WHITE PAPER

USDA Forest Service | Pacific Northwest Region | Umatilla National Forest

White Paper F14-SO-WP-Silv-06 **June 2011**

Fire Regimes of the Blue Mountains

David C. Powell; Forest Silviculturist
Supervisor's Office; Pendleton, OR

Initial Version: **MAY 2005**

1. Selected characteristics for historical fire regimes of the Blue Mountains.

	HISTORICAL FIRE REGIMES *			
Fire Regime Characteristic	**I**	**II**	**III**	**IV**
Fire return interval (mean; in years)[1]	< 25	< 35	35-100+	35-100+
FRCC: fire frequency interval[2]	0-35 years	0-35 years	35-200 yrs	35-200 years
Fire severity on upper canopy layer[3]	Low	Replacement	Mixed	Replacement
Upper canopy layer mortality[3]	≤ 25%	> 75%	26-75%	> 75%
FRCC: fire severity name[2]	Low/Mixed	Replacement	Mixed/Low	Replacement
Fire intensity adjective[4]	Low	Low-Moderate	Moderate-High	High
Fireline intensity (flame length; feet)[5]	< 3	< 3	3-10	> 10
Fuel component driving fire spread[4]	Surface	Surface	Surface/canopy	Canopy
Ecosystem example[4]	Ponderosa pine	Grassland/ shrub	Mixed-conifer forest	Subalpine forest
Historical burned area (percent)[6]	75	5	15	5
Estimated fire size (acres)[7]	1-3,000	Unknown	1-10,000	1-5,000
Measured fire size (acres)[8]	2,950	Unknown	900	Unknown
Fire size variability (acres; min-max)[9]	50-19,960	Unknown	250-1,940	Unknown
Fire timing (seasonality)[10]	Summer and fall	Spring and summer	Summer and fall	Summer and fall

* **Historical fire regime** is a characterization of the historical combination of fire frequency and severity under which plant communities evolved and were maintained (Schmidt et al. 2002). Five fire regimes are currently recognized (Barrett et al. 2010):
Fire regime I: 0- to 35-year fire frequency; low or mixed fire severity on upper canopy layer vegetation.
Fire regime II: 0- to 35-year fire frequency; replacement fire severity on upper canopy layer vegetation.

Fire regime III: 35- to 200-year fire frequency; mixed or low fire severity on upper canopy layer vegetation.
Fire regime IV: 35- to 200-year fire frequency; replacement fire severity on upper canopy layer vegetation.
Fire regime V: 200+ year fire frequency; replacement fire severity on upper canopy layer vegetation.
Note: no fire regime V is shown in the table because it is uncommon in the Blue Mountains.

[1] **Fire return interval** (years) is the frequency between successive fire events; table data is based on Hall (1976), Heyerdahl and Agee (1996), Maruoka (1994), and Schmidt et al. (2002).

[2] **FRCC** (fire regime condition class) is a process for evaluating whether current conditions have departed from historical reference conditions and, if so, the magnitude of the departure; the FRCC frequency and severity names, by fire regime group, are taken from Barrett et al. (2010).

[3] **Fire severity on upper canopy layer** is the effect of fire on dominant plants: no more than 25% of upper canopy layer plants are killed by low-severity fire, whereas 75% or more are killed by high-severity fire; moderate-severity fires have survival percentages between these extremes (the 25% and 75% mortality thresholds were established by FRCC; see Barrett et al. 2010, page 99).

[4] **Fire intensity, fuel component,** and **ecosystem example** were taken from Keeley et al. 2009 (table 1).

[5] **Fireline intensity** refers to the energy release rate of a fire. Since intensity is generally proportional to flame length, fireline intensity is frequently expressed as a flame length, in feet. Table data were taken from Agee (1996).

[6] **Historical burned area** is an estimate of annual burned area (percent) for the Blue Mountains area prior to Euro-American settlement (defined as pre-1850); table data were adapted from Agee (1996).

[7] **Estimated fire size** provides an indication of average wildfire extent (in acres) for the Blue Mountains, as derived using an expert panel approach and involving 50 employees from the Malheur, Umatilla, and Wallowa-Whitman National Forests (Johnson 1993).

[8] **Measured fire size** provides an indication of average wildfire extent (in acres) from a Blue Mountains fire history study (Heyerdahl and Agee 1996, Heyerdahl 1997); the appendix provides a detailed listing of fire size (acres) and fire-free interval (years) for the four Blue Mountain areas sampled for this study.

[9] **Fire size variability** shows how historical wildfire extent varied (in acres) from a Blue Mountains fire history study (Heyerdahl and Agee 1996, Heyerdahl 1997); the appendix provides a detailed listing of fire size (acres) and fire-free interval (years) for the four Blue Mountain areas sampled for this study. Note that the fire size variability characteristic might have been influenced by the number of fires sampled (fire regime 1 included 210 fires, but fire regime 3 included only 8 fires), and because the mapped fire extent was truncated at the study area boundary for some of the sampled fires.

[10] **Fire timing** refers to the typical season of wildland fire. Table data were taken from Agee (1996).

2. Literature cited in section 1.

Agee, J.K. 1996. Fire in the Blue Mountains: a history, ecology, and research agenda. In: Jaindl, R.G.; Quigley, T.M., eds. Search for a solution: sustaining the land, people, and economy of the Blue Mountains. Washington, DC: American Forests in cooperation with the Blue Mountains Natural Resources Institute: 119-145.

Barrett, S.; Havlina, D.; Jones, J.; Hann, W.; Frame, C.; Hamilton, D.; Schon, K.; Demeo, T.; Hutter, L.; and Menakis, J. 2010. Interagency Fire Regime Condition Class Guidebook. Version 3.0 [Homepage of the Interagency Fire Regime Condition Class website, USDA Forest Service, US Department of the Interior, and The Nature Conservancy]. [Online], Available: **www.frcc.gov.**

Hall, F.C. 1976. Fire and vegetation in the Blue Mountains – implications for land managers. In: Komarek, E.V. Sr., chair. Proceedings of the annual Tall Timbers fire ecology conference No. 15. Tallahassee, FL: Tall Timbers Research Station: 155-170.

Heyerdahl, E.K. 1997. Spatial and temporal variation in historical fire regimes of the Blue Mountains, Oregon and Washington: the influence of climate. Ph.D. dissertation. Seattle, WA: University of Washington, College of Forest Resources. 224 p.

Heyerdahl, E.K.; Agee, J.K. 1996. Historical fire regimes of four sites in the Blue Mountains, Oregon and Washington. Final Rep. Seattle, WA: University of Washington, College of Forest Resources. 173 p.

Johnson, C.G. 1993 (August 9). Ecosystem screens; file designation 2060 memorandum to Wallowa-Whitman, Umatilla, and Malheur Forest Supervisors. Baker City, OR: USDA Forest Service, Pacific Northwest Region, Wallowa-Whitman National Forest. 4 p (and 6 exhibits). On file with: Umatilla National Forest, 2517 SW Hailey Avenue, Pendleton, OR 97801.

Keeley, J.E.; Aplet, G.H.; Christensen, N.L.; Conard, S.G.; Johnson, E.A.; Omi, P.N.; Peterson, D.L.; Swetnam, T.W. 2009. Ecological foundations for fire management in North American forest and shrubland ecosystems. Gen. Tech. Rep. PNW-GTR-779. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 92 p.

Maruoka, K.R. 1994. Fire history of *Pseudotsuga menziesii* and *Abies grandis* stands in the Blue Mountains of Oregon and Washington. M.S. thesis. Seattle, WA: University of Washington. 73 p.

Schmidt, K.M.; Menakis, J.P.; Hardy, C.C.; Hann, W.J.; Bunnell, D.L. 2002. Development of coarse-scale spatial data for wildland fire and fuel management. Gen. Tech. Rep. RMRS-GTR-87. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station. 41 p (and CD).

3. Selected fire and fuels references for the Blue Mountains.

Agee, J.K. 1993. Fire ecology of Pacific Northwest forests. Washington, DC: Island Press. 493 p. isbn:1-55963-229-1

Summary: It was once widely believed that landscapes become increasingly stable over time until eventually reaching a "climax state" of complete stability. In recent years, however, this idea has been challenged by a new understanding of the importance and inevitability of forces such as storms and fires that keep ecosystems in a state of constant change. The dynamics of fire ecology has emerged as a central feature of the new understanding as scientists and land managers redefine traditional assumptions about the growth and development of ecosystems. Fire Ecology of Pacific Northwest Forests is a historical, analytical, and ecological approach to the effects and use of fire in Pacific Northwest wildlands. James K. Agee, a leading expert in the field of fire ecology, analyzes the ecological role of fire in the creation and maintenance of natural forests common to most of the western United States. In addition to examining fire from an ecological perspective, he provides insight into its historical and cultural aspects, and also touches on some of the political issues that influence the use and control of fire in the United States. In addition to serving as a sourcebook for natural area managers interested in restoring or maintaining fire regimes in Pacific Northwest wildlands, this volume provides an essential base of knowledge for all others interested in wildland management who wish to understand the ecological effects of fire. Although the chapters on the ecology of specific forest zones focus on the Pacific Northwest, much of the book addresses issues not unique to that region.

Agee, J.K. 1996. Fire in the Blue Mountains: a history, ecology, and research agenda. In: Jaindl, R.G.; Quigley, T.M., eds. Search for a solution: sustaining the land, people, and economy of the Blue Mountains. Washington, DC: American Forests in cooperation with the Blue Mountains Natural Resources Institute: 119-145.

Summary (from Introduction to book chapter): fire has been an important disturbance process for millennia in the wildlands of the Blue Mountains of northeastern Oregon and southeastern Washington. Records from early explorers and on many older trees suggest that fires burned at frequent intervals in many Blue Mountain forests and grasslands. Fire has been described as both “benign” and “catastrophic” in the Blue Mountains and elsewhere. To make such judgments requires an understanding of how fire interacts with wildlands, and whether this interaction is desirable or not. This chapter focuses on fire history and effects, with discussion of changes over the past century or more. Fire has been variable in both space and time: low to high intensity, frequent to infrequent, and of small to large extent.

Agee, J.K. 1998. The landscape ecology of western forest fire regimes. Northwest Science. 72(special issue): 24-34.

Abstract: Fire has had a major role in shaping the forested landscapes of the American West. In recent decades, major efforts to quantify that role have been made, and characteristics of historic fire regimes have been defined: frequency, magnitude, variability, seasonality, synergism, and extent. Together, these characteristics also defined the historic landscape effects of fire in low-, moderate-, and high-severity fire regimes. Coarse-filter conservation strategies typically rely on knowledge of natural disturbance regimes to define appropriate forest structure goals, both at the stand and landscape scale, and these will differ by fire regime. Historic patch size increased across the low- to high-severity spectrum, but edge was maximized in the moderate-severity fire regime. Fire exclusion in the 20th century has caused two major types of landscape change: loss of openings in once patchy landscapes, and imposition of high-severity landscape dynamics in areas where wildfires that escape suppression now burn. Effects of historical fire regimes may be in some cases either difficult to mimic or undesirable.

Agee, J.K.; Maruoka, K.R. 1994. Historical fire regimes of the Blue Mountains. Tech Notes BMNRI-TN-1. La Grande, OR: USDA Forest Service, Blue Mountains Natural Resources Institute. 4 p.

Summary (no abstract provided with the note): Fire has been an important natural disturbance process in the Blue Mountains for millions of years. It has favored certain species over others, recycled nutrients, and had a large influence on the landscapes that were first described in writing by pioneers on the Oregon Trail. Fire, however, was not a constant presence on the landscape. It did not occur over entire summers of every year, and had quite variable effects in the different ecosystems found in the Blue Mountains. One way to describe this variability and understand the role of fire is through the concept of the fire regime. A fire regime is a generalized way of describing the characteristics and effects of fire on the environment. Rather than being forced to describe fire simply as either present or absent, the fire regime concept allows us to more specifically categorize fire and its effects. Several ways to define fire regimes have been developed. One system defines fire regimes on the basis of the historical character of the fires themselves: one category might be frequent, low-intensity fires, while another might be infrequent, high-intensity fires. A second fire regime system describes the interactions between fire and vegetation based on plant community descriptions. The effect of various frequencies and intensities of fire are then summarized within each forest type. A third system is based on the effects of fire on dominant plant species in the ecosystem. Impact categories of low, moderate, and high severity, defined by the degree of mortality, can be applied to describe the effects of fire in a particular ecosystem, such as ponderosa pine (*Pinus ponderosa*) or subalpine fir (*Abies lasiocarpa*) forests. An effective way to organize information about fire is to combine the second and third systems, and describe fire severity within specific plant communities. This report adopts this strategy to define the historical fire regimes of the Blue Mountains, supplemented by descriptions of the landscape by early travelers on the Oregon Trail.

Christensen, G.A.; Dunham, P.; Powell, D.C.; Hiserote, B. 2007. Forest resources of the Umatilla National Forest. Res. Bull. PNW-RB-253. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 38 p.

Abstract: Current resource statistics for the Umatilla National Forest, based on two separate inventories conducted in 1993–96 and in 1997–2002, are presented in this report. Currently on the Umatilla National

Forest, 89 percent of the land area is classified as forest land. The predominant forest type is grand fir (26 percent of forested acres) followed by the interior Douglas-fir (25 percent) and ponderosa pine (17 percent) types. The majority of net cubic foot wood volume (55 percent) comes from trees ranging in size from 11 to 23 inches diameter at breast height. The most commonly recorded cause of tree death was bark beetle (primarily *Dendroctonus* spp.) attack, with over half of the mortality volume attributed to these insects. [Note: this report also contains a wildfire risk assessment for the Umatilla National Forest on pages 28-30.]

Diaz-Avalos, C.; Peterson, D.L.; Alvarado, E.; Ferguson, S.A.; Besag, J.E. 2001. Space-time modelling of lightning-caused ignitions in the Blue Mountains, Oregon. Canadian Journal of Forest Research. 31: 1579-1593.

Abstract: Generalized linear mixed models (GLMM) were used to study the effect of vegetation cover, elevation, slope, and precipitation on the probability of ignition in the Blue Mountains, Oregon, and to estimate the probability of ignition occurrence at different locations in space and in time. Data on starting location of lightning-caused ignitions in the Blue Mountains between April 1986 and September 1993 constituted the base for the analysis. The study area was divided into a pixel–time array. For each pixel–time location we associated a value of 1 if at least one ignition occurred and 0 otherwise. Covariate information for each pixel was obtained using a geographic information system. The GLMMs were fitted in a Bayesian framework. Higher ignition probabilities were associated with the following cover types: subalpine herbaceous, alpine tundra, lodgepole pine (*Pinus contorta* Dougl. ex Loud.), whitebark pine (*Pinus albicaulis* Engelm.), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), and grand fir (*Abies grandis* (Dougl.) Lindl.). Within each vegetation type, higher ignition probabilities occurred at lower elevations. Additionally, ignition probabilities are lower in the northern and southern extremes of the Blue Mountains. The GLMM procedure used here is suitable for analysing ignition occurrence in other forested regions where probabilities of ignition are highly variable because of a spatially complex biophysical environment.

Donovan, G.H.; Brown, T.C. 2008. Estimating the avoided fuel-treatment costs of wildfire. Western Journal of Applied Forestry. 23(4): 197-201.

Abstract: Although the importance of wildfire to fire-adapted ecosystems is widely recognized, wildfire management has historically placed less emphasis on the beneficial effects of wildfire. We estimate the avoided fuel treatment cost for 10 ponderosa pine (*Pinus ponderosa*) stands on the Umatilla National Forest in the Pacific Northwest. Results show that fires in stands that show the greatest divergence from the archetypical ponderosa pine stand structure (large trees in an open, parklike stand) tend to have higher avoided costs. This is a reflection of the higher cost of fuel treatments in these stands: treatments designed to restore a stand to a desired condition are normally more expensive than treatments to maintain a stand in a desired condition.

Filip, G.M.; Yang-Erve, L. 1997. Effects of prescribed burning on the viability of *Armillaria ostoyae* in mixed-conifer forest soils in the Blue Mountains of Oregon. Northwest Science. 71(2): 137-144.

Abstract: This study evaluated the influence of prescribed burning, soil depth, antagonistic fungi (*Trichoderma harzianum* Rifai), and time since burning on the viability of the root pathogen *Armillaria ostoyae* (Romagnesi) Herink in wood pieces buried in the soil of a mixed-conifer forest in northeastern Oregon. Red alder (*Alnus rubra* Pong) stem segments colonized with *A. ostoyae* were buried at two soil depths in plots that were burned and not burned. Half of the *Armillaria* segments were buried with segments of *T. harzianum*. Prescribed burning in the fall significantly reduced the recovery of *A. ostoyae* immediately after the burn at a soil depth of 8 cm but not at a soil depth of 30 cm. Adding *T. harzianum* inoculum to the soil did not appear to reduce *A. ostoyae* recovery immediately after the fire, but effects appeared after several months. Differences may also be due to the timing (fall or spring) of the prescribed burns. The effects of fire either natural or prescribed on pathogenic and saprophytic fungi may greatly

influence infections of woody roots, subsequent disease occurrence, and patterns of tree mortality.

Hall, F.C. 1976. Fire and vegetation in the Blue Mountains – implications for land managers. In: Komarek, E.V. Sr., chair. Proceedings of the annual Tall Timbers fire ecology conference No. 15. Tallahassee, FL: Tall Timbers Research Station: 155-170.

Summary (taken from Introduction to the paper): Fire in western forests has been common. Its influence on vegetation and soil was studied in conjunction with a comprehensive ecological evaluation of the 5 million acre (2 million hectare) Blue Mountain land mass in eastern Oregon and southeastern Washington. Both conflagration fire and natural underburning have left their mark. Plant communities dominated by lodgepole pine or western larch are the result of conflagration fire. In contrast, underburning effects on vegetation is often difficult to see. In this paper I will deal only with underburning. Evidence will be presented to document the frequency of underburning, the influence it has had on forest vegetation, interaction effect between tree cover and ground vegetation, fire influence on natural genetic selection of ground vegetation, influence underburning has apparently had on soil development, and in addition, I will briefly discuss some implications these have for land management.

Hall, F.C. 1977. Ecology of natural underburning in the Blue Mountains of Oregon. R6-ECOL-79-001. Portland, OR: USDA Forest Service, Pacific Northwest Region. 11 p.

Summary (taken from Introduction to report): wording is exactly the same as for Hall (1976).

Hall, F.C. 1980. Fire history – Blue Mountains, Oregon. In: Stokes, M.A.; Dieterich, J.H., tech. coords. Proceedings of the fire history workshop. Gen. Tech. Rep. RM-81. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station: 75-81.

Abstract: Interpretation of underburning effects in mixed conifer/pinegrass plant communities (Blue Mountains, Oregon) suggest: underburns occurred at 10-year intervals; ponderosa pine is being replaced by white fir; pine stands did not develop according to “normal stand development;” pine stands require stocking level control to prevent stagnation; range condition must be rated on successional vegetation not climax; range grasses show “downward range trend” due to increasing tree cover complicating trend interpretation; herbaceous plants can sustain livestock use since they developed genetically under periodic 100 percent use by fire; livestock fill a major biotic niche not occupied by wildlife; some plants are dependent upon fire for regeneration; some wildlife depend upon stocking level control and successional trees (pine and larch) formerly provided by underburning; soils developed under fire and are brown forest rather than podzolic; fire hazard is changing from light, flashy fuel under open tree cover to heavy fuels under dense tree cover.

Hansen, H.P. 1943. A pollen study of a subalpine bog in the Blue Mountains of northeastern Oregon. Ecology. 24(1): 70-78.

Summary (no abstract provided with article): This article reports on one in a series of studies on post-Pleistocene vegetation history and general climatic trends in the Pacific Northwest. The forest succession is interpreted from pollen profiles of peat bogs and lake sediments. The peat bog used in this study was located at Mud Lake, one of the Anthony Lakes that lie near the crest of the Blue Mountains. Peat samples were obtained at several locations from a fairly wide sedge zone that extends out about 50 to 100 feet from the lake shore. After analyzing pollen obtained from the peat cores, it was found that tree pollen from three life zones was preserved in the peat profiles. The Hudsonian Zone, with lodgepole and whitebark pines predominant, was best represented in the sediments. The Canadian Zone was not characterized by a particular tree species, although lodgepole pine pollen was common for that zone also. The Arid Transition Zone was best represented by ponderosa pine pollen. Whitebark pine showed a general decline from the bottom of the profiles toward the surface, whereas lodgepole pine was most common in the upper half of the profiles. The relative abundances of western larch and lodgepole pine may indicate fire relationships, or possibly climatic fluctuations. Pollen from Engelmann spruce and subalpine fir were uncommon in the sediments, which the author attributes to their low fire resistance and

slow recovery after fire.

Hatten, J.A.; Zabowski, D.; Ogden, A.; Thies, W. 2008. Soil organic matter in a ponderosa pine forest with varying seasons and intervals of prescribed burn. Forest Ecology and Management. 255(7): 2555-2565.

Abstract: Prescribed burning is used to reduce fuel loads and return ponderosa pine forests of the western U.S. to their historical structure and function. The impact of prescribed burning on soil is dependent on fire severity which is largely managed by burning in the fall or the spring; frequency of fire will also regulate long-term fire impacts. The objective of this study was to determine if soils and soil organic matter (SOM) were affected by prescribed burning in the fall or the spring using singular or multiple prescribed burns. Prescribed burning was initiated in the spring of 1997 and fall of 1997 at 5-year intervals and once during a 15-year period on a study site located within the Malheur National Forest of the southern Blue Mountains of eastern Oregon. Soils were sampled by major genetic horizon in 2004. The 5-year interval plots had burned twice with 1-2 years of recovery while the 15-year interval plots had burned only once with 6-7 years of recovery. Samples were analyzed for pH, carbon (C), nitrogen (N), C/N ratio, cation exchange capacity, base saturation, water repellency, and humic substance composition by alkali extraction. Fall burning decreased C and N capital of the soil (O horizon +30 cm depth mineral soil) by 22-25%. Prescribed burning did not have an effect on fulvic or humic acid C concentration (FA and HA, respectively) of the mineral soil and only a minor effect on FA and HA concentration of the O horizon. One or two fall burns decreased humin and the alkali non-soluble C (NS) content of O horizon by 15 and 30%, respectively. Initiating fall burning in fire-suppressed stands may not preserve soil C, N, humin, and NS content, but may replicate the natural fire regime. Spring burning using a return interval of 5 or more years reduces the fuel load while having little impact on soil C, N, and SOM composition and may be used to prepare a site for subsequent fall burns.

Heyerdahl, E.K. 1997. Spatial and temporal variation in historical fire regimes of the Blue Mountains, Oregon and Washington: the influence of climate. Ph.D. dissertation. Seattle, WA: University of Washington, College of Forest Resources. 224 p.

Abstract: To identify the influence of climate on spatial and temporal variation in fire, low- to high-severity fire regimes were reconstructed from tree-rings in the Blue Mountains. Fire recurrence, extent, severity and seasonality (low-severity fires only) were determined from fire scars and ages of 1426 trees sampled on 2914-8585 ha grids in 4 watersheds. Before 1900, fire regimes varied at regional (among watersheds) and local (within watersheds) spatial scales, although not all parameters of fire varied at both scales. Regionally, fires in ponderosa pine-dominated forests burned more frequently and earlier in the growing season in southern than northern watersheds, consistent with the occurrence of longer and drier fire seasons in the southern Blue Mountains. Fire extent did not vary regionally. Locally, fire recurrence varied with topography (aspect or elevation) in steep terrain but not in gentle terrain, while local variation in fire extent was unrelated to topography in any watershed. Temporal variation in the extent of low-severity fires was compared to existing tree-ring reconstructions of regional precipitation and an index of the Southern Oscillation (SOI). In southern watersheds, fire extent varied inversely with precipitation on annual and longer time scales. In northern watersheds, SOI tended to be low (El Nino conditions) during fire years, consistent with shorter snow-cover duration to the north during El Nino years. Prior year's climate (regional precipitation or SOI) did not influence fire extent in any watershed. Despite some regional synchrony in precipitation, fires rarely burned in more than one of the sampled watersheds during a given year, probably because processes that influence the ignition and/or spread of fire operate at sub-regional spatial scales (e.g., lightning strikes, precipitation from convective storms). After about 1900, few fires occurred in any of the watersheds. These results suggest that to predict spatial variation in fire regimes within a given forest type, the spatial scales at which the controls of fire (e.g., climate and topography) operate must be considered. These results also imply that future fire regimes could be affected by changes in the duration of snow cover or by changes in the amount or timing of ignition.

Heyerdahl, E.K.; Agee, J.K. 1996. Historical fire regimes of four sites in the Blue Mountains, Oregon and Washington. Final Report. Seattle, WA: University of Washington, College of Forest Resources. 173 p.

Abstract: We present here tree-ring reconstructions of fire regimes in the Blue Mountains. Four sites were sampled on roughly regular grids. Both dry and mesic forests were sampled at all but one site which had only dry forests. Establishment dates of age classes were used to identify fires in mesic forests and scar dates were used to identify fires in dry forests. Cores or fire-scarred sections were removed from 1,500 trees at 300 plots distributed over 47,000 acres. From the fire-scarred sections, over 4,000 scars were dated. In dry forests, 32 to 65 separate fire years, from 1687 to 1994, were identified at each site. In mesic forests, 4 fire years, from 1750 to 1994, were identified at two sites but fire years could not be distinguished using age classes at the third site. Although dry forests experienced a broad range of annual fire extents (50 to 20,000 acres), most extents were small relative to the size of the sampling site (during half the fire years, less than 24% of sampling area was burned) but large relative to modern classifications of fire size (during half the fire years, at least 1000 acres burned). Although there were no major changes in cumulative fire extent early in the record, dry forests at all four sites experienced a dramatic decrease beginning in the late 1800s. Historical fire regimes at the northern two sites were similar but differed from those of the southern two sites. In dry forests, fire occurred half as frequently at the northern sites as at the southern sites, regardless of dry forest zone. At the northern sites, fire occurred one-fourth as frequently in mesic forests as in dry forests. We found no relationship between topography and fire intervals except at one site where fire was less frequent at higher elevations. Based on the position of scars within annual rings, most historical fires occurred in the late summer or fall although five fires at the southern sites appear to have occurred earlier in the year. Sampling at a landscape scale while retaining within-site variability yields a robust picture of the historical fire regimes in the watersheds we sampled. We did not find a single historical fire regime for the Blue Mountains but rather found differences between fire regimes in dry and mesic forests and between similar dry forest zones at different sites. We speculate that the differences in fire regimes between sites are due to climate and landscape position.

Heyerdahl, E.K.; Brubaker, L.B.; Agee, J.K. 2001. Spatial controls of historical fire regimes: a multiscale example from the interior west, USA. Ecology. 82(3): 660-678.

Abstract: Our objective was to infer the controls of spatial variation in historical fire regimes. We reconstructed a multicentury history of fire frequency, size, season, and severity from fire scars and establishment dates of 1426 trees sampled on grids in four watersheds (64 plots, over 1620 ha each) representative of the Blue Mountains, Oregon and Washington, USA. The influence of regional climate, a top-down control, was inferred from among-watershed variation in fire regimes, while the influence of local topography, a bottom-up control, was inferred from within-watershed variation. Before about 1900, fire regimes varied among and within watersheds, suggesting that both top-down and bottom-up controls were important. At the regional scale, dry forests (dominated by ponderosa pine), burned twice as frequently and earlier in the growing season in southern watersheds than in northern watersheds, consistent with longer and drier fire seasons to the south. Mesic forests (dominated by subalpine fir or grand fir) probably also burned more frequently to the south. At the local scale, fire frequency varied with different parameters of topography in watersheds with steep terrain, but not in the watershed with gentle terrain. Frequency varied with aspect in watersheds where topographic facets are separated by significant barriers to fire spread, but not in watersheds where such facets interfinger without fire barriers. Frequency varied with elevation where elevation and aspect interact to create gradients in snow-cover duration and also where steep talus interrupts fuel continuity. Frequency did not vary with slope within any watershed. The presence of both regional-scale and local-scale variation in the Blue Mountains suggests that top-down and bottom-up controls were both important and acted simultaneously to influence fire regimes in the past. However, an abrupt decline in fire frequency around 1900 was much greater than any regional or local variation in the previous several centuries and indicates that 20th-century fire regimes in these wa-

tersheds were dramatically affected by additional controls such as livestock grazing and fire suppression. Our results demonstrate the usefulness of examining spatial variation in historical fire regimes across scales as a means for inferring their controls.

Johnson, C.G., Jr. 1998. Vegetation response after wildfires in national forests of northeastern Oregon. Tech. Pub. R6-NR-ECOL-TP-06-98. Portland, OR: USDA Forest Service, Pacific Northwest Region. 155 p.

Summary (no abstract provided with the report): In 1986, a rash of wildfires occurred across a wide area of the Blue and Wallowa mountains and adjacent canyon lands of northeastern Oregon. The fires, starting in August and coupled with dry vegetation, produced burns of larger sizes and greater severities than had been the historic norm. This study was initiated in response to the atypical number and severity of the 1986 fires. One of the underpinnings of the study was that many ecology plots and rangeland condition and trend (C & T) transect clusters predating the fires were located on the largest portion of the 1986 fires. Vegetation cover data by species and photographs taken from fixed camera points documented plant community characteristics prior to the burns. Where plots did not exist, plots and camera points were established as reference points for following plant succession after the fires. The study included three phases: (1) observations were made soon after the fire suppression activities had ceased; (2) vegetation response was documented by sampling plant composition during the first growing-season following the fire; and (3) additional sampling and photographic documentation was completed in the fifth year after the "first year" sampling had been conducted. Thirty fires were included in this study, ranging from 18 occurring in 1986 to 5 in 1994, and a total of 185 measurement plots were used to provide information for comparative analysis. Usually the plots were sampled in the first and fifth years following the burn, although one fire (Deardorff) was resampled in the eighth year instead of the fifth year. This report provides quantified post-fire vegetation trend information and copious photographic documentation for 30 wildfires occurring in northeastern Oregon.

Kerns, B.K.; Thies, W.G.; Niwa, C.G. 2006. Season and severity of prescribed burn in ponderosa pine forests: implications for understory native and exotic plants. Ecoscience. 13(1): 44-55. doi:10.2980/1195-6860(2006)13[44:SASOPB]2.0.CO;2

Abstract: We investigated herbaceous richness and cover in relation to fire season and severity, and other variables, five growing seasons following prescribed fires. Data were collected from six stands consisting of three randomly applied treatments: no burn, spring burn, and fall burn. [This study was conducted on the Burns Ranger District of the Malheur National Forest; see Thies et al. 2005, 2006, 2008 for more details.] Fall burns had significantly more exotic/native annual/biennial (an/bi) species and greater cover of these species (6.5% exotic; 1.7% native) compared to spring and unburned areas. These patterns are likely related to indirect fire effects associated with fire severity and resource availability, rather than direct fire effects due to burn timing. CART models indicated that high native and exotic an/bi richness and cover were associated with overstory gaps and higher fire severity areas, conditions common to fall burns. Exotics may be more successful at exploiting these environments. No treatment differences were found for native perennials. Location was important for explaining native perennial patterns, but richness and cover were also positively associated with lower fire severity, greater tree cover, and coarse woody debris. Expectations for increased native perennial plant diversity and abundance following prescribed fires may not necessarily be met and exotic species spread may compromise other ecosystem attributes. Restoration in these forests presents a challenge as prescribed fires interact with present environmental conditions that are very different from historical ones.

Maruoka, K.R.; Agee, J.K. 1994. Fire histories: overview of methods and applications. Tech Notes BMNRI-TN-2. La Grande, OR: USDA Forest Service, Blue Mountains Natural Resources Institute. 4 p.

Summary (no abstract provided with the note): Fire has the potential to change the structure and species composition of a forest and has undoubtedly influenced the development of the forests we see today in the Blue Mountains. While we can directly observe the effects of recent fires on present forest structure and composition, we must infer the effects of previous fires using current stand structure and composition together with a record of fire occurrences. Fire can be thought of as part of a “disturbance complex” comprising insects, pathogens, wind, and other disturbances, which contribute to landscape and species diversity. The interactions are dynamic with combinations unique to every forest. Because these factors are interdependent, removing or altering one of them changes the roles of the other interacting disturbances. For instance, it has been suggested that fire exclusion has resulted in larger western spruce budworm (*Choristoneura occidentalis*) outbreaks than previously recorded. In the absence of fire, the western spruce budworm plays a similar role in the forest, killing tree species and age classes that would have burned previously if wildfire ignitions had not been successfully suppressed. Because larger outbreaks increase the number of dead and weakened trees, they influence the magnitude of subsequent fire and wind events. Determining the historic fire frequency for a stand helps us understand the role fire has played in stand development. This information is important for interpreting several of the current “forest health” issues in the Blue Mountains, and serves as base information for forming forest management strategies that incorporate natural or prescribed fire.

Maruoka, K.R. 1994. Fire history of *Pseudotsuga menziesii* and *Abies grandis* stands in the Blue Mountains of Oregon and Washington. M.S. thesis. Seattle, WA: University of Washington. 73 p.

Abstract: Fifteen sites in the Blue Mountains of Oregon and Washington were sampled to survey fire frequency in stands ranging from *Pseudotsuga menziesii* associations to dry *Abies grandis* associations. Current stand structure at 80% of the sites consists of an overstory dominated by ponderosa pine, with Douglas-fir and grand fir the understory dominants. Pulses of establishment of Douglas-fir and grand fir occurred after the last recorded fire at 53% of the sites, while establishment pulses occurred amidst years of recorded fires at 47% of the sites. Patchiness in fire severity and fire spread, variable regeneration patterns, and sampling design may have influenced the interpretation of current stand structure in the context of fire. Fire scar analyses reveal high variability in fire return intervals. Mean fire intervals at each site range from 9.9 years to 49.0 years. Individual fire return intervals range from 2 years to 119 years, but may be highly subject to sampling limitations. Fire frequency variability could not be linked between sites to physical or geographic gradients.

McIver, J.D.; McNeil, R. 2006. Soil disturbance and hill-slope sediment transport after logging of a severely burned site in northeastern Oregon. Western Journal of Applied Forestry. 21(3): 123-133.

Abstract: Despite considerable public debate in recent years on the practice of postfire logging, few studies have directly evaluated its effects. Soil disturbance and hill-slope sediment transport were measured after a postfire logging operation conducted two years after the 1996 Summit Wildfire (Malheur National Forest), in northeastern Oregon. The wildfire was relatively severe, killing an average of 86% of the trees in experimental units, and leaving an average of 34% mineral soil exposed one year after the fire. Soil disturbance was measured both pre- and postharvest in four replicate units in each of three postfire harvest treatments (unlogged control, commercial harvest [most dead merchantable trees removed], fuel reduction harvest [most dead merchantable trees removed plus most dead trees >10-cm diameter]). There was a significant difference among treatments in the percentage of mechanically disturbed soil area, with an average of 19.4% disturbed in fuel reduction units and 15.2% in commercial units. Displacement (13.7% of soil area), apparent compaction (3.1%), and erosion (0.4%) were the most common types of machine-caused soil disturbance. Controls had significantly less change in mean displacement from pre- to post-treatment compared to fuel reduction units, and significantly less change in erosion compared to commercial units. At the experimental unit level, there was a significant correlation between the number of stems removed and the total amount of mechanical soil disturbance observed. Multiple regressions indicated that logging activity, reflected by the number of stems removed, explained more variation in soil disturbance than relative fire severity, reflected by tree mortality, forest floor mass, or the percentage of mineral soil exposed. There was no correspondence between disturbance within units and hill-slope sediment collected in silt fences below units. Visual inspections and sediment collected in silt fences indicated that little sediment exited the experimental units in the short term, and that the existing road system caused most of the observed hill-slope sediment transport. Low observed levels of sediment transport were likely due to a combination of low-to-moderate slopes, low-to-moderate-risk soils, logging over snow or dry ground, hand felling, no new roads, two years recovery of ground cover between the fire and the logging, problems with measuring hill-slope sediment, and the absence of severe weather events in the two years after postfire logging. Given these mitigating factors, hill-slope sediment transport measured in this study should be considered as representative of the low end of the range that would be expected in a postfire tractor logging operation on similar soils and under similar burn severity conditions.

McIver, J.D.; Ottmar, R. 2007. Fuel mass and stand structure after post-fire logging of a severely burned ponderosa pine forest in northeastern Oregon. Forest Ecology and Management. 238(1-3): 268-279.

Abstract: Stand structure and fuel mass were measured before and after a post-fire logging operation conducted 2 years after the 1996 Summit Wildfire (Malheur National Forest), in a ponderosa pine-dominated forest in northeastern Oregon. Variables were measured both pre- and post-logging in four replicate units for each of three treatments [un-logged control, commercial harvest (most dead merchantable trees removed), fuel reduction harvest (most dead merchantable trees removed plus most dead trees >10 cm diameter)]. Post-fire logging resulted in a significant decrease in mean basal area, down to 46% pre-treatment level in commercial units, and down to 25% in fuel reduction units. Logging significantly reduced tree density, especially for the smallest (<22 cm diameter) and intermediate (23-41 cm) diameter classes. Fuel reduction units also had significantly fewer snags (dead trees >30 cm diameter--4 ha-1), compared to both commercial (23 ha-1) units and to un-logged controls (64 ha-1) in the year following timber harvest. Logging did not change ladder height or tree species composition (% ponderosa pine, Douglas-fir and grand fir). Total woody fuel mass increased significantly in fuel reduction units when compared to controls, with the greatest difference among treatments occurring in the slash fuel (<7.6 cm diameter) component (mean of 6.2 Mg/ha for fuel reduction stands versus 1.3 Mg/ha for un-logged stands). Logging activity caused no change in the mass of the forest floor (litter or duff). Model projections of the fuel bed using the fire and fuels extension of the forest vegetation simulator (FVS-FFE) indicate that the disparity in slash fuel mass between fuel reduction and un-logged units would be sustained until about 15 years post-logging, but a re-burn of moderate intensity occurring during this time would likely kill all young trees, even in un-logged units, because of the influence of other components of the fuel bed, such as grasses and shrubs. Model projections of 1000-h fuels (woody fuels >7.6 cm diameter) indicate that standing structure in all stands would collapse quickly, with the result that un-logged stands would contain two- or three-fold greater masses at 25 and 50 years post-logging, leading to much higher consumption rates of fuel in the event of a re-burn in the same place. Variation in dead tree fall and decay rates did not change the relationship among treatments in 1000-h fuel loads, but changed the time at which treatment differences were projected to disappear. Despite treatment differences in heavy fuel accumulations over time however, FVS-FFE predicts no differences among treatments in mortality of young trees due to either moderate or high intensity fire occurring in the same place at 25, 50, or 100 years post-fire logging. The lack of a re-burn effect is in part due to the reliance on flame length as the primary mechanism leading to tree death in the fire effect models used by FVS-FFE. If tree death turns out to be caused more by root burning or cambial heating, the observed variations in 1000-h fuel loadings among treatments could be significant in the event of a future re-burn.

Mehringer, P.J., Jr. 1997. Late Holocene fire and forest history from Lost Lake, Umatilla National Forest, Blue Mountains, Oregon. Challenge Cost-Share Agreement No. CCS-06-95-04-058. John Day, OR: USDA Forest Service, Malheur National Forest. 29 p.

Introduction from report: I [Mehringer] first visited Lost Lake in 1985 at the request of June B. Wilburn, Umatilla Forest archaeologist. Soon after, Guy Marden, Wallowa-Whitman National Forest, archaeologist, and my colleague Kenneth Reid, then studying the archaeology of the Blue Mountains, expressed interest in Holocene environments of the Wallowas. Their encouragement, WSU student volunteers, and Forest Service funding sufficient to transport coring equipment and begin dating the lake sediments led to these studies. Consequently, the first Wallowa Mountain pollen record, from Twin Lakes, was the recent subject of a WSU masters thesis (Beck 1996) and I report herein initial studies of cores from Lost Lake. Though more a large shallow pond than a lake, Lost Lake seemed a potential source of paleoenvironmental information spanning the Holocene. In 1986 a lightning-caused duff-destroying blaze swept up the drainage above and around Lost Lake leaving the area of dense, green mixed-conifer forest bare with blackened and oxidized earth. We finally cored the lake sediments in July of 1987 expecting to obtain a history of former fires and of vegetation changes since Pleistocene ice left this area of the Blue Mountains more than 12,500 years ago. I had, however, underestimated the mass of Mazama tephra that might have fallen and been washed into the depression of Lost Lake. The >4 meters of volcanic ash from Crater Lake, Oregon, brought coring to a standstill. We had to settle for the post-Mazama sequence spanning the last 6,850 radiocarbon years (5,675±45 cal yr BC). As a 1988 palynology class project, Washington State University graduate students described, partially sampled, and analyzed pollen and algae from a few samples. Their studies showed the likelihood of a complete post-Mazama section, distinct charcoal-rich layers washed-in after major fires such as the 1986 burn, tephra layers, well preserved fossil pollen, and some macrofossils as well. Several years later interest by Suzanne Crowley Thomas, Malheur National Forest, John Day, resulted in a Challenge Cost-Share Agreement that reopened investigations of the Lost Lake cores. Studies resulting from this agreement and presented herein include pollen and algae analyses emphasizing the last 3,400 years, tephra identifications, and radiocarbon dates. A colleague, Joy Mastrogiuseppe, cooperated in examination of macrofossils mostly from charcoal-rich layers in the upper 1.7 meters of the cores.

Munger, T.T. 1917. Western yellow pine in Oregon. Bull. No. 418. Washington, DC: U.S. Department of Agriculture. 48 p.

Introduction from bulletin: Western yellow pine (*Pinus ponderosa* Laws.) is known throughout its range simply as pine or yellow pine, and in the lumber trade of the Northwest as western pine. It is sometimes called western soft pine or, more rarely, Oregon white pine. The terms used by California lumbermen are "western white pine" and" California white pine." It is the most widely distributed pine in the United States and one of the most valuable. It is suited to a great variety of uses and throughout much of its range supplies nearly every local need. Its large size, good form, occurrence in large and easily accessible bodies, and the high technical qualities of its wood place it near the top of the list of commercially important American timber trees. The reported cut in the United States in 1915 was 1,252,244,000 feet, which places yellow pine seventh in rank if the oaks are considered collectively. California leads the States, with a cut (in 1915) of 389,991,000 feet, and Oregon is third with an annual output of 189,203,000 feet. There is estimated to be in the United States 400,000,000,000 feet of this pine, more than there is of any other single species except Douglas fir. The annual cut is less than 0.004 of the stand. Western yellow pine occurs naturally from southern British Columbia to Lower California and northern Mexico, and from the Pacific coast nearly as far east as to the one-hundredth meridian. It is found in the forests of every State west of the Great Plains, and in more than half of them it is the most important and valuable forest tree. In Arizona and New Mexico there is a western yellow pine forest which is said to be the largest continuous body of timber in the country.

Summary (from author of this white paper): This is the definitive early work on ponderosa pine in Oregon, including a map showing the distribution of Oregon's pine forests around 1915. Included is the following information about ponderosa pine forests in Oregon: distribution, silvical requirements, reproduction, fire effects, insect and pathogen influences, stand characteristics, timber volumes, tree growth, wood characteristics, utilization, logging and milling, planting, stock grazing, and forest management practices. Appendices provide 2 regional volume tables, including one for the Blue Mountains, as well as

marking guides and slash disposal specifications. Several excellent black-and-white photographs are also included. Note that several of the office reports that formed the basis for this bulletin are also included in the history archives, such as "A study of the growth of yellow pine in Oregon" by G. A. Bright (1912). This excellent work includes interesting insights about early forest conditions in eastern Oregon and the Blue Mountains, as illustrated here: "In most of the pure yellow-pine forests of the State the trees are spaced rather widely, the ground is fairly free from underbrush and debris, and travel through them on foot or horseback is interrupted only by occasional patches of saplings and fallen trees. The forests are usually not solid and continuous for great distances, except along the eastern base of the Cascades, but are broken by treeless "scab-rock ridges," or natural meadows;" "In the Blue Mountains the herbage is rather more luxuriant and varied than on the eastern slopes of the Cascades and their outstanding ranges. In the early summer the open yellow-pine forests are as green with fresh herbage as a lawn, except here and there where the green is tinged with patches of yellow or purple flowers. Some of this luxuriant herbage is pine grass (*Calamagrostis* sp.), a plant which is not eaten by stock except very early in the season; but much of the ground cover makes excellent range for cattle and sheep;" "In the Blue Mountains western larch (*Larix occidentalis*) is its [western yellow pine] usual companion and grows with it in an intimate and harmonious mixture. In the moister situations white fir (*Abies concolor*) is a common associate, as is also Douglas fir (*Pseudotsuga taxifolia*) in most parts of the State. In the Blue Mountains it is common for the south slopes to be covered with a fine stand of yellow pine, while the north slopes are covered almost entirely with larch, white fir, and Douglas fir;" "In the Blue Mountains the reproduction of yellow pine is very abundant, both in the virgin forest and after cuttings. Perhaps it is more prolific here than anywhere else. In this region where an area has not been burned over by a surface fire for a number of years, there is quite commonly a veritable thicket of little trees from a few inches to several feet high. Actual counts have shown that there are sometimes 14,000 seedlings on a single acre, the ages ranging from 13 to 21 years;" "In pure, fully stocked stands in the Blue Mountains region there are commonly from 20 to 30 yellow pines per acre over 12 inches in diameter, of which but few are over 30 inches. Over large areas the average number per acre is ordinarily less than 20. In mixed stands the number of yellow pines of merchantable size is naturally less, though the total number of trees of all species is as a rule larger, the moist soil on which the mixed forest grows being able to carry a denser stand;" "Yellow pine grows commonly in many-aged stands; i.e., trees of all ages from seedlings to 500-year-old veterans, with every age gradation between, are found in intimate mixture. Usually two or three or more trees of a certain age are found in a small group by themselves, the reason being that a group of many young trees usually starts in the gap which a large one makes when it dies;" "Light, slowly spreading fires that form a blaze not more than 2 or 3 feet high and that burn chiefly the dry grass, needles, and underbrush start freely in yellow-pine forests, because for several months each summer the surface litter is dry enough to burn readily. Practically every acre of virgin yellow-pine timberland in central and eastern Oregon has been run over by fire during the lifetime of the present forest, and much of it has been repeatedly scourged. It is sometimes supposed that these light surface fires, which have in the past run through the yellow-pine forests periodically, do no damage to the timber, but that they "protect" it from possible severe conflagrations by burning up the surface debris before it accumulates. This is a mistake. These repeated fires, no matter how light, do in the aggregate an enormous amount of damage to yellow-pine forests, not alone to the young trees, but to the present mature merchantable timber;" "A careful cruise of every tree on 154½ sample acres in typical yellow-pine stands in several localities in the Blue Mountains showed that 42 out of every 100 trees were fire-scarred;" "Ordinarily, a fire in yellow-pine woods is comparatively easy to check. Its advance under usual conditions may be stopped by patrolmen on a fire line a foot or so wide, either with or without backfiring. The open character of the woods makes the construction of fire lines relatively easy, and in many places horses may be used to plow them."

Mutch, R.W.; Arno, S.F.; Brown, J.K.; Carlson, C.E.; Ottmar, R.D.; Peterson, J.L. 1993. Forest health in the Blue Mountains: a management strategy for fire-adapted ecosystems. Gen. Tech. Rep. PNW-GTR-310. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 14 p.

Abstract: The fire-adapted forests of the Blue Mountains are suffering from a forest health problem of catastrophic proportions. Contributing to the decline of forest health are such factors as the extensive harvesting of the western larch and ponderosa pine overstory during the 1900s, attempted exclusion of fire from a fire-dependent ecosystem, and the continuing drought. The composition of the forest at lower elevations has shifted from historically open-grown stands primarily of ponderosa pine and western larch to stands with dense understories of douglas-fir and grand fir. Epidemic levels of insect infestations and large wildfires now are causing widespread mortality that has a profound effect on forest health by adversely affecting visual quality, wildlife habitat, stream sedimentation, and timber values. The Blue Mountains situation may foretell of a much broader forest health decline across the western United States.

A management strategy to restore forest health at lower elevations will require that the seral ponderosa pine and western larch stands be managed for much lower tree densities and a more open coniferous understory than have been the case. A combination of silvicultural partial cutting and prescribed fire on a large scale will be needed to produce the desired future condition of healthy, open, and parklike forests. We have attempted to exclude fire from fire-dependent ecosystems with disastrous results. Now we must take bold steps in restoring forest health to the Blue Mountains through an integrated strategy of silvicultural and fire prescriptions.

Olson, D.L. 2000. Fire in riparian zones: a comparison of historical fire occurrence in riparian and upslope forests in the Blue Mountains and southern Cascades of Oregon. M.S. thesis. Seattle, WA: University of Washington. 274 p.

Abstract: Despite the ecological importance of fire in Pacific Northwest forests, its role in riparian forests is not well documented. This study reconstructed the historical occurrence of fire within riparian forests along different stream sizes within three different national forests in Oregon. Two study areas were located in mostly dry, low-severity fire regime forests in the Blue Mountains of northeastern Oregon (Dugout and Baker) and the third study area was located in more mesic, moderate-severity fire regime forests on the western slopes of the southern Oregon Cascades (Steamboat). Fire scar dates and tree establishment dates were determined from a total of 424 fire scarred tree wedges and 81 increment cores taken from 67 riparian and upslope plots. Based on the data from this study, fire was common historically in the riparian zones of all three study areas. Weibull median probability fire return intervals (WMPIs) for riparian forests in Dugout ranged between 13 and 14 years, and were only slightly longer than those for upslope forests (averaging one year longer). In Baker, differences between riparian and upslope forest WMPIs were greater, ranging between 13 and 36 years for riparian WMPIs, compared to 10 to 20 years for upslope WMPIs. However, further analyses suggested that forest type and slope aspect play a larger role than proximity to a stream when it came to differentiating fire regimes in this study area. For both Dugout and Baker it appeared that stream channels did not necessarily act as fire barriers during the more extensive fire years. Steamboat riparian WMPIs were somewhat longer (ranging from 35-39 years) than upslope WMPIs (ranging from 27-36), but these differences were not significant. Fires were probably more moderate in severity and likely patchy, considering the incidence of fires occurring only at a riparian plot or an upslope plot within a pair, but not at both. It is possible that fire return interval lengths were associated with aspect, but more sampling would need to be done to show this. Based on the results from this study, it is evident that: 1) restoring fire, or at least conducting fuel reduction treatments, will be necessary to protect riparian forests in comparable forest ecosystems, 2) forests should be managed according to forest type, not just by proximity to a stream, and 3) historical recruitment of large woody debris was likely small but continuous for low-severity fire regime riparian forests, with a relatively short residence time, and patchy and more pulsed for the more moderate-severity fire regime forests.

Porter, O.M. 1915? The fire problem on the Malheur National Forest. Ann. Tech. Rep. Unpublished typescript report obtained from the National Archives, College Park, MD; record group 95. 55 p. On file with: Umatilla National Forest, Supervisor's Office, Pendleton, OR.

Summary (from author of this white paper): The Malheur NF, located in the heart of the Blue Mountains of northeastern Oregon, comprised a gross area of 1,262,840 acres when this report was written. It contained an open but valuable timber stand that was estimated at six and one-half billion board feet of western yellow pine, Douglas-fir, western larch, and several minor species. The timber was conservatively estimated to be worth thirteen million dollars. Due to its openness, nearly every acre of the Forest provided forage for domestic livestock – 24,300 cattle and horses, and 135,500 sheep, grazed on it each year. Settlers and ranchers of the John Day and Harney valleys depended on the timber and forage resources of the Forest for their livelihoods. As a result of its value for timber production and livestock grazing, fire protection was important on the Malheur NF. This report describes the methods and policies pertaining to fire protection on the Forest. It includes the following sections: introduction; hazard; fire season; character of fires (types, causes, speed of burning); cooperation (advantages, results, suggested system of cooperation); methods of prevention (enforcement of fire laws, signs); method of detection (present system, suggested system); methods of suppression (tools, trenching and fire lines, back firing); and conclusion. In the five years previous to the preparation of this report, an average of 16.4 fires had occurred per year on the Forest. The author noted that the incidence of fires had been slowly increasing since establishment of the national forests, but was unsure of the reasons for the increase. There were three main types of fire on the Malheur: timber fires, brush fires, and sagebrush fires. Primary causes of fires for the previous five-year period included: lightning (33%), brush burning (1%), campers (28%), saw mills (1%), miscellaneous (10%), and unknown (27%). The unknown category included carelessness in the use of matches and tobacco, and any malicious fires. A two-page table summarizes information from all of the annual fires reports for the period of 1911 to 1915, inclusive. In the section discussing prevention, the author poses several ideas for handbills and other materials that could be provided to school children so that they could bring them home to their parents. At the time this report was written, the Forest had one operating fire lookout on Strawberry Mountain. The author was not in favor of the lookout system because so few existed on the Forest; he believed that systematic patrols during the fire season was a more effective detection method.

Powell, D.C. 2009. Historical fires in the headwaters portion of the Tucannon River watershed. Unpub. Rep. Pendleton, OR: USDA Forest Service, Pacific Northwest Region, Umatilla National Forest. 52 p.

Summary (from Introduction to the white paper): The greatest insights into past fire regimes have come from deciphering the history of climate, forest fire, and insect outbreaks as recorded in the annual growth rings of living and dead trees – this is the science of dendrochronology (Banks 1991, Fritts and Swetnam 1989). By precisely dating fire scars in the tree-ring record and then mapping the locations of trees with scars of the same age, it is possible to reconstruct a relatively accurate picture of fire frequency and size for the time period before Euro-American settlement (Arno and Sneck 1977). The fire-scar analysis technique is used to characterize the presettlement fire regime for dry-forest areas because fires tend to be stand maintaining in this biophysical environment, so they leave a fire history record by scarring live trees.

Analyzing the age structure of forest stands for areas that burned with relatively high severity also reveals the characteristics of presettlement fires, particularly if landscape fire patterns were not subsequently disrupted by timber harvest. Since crown fires generally result in nearly complete stand replacement (killing most or all of the existing trees), and because they initiate a new stand of trees (or shrub fields in some instances), it is generally not possible to study tree scars for fire regimes dominated primarily by crown fires. The stand-age analysis technique is used to characterize the presettlement fire regime for moist-forest sites because fires tend to be stand initiating in this biophysical environment, so they leave a fire history record by creating a mosaic of stand ages across the landscape.

The Tucannon River watershed was one of four areas included in a study of historical fire regimes for the Blue Mountains of northeastern Oregon and southeastern Washington. Forty individual fire years were interpreted for the Tucannon River watershed, with the first one occurring in 1583 and the last one in 1898. Emily Heyerdahl provided us with shapefiles of her mapped fire extents for the Tucannon River study area. The individual fire extents were then overlaid with a base map consisting of four biophysical environments: cold upland forest, dry upland forest, moist upland forest, and nonforest (nonforest is comprised of all shrubland and herbland potential vegetation groups or PVGs).

Powell, D.C. 2010. Estimating crown fire susceptibility for project planning. Fire Management Today. 70(3): 8-15. http://www.fs.fed.us/fire/fmt/fmt_pdfs/FMT70-3.pdf

Summary (from Introduction to article): Fire managers traditionally recognize three types of fire: (1) ground fires burning in organic materials such as peat; (2) surface fires burning in herbs and other fuels lying on or near the ground surface; and (3) crown fires burning in elevated canopy fuels. When considering fire effects on vegetation and other ecosystem components, crown fire is acknowledged to be the most severe of the three fire types. Although crown fire is normal and expected for fire regimes III, IV, and V, a large amount of crown fire is neither normal nor expected for the dry forests of fire regime I. Because dry forests are affected by crown fire with increasing regularity and silvicultural treatments are being planned for the wildland-urban interface where crown fire can seldom be tolerated regardless of fire regime, fire managers need tools to help them evaluate crown fire susceptibility for all forested lands. As expressed by Scott and Reinhardt (2001) “Crown fires result from certain combinations of fuels, weather, and topography.” Land managers cannot control weather and topography, but if they could identify areas with high potential for crown fire, the areas could be targeted for application of prescribed fire and thinning, two treatments with demonstrated effectiveness for reducing stand susceptibility to crown fire behavior. Crown fire susceptibility refers to the potential for crown fire based on inherent stand characteristics such as species composition, forest structure, and tree density. In this context, crown fire susceptibility and crown fire hazard are considered to be interchangeable terms. This article relates five common measures of stand density (stand density index, trees per acre, basal area per acre, canopy cover, and equilateral tree spacing) to three categories of crown fire susceptibility (high, moderate, and low). The use of stand density measures to estimate crown fire susceptibility is a practical approach – it is not feasible to directly measure canopy bulk density (CBD), the measure of available crown fuels, except in a research context, and these other measures can be collected as part of stand data. In addition, it is easier to relate stand density to CBD than to use indirect estimation techniques relying on hemispherical photography, ceptometers, or spherical densiometers.

Powell, D.C.; Johnson, C.G., Jr.; Crowe, E.A.; Wells, A.; Swanson, D.K. 2007. Potential vegetation hierarchy for the Blue Mountains section of northeastern Oregon, southeastern Washington, and west-central Idaho. Gen. Tech. Rep. PNW-GTR-709. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 87 p.

Abstract: The work described in this report was initiated during the Interior Columbia Basin Ecosystem Management Project (ICBEMP). The ICBEMP produced a broad-scale scientific assessment of ecological, biophysical, social, and economic conditions for the interior Columbia River basin and portions of the Klamath and Great Basins. The broad-scale assessment made extensive use of potential vegetation (PV) information. This report (1) discusses certain concepts and terms as related to PV, (2) describes how a PV framework developed for the broad-scale ICBEMP assessment area was stepped down to the level of a single section in the national hierarchy of terrestrial ecological units, (3) describes how fine-scale potential vegetation types (PVTs) identified for the Blue Mountains section were aggregated into the midscale portion of the PV hierarchy, and (4) describes the PVT composition for each of the midscale hierarchical units (physiognomic class, potential vegetation group, plant association group).

Robichaud, P.R.; Brown, R.E. 1999. What happened after the smoke cleared: onsite erosion rates after a wildfire in eastern Oregon. In: Olsen, D.S.; Potyondy, J.P., eds. Proceedings of specialty conference on wildland hydrology. Bozeman, MT. [Place of publication unknown]: American Water Resources Association: 419-426.

Abstract: Recent fires have renewed interest in fire’s effect on different components of the ecosystems, particularly erosion and soil productivity. Our objectives were to (1) determine hillslope erosion rates after a high severity wildfire in an unmanaged forest stand; (2) determine fire’s short-term effects on nutrient loss. The study site was within an unmanaged forest area in the Wallowa-Whitman National Forest, eastern Oregon (the Twin Lakes fire area, which burned in August of 1994). The fire consumed all downed woody debris larger than 75 mm diameter and all standing trees were killed. In addition the entire forest floor (duff) was consumed, leaving mineral soil exposed to raindrop impact and overland flow.

Onsite erosion measurements were conducted for four years after the wildfire. Silt fences were used to collect eroded sediment on three slope classes (20, 30, and 60 percent), replicated twice, all within a high severity burn area. Mean first year erosion rates were 1.9 Mg ha^{-1}, decreasing to 0.1 Mg ha^{-1} the second year, then to 0.03 Mg ha^{-1} the third. No erosion occurred the fourth year. In year one, the 60 percent slope sites produced twice as much sediment as did the 20 percent slope sites. Soil nutrient losses followed the same pattern as the sediment losses. High severity wildfires can produce accelerated erosion and nutrient loss for the first year before establishment of natural regeneration.

Ryan, K.C.; Pickford, S.G. 1978. Physical properties of woody fuels in the Blue Mountains of Oregon and Washington. Res. Note PNW-315. Portland, OR: USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. 10 p.

Summary: Physical properties were determined for some fuels in the surface litter of stands in the Blue Mountains of Oregon and Washington. Average and quadratic mean diameters for both 0- to 1/4-inch and ¼- to 1-inch fuels were determined in stands of Douglas-fir and grand fir, western larch, lodgepole pine, ponderosa pine, subalpine fir, and Engelmann spruce. Specific gravities were also determined for both size classes of Douglas-fir, grand fir, western larch, and lodgepole pine fuels.

Scott, D.W.; Schmitt, C.L.; Spiegel, L.H. 2002. Factors affecting survival of fire injured trees: a rating system for determining relative probability of survival of conifers in the Blue and Wallowa Mountains. BMPMSC-03-01. La Grande, OR: USDA Forest Service, Pacific Northwest Region, Wallowa-Whitman National Forest, Blue Mountains Pest Management Service Center. 66 p.

Summary (Introduction of report): The marking of trees for salvage following wildfire is often difficult and controversial owing to the varied and complex factors governing the survival of fire injured trees. Numerous factors often interact to determine the fate of trees following wildfire, including, but not limited to age, size, crown ratio, bark thickness, and other fire-resistance characteristics of the affected tree species; stand density, fuel loads, season of fire, and growing site quality characteristics that influence the intensity and duration of the fire, and degree of damage to trees; and insect populations and disease status within affected stands.

In addition, the Forest Service must balance various management directions as to the appropriate management for fire-damaged stands and trees. The agency has an obligation to recoup public funds spent on establishing, growing, and managing commercial timber stands damaged by wildfire. The agency also has an obligation to protect sensitive habitats and restore damaged ecosystems following wildfire. Resource managers must balance the need to remove damaged trees while still merchantable with the need to protect legacy habitats. They must protect residual stands from future wildfires that may re-burn the area if the fire created an increase in fuels. Managers also must weigh the potential harm to post-fire residual forests from secondary insects.

Given that insect attack of fire-injured trees are often a concern following wildfire, the wildfire season of 2002 prompted requests from National Forest offices for help from the Blue Mountains Pest Management Service Center in determining the survival potential of these trees. An earlier effort developed preliminary burn severity guidelines to assess relative risk of tree mortality from insects and/or fire. In many instances over the past half-decade, Ranger Districts used that information to develop specific salvage-marking guidelines. Since that time, more information on fire effects has become available in the published literature, mortality trends associated with measured conditions of fire injury have been observed from formal fire monitoring plots on numerous wildfires in the Blue Mountains, and tree mortality probability models have been refined and become more widely available.

Accordingly, to provide the National Forests with information to aid in their decision-making process regarding survival of fire-injured timber resources, we herein provide a standardized rating system for determining three relative survival decision classes describing High, Moderate, and Low probability of tree survival following wildfire. By defining the ranges for these class distinctions, we assume that roughly 50% of the trees falling within the Moderate survival class will survive and 50% will not.

Our intent is for these procedures to provide a basis upon which Districts may further develop their own specific marking guidelines. By providing these procedures we are not prescribing marking guidelines. It is possible for Forests to adopt this system, combined with other criteria for marking trees for salvage. The rating system incorporates the current state of the science and should be adequate for separating fire-injured trees into the three broad survival classes indicated above.

Shindler, B.; Kemp, B.; McIver, J. 1996. Forest management in the Blue Mountains: public perspectives on prescribed fire and mechanical thinning. Unnumbered Rep. Corvallis, OR: Oregon State University, Department of Forest Resources. 69 p.

Abstract: Insect and disease epidemics have created unhealthy and overstocked conditions in national forests of the Blue Mountains. Two of the most important management tools for reducing fuel loads and restoring forest health are prescribed fire and mechanical thinning practices. Accurate information about public support for these practices is essential for implementing effective long-term management policies. By assessing public attitudes, we improve our understanding of the often contentious environment in which resource management decisions are made. This report presents a summary of findings from public opinion surveys conducted in Blue Mountains communities in the spring of 1996. Questionnaires were developed based on interviews with Forest Service personnel and focus group meetings with community residents. The data reflect responses from 535 individuals (56% response rate) who completed a mail questionnaire.

Thies, W.G.; Westlind, D.J.; Loewen, M. 2005. Season of prescribed burn in ponderosa pine forests in eastern Oregon: impact on pine mortality. International Journal of Wildland Fire. 14(3): 223-231. doi:10.1071/WF04051

Abstract: A study of the effects of season of prescribed burn on tree mortality was established in mixed-age ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) at the south end of the Blue Mountains near Burns, Oregon. Each of six previously thinned stands was subdivided into three experimental units and one of three treatments was randomly assigned to each: fall 1997 burn, spring 1998 burn, and no burning (control). Burns were conducted as operational prescribed burns. Trees within six 0.2-ha circular plots on each experimental unit were observed for four post-burn growing seasons to determine fire damage and to detect immediate and delayed mortality and occurrence of black stain root disease (BSRD). There were 5321 tagged ponderosa pines alive at the time of the burns. The percentage of ponderosa pine dying was higher after fall burns than after spring burns. Differences in percentages of fire-caused mortality may be because fall burns are inherently more severe than spring burns. Although present in many trees, BSRD appeared to have little impact on mortality. The lion's-tail appearance, thought to be a symptom of BSRD, was found to be an unreliable indicator of BSRD in the six test stands.

Thies, W.G.; Westlind, D.J.; Loewen, M.; Brenner, G. 2006. Prediction of delayed mortality of fire-damaged ponderosa pine following prescribed fires in eastern Oregon, USA. International Journal of Wildland Fire. 15(1): 19-29. doi:10.1071/WF05025

Abstract: Prescribed burning is a management tool used to reduce fuel loads in western interior forests. Following a burn, managers need the ability to predict the mortality of individual trees based on easily observed characteristics. Astudy was established in six stands of mixed-age ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) with scattered western junipers at the south end of the Blue Mountains near Burns, Oregon, USA. Stands were thinned in either 1994 or 1995. Three treatments, a fall burn, a spring burn, and an unburned control, were randomly assigned to 12-ha experimental units within each stand. Prescribed burns occurred during mid-October of 1997 or mid-June of 1998 and were representative of operational burns, given weather and fuel conditions. Within each experimental unit, six 0.2-ha plots were established to evaluate responses to the burns. Ponderosa pine plot trees (n =3415) alive 1 month

after the burns were evaluated and observed for four growing seasons. Nine fire damage and tree morphological variables were evaluated by logistic regression. A five-factor full model and a two-factor reduced model are presented for projecting probability of mortality. Significant variables in the full model included measures of crown, bole, and basal damage.

Thies, W.G.; Westlind, D.J.; Loewen, M.; Brenner, G. 2008. A field guide to predict delayed mortality of fire-damaged ponderosa pine: application and validation of the Malheur model. Gen. Tech. Rep. PNW-GTR-769. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 16 p.

Abstract: The Malheur model for fire-caused delayed mortality is presented as an easily interpreted graph (mortality-probability calculator) as part of a one-page field guide that allows the user to determine postfire probability of mortality for ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.). Following both prescribed burns and wildfires, managers need the ability to predict the mortality of individual ponderosa pine trees based on burn damage. The model was developed from fire-caused delayed mortality observed for 4 years postburn in a replicated study of 12 burn units and 6 nonburned units near Burns, Oregon. During the fourth year, the percentage of mortality on burned units was not statistically different from that on nonburned units. Here we report validation data from 3,237 ponderosa pines in 10 additional burns, observed for 3 years postburn, from the southern Blue Mountains and northern California that indicate a good fit between mortality predicted by the Malheur model and observed mortality. Tear-out copies of the field guide on water proof paper are provided.

Tiedemann, A.R.; Klemmedson, J.O.; Bull, E.L. 2000. Solution of forest health problems with prescribed fire: are forest productivity and wildlife at risk? Forest Ecology and Management. 127: 1-18. doi:10.1016/S0378-1127(99)00114-0

Abstract: Advanced forest succession and associated accumulations of forest biomass in the Blue Mountains of Oregon and Washington and Intermountain area have led to increased vulnerability of these forests to insects, diseases, and wildfire. One proposed solution is large-scale conversion of these forests to seral conditions that emulate those assumed to exist before European settlement: open-spaced stands (ca. 50 trees per ha), consisting primarily of ponderosa pine (*Pinus ponderosa* Laws.) and western larch (*Larix occidentalis* Nutt.). We question how well presettlement forest conditions are understood and the feasibility and desirability of conversion to a seral state that represents those conditions. Current and future expectations of forest outputs and values are far different from those at presettlement times. Emphasis on prescribed fire for achieving and maintaining this conversion raises questions about how well we understand fire effects on forest resources and values. We consider here potential effects of prescribed fire on two key aspects of forest management–productivity and wildlife. Use of large-scale prescribed fire presents complex problems with potential long-term effects on forest resources. Before implementing prescribed fire widely, we need to understand the range of its effects on all resources and values. Rather than attempting to convert forests to poorly described and understood presettlement seral conditions, it would seem prudent to examine present forest conditions and assess their potential to provide desired resource outputs and values. Once this is achieved, the full complement of forest management tools and strategies, including prescribed fire, should be used to accomplish the desired objectives. We suggest a more conservative approach until prescribed fire effects are better understood.

Thompson, J. 2006. Prescribed fires are not created equal: fire season and severity effects in ponderosa pine forests of the southern Blue Mountains. Science Findings 81. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 5 p.

Summary (from Introduction to the Findings): In the early 1990s, foresters working on the Malheur National Forest in central Oregon started getting nervous. Black stain root disease appeared to be spreading, threatening the ponderosa pine forest. In particular, the foresters thought they saw more diseased trees in stands treated with spring season prescribed fires, compared to those burned in the fall. The fungus that causes black stain root disease can be a real problem for foresters. It infects and kills several species of western conifers and can cause significant losses. Infected trees wilt and can die within a few years. Managers on the Malheur needed to find out if their springtime prescribed burning program was contributing to disease spread. Why might season matter? In the first place, ponderosa pine forests evolved with frequent late-summer and early-fall burns. In contrast, there is little historical precedent for spring fires. Could the trees be more vulnerable in the spring, when their buds are opening and the annual growth spurt is just getting underway? Perhaps pines are simply not adapted to spring fires. It is a plausible theory, and one, the foresters thought, that might extend to other plant species, such as understory grasses and forbs. Although black stain root disease is not an issue for grasses and forbs, these plants could be more vulnerable to burning in the spring when they are actively growing. The managers had legitimate concerns but they didn't want to give up on spring burning. There is only a short window in the spring and the fall when prescribed fires can safely be used. Most of the year, it is either too wet to carry fire or so dry that fire is difficult to control. If spring burning were eliminated, then fire managers would be left with only a few weeks in the fall. Given the thousands of acres needing to be burned, cutting the available days in half would effectively double the challenge. "They had interesting questions stemming from their observations. In response, several of us in the research branch designed a program of study tailored to their questions," says Walt Thies, a research plant pathologist at the PNW Research Station in Corvallis, Oregon. What resulted was synergy between the managers on the Malheur National Forest and researchers in the Station.

Williamson, N.M. 1999. Crown fuel characteristics, stand structure, and fire hazard in riparian forests of the Blue Mountains, Oregon. M.S. thesis. Seattle, WA: University of Washington. 98 p.

Summary (from Introduction to thesis): Disturbances are inherent components of all forest ecosystems. They play an extremely important role in the shaping of populations and communities through the alteration of landscape pattern and subsequent impacts on future ecological processes. The type, timing, extent, and intensity of disturbances can dramatically affect species distributions, successional pathways, and community composition and structure in forest ecosystems. For example, a relatively frequent patchy or discontinuous disturbance may generate substantial spatial and temporal heterogeneity within a landscape and potentially increase species diversity by creating a variety of different habitats. On the other hand, a less recurrent, more widespread disturbance of greater severity may have the opposite effect, creating a more homogeneous environment. Disturbances can both create, and be constrained by, landscape pattern. Any alteration in disturbance regime can, and likely will, result in an alteration in community composition and structure. Successful management of forested communities requires an understanding of disturbance processes. Increasingly there is an interest (and need) within land management to better incorporate natural disturbances into management planning. Of the many disturbance types found in natural systems (e.g. wind, floods, insects, and disease), perhaps the most widespread is that of fire. Fire has played a significant role in the shaping of many of the inland Northwest's diverse plant communities. The current structure, species composition, and dynamics of many ecosystems are often the direct result of past fires or, in other cases, the result of other processes that have themselves been affected by fire. In turn, other processes may have effects on the occurrence of fire across a landscape. An example of the complex relationships between disturbances is that of fire and insect outbreaks. It is hypothesized that fire exclusion has led to more widespread and more severe western spruce budworm (*Choristoneura occidentalis*) outbreaks within this century. However, fire-induced stress can also predispose stands to insect attacks. There is a great concern among land managers that the hazard of high-severity wildfires has increased throughout western North America in this century as a result of fire exclusion and various land use practices. High-severity fires are difficult to control and can often result in extensive damage to aquatic systems. This damage can occur directly, as when riparian forests burn, or indirectly as when upslope fires result in large inputs of sediment and debris to aquatic systems.

There is a growing interest in the use of prescribed fire and silvicultural treatments to reduce the ha-

zards of stand-replacement fire. Although much is known about the historic role of fire in upland forests, very little attention has been paid to the role of fire in riparian forests. The success of efforts to protect these sensitive areas requires a thorough understanding of the disturbance processes that created and maintained these forests and how these processes have changed over the last century. This study examines a number of factors that influence fire behavior and in particular influence the occurrence of crown fire behavior. This study also compares crown fire hazard between riparian and upslope stands in the Blue Mountains of northeast Oregon. It is hoped that the results of this study will increase our understanding of the fire hazards faced by land managers in the inland Northwest and perhaps contribute to a means of accurately assessing those hazards.

Wimberly, M.C.; Cochrane, M.A.; Baer, A.D.; Pabst, K. 2009. Assessing fuel treatment effectiveness using satellite imagery and spatial statistics. Ecological Applications. 19(6): 1377-1384. doi:10.1890/08-1685.1

Abstract: Understanding the influences of forest management practices on wildfire severity is critical in fire-prone ecosystems of the western United States. Newly available geospatial data sets characterizing vegetation, fuels, topography, and burn severity offer new opportunities for studying fuel treatment effectiveness at regional to national scales. In this study, we used ordinary least-squares (OLS) regression and sequential autoregression (SAR) to analyze fuel treatment effects on burn severity for three recent wildfires: the Camp 32 fire in western Montana, the School fire in southeastern Washington, and the Warm fire in northern Arizona. Burn severity was measured using differenced normalized burn ratio (dNBR) maps developed by the Monitoring Trends in Burn Severity project. Geospatial data sets from the LANDFIRE project were used to control for prefire variability in canopy cover, fuels, and topography. Across all three fires, treatments that incorporated prescribed burning were more effective than thinning alone. Treatment effect sizes were lower, and standard errors were higher in the SAR models than in the OLS models. Spatial error terms in the SAR models indirectly controlled for confounding variables not captured in the LANDFIRE data, including spatiotemporal variability in fire weather and landscape-level effects of reduced fire severity outside the treated areas. This research demonstrates the feasibility of carrying out assessments of fuel treatment effectiveness using geospatial data sets and highlights the potential for using spatial autoregression to control for unmeasured confounding factors.

APPENDIX

FIRE SIZE (ACRES) AND FIRE-FREE INTERVAL (YEARS) FOR FOUR SAMPLED AREAS IN A BLUE MOUNTAINS FIRE HISTORY STUDY (HEYERDAHL AND AGEE 1996)

		DRY-SITE FIRES		MESIC-SITE FIRES	
Study Area	Fire Year	Size (Acres)	Fire-Free Interval (Years)	Size (Acres)	Fire-Free Interval (Years)
Tucannon	1583	901			
Tucannon	1618	954	35		
Tucannon	1630	973	12		
Tucannon	1635	354	5		
Tucannon	1652	1,937	17		
Tucannon	1664	544	12		
Tucannon	1671	1,930	7		
Tucannon	1685	398	14		
Tucannon	1695	1,050	10		
Tucannon	1703	1,185	8		
Tucannon	1705	318	2		
Tucannon	1706	1,206	1		
Tucannon	1712	707	6		
Tucannon	1734	376	22		
Tucannon	1743	1,056	9		
Tucannon	1748	515	5		
Tucannon	1751	75	3		
Tucannon	1754			249	
Tucannon	1756	250	5		
Tucannon	1759	3,191	3		
Tucannon	1765	670	6		
Tucannon	1774	2,503	9	1,655	20
Tucannon	1776	295	2		
Tucannon	1779	823	3		
Tucannon	1791	425	12		
Tucannon	1799	173	8		
Tucannon	1816	1,131	17		
Tucannon	1828	2,443	12		
Tucannon	1839	1,817	11		
Tucannon	1841			296	67
Tucannon	1855	2,543	16		
Tucannon	1863	269	8		
Tucannon	1865	857	2		
Tucannon	1869	1,088	4		

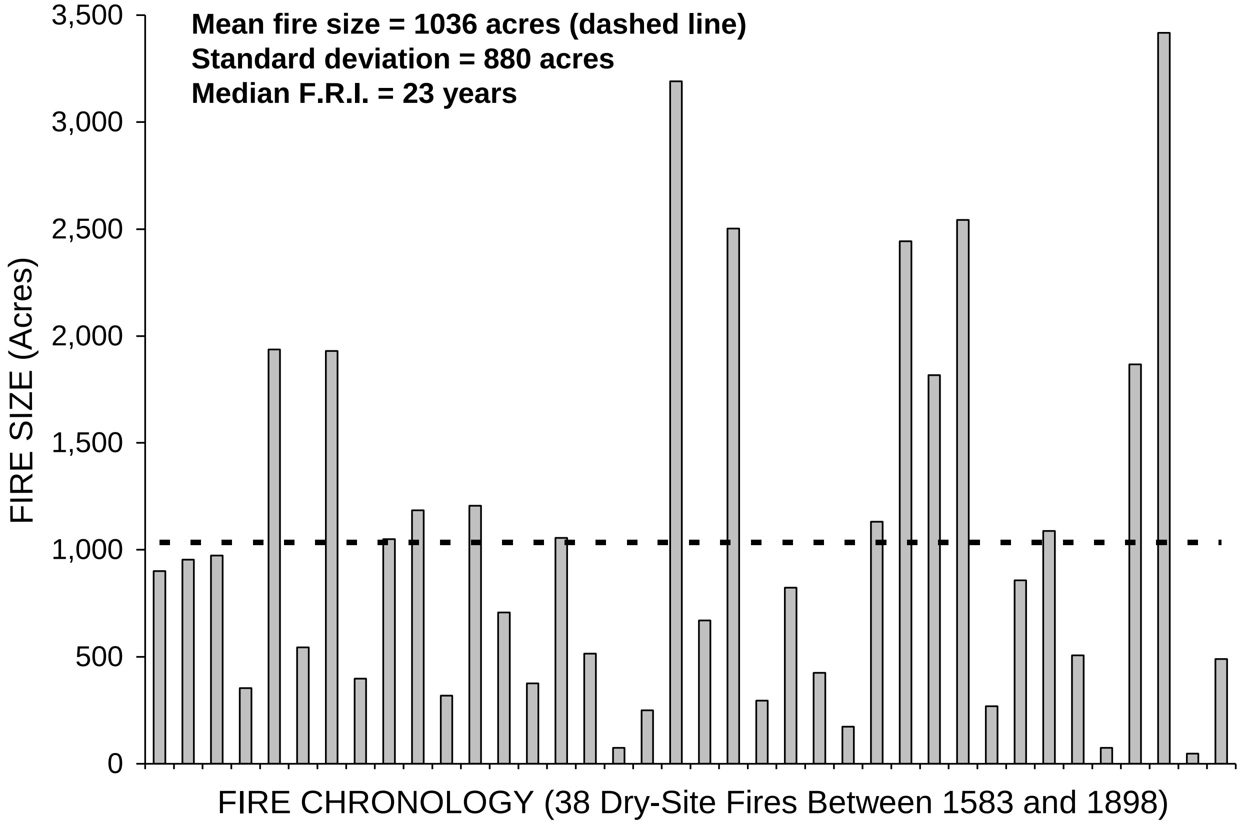
Study Area	Fire Year	DRY-SITE FIRES Size (Acres)	DRY-SITE FIRES Fire-Free Interval (Years)	MESIC-SITE FIRES Size (Acres)	MESIC-SITE FIRES Fire-Free Interval (Years)
Tucannon	1873	507	4		
Tucannon	1883	75	10		
Tucannon	1886	1,868	3		
Tucannon	1888	3,417	2	1,720	47
Tucannon	1893	47	5		
Tucannon	1898	490	5		
Tucannon	Mean	1,036	9	980	
	Min	47	1	249	
	Max	3,417	35	1,720	
	Count	(38)		(4)	
Imnaha	1632	96			
Imnaha	1652	96	20		
Imnaha	1661	294	9		
Imnaha	1671	678	10		
Imnaha	1681	96	10		
Imnaha	1687	1,434	6		
Imnaha	1705	1,768	18		
Imnaha	1712	644	7		
Imnaha	1722	607	10		
Imnaha	1724	301	2		
Imnaha	1747	200	23		
Imnaha	1751	1,251	4		
Imnaha	1752	606	1		
Imnaha	1754	390	2		
Imnaha	1763	1,347	9		
Imnaha	1778	1,731	15		
Imnaha	1783	4,289	5		
Imnaha	1795	1,583	12		
Imnaha	1798	1,847	3	1,936	
Imnaha	1831	316	33		
Imnaha	1834	4,824	3	625	36
Imnaha	1844	2,671	10		
Imnaha	1846	63	2		
Imnaha	1852	697	6		
Imnaha	1863	329	11		
Imnaha	1864			346	30
Imnaha	1869	1,764	6		
Imnaha	1871	1,682	2		
Imnaha	1885	971	14		
Imnaha	1886	1,329	1	403	22

		DRY-SITE FIRES		MESIC-SITE FIRES	
Study Area	Fire Year	Size (Acres)	Fire-Free Interval (Years)	Size (Acres)	Fire-Free Interval (Years)
Imnaha	1889	98	3		
Imnaha	1890	544	1		
Imnaha	1896	365	6		
Imnaha	1897	757	1		
Imnaha	1898	695	1		
Imnaha	1902	600	4		
Imnaha	1905	437	3		
Imnaha	1917	99	12		
Imnaha	1919	193	2		
Imnaha	Mean	992	8	828	29
	Min	63	1	346	22
	Max	4,824	33	1,936	36
	Count	(38)		(4)	
Baker	1634	3,726			
Baker	1646	3,458	12		
Baker	1652	2,933	6		
Baker	1656	3,478	4		
Baker	1668	988	12		
Baker	1671	3,443	3		
Baker	1679	3,419	8		
Baker	1695	8,184	16		
Baker	1706	1,121	11		
Baker	1708	6,046	2		
Baker	1712	1,048	4		
Baker	1717	2,276	5		
Baker	1721	1,154	4		
Baker	1722	4,559	1		
Baker	1729	7,485	7		
Baker	1739	6,499	10		
Baker	1751	6,923	12		
Baker	1756	122	5		
Baker	1762	6,375	6		
Baker	1767	1,901	5		
Baker	1770	550	3		
Baker	1776	2,479	6		
Baker	1777	1,154	1		
Baker	1778	4,660	1		
Baker	1781	909	3		
Baker	1783	6,155	2		
Baker	1788	842	5		

		DRY-SITE FIRES		MESIC-SITE FIRES	
Study Area	Fire Year	Size (Acres)	Fire-Free Interval (Years)	Size (Acres)	Fire-Free Interval (Years)
Baker	1791	7,319	3		
Baker	1794	877	3		
Baker	1797	1,321	3		
Baker	1798	2,585	1		
Baker	1800	5,925	2		
Baker	1807	283	7		
Baker	1812	3,532	5		
Baker	1816	2,626	4		
Baker	1822	6,736	6		
Baker	1826	1,738	4		
Baker	1828	1,579	2		
Baker	1833	1,411	5		
Baker	1834	5,592	1		
Baker	1839	2,711	5		
Baker	1846	9,140	7		
Baker	1854	487	8		
Baker	1855	2,266	1		
Baker	1857	2,272	2		
Baker	1865	723	8		
Baker	1869	3,026	4		
Baker	1871	647	2		
Baker	1872	93	1		
Baker	1879	190	7		
Baker	1880	121	1		
Baker	1883	82	3		
Baker	1892	233	9		
Baker	1962	93	70		
Baker	Mean	2,880	6		
	Min	82	1		
	Max	9,140	70		
	Count	(54)			
Dugout	1529	784			
Dugout	1540	1,072	11		
Dugout	1547	121	7		
Dugout	1565	2,939	18		
Dugout	1570	1,735	5		
Dugout	1593	537	23		
Dugout	1598	3,108	5		
Dugout	1629	13,668	31		
Dugout	1645	6,627	16		

		DRY-SITE FIRES		MESIC-SITE FIRES	
Study Area	Fire Year	Size (Acres)	Fire-Free Interval (Years)	Size (Acres)	Fire-Free Interval (Years)
Dugout	1652	1,472	7		
Dugout	1656	12,319	4		
Dugout	1664	801	8		
Dugout	1667	2,935	3		
Dugout	1676	9,499	9		
Dugout	1685	93	9		
Dugout	1687	16,611	2		
Dugout	1688	848	1		
Dugout	1690	1,193	2		
Dugout	1694	1,613	4		
Dugout	1697	3,523	3		
Dugout	1700	7,909	3		
Dugout	1707	2,655	7		
Dugout	1710	18,318	3		
Dugout	1721	19,959	11		
Dugout	1729	3,102	8		
Dugout	1732	2,753	3		
Dugout	1733	323	1		
Dugout	1734	5,981	1		
Dugout	1737	914	3		
Dugout	1739	4,734	2		
Dugout	1740	1,345	1		
Dugout	1741	10,588	1		
Dugout	1743	250	2		
Dugout	1745	1,937	2		
Dugout	1751	13,149	6		
Dugout	1753	932	2		
Dugout	1755	1,677	2		
Dugout	1756	9,975	1		
Dugout	1759	9,548	3		
Dugout	1765	2,147	6		
Dugout	1771	15,426	6		
Dugout	1774	1,919	3		
Dugout	1775	390	1		
Dugout	1776	3,540	1		
Dugout	1780	9,509	4		
Dugout	1783	8,797	3		
Dugout	1788	1,881	5		
Dugout	1789	733	1		
Dugout	1792	1,427	3		

Study Area	Fire Year	DRY-SITE FIRES Size (Acres)	DRY-SITE FIRES Fire-Free Interval (Years)	MESIC-SITE FIRES Size (Acres)	MESIC-SITE FIRES Fire-Free Interval (Years)
Dugout	1794	18,283	2		
Dugout	1799	8,251	5		
Dugout	1800	7,339	1		
Dugout	1802	3,633	2		
Dugout	1804	3,526	2		
Dugout	1806	259	2		
Dugout	1807	796	1		
Dugout	1812	3,876	5		
Dugout	1814	556	2		
Dugout	1822	3,886	8		
Dugout	1823	2,408	1		
Dugout	1829	19,292	6		
Dugout	1830	1,137	1		
Dugout	1835	6,856	5		
Dugout	1840	1,523	5		
Dugout	1844	18,437	4		
Dugout	1849	914	5		
Dugout	1856	7,964	7		
Dugout	1868	496	12		
Dugout	1869	18,910	1		
Dugout	1873	1,058	4		
Dugout	1877	590	4		
Dugout	1878	732	1		
Dugout	1883	1,539	5		
Dugout	1887	846	4		
Dugout	1888	2,570	1		
Dugout	1889	5,055	1		
Dugout	1898	2,003	9		
Dugout	1899	919	1		
Dugout	1914	635	15		
Dugout	1926	57	12		
Dugout	Mean	4,846	5		
	Min	57	1		
	Max	19,959	31		
	Count	(80)			
All Areas	Mean	2,953	6	904	37
	Min	47	1	249	20
	Max	19,959	70	1,936	67
	Count	(210)		(8)	



Spatial variability in fire extent for dry-forest sites in the Tucannon watershed, northern Blue Mountains of southeastern Washington (figure based on data from Heyerdahl 1997).

Forty individual fire years were determined for the Tucannon River watershed, and 38 of them included fires on what are predominantly dry-forest sites. The smallest fire extent on dry-forest sites was 47 acres and the largest was 3,417 acres. Average fire extent for the dry-site fires was 1,036 acres (the dashed line shows the average). Note that the last recorded fire for this watershed occurred in 1898 (Heyerdahl 1997).