, therefore, may not need restoration (Schoennagel and Nelson 2011; but see below regarding landscape-scale structure). Techniques used to restore frequent, low-severity fire regimes should not be used in these cool/moist forest types that historically burned with high severity, unless there is another management goal (e.g., protection of wildland-urban interface assests or infrastructure). Even so, mimicking the natural disturbance structure (i.e., high-severity fire patches) would be more ecologically sound than trying to create an open, park-like cool/moist mixed-conifer stand. We also recognize that other anthropogenic land uses (e.g., logging or intensive livestock grazing) could also necessitate restoration. This may be particularly true for mixed-conifer stands that were high-grade logged for Douglas-fir or Engelmann spruce.

Landscape Structure

Although much of our knowledge and restoration focus is at the stand level, there should also be a greater focus on assessing the NRV of landscape-scale forest patch structure. Cool/moist mixed-conifer stands are often intermixed with warm/dry mixed-conifer stands (and other forest types). For example, in many landscapes adjacent cool/moist and warm/dry mixed-conifer stands historically formed a mosaic of discontinuous crown fuels, but they have since filled-in following fire exclusion and now form a homogenous canopy fuel layer that can support larger areas of high-severity fire (e.g., Santa Fe Watershed, NM, Margolis and Balmat 2009; Grand Canyon, AZ, White and Vankat 1993). For instance, preliminary analysis of the 2012 Whitewater-Baldy Fire suggests that recent patch sizes in the mixed-conifer forests may be larger than historical conditions, because after a century without fire much of the warm/dry mixed-conifer can now support crown fire (in addition to the naturally dense, cool/moist mixed-conifer). This increased homogeneity is leading to potentially anomalous, large stand-replacing fire patches. Therefore, restoring more open warm/dry mixed-conifer forests will begin to restore the landscape heterogeneity of the forests and reduce the potential size of future high-severity patches.

In this paper, we focus on the historical fire regimes and reference conditions of mixed-conifer forests. However, it is important to remember that historically these forests were, and still are, connected and influenced by the fire regime and forest (fuel) structure of adjacent forests. Therefore, a landscape-scale approach is increasingly important when assessing areas for management and ecological restoration.

Summary

- For the sake of description and to inform restoration-related activities, it is beneficial to divide mixed-conifer forests into two groups: 1) warm/dry mixed-conifer, where ponderosa pine is present and low-severity fire regimes were dominant historically, and 2) cool/moist mixed-conifer, where ponderosa pine is generally absent and high-severity fire regimes were typical historically (Romme et al. 2009).
- Understanding an ecosystem's reference conditions allows restoration practitioners to measure the degree of degradation (departure), set goals, and measure success. For forest ecosystems, information about natural disturbance regimes, forest structure, and species compositions forms the foundation for developing sound ecological restoration and conservation strategies (Moore et al. 1999).
- At the stand level, restoration approaches for warm/dry mixed-conifer forests should strive to reduce the risk of high-severity fire and re-estab-

lish structural characteristics and spatial patterns similar to the site's NRV.

- Many cool/moist mixed-conifer forest stands may not be outside of their NRV in terms of forest structure, composition or fire regime and, therefore, may not need restoration (Schoennagel and Nelson 2011).
- It is important to remember that historically these forests were, and still are, connected and influenced by the fire regime and forest (fuel) structure of adjacent forests. Therefore, a landscape-scale approach is increasingly important when assessing areas for management and ecological restoration.

Acknowledgments

Support was provided by the Southwest Fire Science Consortium and the ERI. This work was funded in part by a grant from the USDA Forest Service. The manuscript was improved by comments from reviewers: Barb Satink Wolfson (Northern Arizona University), Dave Lawrence (Santa Fe National Forest), Larissa Yocom (Northern Arizona University), Andrew Stevenson (Coconino National Forest), and Zander Evans (Forest Guild).

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NAU Printing Services/74375/300/02-13

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