Fire regimes of conifer forests in the Blue Mountains

2017

Abstract—Wildland fire is an important disturbance in forests of the Blue Mountains of Oregon and Washington. Understanding the historical role of fire is critical to understanding how these forests are shaped and how to manage them. Here FEIS synthesizes the scientific literature on historical patterns and contemporary changes in fuels, stand structures, and fire regimes in these forests. Four fire history studies covering 34 sites in dry forests and mesic mixed-conifer forests suggest that prior to fire exclusion, mean fire-return intervals ranged from 10 to 49 years in sites that experienced low-severity fire, and most fire-return intervals were less than 20 years. Fires were at least twice as frequent in the southern than in the northern part of the Blue Mountains. Low-severity fires were most common in dry forests, and mixed-severity fires with substantial moderate and high severity were typical in mesic mixed-conifer forests. While precise sizes of presettlement fires are unknown, fire-scar and age-class studies suggest that most fires (60%) burned areas larger than 600 acres (250 ha) but less than 1,000 acres (400 ha). Since the early 1900s, fires became less frequent due to fire exclusion, logging, and overgrazing. Forests grew denser and the basal area of shade-tolerant conifers greatly increased. Climate changes may lead to longer fire seasons, lower soil and fuel moisture, a greater likelihood of large fires, and subsequent changes in forest composition and structure. However, models of predicted changes in forest composition and distribution in the Blue Mountains differ. Managing for resilience in fire-excluded forests in the Blue Mountains may require reducing fuel loads, restoring historical stand structure, and returning frequent fire to the landscape.

Figure 1—The 2016 Rail wildfire burning on the Wallowa-Whitman National Forest. Photo courtesy of InciWeb.

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INTRODUCTION

This Fire Regime Synthesis brings together information from two sources: the scientific literature as of 2016, and the Biophysical Settings (BpS) models and associated Fire Regime Data Products developed by LANDFIRE, which are based on literature, local data, and expert estimates. This synthesis:

- provides information on historical fire regimes and contemporary changes in fuels and fire regimes,
- identifies areas lacking fire history data,
- supplements information provided by FEIS Species Reviews, and
- assists LANDFIRE with data revisions.

Common names are used throughout this synthesis. See table A2 for a complete list of common and scientific names of plant species mentioned in this synthesis and links to FEIS Species Reviews.

DISTRIBUTION AND PLANT COMMUNITIES

Distribution

The Blue Mountains encompass the Aldrich, Elkhorn, Greenhorn, Ochoco, Strawberry, Wallowa, and Wenaha mountain ranges, which stretch from north-central Oregon to southeastern Washington [31]. These ranges function as a floristic bridge between the Cascade Range to the west and the Rocky Mountains to the east [34]. Collectively, the Blue Mountains cover 5 million acres (2 million ha), with elevations ranging from 2,300 feet to 9,000 feet (700-2,700 m) [16, 39]. Soils across the Blue Mountains have accumulated ash depositions due to eruptions from Mount Mazama and Glacier Peak [31, 40]. Ash soils provide high water-holding capacity and available nutrients [40], which are critical to sustaining plant growth and ecosystem function in dry forests [31, 40].

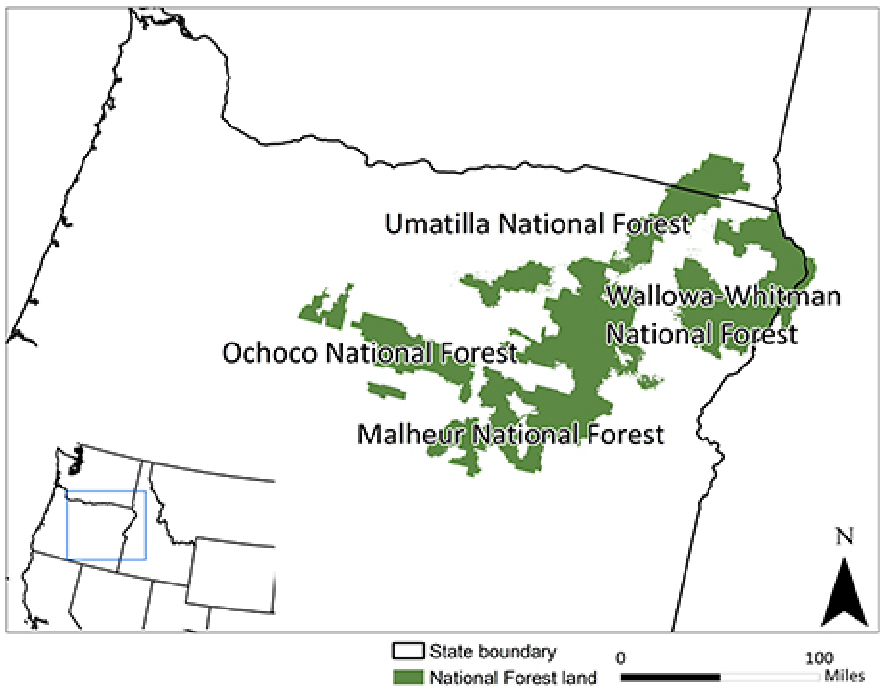

Figure 2—National Forests of the Blue Mountains.

The climate of the Blue Mountains is generally dry, with low annual precipitation (mean = 17.5 inches (444 mm), 1985-1996) [46]. Most precipitation (71%) falls between November and May. Winters are cold (mean = 30.2° F (-1° C)) and summers are warm (mean = 66.2° F (19° C)) [32]. Precipitation decreases from north to south. Moist, westerly air from the Pacific flows along the Columbia Gorge, providing precipitation to the north, while the south is tucked behind the rain shadow of the Oregon Cascade Range [46]. This regional precipitation gradient affects duration of snow cover, which is less in the south than in the north. From late summer to early autumn, lightning storms traverse the Blue

Mountains, igniting wildland fires [31]. These mountain ranges were named the Blue Mountains in recognition of fires that historically shrouded the area in smoke [48].

The Blue Mountains span the 45° N parallel. At this latitude, steep south-facing slopes (≥50%) are exposed to twice the amount of direct solar energy of north-facing slopes [28]. At comparable elevations, south-facing slopes have higher surface temperature and lower relative humidity than north-facing slopes [24], so they are drier.

Plant Communities

Plant community composition changes with elevation and moisture in the Blue Mountains [31]. The following community descriptions are organized along elevational and moisture gradients from dry, low elevations to mesic, high elevations [14, 31, 49, 53]. BpS series are provided in parentheses.

Dry forests (10450, 10531, 10532, 11650, and 11660 BpS series) occur at low elevations or on south-facing slopes from about 1,700 to 5,000 feet (520-1,500 m) [16]. In the Blue Mountains, they are typically adjacent to perennial bunchgrass or sagebrush communities. Douglas-fir, grand fir, or ponderosa pine dominate dry forest associations (table A3). Ponderosa pine historically dominated the overstory, though Douglas-fir or grand fir were often present. Perennial bunchgrasses were abundant in the understory, while shrubs were uncommon due to frequent fire. The following shrubs occur in dry forests: antelope bitterbrush, birchleaf spirea, common snowberry, and mountain snowberry. Graminoids that are common on warm, dry, exposed sites include bluebunch wheatgrass, blue wildrye, elk sedge, Idaho fescue, mountain rough fescue, pinegrass, and Ross's sedge. Pinegrass and elk sedge may also occur on mesic sites. Prior to fire exclusion, potentially 40% to 75% of the forested landscape in the Blue Mountains was composed of dry forests dominated by ponderosa pine [31].

Mesic mixed-conifer forests (10450 and 10470 BpS series) were historically dominated by Douglas-fir and ponderosa pine [14]. They occur from about 4,000 to 6,000 feet (1,200-1,800 m) [16]. Engelmann spruce, grand fir, lodgepole pine, and western larch also occur in the overstory. Grand fir dominates most associations in mesic mixed-conifer forests (table A3). Common shrubs include common snowberry, mallow ninebark, Rocky Mountain maple, thinleaf huckleberry, and white spirea.

Riparian forests in dry forests and mesic mixed-conifer forests are dominated by the same overstory species as adjacent forests, though they are often more dense and structurally complex [51].

Lodgepole pine forests (11670 BpS series) are often restricted to nutrient-limited pumice deposits, which are extensive in the Blue Mountains [49, 53]. They occur from about 4,000 to 7,500 feet (1,200-2,300 m) [16]. In areas with fine-textured soil, Douglas-fir, ponderosa pine, white fir, and quaking aspen may occur. Common shrubs include common juniper, mountain big sagebrush, and pinemat manzanita in dry areas, while common snowberry and thinleaf huckleberry occur in mesic areas. Pinegrass and elk sedge are common in the ground layer [49, 53].

Subalpine fir-Engelmann spruce forests (10550 and 10560 BpS series) are dominated by one or both of these species [31, 53]. They occur from about 6,000 to 8,000 feet [16]. Douglas-fir, lodgepole pine, white fir, and western larch also occur. Barberry, elk sedge, and pinegrass are common in dry areas, while thinleaf huckleberry, twinflower, queencup beadlily, and western bugbane are common in mesic areas [31, 53].

HISTORICAL STAND STRUCTURE AND FUELS

In this synthesis, the historical period refers to the time before fire exclusion. This occurred in the late 1800s to early 1900s in the Blue Mountains [5, 27, 44].

Prior to fire exclusion, dry forests tended to be open, while mesic forests were denser. Dry forests in the Ochoco Mountains contained an estimated 12 mature ponderosa pines/acre (30/ha) and 5 mature Douglas-firs/acre (12/ha) [44]. Pine needle litter and abundant bunchgrass cover provided fine fuel continuity. Fuels rarely accumulated due to frequent fire and low productivity [5, 23]. Mesic mixed-conifer forests in the Ochoco Mountains had an estimated 10 to 15 mature ponderosa pines/acre (25-37/ha), 3 mature Douglas-firs/acre (7/ha), and 6 mature grand firs/acre (15/ha) [44]. Compared to dry forests, the high productivity of mesic mixed-conifer forests enabled fine fuels to rapidly increase between fires [5]. Surface fuels included herbaceous and woody material that burned at variable severities, which maintained a mosaic of tree species and age classes [5, 39]. Historical stand structure and fuels in lodgepole pine and subalpine fir-Engelmann spruce forests had not been estimated as of 2016, but their current fuel loads may be comparable to historical conditions [5].

HISTORICAL FIRE REGIMES

Fire Ignition and Season

Fire ignition

Lightning is the primary source of ignition throughout the Blue Mountains [5]. Summer lightning storms are common across the region but most frequent in the south [47]. In 1973, there were 220 lightning-ignited fires in the Blue Mountains, averaging one fire for every 23,000 acres (9,000 ha)/year (Anon. 1973 cited in [16]).

Fires set by American Indians were common in the Blue Mountains into the mid-1800s [63]. Fires were frequently set in dry forests. In mixed-conifer forests, they were set in autumn after rain had begun to fall [36]. Native tribes including the Cayuse, Nez Perce, Paiute, Shoshone, and Umatilla burned forests throughout the Blue Mountains to improve hunting and grazing and to increase production of edible berries and roots [63].

Fire season

Prior to fire exclusion, fires typically burned from summer (July-August) until precipitation fell in autumn (September-October) [5]. Across the Blue Mountains, the fire season began earlier and was longer in the south than in the north. Fires occurred during the growing season (May-July) more often in the south. One study found nearly half of the fire scars formed in the early- or latewood in the south, while only 8% of the scars occurred in these positions in the north [24]. This was likely due to earlier snowmelt and less precipitation in the south than in the north.

Fire Frequency and Type

In the Blue Mountains, fire frequency varies more strongly with latitude than with forest type, suggesting that fire frequency is at least partly controlled by the regional climate. From 1687 to 1900, for example, an average of 14 fires burned sites in dry forests in the south, while an average of 5 fires burned sites in dry forests in the north [24]. Fires burned at least twice as frequently in the south than in the north due to less summer precipitation, longer snow-free periods, and possibly more lightning strikes in the south [24, 47]. This contributes to lower fuel moisture contents and a higher probability that fires will ignite and spread [24].

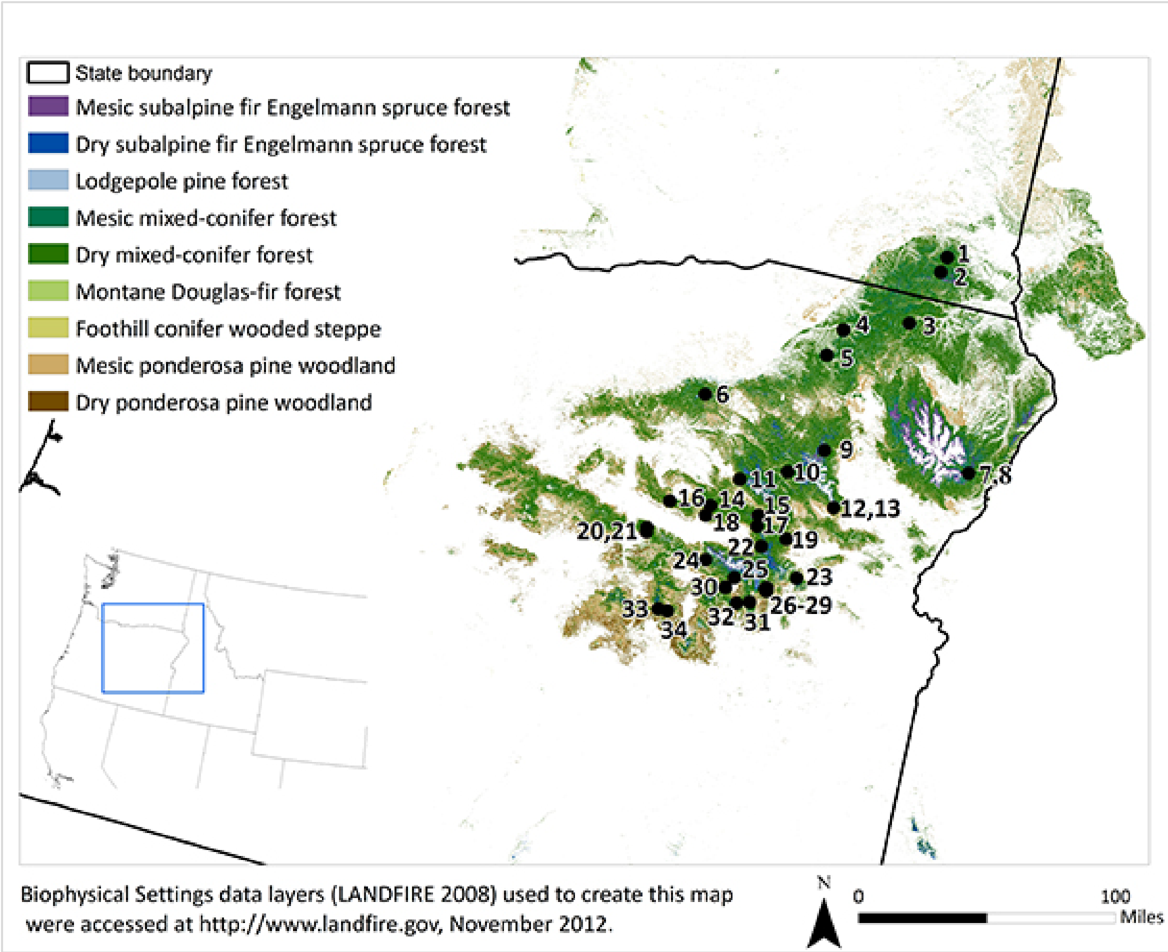

Figure 3—Locations of fire history studies from table A3. Land cover distribution of Blue Mountain conifer communities is based on the LANDFIRE Biophysical Settings (BpS) data layer [35]. Click on the map for a larger image.

Fire frequency varies with topography [24, 32, 39] due to its influence on fuel moisture, forest structure, and forest type. Prior to fire exclusion variation in topography had a stronger effect on forest structure and composition than fire frequency in the Blue Mountains [32, 39]. Fires are less frequent on steep north and east aspects, where fuels are typically wetter than on south and west aspects. They are also less frequent on high-elevation, cold sites where snowmelt is delayed and where topographic features such as talus provide barriers to fire spread [24].

This synthesis compiles fire frequencies in the Blue Mountains from four studies on 34 sites [27, 32, 39, 51]. Fire scar data were collected from sites in dry forests, mesic mixed-conifer forests, and riparian forests. The shortest historical mean fire-return interval was 10 years and the longest was 49 years (table 1, table A3), with fires typically occurring at less than 20-year intervals (figure 4). Because mean fire-return intervals reported here were determined from fire scars, they apply to sites that burned with low to moderate severity. As of 2016, fire history studies were not available for lodgepole pine forests.

Table 1—Fire frequencies in the Blue Mountains compiled from fire scar studies and LANDFIRE models. Table A1 summarizes data generated by LANDFIRE succession modeling for the Biophysical Settings (BpS) covered in this synthesis. Table A3 details data compiled from fire scar studies.

Forest type	Mean fire-return interval (years)	Median fire-return interval (years)	LANDFIRE mean fire-return interval [35]	References
Dry forest (*n* = 23)	10-49	18	6-54	[27, 32, 39, 51]
Mesic mixed-conifer forest (*n* = 9)	10-25	17	19-71	[32, 39, 51]
Riparian forest (*n* = 2)	15-20	17	not available	[51]
Lodgepole pine forest	not available	not available	40	
Subalpine fir-Engelmann spruce forest	not available	not available	99-125	

Dry forests were predominately burned by surface fires at low severity to moderate severity in historical times [1, 23, 27]. Conditions capable of producing high-severity fires were limited and spatially isolated due to low tree density and clumped tree distribution maintained by the relatively frequent low- and moderate-severity fires [23]. Fire scars from 4 studies that span the Blue Mountains indicate that prior to fire exclusion, mean fire-return intervals in dry forests ranged from 10 to 49 years (table 1, table A3) [27, 32, 39, 51].

Fire occurrence in dry forests across the Inland Northwest, including the Blue Mountains, is influenced by large-scale climate patterns. In the Pacific Northwest, phases of El Niño–Southern Oscillation (ENSO) affect weather during the following year. After El Niño phases, winters and springs are warm and dry, resulting in anomalously shallow snow packs. The Pacific Decadal Oscillation (PDO) causes climate variation similar to El Niño, though its impact on weather varies on longer timescales [25]. From 1651 to 1900, more fires occurred when ENSO and PDO were both in the warm phase, and fewer occurred when they were both in the cool phase ($P = 0.02$). Independently, neither ENSO nor PDO had a strong impact on fire frequency in dry forests [26].

Mesic mixed-conifer forests historically experienced frequent low-severity fires [32, 39], and moderate- and high-severity fires (as determined by overstory mortality) at undetermined intervals [2, 27]. Fire scar data collected from sites throughout mesic mixed-conifer forests in the Blue Mountains indicate that prior to fire exclusion, the mean fire-return interval ranged from 10 to 25 years (table 1, table A3) [32, 39, 51]. Sites with high soil water availability had less frequent fire than drier sites ($P \leq 0.05$) [32, 39].

Of the four studies that examined fire history in mesic mixed-conifer forests, three [32, 39, 51] found evidence of frequent, low-severity fire from fire scars. However, Heyerdahl et al. [24, 27] did not find substantial evidence for frequent, low-severity fire in mesic mixed-conifer forests, though they sampled the most plots and the most trees, and used both fire scars and establishment dates of postfire cohorts to record evidence of fire. In their study, only a few plots in mesic mixed-conifer forests contained fire-scarred trees, while most had cohorts of early-seral trees. Different study findings may be due to differences in study site locations and sampling methods. Results from these four studies suggest mesic mixed-conifer forests experienced moderate- and high-severity fires as well as low-severity fires [24, 27] (see Fire Severity and Intensity).

Riparian forests are thought to have historically burned at similar frequencies as adjacent dry forests or mesic mixed-conifer forests. However, only one fire history study was available for riparian conifer forests in the Blue Mountains as of 2016. It found that a ponderosa pine/common snowberry riparian site downslope from dry ponderosa pine forest had a mean fire-return interval of 15 years. A grand fir/Rocky Mountain maple riparian site downslope from mesic grand fir forest had a mean fire-return interval of 20 years [51].

Lodgepole pine forests are thought to have historically had mixed-severity fires that varied across space and time from low-severity surface fires to high-severity surface and crown fires (review by [3]). An unpublished fire history study conducted in a lodgepole pine stand in the Elkhorn Mountains suggests that prior to fire exclusion, the mean fire-return interval ranged from 66 years to 200 years (Bork 1984, cited in [39]). As of 2016, additional fire studies were not available for lodgepole pine communities in the Blue Mountains.

Subalpine fir-Engelmann spruce forests apparently historically had mixed-severity surface and crown fires and long-interval stand-replacement crown fires ([24], reviews by [4, 21]), though the relative frequencies of these fire types is unknown. These forests occur at high elevations and on northern slopes and are composed of fire-sensitive species [31]. As part of a larger study throughout the Blue Mountains, Heyerdahl et al. [24, 27] measured cohorts of early-seral trees at three sites in subalpine fir-Engelmann spruce communities in the Blue Mountains. Two sites were located in the north and a third in the south. The two northern sites had more than one cohort in 33% and 52% of plots, suggesting these sites experienced moderate and severe fire [24, 27]. No postfire cohorts were found in the southern sites; however, early-seral trees were abundant in the south. The authors suggest that sites with abundant early-seral trees and without detectable cohorts experienced frequent moderate-severity fires, which made cohorts undetectable [24].

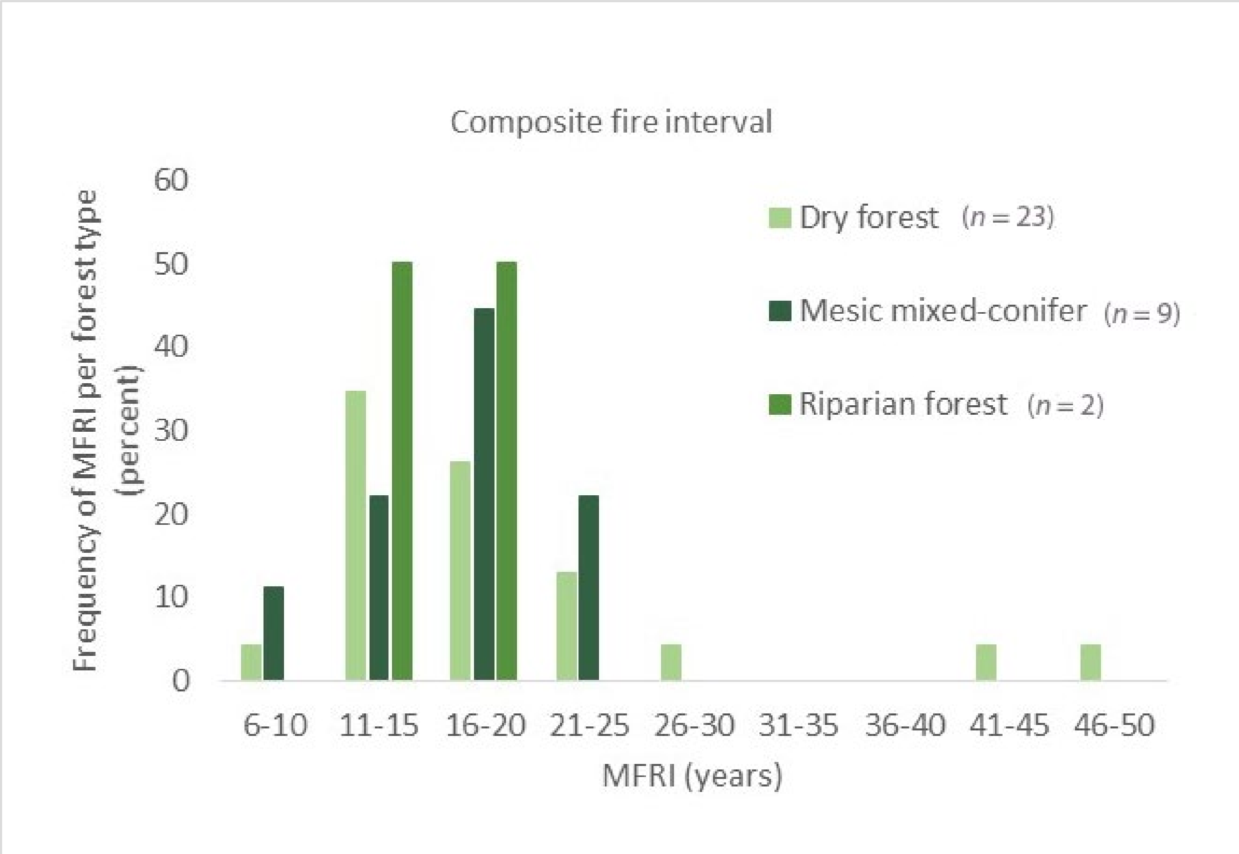

Figure 4—Frequency distribution of mean fire-return intervals (MFRIs) from 34 study sites across 3 of the forest types included in this synthesis [27, 32, 39, 51]. Results are based on composite fire intervals. Fire scar studies were not available for lodgepole pine or subalpine fir-Engelmann spruce forests. See table A3 for data and site details.

A paleoecology study within the Blue Mountains region at Blue Lake, Idaho, found that the frequency of fire events varied with climate and local vegetation (table 2). Evidence of fire events was recorded in microscopic charcoal deposits and graded lakebeds rich in charcoal. The author speculated that frequent low-severity fires probably burned the understories of forests surrounding Blue Lake. However, these fires did not deposit organic detritus, so they were not documented in this study. Conifer forests have persisted over the past 4,300 years at Blue Lake, though climate and fire have altered the forest composition during that time. Between 4,300 to 4,000 BP, a warm-moist climate supported an open Douglas-fir forest. Fire events occurred about every 100 years. From 4,000 to 3,100 years BP, Douglas-fir forest transitioned to mixed-conifer forest as the climate cooled. Fire events around 4,000 and 3,600 years BP produced thick beds of charcoal, indicating extensive erosion and potentially large fires. Between 3,100 to 1,700 years BP, the mixed-conifer forest remained dominant, though fire events were more than twice as frequent. The author speculated that this was due to drying climate conditions. From 1,700 to 1,000 years BP, the forest transitioned to open ponderosa pine as the climate warmed. On average, fire events occurred every 175 years. In the past 100 years, an open Douglas-fir forest has established around Blue Lake [57].

Table 2—Fire events indicated by peaks in charcoal deposition in Blue Lake, Idaho, during the late Holocene [57].

Time period (years BP)	Interval length (years)	Number of fire events	Forest type	Climate
4,300-4,000	300	5	open Douglas-fir	warm, potentially moist
4,000-3,100	900	2	mixed conifer	cool
3,100-1,700	1,400	5	mixed conifer	dry
1,700-100	700	4	open ponderosa pine	warm
100-present	100	0	open Douglas-fir	warm

Fire Severity and Intensity

Historically, forests of the Blue Mountains experienced predominantly low- and mixed-severity fires. In dry, mesic mixed-conifer, and subalpine fir-Engelmann spruce forests, individual fires tended to be of mixed severity, with areas of low severity (as inferred by fire scarred trees) adjacent to areas of moderate or high severity (as inferred by postfire cohorts) [24]. Agee [5] suggests that about 80% of the forest area was historically burned by low-severity fire, 15% was burned by moderate-severity fire, and 5% was burned by high-severity fire. However, models developed by Williams and Baker [64] from land surveys conducted in the 1880s suggest that 40% of the forested area within the Blue Mountains experienced mixed- and high-severity fires.

Fire severity varies by forest type throughout the Blue Mountains; dry forests tend to have mostly low-severity fire and mesic mixed-conifer and subalpine fir-Engelmann spruce forests mostly moderate- and high-severity fires. A fire history study on four watersheds across the Blue Mountains used fire scars and establishment dates of postfire cohorts to record evidence of low-, moderate-, and high-severity fire. Ponderosa pine dominated dry forests, including Douglas-fir and grand fir dry forest associations (table A3). Grand fir or subalpine fir dominated mesic forests. The study found that almost all plots with fire-scarred trees were in dry forests (98%) and 92% of trees in dry forest plots had fire scars, suggesting that these forests historically experienced low-severity fires. In contrast, 88% of plots with early-seral, postfire cohorts were in mesic mixed-conifer and subalpine fir-Engelmann spruce forests, and 96% of these forest plots had cohorts of early-seral trees, suggesting that mesic mixed-conifer and subalpine fir-Engelmann spruce forests experienced moderate- and high-severity fires [24].

Across the Blue Mountains, fire severity varies among and within watersheds, suggesting that both regional climate and local topography affect the severity and extent of fire. In the northern Blue Mountains, fire severity varies with aspect; moderate-severity fires predominantly occur on north-facing slopes (80%-93%) and low-severity fires on south-facing slopes (86%). In the southern Blue Mountains, fires severity varies with aspect and elevation; low-severity fires predominantly (96%) occur at low elevation (<5,600 feet (1,700 m)), while moderate-severity fires (96%) occur at higher elevations [24].

Information was not available on historical fire intensity.

Fire Pattern and Size

Prior to fire exclusion around 1900, an average of approximately 425,000 acres (175,000 ha) of forested area burned annually; around 8.5% of the 5-million-acre (2-million-ha) Blue Mountain region [5, 16]. Fine fuels typically carried fires in dry forests and mesic mixed-conifer forests [5]. Because fine fuels gain and lose moisture rapidly, annual variation in fire size was affected by climate during the current, but not preceding years; moisture content of fine fuels did not persist from one season to the next [25].

Variation in fire size and pattern is influenced by climate in the Blue Mountains. ENSO and PDO influence fire pattern and size due to their influence on the current-year climate [25, 32]. A study evaluating annual variation in fire patterns found that large areas (>20% of sites sampled in a 46,700-acre (18,900-ha) study area) in dry forests burned during years of low precipitation and El Niño phases, while small areas (<20% of sites sampled) burned regardless of these climate parameters. Precipitation was lower during large fire years (>20% of the sample area burned) compared to years immediately before and after ($P < 0.05$) [25]. Decadal variation in fire size suggests that extent burned varies with precipitation, possibly due to weather patterns resulting from the PDO [25, 59]. In the southern Blue Mountains, El Niño phases were associated with large fire years, when multiple sites in dry forests and mesic mixed-conifer forests burned within a 1.7-million-acre (688,000-ha) study area. In addition, many fires burned during synchronous El Niño and positive PDO phases [32].

While precise fire sizes are not known for the historical period, fire scar and tree cohort dates throughout the Blue Mountains indicate that from 1687 to 1900, fires in dry, mesic mixed-conifer, and subalpine fir-Engelmann spruce forests often (60%) burned areas larger than 600 acres (250 ha), though most fires did not exceed 1,000 acres (400 ha) [24]. Most recorded fires (73%) burned more than 1 plot/60 acres (20 ha), suggesting that many fires were at least moderate in size. However, fire-scar studies often do not detect small fires [8, 12], and small fires likely occurred. A fire history study in the southern Blue Mountains found that from 1760 to 1890 in an “average fire year”, fires burned approximately 25% of study sites in dry forests and mesic mixed-conifer forests [32].

The following FEIS publications cover fire regimes of conifer forest ecosystems in regions adjacent to the Blue Mountains:

- Pacific Northwest subalpine mixed conifer
- Eastern Cascades mixed conifer
- Northern Rocky Mountain ponderosa pine
- Northern Rocky Mountains montane mixed conifer

CONTEMPORARY CHANGES IN STAND STRUCTURE, FUELS, AND FIRE REGIMES

Contemporary Changes in Stand Structure, Composition, and Fuels

Fire exclusion has altered forest composition and structure, resulting in increased fuel loads [31, 44]. Dry forests and mesic mixed-conifer forests have become denser due to fire exclusion, with shade-tolerant conifers such as Douglas-fir and grand fir creating ladder fuels [5, 44]. Additionally, litter and duff have accumulated beneath tree canopies [45]. As a result, mature trees are more susceptible to basal injuries to their cambium layer due to smoldering fires [55]. Deep-rooted trees, such as ponderosa pine, Douglas-fir, and western larch, have fine surface roots that are susceptible to injury during ground fires [31]. Increased duff accumulation and fire severity pose increased risks of tree mortality due to prolonged lethal temperatures to tree boles and fine roots at shallow depths [5, 31].

Since fire exclusion, basal area—especially that of shade-tolerant trees—has increased throughout the Blue Mountains. Between 1860 and 2010, basal area increased by 548% in dry forests and mesic mixed-conifer forest in the southern Blue Mountains. Basal area increased for all conifer species except western larch, a fire tolerant and shade-intolerant species, which declined by almost 60% from 5.53 ft^2/acre (1.27 m^2/ha) in 1860 to 2.40 ft^2/acre (0.55 m^2/ha) in 2010. In contrast, basal area of grand fir, a fire intolerant and shade-tolerant species, increased by 2,000% from 2.35 ft^2/acre (0.54 m^2/ha) in 1860 to 57.5 ft^2/acre (13.2 m^2/ha) in 2010 [32]. Tree species composition and density in mesic mixed-conifer forests have departed substantially from historical conditions, with shade-tolerant species becoming forest dominants. Within dry forests, the ponderosa pine series continues to be dominated by ponderosa pine, though stand density has increased. Douglas-fir and ponderosa pine codominate the Douglas-fir series, but stand density has increased and Douglas-fir now dominates the understory [44].

Due to contemporary land uses, forests in the Blue Mountains have less old growth and are younger and denser than they were historically. Tree establishment was rapid from the 1880s to 1910s, when moist growing conditions coincided with livestock grazing. Grazing reduced herbaceous vegetation and exposed mineral soil, which resulted in increased seedling establishment of conifers [30, 44]. Although fire suppression was largely ineffective until the 1940s, this time period coincided with a sudden decrease in fire frequency and extent [24]. In the Ochoco Mountains, approximately 87% of trees present in a 2012 survey established after 1890. Conifer establishment rapidly decreased around 1930 across forest types, which the authors attributed to a dense stand structure that limited further conifer establishment [44]. Changes in stand structure and age in the Blue Mountains were evaluated by comparing aerial photos from 1932 to 1966 to photos from 1981 to 1993. In the latter period, stand initiation and open-canopy forests decreased—potentially due to fire exclusion—while old growth declined due to extensive logging. In contrast, multistory, young forest cover increased ($P \leq 0.2$ for all variables) [21].

Invasive annual grasses have replaced perennial bunchgrasses in many conifer stands. This shift is due, in part, from livestock overgrazing [5, 24]. Nonnative, invasive annual grasses, including cheatgrass and ventenata, have established and spread across dry forests in the Blue Mountains [7, 31, 65]. These nonnative grasses outcompete native bunchgrasses for soil moisture and nutrients [11, 29].

Contemporary Changes in Fire Regimes

Overgrazing, fire exclusion, logging, and nonnative annual grasses have impacted fire regimes in the Blue Mountains [5, 23, 24]. Livestock grazing, which began in the mid-1800s, reduced the abundance and continuity of herbaceous fine fuels that had previously carried surface fires across the landscape [22, 30]. By the early 1900s fires had become less frequent due to overgrazing, and this pattern continued with the advent of effective fire suppression in the 1940s [27]. Fire exclusion reduced the area of forest that burns annually from an estimated 425,000 acres (175,000 ha) prior to fire exclusion to an average of 99,000 acres (40,000 ha) from 1986 to 1992 [5]. From 1900 to 2000 only a few small fires were recorded [24]. On the Malheur National Forest, a wildfire in 1910 burned approximately 14% of the forest. The next two largest fires (in 2001 and 2007) each burned less than 9% of the forest [32]. From the 1920s through the 1980s, extensive high-grade logging and clearcutting removed large, fire-tolerant trees (Douglas-fir, ponderosa pine, and western larch) from forests across the Inland Northwest [22]. Removal of canopy dominants and fire exclusion enabled shade-tolerant, fire-intolerant conifer species to proliferate [23] and led to development of even-aged, dense forests that can sustain stand-replacement fires [21]. In addition, the establishment of nonnative grasses such as bulbous bluegrass, cheatgrass, and ventenata has increased fine fuel continuity [5, 11]. Because annual grasses such as cheatgrass and ventenata dry out earlier than perennial grasses [5, 11], fine fuels are available earlier in the growing season [11]. In forests of the Intermountain West, areas where nonnative annual grasses dominate the ground layer often have longer fire seasons, increased fire sizes, and increased rates of spread than areas where native perennial grasses dominate the ground layer [11]. On the Ochoco National Forest, for example, ventenata contributed to fuel continuity and fire spread during the 2015 Corner Creek Fire. Firefighters witnessed rapid fire spread from ventenata-infested scablands into ponderosa pine woodlands (Hallmark 2016 personal communication [17]). Denser forest structure and changes in plant species composition may increase fire severity and alter successional pathways of forests in the Blue Mountains [5, 16, 21, 31].

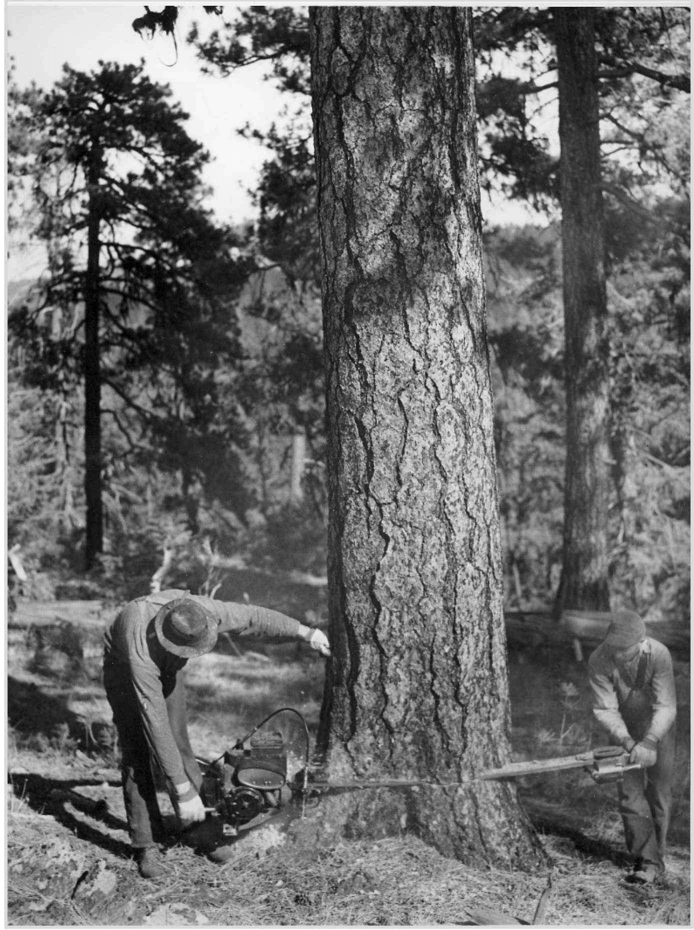

Figure 5—Logging a large, fire-resistant ponderosa pine on the Umatilla National Forest. U.S. Forest Service photo by Kenneth Brown.

Dense forests with abundant shade-tolerant trees may be susceptible to a variety of insect pests and drought mortality, and they may experience more severe fires [15, 62] than open forests dominated by shade-intolerant trees. Over the past century, the Blue Mountains have experienced periodic and extensive insect outbreaks [18]. As forest composition transitioned to more shade-tolerant species, the variety of forest pests increased [61]. The area impacted by native insect pests in the Blue Mountains exceeds the area impacted by contemporary wildfire [43].

Table 3—Insect pests and forest area impacted in the Blue Mountains [18].

Forest pest	Area affected	Time period
Douglas-fir tussock moth	630,000 acres (250,000 ha)	1971-1975
Mountain pine beetle	650,000 acres (263,000 ha)	1955-1966
Western spruce budworm	900,000 acres (360,000 ha)	1944-1958
Western pine beetle	9,900-86,500 acres (4,000-35,000 ha)	1953-1980

While large areas of forest have been impacted by insects in the Blue Mountains, the likelihood of wildfire has not been found to consistently increase or decrease following insect outbreaks [13, 42]. From 1970 to 2012 across the inland Pacific Northwest, forest fire severity was reduced for at least 20 years following insect outbreaks. Insect-induced tree mortality creates heterogeneity by altering forest structure [13]. Vertical and horizontal fuel distributions shift after insect outbreaks as trees defoliate, die, and transition from canopy to surface fuels [43]. By reducing subsequent fire severity, insect outbreaks may buffer rather than intensify fire regime changes that may occur due to climate change, drought, and invasive plants [38, 43].

Climate Change

Predicted Forest Communities

Predicted increases in temperature and subsequent changes in available soil moisture may alter forest composition and structure [56]. In the Blue Mountains, mean annual temperature increased by 0.11˚F (0.06 ˚C) each decade from 1895 to 2013, which is consistent with the temperature trend of the Pacific Northwest (NOAA National Centers for Environmental Information 2015, cited in [18]). Warming temperatures lead to decreases in snowpack and increases in evapotranspiration, which are expected to increase the frequency and severity of drought stress [10]. Low-elevation forests in the Blue Mountains that are moisture limited may be particularly vulnerable to drought stress [10, 37], which may make these forests more vulnerable to wildfire, insect, and disease outbreaks. Some models indicate that the abundance of ponderosa pine may decline if water stress increases as the climate warms. In contrast, paleoecological evidence indicates ponderosa pine persisted across the western United States by migrating north or up in elevation during previous climate warming. Predictive models and paleoecological evidence suggest climate change may cause moderate to extreme loss of mesic mixed-conifer forest in the Blue Mountains, though results from a dynamic global vegetation model results suggest the opposite. Future warming with increased precipitation may lead to expansion of mesic mixed-conifer forests into subalpine forest communities in the Blue Mountains [34].

Model and autecological assessments suggest climate change could substantially alter establishment, growth, phenology, and persistence of subalpine forests in the Blue Mountains [34]. Subalpine forests may shift or increase their distribution by advancing into alpine communities due to warmer temperatures, reduced snowpack, and longer growing seasons [41]. However, data from a long-term global analysis revealed that over the last century, only half of subalpine forest sites showed evidence of treeline advancement into alpine sites [19]. Predictions about future forest conditions are conflicting, though there is strong consensus from global climate models that temperatures in the Pacific Northwest will be warmer in the near future [18].

Predicted Fire Regime

Greenhouse gases, which contribute to climate warming, are predicted to increase cloud-to-ground lightning strikes in the United States [54]. Fire frequency could increase with predicted increases in lightning strikes across the Blue Mountains if climate conditions remain conducive to fire ignition and spread [25].

Decreasing snow cover in the Blue Mountains may increase the length of the fire season and the potential for larger fires [25]. Mean annual precipitation in the Blue Mountains is low, and most falls during the winter as snow [24]. Historically, snowmelt at the beginning of each fire season yielded high soil and fuel moistures, so low fuel moistures from the previous year did not persist into the next year. If predicted warming results in watersheds not accumulating much snow over winter, below-average precipitation levels from preceding years may increase the potential for fire in a subsequent year [25]. By the 2040s, mountain basins in the Pacific Northwest are projected to transition from snow-dominant to mixed rain- and snow-dominant basins in response to warming. Analyses suggest vulnerability to warming temperatures and subsequent loss of snowpack is relatively high throughout the Strawberry Mountains, Monument Rock Wilderness, and Wenaha-Tucannon Wilderness; and at midelevations in the North Fork John Day, Eagle Cap, and Hells Canyon wildernesses. Snowpack may be retained longer at high elevations in the Wallowa Mountains, Greenhorn Mountains, and Hells Canyon Wilderness. However, snowpack loss may still be substantial, with 40% to 100% loss predicted in portions of these areas [18].

Models developed to evaluate change in vegetation composition and fuel loads across the western United States, including modeled points located in the Blue Mountains, indicate fire severity and frequency may increase in future decades [38, 52]. Increased fire severity may occur due to higher fuel loads and lengthening fire seasons, with fire danger becoming more extreme [33]. However, by the mid-21st century, more frequent fire may lead to lower fire severities for large portions of the western United States [38, 52]. This is attributed to high water deficits that result in low plant productivity and consequently, less burnable biomass [52]. The authors of these studies suggest that improving landscape resilience under a changing climate may require increased use of wildland fire [50, 52].

Restoration Efforts

As of 2006, approximately 11.6 million acres (4.7 million ha) of Forest Service, U.S. Department of Agriculture lands across Oregon and Washington—roughly 40% of all coniferous forests—required reductions in stand density to restore forest structure to a natural range of variability at the landscape scale [20]. From 2003 to 2013, the Forest Service annually treated approximately 30,000 acres (12,000 ha) of hazardous fuels in Oregon and Washington (USFS, Pacific Northwest Region, unpublished data cited in [20]). If these treatments are additive and address restoration needs, at the current pace it will take over 50 years to meet identified needs on Forest Service lands. The Pacific Northwest Region is increasing the rate of restoration treatments, notably in the Blue Mountains [20].

Efforts are underway to improve forest resilience by mechanically thinning stands and reintroducing fire to the landscape to restore historical stand structure [60]. The Fire and Fire Surrogates Study evaluated the impacts of fire and thinning on forest ecosystem structure and function in dry forests and mesic mixed-conifer forests of the Wallowa Mountains by evaluating the following treatments:

thin – a single entry thin from below
burn – a single underburn
thin + burn – a single entry thin from below followed by an underburn
control – untreated [65].

Thin + burn was the only treatment that reduced total basal area to the target level of 70 feet^2/acre (16 m^2/ha). It yielded multiple age classes of ponderosa pine and Douglas-fir trees and stand densities below the threshold where serious mortality from bark beetles would be expected [65]. Though all treatments opened stands and altered tree species composition, none—including the thin + burn treatment—restored the stands to historical conditions. The authors suggested that repeated thin + burn treatments are needed at 10- to 15-year intervals to bring stand structure and composition more in line with historical conditions. They commented that one set of treatments is not likely to mitigate nearly 80 years of fire exclusion and fuel accumulation in low-elevation, dry forests [66]. For additional details, see FEIS's Research Project Summary of the Youngblood et al. [65, 66] studies.

Figure 6—Prescribed burning on the Umatilla National Forest. U.S. Forest Service photo.

Reintroducing fire into forested areas of the Blue Mountains at intervals similar to historical intervals may improve forest community resilience to wildfire and insect infestations [48, 66]. The impact of repeated prescribed burning on target retention trees was evaluated in dry forests of the southern Blue Mountains. Spring and fall prescribed burning was conducted and then replicated 5 years later. There were no significant differences in ponderosa pine mortality after the first and second prescribed fires due to fire season, repeat burning, or their interacting effects ($P > 0.05$) [58].

Successfully implementing forest restoration treatments requires careful consideration of challenging ecological conditions [9, 23]. Prioritization is needed due to limited funds and the extensive area in need of treatment [6]. Treatments are often focused on landscapes that historically experienced predominately low-severity surface fires, such as dry forests [22, 23]. However, in the southern Blue Mountains, mesic mixed-conifer forests have experienced the same or greater change in forest structure and composition as dry forests ($P \leq 0.02$) [32]. This suggests that in addition to targeting dry forests for restoration treatments, mesic mixed-conifer forests with high tree densities and altered species composition could also be targeted for restoration treatments [32, 44].

LIMITATIONS OF INFORMATION

As of 2016, quantitative information on historical fire regimes and stand structure in lodgepole pine forests in the Blue Mountains was not available, and only limited information was available for subalpine fir-Engelmann spruce forests.

APPENDICES

- Table A1: Summary of fire regime information for Biophysical Settings covered in this synthesis
- Table A2: Common and scientific names of plant species and links to FEIS Species Reviews
- Table A3: Summary of fire frequencies for fire history studies

Table A3—Site characteristics and fire history data for plant communities included in this synthesis. Mean fire-return intervals (MFRI) were derived from composite fire intervals.

Dry forest

Map # from figure 3	Site name and National Forest	Plant communities (BpS series)	MFRI (range)	MFRI (range of LANDFIRE models)	Elevation (feet)	Period studied	# trees sampled/site	Reference
2	Tucannon, Umatilla NF	Douglas-fir/pinegrass[a] (10531, 10532, 11650)	29[b] (12-56)	6-54	3,200-6,000	1687-1900	357	[27]
5	Spring Mountain, Umatilla NF	Douglas-fir/elk sedge (10531, 10532, 11650)	30.8 (14-68)	6-54	3,510	1640-1900	50	[39]
6	Five Mile Creek, Umatilla NF	Douglas-fir/pinegrass (10531, 10532, 11650)	9.9 (3-20)	6-54	4,000	1640-1900	50	[39]
8	Imnaha, Wallowa-Whitman NF	Douglas-fir/pinegrass[c] (10531, 10532, 11650)	25[b] (12-55)	6-54	4,200-6,220	1687-1900	357	[27]
9	Anthony Burn, Wallowa-Whitman NF	grand fir/elk sedge (10450, 10470, 11660)	16 (4-28)	19-71	6,000	1640-1900	50	[39]
10	Spaulding Gulch, Wallowa-Whitman NF	grand fir/pinegrass[c] (10450, 10470, 11660)	24 (16-48)	19-71	5,300	1640-1900	50	[39]

[a]Most common association is listed in table. Site also included Douglas-fir/elk sedge, grand fir/pinegrass, ponderosa pine/elk sedge, ponderosa pine/pinegrass associations.
[b]Site MFRI was calculated from plot MFRI provided in [27].
[c]Most common association is listed in table. Site also included Douglas-fir/elk sedge, grand fir/pinegrass, and ponderosa pine/pinegrass associations.

Dry forest

Map #	Site name and National Forest	Plant communities (BpS series)	MFRI (range)	MFRI (range of LANDFIRE models)	Elevation (feet)	Period studied	# trees sampled/site	Reference
12	Baker, Wallowa-Whitman NF	Douglas-fir/pinegrass[d] (10531, 10532, 11650)	11[e] (9-38)	6-54	4,360-7,620	1687-1900	357	[27]
13	Baker, Wallowa-Whitman NF	Douglas-fir/pinegrass (10531, 10532, 11650)	11 (9-38)	6-54	2,000-5,700	1650-1900	168	[27]
17	Dixie Butte, Malheur NF	grand fir/elk sedge (10450, 10470, 11660)	49 (42-57)	19-71	5,250	1640-1900	50	[39]
18	Thompson, Malheur NF	ponderosa pine/blue wildrye (10531, 10532, 11650)	14.9	6-54	4,100	1760-1890	135	[32]
20	Reynolds, Malheur NF	grand fir/elk sedge (10450, 10470, 11660)	18	19-71	5,200	1760-1890	135	[32]
21	Widow's Creek, Malheur NF	Douglas-fir/elk sedge (10531, 10532, 11650)	11 (4-37)	6-54	5,000	1640-1900	50	[39]
22	Dry Cabin, Malheur NF	grand fir/elk sedge (10450, 10470, 11660)	19.2	19-71	5,850	1760-1890	135	[32]

[d]Most common association is listed in table. Site also included Douglas-fir/elk sedge, grand fir/elk sedge, grand fir/pinegrass, ponderosa pine/elk sedge, ponderosa pine/Idaho fescue associations.
[e]Site MFRI was calculated from plot MFRI provided in [27].

Dry forest

Map #	Site name and National Forest	Plant communities (BpS series)	MFRI (range)	MFRI (range of LANDFIRE models)	Elevation (feet)	Period studied	# trees sampled/site	Reference
23	East Camp Creek, Wallowa-Whitman NF	grand fir/pinegrass (10450, 10470, 11660)	43.2 (9-119)	19-71	6,000	1640-1900	50	[39]
24	Canyon, Malheur NF	grand fir/elk sedge (10450, 10470, 11660)	18.3	19-71	5,070	1760-1890	135	[32]
25	Lake, Malheur NF	grand fir/elk sedge (10450, 10470, 11660)	18.4	19-71	5,310	1760-1890	135	[32]
26	Stink, Malheur NF	Douglas-fir/pinegrass (10531, 10532, 11650)	13.1	6-54	5,080	1760-1890	135	[32]
27	North Fork, Malheur NF	ponderosa pine/pinegrass (10531, 10532, 11650)	10.6	6-54	4,890	1760-1890	135	[32]
28	Dugout, Malheur NF	Douglas-fir/pinegrass[f] (10531, 10532, 11650)	13[g] (9-32)	6-54	4,600-5,960	1687-1900	357	[27]

[f]Most common association is listed in table. Site also included Douglas-fir/elk sedge, grand fir/elk sedge, grand fir/pinegrass, ponderosa pine/elk sedge, ponderosa pine/pinegrass associations.
[g]Site MFRI was calculated from plot MFRI provided in [27].

Dry forest

Map #	Site name and National Forest	Plant communities (BpS series)	MFRI (range)	MFRI (range of LANDFIRE models)	Elevation (feet)	Period studied	# trees sampled/site	Reference
29	Dugout, Malheur NF	Douglas-fir/pinegrass (10531, 10532, 11650)	13 (9-32)	6-54	2,000-5,770	1650-1900	168	[27]
30	Little Bear Burn, Malheur NF	grand fir/pinegrass (10450, 10470, 11660)	17.8 (5-35)	19-71	5,000	1640-1900	50	[39]
31	Crane, Malheur NF	grand fir/pinegrass (10450, 10470, 11660)	24	19-71	6,110	1760-1890	135	[32]
32	Malheur, Malheur NF	Douglas-fir/pinegrass (10531, 10532, 11650)	11	6-54	4,910	1760-1890	135	[32]
33	West Myrtle Creek, Malheur NF	grand fir/pinegrass (10450, 10470, 11660)	15.3 (5-23)	19-71	6,000	1640-1900	50	[39]
34	Myrtle, Malheur NF	ponderosa pine/elk sedge (10531, 10532, 11650)	10.7	6-54	5,380	1760-1890	135	[32]

Mesic mixed-conifer forest

Map #	Site name and National Forest	Plant communities (BpS series)	MFRI (range)	MFRI (range of LANDFIRE models)	Elevation (feet)	Period studied	# trees sampled/site	Reference
1	Smoothing Iron Ridge, Wallowa-Whitman NF	grand fir/twinflower (10450, 10470, 11660)	10.6 (3-29)	19-71	5,000	1640-1900	50	[39]
3	Troy, Umatilla NF	grand fir/white spirea (10450, 10470, 11660)	19.4 (5-36)	19-71	4,985	1640-1900	50	[39]
4	Finley Sale Area, Umatilla NF	grand fir/white spirea (10450, 10470, 11660)	24.8 (9-39)	19-71	4,000	1640-1900	50	[39]
7	Imnaha, Wallowa-Whitman NF	grand fir/thinleaf huckleberry (10450, 10470, 11660)	9.9 (2-29)	19-71	4,200	1640-1900	50	[39]
11	Mosquito, Malheur NF	grand fir/twinflower (10450, 10470, 11660)	18	19-71	4,500	1760-1890	135	[32]
14	Deerborn, Malheur NF	grand fir/twinflower (10450, 10470, 11660)	21.2	19-71	4,800	1760-1890	135	[32]

Mesic mixed-conifer forest

Map #	Site name and National Forest	Plant communities (BpS series)	MFRI (range)	MFRI (range of LANDFIRE models)	Elevation (feet)	Period studied	# trees sampled/site	Reference
15	Jugow, Malheur NF	grand fir/twinflower (10450, 10470, 11660)	11.8	19-71	5,700	1760-1890	135	[32]
16	Raddue, Malheur NF	grand fir/grouse whortleberry (10450, 10470, 11660)	15.7 (4-53)	19-71	5,000	1640-1900	50	[32]
19	Seed Orchard, Wallowa-Whitman NF	grand fir/white spirea (10450, 10470, 11660)	17 (7-34)	19-71	4,300	1640-1900	50	[32]

Riparian forest

Map #	Site name and National Forest	Plant communities (BpS series)	MFRI (range)	MFRI (range of LANDFIRE models)	Elevation (feet)	Period studied	# trees sampled/site	Reference
13	Baker, Wallowa-Whitman NF	grand fir/Rocky Mountain maple (no associated riparian BpS)	20 (13-36)	N/A	2,000- 5,700	1650-1900	168	[51]
29	Dugout, Malheur NF	ponderosa pine/common snowberry (no associated riparian Bps)	14.5 (13-36)	N/A	2,000- 5770	1650-1900	168	[51]

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