Fire Regimes, Fire History and Forest Conditions in the Klamath-Siskiyou Region: An Overview and Synthesis of Knowledge

By

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INTRODUCTION

For thousands of years, fire has been a major evolutionary force in the Klamath Mountains[1] of northwest California and southwest Oregon, influencing forest structure, species composition, soil properties, wildlife habitat, landscape patterns, watershed hydrology, nutrient cycling and numerous other ecosystem processes (Chang 1996, Agee 1993). Most native species and communities have evolved with fire and many are adapted to, if not dependent on, fire's periodic occurrence (Barbour & Minnich 1999, Martin 1997, Kauffman 1990). Some researchers have suggested that the region's globally outstanding biodiversity is due at least in part to the natural disturbance regime in general and fire in particular (Martin & Sapsis 1992, Christensen 1991, 1985). It follows that successfully conserving ecological integrity in the Klamath Mountains depends on the extent to which fire is allowed to play its essential role in the ecosystem.

Many conservation biologists and ecologists have suggested that to be effective over the long-term, ecosystem management strategies for federal lands should restore fire using historic patterns of frequency, intensity, seasonality and spatial extent as an appropriate template for restoration (Cissel *et al.* 1999, Delong 1998, Baker 1994, Swanson *et al.* 1992, Hunter 1991). Although the specific characteristics of fire regimes before Euro-American settlement may be difficult to determine and likely varied over time, they were apparently part of an ecologically sustainable pattern that maintained biodiversity at multiple scales of organization (Swanson *et al.* 1997, Bunting 1996, Attiwell 1994). If land management agencies are to consider increasing the use of fire in the Klamath-Siskiyou region, then understanding the historic fire regimes, their natural range of variability, and how they may have changed as a result of human activities is essential (Cissel *et al.* 1999, Stephenson 1999, Delong 1998, Hardy & Arno 1996, Morgan *et al.* 1994).

This report compiles and synthesizes currently available information relating to the historic and contemporary role of fire in forest ecosystems of the Klamath Mountains. The primary objectives in conducting this synthesis are to: 1) provide the scientific foundation for developing ecologically-based fire and forest management plans, 2) evaluate the extent to which fire regimes in the region have been altered as a result of human activities since Euro-American settlement, and 3) identify existing levels of uncertainty and limits to our understanding of the ecological role of fire in this region. The central questions that will be addressed include:

- What were the historic fire regimes across the diversity of forest types and topographic settings that occur in the Klamath Mountains?

- What effects did historic fire regimes have on ecosystem dynamics and landscape patterns and what can be determined regarding the natural range of variability?

- How have fire regimes and forest conditions changed as a result of human activities since Euro-American settlement?

- Does the pattern of fires that have occurred in the 20th century provide evidence of any significant changes in fire regimes and vegetation patterns?

[1] We use the terms 'Klamath Mountains', 'Klamath-Siskiyou region' and 'Klamaths' interchangeably in this report, defined as the contiguous complex of mountain ranges that include the Siskiyou, Marble, Trinity, Salmon, Scott, and Yolla Bolly Mountains.

Information on fire history, ecology and management has been comprehensively integrated in other portions of the western U.S. (e.g. Hann *et al.* 1997, SNEP 1996) but no such effort has been made in the Klamath Mountains, a region that is gaining increasing conservation attention (Noss *et al.* 1999, DellaSala *et al.* 1999, Wagner 1997).

I. THE REGIONAL FIRE ENVIRONMENT

The coniferous and mixed evergreen forests of the Klamath-Siskiyou region are widely recognized for their globally outstanding levels of biodiversity (DellaSala *et al.* 1999, Wagner 1997, Whittaker 1961). Elements of the Pacific Northwest, California and Great Basin floras intergrade with many endemic species, including Brewer spruce (*Picea breweriana*), Baker's cypress (*Cupressus bakeri*) and Sadler's oak (*Quercus sadleriana*). The region includes the southern distributional limit of Pacific silver fir (*Abies amabilis*), Alaska cedar (*Chamaecyparis nootkatensis*) and Engelmann spruce (*Picea engelmannii*), as well as the northern limit for coast redwood *(Sequoia sempervirens*), Jeffrey pine (*Pinus jeffreyi*) and Shasta red fir (*Abies magnifica* var. *shastensis*). The unique flora, combined with varied parent materials, topographic heterogeneity and steep climatic gradients, has created an extraordinary variety of forest types ranging from coastal temperate rainforest to semi-arid oak woodlands. As a result, a broad range of fire environments and resulting fire regimes are also present.

The region's mild Mediterranean climate, characterized by warm, dry summers and cool, wet winters, is one of the primary factors affecting vegetation and fire regimes. The Klamath Mountains can be subdivided into three subregions with differing climates, forest types and fire environments (Atzet *et al.* 1992, Atzet & Wheeler 1982, Sawyer & Thornburgh 1977; Figure 1). The coastal zone, stretching from the Pacific Ocean in the northern part of the region to approximately 40 kilometers inland, has a strong maritime influence and is generally cool and wet. The environment of the western subregion, including the Marble Mountains, western Salmon Mountains, and western Trinity Alps, can be characterized as warm and moist. In comparison with the coastal subregion, fog influence here is limited, lightning is more frequent, and the summer dry season is more pronounced. The eastern subregion, located in the rainshadow of the highest peaks and including the Trinity Mountains, eastern Siskiyous, eastern Salmons, and eastern Trinity Alps, is warm and dry with the most extreme fire environment.

In addition to climate, fire regimes can generally be predicted based on characteristics of the vegetation and topography. Most of the Klamath-Siskiyou region is characterized by steep slopes and continuous areas of flammable vegetation, which together create conditions that allow fires to spread across large areas (McCutchan 1977, Schroeder & Buck 1970). Unlike the vegetation patterns found in the neighboring southern Cascades and Sierra Nevada – where forest communities typically occupy distinct altitudinal zones across relatively gentle topography – Klamath forest types are often intermixed with one another at fine scales. This extreme variability makes it relatively difficult to predict the fire regime of a particular patch of forest, as it may be equally or more influenced by the spread of fire from adjacent vegetation (e.g. Taylor &

Skinner 1998). Extrapolation of fire history information from other regions may therefore be inappropriate.

II. FIRE REGIMES IN THE KLAMATH MOUNTAINS

Reconstructing and Interpreting Fire Regimes

The role of fire in shaping the vegetation and biota of the Klamath Mountains can be assessed by understanding how these ecosystems interacted with fire in the past. Historical conditions or processes are most often characterized in terms of fire regimes, which are described in terms of ignition, frequency, severity, seasonality and spatial extent of fires occurring in a given area (Agee 1993, 1990). Fire regimes can vary considerably by vegetation type and between landscapes, and provide a generally accepted way to categorize areas for study and management purposes (Smith & Fisher 1997, Skinner & Chang 1996, Agee 1994).

Measures of historic fire regimes (e.g. length of fire return interval, severity of fire effects, size of area burned) provide a biophysical baseline – often referred to as "reference conditions" – against which current conditions and proposed management can be assessed. Increasingly, reference conditions derived from historic information are being used to create ecologically justifiable goals for forest management and restoration (Moore *et al.* 1999, Stephenson 1999, Kaufmann *et al.* 1998, Fule *et al.* 1997, White & Walker 1997, Manley *et al.* 1995). However, some researchers have expressed concern that historical conditions may not represent valid reference points for the current climatic period (Millar & Woolfenden 1999). Broad consensus appears to be emerging that managers should use historical ecology to guide the general direction rather than the precise details of restoration treatments (Landres *et al.* 1999).

Most of our knowledge of long-term fire regimes is restricted to what can be derived from analysis of fire scars preserved within the annual growth rings of old trees (Agee 1993, Arno & Sneck 1977). Depending on the spatial extent of sampling, fire histories from fire scar analysis can be related to individual tree, forest stand or landscape scales. Most studies summarized in this report represent stand-level fire histories, meaning that they are based on information collected from multiple fire-scarred trees in an area of several hectares or less. Fire history information for small, specific sites is useful for comparing fire effects within and among different vegetation types, but it does not provide much information on how fire would have influenced landscape dynamics spatial patterns. Very few landscape-scale studies have been completed in Klamath forests (Taylor & Skinner 1998).

Relatively few fire history studies have been completed in the Klamath Mountains compared to neighboring forested regions (e.g. Sierra Nevada, Cascades). Within a particular forest type, generally only a few different sites have been studied, and these fail to represent the full range of regional variability that exists within these forests. Table 1 summarizes fire history information from various published and unpublished sources for the Klamath Mountains and areas in adjacent regions that have somewhat similar vegetation and climate. Data are presented by forest type, based on the dominant tree species reported. The spatial extent of the area sampled is given to facilitate comparison and convey variation in methodologies used. The data summarized represent a period that generally encompasses several hundred years prior to Euro-American settlement.

Not surprisingly, fire histories of the forest types that occur in the region have not been equally studied. Most publications concentrate on the commercially valuable mid-montane Douglas-fir and mixed conifer forests, whereas very little of the literature includes data on foothill/lower montane, upper montane/subalpine zones and forests associated with riparian areas and ultramafic soils. Similarly, some fire regime characteristics (e.g. fire frequency) have been documented much more than others (e.g. fire size, severity). The remainder of this section will summarize what is currently known about each of the fire regime characteristics in the Klamath Mountains, followed by more specific information for the region's major forest types. Forest types are categorized into general groups based on their elevation range and geographic location.

Fire Ignitions

Lightning and humans are the two sources of fire ignitions that occurred historically and continue to occur in the Klamath Mountains. Lightning strikes are frequent across most of the region during the summer and have a sufficiently high density to ignite numerous fires (LaLande 1980, Cooper 1939, Morris 1934). Agee (1993) reported that the Siskiyou Mountains exhibit the highest patterns of lightning occurrence in the Pacific Northwest, as much as twice the number of lightning ignitions that occur in either the Cascades or Olympic Mountains (Agee & Flewelling 1983). The higher number of lightning ignitions are due to both increased lightning frequency and decreasing summer precipitation patterns characteristic of the Klamath-Siskiyou region.

July and August have been reported as the months of greatest number of lightning strikes, but August and September have the highest proportion of actual lightning-caused fire ignitions. The low probability of precipitation during the season of lightning occurrence probably allows fires to die down but not be extinguished during periods of low winds or moderate weather, and remain capable of renewed spread under patterns of windier or warmer weather.

Some lightning storms are very localized while others are regional in extent. The regional storms can ignite hundreds of fires almost simultaneously and can easily overwhelm fire suppression capabilities. For example, during the major fire episode of 1987, more than 1,600 lightning strikes were recorded during a twelve hour period in late August in southwest Oregon alone, leading to ignition of 600 fires (Helgerson 1988). These and similar strikes in northwest California led to fires on almost 400,000 hectares in the region (Walstad 1992). According to Atzet *et al.* (1988), essentially all of southwestern Oregon is sufficiently saturated with lightning to ensure that all sites will have the opportunity to burn if fuels are present and dry.

Anthropogenic (human-caused) ignitions have also been important in many forest types of the Klamath-Siskiyou region and can be divided into those started by Native Americans and white settlers. While the exact extent and frequency of Native American ignitions remains unknown, it is clear from historic accounts that most tribes used fire for many reasons. Indian burning appears to have been most frequent in low-elevation oak woodlands, prairies in the coastal forest belt, and eastside ponderosa pine/Douglas-fir forests (Sugihara *et al.* 1987). Aside from these generalities, it is not possible to separate the role of Native American ignitions from lightning sources over the last several thousand years. The most common belief is that while Native American ignitions were locally important, lightning was responsible for a large majority of historic fires and is sufficient to explain long-term fire regimes (Swetnam & Baisan 1996, Agee 1991b, Burke 1979).

After Euro-American settlement, the relatively stable areas of land burned on a regular basis by Native Americans was replaced by accidental and land use fires ignited by white settlers (LaLande 1995, 1980, McKinley & Frank 1995). Beginning in the mid-1800's and through early decades of 20th century, miners and ranchers were responsible for frequent ignitions, often during periods of extreme summer fire weather. These settlement fires differed in terms of periodicity and seasonality from fires set by Native Americans (LaLande 1995; see section on European settlement). Historical data from 1900 to 1969 for the Rogue River National Forest indicate that between 10 – 60% of fires per year were human-caused (Brown 1960). Contemporary human-caused ignitions tend to occur along travel routes and in highly accessible/developed areas where people are concentrated (USDA Forest Service 1998, 1996, Burke 1979).

Fire Frequency

Fire frequency, typically expressed in terms of the fire return interval (FRI), is the most commonly reported attribute of the fire regime. The FRI integrates fire occurrence frequency and fire size to describe the period of time it takes for fire to burn most or all of a unit area of land (Agee 1993). In most fire history studies, multiple fire-scarred trees are sampled at each site, and when fire scars have been dated, the mean or median period of time between all recorded fires is computed. While many studies have reported means as a statistic of central tendency, medians are more appropriate for fire history studies because FRIs are often not represented by a normal distribution (Skinner & Chang 1996). In addition, the pattern of fire return intervals often varies from period to period, and therefore a simple mean may not be representative of longer records (Swetnam 1993).

Some of the data on fire frequency reported for the Klamath Mountains should be interpreted with considerable caution because of methodological problems and potentially erroneous assumptions. For example, fire return intervals reported by Atzet & Martin (1992) and White *et al.* (in press) are based on specific age classes of trees that are assumed to indicate dates of historic fires, rather than on analysis of fire scars. While regeneration of shade-intolerant tree species may be expected to increase after fire, some evidence suggests that tree age cohorts can not be reliably correlated with fire events in the Klamath-Siskiyou region (Stuart & Salazar in press, Tom Sensenig, Medford District BLM, pers. communication). Other variables, such as seed availability, post-fire weather, and variations in soil conditions may also obscure fire-induced patterns of stand development.

Other studies may have produced biased fire return intervals because of a small sample size or restricted location of the study area. The FRI statistic is sensitive to the area sampled, therefore, to make relative comparisons, the spatial scale of sampling has to be taken into account (Agee 1993). The return intervals reported here (Tables 1 and 2) are mostly point or plot composites, which means they are the sum of fire intervals for several to many trees at sites of one to several hectares in size. However, a few studies calculated fire return intervals for significantly larger areas, up to 91 hectares in the Klamath-Siskiyou region (Agee 1991a), and larger for some studies conducted in the southern Cascades. Variation in size of area for which fire return intervals are calculated makes comparisons between some studies problematic.

Given these caveats, available studies indicate that median fire return intervals in forests of the Klamath Mountains vary considerably with forest type, ranging from as high as 140 years in Douglas-fir/mixed conifer forests (van Norman 1998) to 10 years or less in tanoak, jeffrey pine

(White *et al.* in press) and ponderosa pine/Douglas-fir (Taylor & Skinner 1994; Table 1). Both subregional and forest type differences are evident, but overall, fires were moderately frequent, averaging between 15-40 years in 19 of the 32 fire return intervals that have been reported. Generally, it appears that fire frequency increases from west to east and from higher to lower elevations (Atzet & Wheeler 1982).

Mean or median return intervals for forest types primarily associated with the coastal subregion (coast redwood, western hemlock, and Port Orford cedar) are at least 50 years, and are often likely to be considerably longer. Although no data are presented, Atzet & Wheeler (1982) estimate that the fire-free period varies between 100 – 200 years in the coastally-influenced portion of southwest Oregon. Similarly, Veirs (1985) reports that fire frequency in the North Coast Range of California is much lower than inland areas, due to the maritime influence on relative humidity and fuel moisture. The frequency of lightning ignitions is also known to decrease with closer proximity to the coast (Stuart & Salazar, in press).

Variation in fire return intervals from one study area to another within the same forest type is often significant. Within Douglas-fir/mixed conifer forests, for example, average intervals between fires vary from modal values of 15 years (Taylor & Skinner 1998) to 120 years (van Norman 1998). Furthermore, the large majority of studies show considerable variation in fire frequency within individual study areas. Stuart & Salazar (in press) report a mean FRI of 39 years for white fir *(Abies concolor*) forests in the western Klamath Mountains, with a range of fire-free periods from 12 to 161 years. Other studies conducted in the region report similarly wide ranges in the intervals between fires, which overall appear to be wider than those from similar forest types in the southern Cascades (Table 1) and Sierra Nevada (Skinner & Chang 1996).

Ecologists have recognized that the variation in intervals between fires at any one site may be more critical than average intervals to understanding the effects of fire over time on vegetation (Taylor & Skinner 1998, White *et al.* in press, Skinner 1997). For example, one 40 year interval between fires on a site is sufficient to allow shade-tolerant tree species (e.g. white fir, incense cedar) to establish and grow to a size where they are relatively fire-resistant (Agee 1993, Taylor 1993, Sugihara & Reed 1987). Fire-free periods of this length have been reported in many Klamath fire history studies, even in forest types with relatively high fire frequency (White *et al.* in press, Taylor & Skinner 1998, Adams & Sawyer 1980). Christensen (1985) proposed that species diversity in many ecosystems may actually depend on such variation. Ecological process modeling (Keane *et al.* 1990) indicates that vegetation and fuels would be significantly different from pre-settlement patterns if fire return intervals were regular, without variation.

The wide variation in fire return intervals characteristic of fire regimes the Klamath Mountains has been attributed to the effects of topography, elevation, weather, fire regimes in adjacent areas, and chance (Moir & Mowrer 1995, Brown 1994, Agee 1991a). Cursory examination of the data in Tables 1 and 2 suggests that forest types with the greatest variability in fire return intervals tend to occur in more mesic environments and at higher elevations. Moister sites (e.g. coastal areas, canyon bottoms, north-facing slopes and higher elevations), are less likely to have fuels sufficiently dry to burn as on drier sites or south-facing slopes (Heyerdahl *et al.* in press, Teensma 1987, Kilgore & Taylor 1979). Some studies have found at least a weak correlation between topographic variables (aspect, slope steepness, slope position) and fire frequency (Taylor & Skinner 1998, 1997, Key 2000), while others have not (White *et al.* in press, Cissel *et al.* 1999, van Norman 1998). Refer to Tables 1 and 2 and the next section of this report for more information on variation in fire frequencies associated with particular forest types.

Fire Intensity and Severity

Fire intensity and severity are two terms associated with the magnitude of fire effects, but have distinctly different meanings in the fire ecology literature. Fire intensity is defined as the amount of energy released from a fire, and may or may not be directly related to effects of fire on the biota. Descriptive measures of fire intensity include the mass of fuel consumed, and the rate of spread of the fire, and the position of the fire front within the forest profile (ground, subcanopy, overstory). The following discussion will focus primarily on fire severity.

Fire severity is a more qualitative measure of magnitude used to describe the degree to which vegetation and site conditions have been altered by a fire. This attribute generally reflects mortality of dominant tree species present in a given area, and is useful in recognize the variability in fire that occurs within or between fires. Three levels of fire severity are typically recognized in the literature (Agee 1994, 1993, Wright & Bailey 1982):

High severity – Most trees, including overstory trees, are killed.

Moderate severity – Partial stand-replacement fires that include areas of both low and high severity. Some overstory trees are killed or heavily damaged in high severity patches.

Low severity – Light surface fires that have minimal impacts on forest overstories, but may kill small trees and shrubs.

It is usually not possible to measure historic fire severity directly. Inferences are generally drawn based on patterns of fire return intervals, stand age class structures and species composition.

In general, there is an inverse relationship between fire frequency and severity; longer intervals between fires allow for a greater accumulation of fuels that lead to hotter, more severe fires when ignited (Agee 1993). Since most of the forests in the Klamath-Siskiyou region burned at moderate to high frequencies, it follows that most fires produced moderate to low-severity effects on the vegetation. Examination of early historical accounts of fires in the Klamath Mountains generally supports this conclusion (LaLande 1995, McKinley & Frank 1995, Morris 1934). Evidence collected from dendrochronology studies indicates the dominance of moderate or “mixed” severity fires (Tables 1 and 2), where a complex, irregular pattern of tree mortality and openings are created. The patchiness associated with moderate severity fires has been instrumental in promoting species and habitat diversity in the Klamath-Siskiyou region (Sapsis & Martin 1993, Martin & Sapsis 1992).

Within an individual fire, severity is a result of the complex interaction of many temporal and spatial factors including forest structure, fuel availability and moisture, topography, weather, and fire behavior in adjacent areas (Heyerdahl *et al.* in press). Patches of high tree mortality, ranging in size from individual trees to hundreds of acres, are thought to have been relatively common and occurred in areas with heavy fuel accumulations sometimes reinforced by steep slopes or extreme weather conditions (van Norman 1998, Wills & Stuart 1994, Stephenson *et al.* 1991, Agee 1991a). Fires would be most likely to burn at low intensity during cool nights, periods of mild weather, in areas with low fuel loads, and/or under mesic conditions (Agee 1991b). Larger stand replacement fires probably occurred in moderate severity fire regimes, but at relatively long intervals (>300 years) and likely under extreme fire weather conditions (Stuart & Salazar in press, Atzet & Wheeler 1982).

White *et al.* (in press) found that forest types characterized by low-severity fires (e.g. Jeffrey pine and mountain hemlock series) were generally drier (mean annual precipitation) or cooler (mean annual temperature) than forests with more moderate intensity fires (e.g. tanoak series). They suggested that fire severity may be correlated with forest productivity, because fuels accumulation is more limited in dry and cool environments. Taylor & Skinner (1998) found that fires tended to burn at higher severity on upper slopes, ridgetops and south- and west-facing slopes than lower slopes or east- and north-facing slopes. Fires on sites with rocky or very shallow soils with scattered trees, such as those often found in canyon live oak or subalpine forests, result in little mortality due to lack of fuels (Agee 1993).

These historic patterns of fire severity are consistent with observations of recent fires in wildlands of the Klamath Mountains, many of which continue to burn in a mosaic pattern and result in varying levels of tree mortality. For example, of the 38,200 ha affected by the Silver Fire in southwest Oregon, 9% was high severity, 32% was moderate severity and 59% was low severity (USDA Forest Service 1988). Patches of high mortality were generally less than several hundred acres. The 1994 Dillon Fire on the Klamath National Forest, and the Big Bar and High Fire complexes that occurred in 1999 on the Shasta-Trinity National Forest also burned as primarily low-severity fires with varying-sized stand replacement patches (USDA Forest Service 1999). Additional discussion on the potential change in fire severity from the pre-settlement to contemporary era will be presented later in this report.

Seasonality

The vegetation found within a particular ecosystem has generally adapted over long period of time to the season(s) in which fires generally occur; therefore the seasonality or timing of fire occurrence can be very important in determining fire effects (Skinner & Chang 1996, Agee 1993).
For example, spring burning occurs at a time when buds are flushing and are much more susceptible to damage than fires burning in summer or fall (Parker 1987).

The position of fire scars within annual growth rings (e.g. late wood vs. early wood) of trees is commonly used to provide an estimate of the season of past fire occurrence (Dieterich & Swetnam 1984). Data on seasonality of fire is limited in forests of the Klamath Mountains – to date, only a few studies have investigated this fire regime characteristic. In general, seasonal fire scar positions have been found in the latter portions of annual rings, indicating that most fires occurred late in the growing season, from mid-summer to early fall. This is consistent with typical lightning patterns observed in the region, with most of it striking in the late summer (Automated Lightning Detection System 1999).

After being ignited in July and August, many fires appear to have the ability to spread over weeks or months, with periods of smoldering or slow progression alternating with aggressive runs when weather becomes hot or windy. Morris (1934) quotes the Jacksonville newspaper in 1864: “during the past few weeks…the fires [in the Siskiyous] have been raging with increasing fury”. About 70% of recent large fires in the two most northwestern California counties burned during August and September (Gripp 1976). Large fires may burn until autumn rains arrive in October or even later, as was the case with the 1987 wildfires that burned into November (Helgerson 1988).

Although the greatest number of fires and large fire events occur in late summer and early fall, the climate is variable enough to allow occasional fires during favorable periods in the late spring and early summer, particularly on warm, dry sites (C. Skinner, Pacific Southwest Research Station, pers. communication). The more xeric, low-elevation forest types, including interior oak woodland, ponderosa pine, and jeffrey pine are the forests that are most likely to burn early in the fire season, especially those on southerly aspects. The shorter duration of snow cover on south aspects results in longer periods during which fuels are sufficiently dry for fires to ignite and spread (Heyerdahl *et al.* in press).

Spatial Extent and Landscape Pattern

The spatial extent of past fires refers to the size of the area affected by a fire and the landscape patterns that are created as a result (Agee 1993). Fire extent is difficult and time-consuming to determine in ecosystems characterized by mostly low- and moderate-intensity fires, because it requires numerous cross-dated fire scars from a wide area of the landscape, from which deductions of past fire extent can be drawn. But even this technique is incomplete because such fires would not have scarred every tree within the fire perimeter. In forests that burn with high severity, fire extent may be obvious for a century or more from the mosaic pattern of different-aged stands (Agee 1993).

Relatively few of the fire history studies conducted in the Klamath Mountains have presented data on the spatial extent of fires. Agee (1991a) found that mixed severity fires in Douglas-fir and white fir forests of Oregon’s Siskiyou Mountains were historically small to intermediate sizes, ranging from 86 to 576 hectares. Working in similar forest types in northwest California, Taylor & Skinner (1998) reported a mean size of 350 ha. for historical fires, with a range of 28 to 1340 ha, and suggest that large spreading fires are characteristic of Douglas-fir dominated forests in this region. Most of the fires that burned in the 45,000 hectare Little River watershed (near the northern boundary of the Klamath-Siskiyou region) were between 10 and 400 hectares, with a few up to 3,000 hectares in size (van Norman 1998). The dominance of small and intermediate-sized fires in the Klamaths is similar to findings from nearby regions with similar vegetation and climate (Table 1).

The range of variability in spatial extent of historic fires is important in understanding fire as an ecosystem process. Evidence of fire sizes taken from giant sequoia groves in the Sierra Nevada indicates that when fires were more frequent, they appear to have been relatively small and patchy, but during periods of less frequent fires, they were larger and generally more continuous (e.g. drought; Swetnam 1993). Large fire years are often associated with regional events and extreme climatic conditions (McKelvey & Busse 1996, LaLande 1995, Morford 1970). According to Atzet & Wheeler (1982), very large, often stand-replacement fires occur, on average, every 200 years in coastal and western subregions. The 1987 wildfires and 49,000 hectare Big Bar fire complex that burned in 1999 are the most recent examples of this pattern.

It seems probable that the extreme topographic variability characteristic of the Klamath Mountains may help to control the extent and pattern of most fires by inhibiting fire spread (Taylor & Skinner 1998, Swetnam & Baisan 1996, Swanson *et al.* 1988). Forests in this region are typically embedded in and distributed across highly dissected terrain where rivers, ridges, serpentine barrens, and rocky outcrops interrupt the continuity of surface fuels and thereby help to limit fire size (Franklin & Dyrness 1973). In areas where forest types with different fire regimes are closely juxtaposed, the characters of each intermingle and are sometimes indistinguishable (Heyerdahl *et al.* in press, Taylor & Skinner 1998, Agee *et al.* 1990). Local-scale variation in topography can affect the moisture content of fuel by influencing microclimate and can further affect fire regimes by influencing fuel continuity (Taylor & Skinner 1998, Wright 1996, Tande 1979).

The relationship between fire attributes and topography appears somewhat contradictory from the literature, with significant correlations reported in some studies but not others. Taylor & Skinner (1998) found that slopes with south- and west-aspects tended to burn more frequently and at higher severity (Key 2000) than those with north- and east slopes. Similarly, fires were slightly more frequent at low elevations, on ridgetops and steep slopes in Douglas-fir forests of the North Umpqua Basin (van Norman 1998) and western Oregon Cascades (Weisberg 1998). In contrast, White *et al.* (in press) detected no relationship between fire severity and aspect, slope or slope position in Jeffrey pine and mountain hemlock forests. In the Blue Mountains of northeast Oregon, Heyerdahl *et al.* (in press) found no difference in fire attributes between aspects where different slopes interfinger without fire barriers.

It is speculative but consistent to infer that variation in topography at the local scale at least partially explains the wide range of fire sizes and large number of patch types that are characteristic of the Klamath-Siskiyou region. Over several decades to centuries, a mid-scale watershed is likely to have experienced considerable shifting of patch locations and types. Some patches may have had dominantly young trees, resulting from areas of high-intensity fire and could be considered early successional; more often patches would be comprised of mixed age classes and species composition, resulting from numerous fire events of varying intensity. Individual trees persisted to old age within many different patch settings, ranging from dense, near even-aged stands of old trees to scattered, even solitary old trees surrounded by shrublands or other non-forest vegetation (Wills & Stuart 1994, van Norman 1998). More landscape-level fire history studies are needed in order to better understand how fire affected vegetation patterns, wildlife habitat and other attributes of ecosystems that occur at larger spatial scales.

III. FIRE REGIMES OF MAJOR FOREST TYPES

Coastal/Lowland Forests

The boundary of the Klamath-Siskiyou region as defined by Noss *et al.* (1999; Figure 1) extends west to meet the Pacific Ocean near the mouth of the Klamath River in Del Norte County and continues north along the coast through Oregon. This coastal subregion of the Klamaths is dominated by wet, lowland forest types, similar in structure to those found further north in the Oregon Coast Range. Two coastally-influenced forest types will be considered here, based on their dominance in this subregion and the availability of fire history information: coast redwood *(Sequoia sempervirens*) and western hemlock (*Tsuga heterophylla*).

Coast Redwood

Coast redwood forests extend north into the Klamath-Siskiyou region in Del Norte County and in extreme southwest Oregon (Sawyer *et al.* 1999a). Coast redwood is the principal tree but associated species include Sitka spruce (*Picea sitchensis*), western hemlock, grand fir (*Abies grandis*), Douglas-fir (*Pseudotsuga menziesii*) and western redcedar (*Thuja plicata*). Tanoak (*Lithocarpus densiflorus*), bigleaf maple (*Acer macrophyllum*), vine maple (*Acer circinatum*) and California bay (*Umbellularia californica*) are common hardwoods. Redwood forests are found from sea level to about 2,000 feet elevation, with the best developed stands below 1,000 feet. Annual precipitation is high and summer fog is common (Sawyer *et al.* 1999b).

Despite a number of fire history investigations, the role of fire in coast redwood forests is still incompletely understood. A 1984 workshop on fire ecology and fire management in coast redwood (Veirs 1985), concluded that “our understanding of the role of fire is inadequate to clearly define the effects of a given fire regime in redwood forests”. For example, even whether redwood should be considered a fire-dependent species is still debated (J. Sawyer, Humboldt State Univ., pers. communication). The dominant view is that fire has a low to moderate ecological impact in those redwood forests that occur in and immediately adjacent to the Klamath-Siskiyou region (Agee 1993). Most available data on fire history comes from analyses of fire frequency.

Fire return intervals reported for northern redwood forests are highly variable, and probably reflect differences in local topography and climatic conditions (Brown 1991). Veirs (1980a) used stand age structure distributions to suggest that FRI varied along an increasingly dry ocean to inland gradient. The most mesic, coastal sites experienced fires every 250-500 years, intermediate sites 150-200 years, and inland xeric sites 33-50 years. In contrast, Brown and Swetnam (1994) reported a pre-settlement mean FRI of only 7 years from a cross-dated fire history study in old-growth redwood forests of Prairie Creek State Park, California. Researchers working in redwoods further south, outside of the Klamath-Siskiyou region, have reported FRIs of 31 years (Humboldt Redwoods State Park; Stuart 1987), 20-29 years (Salt Point and Annadale State Park; Finney & Martin 1992, 1989) and 22-27 years (Muir Woods National Monument; Jacobs *et al.* 1985)

The origins of fires in redwood forests are not understood, because lightning is infrequent in these coastal locations (Sibley, unpublished data, cited in Veirs 1982). Native Americans were known to burn the open “prairies” (Lewis 1973, Drucker 1937); it follows that redwood forests located near the edge of these prairies may have burned quite frequently (e.g. Brown & Swetnam 1994). Veirs (pers. communication) has suggested that fires were driven into these forests by dry winds from the interior in late summer and autumn. The spatial extent of past fires in redwood forests has not been documented. Stuart (1987) reported mean fire sizes of 786 – 2,018 ha in Humboldt Redwoods State Park (south of the Klamath-Siskiyou region), which may be larger than those expected in the more mesic northern stands.

Historic fires appear to have been mostly low to moderate severity, with rare high-severity fires (Sawyer *et al.* 1999b). Coast redwood trees are very fire-resistant, are capable of basal sprouting following fires and regenerate well on bare mineral soil (Sawyer *et al.* 1999b). Because of this, some authors have suggested that redwood is a fire-dependent species (Stone & Vasey 1968, Cooper 1965). Other tree species that occur in these coastal forests, including grand fir, Sitka spruce, tanoak and western hemlock, have little fire tolerance and may be killed even by light underburns (Agee 1993).

Western Hemlock

Forests dominated by western hemlock occur in extreme northwest California and southwest Oregon on warm, wet coastal sites and protected inland areas with deep soils and northerly aspects (Sawyer & Keeler-Wolf 1998, Atzet *et al.* 1992). Elevational distribution ranges from near sea level to 4,000 feet on the western slopes of the Siskiyou Mountains (Atzet *et al.* 1992). Other important tree species include Douglas-fir, tanoak, Port Orford-cedar (*Cupressus lawsoniana*) and California bay (*Umbellularia californica*). *Tsuga heterophylla* forests in the Klamath-Siskiyou region represent the drier, southern-most extension of a type that is much more widespread in western Oregon and Washington.

Very little is known about the fire history of western hemlock forests in the Klamath-Siskiyou region. Most research in this forest type has occurred further north, where conditions are considerably different. The closest studies known are from the central Oregon Cascades, where fire return intervals of 95-145 years (Morrison & Swanson 1990) and 100 years (Teensma 1987) have been reported. However, other stands 500 years old or older exist without much evidence of fire. Atzet & Martin (1992) reported a mean FRI of 65 years in western hemlock forests, a figure which was estimated from total disturbance history of sampled stands as opposed to fire scar analysis.

Fire severity in these drier *Tsuga heterophylla* forests is generally considered patchy, with individual fires including areas of stand replacement, partial mortality, and cool underburns (Weisberg 1998, Morrison & Swanson 1990, Means 1982). Light ground fires that do not open the canopy favor western hemlock regeneration but may lead to mortality of older hemlocks, which are not very fire tolerant (Agee 1993). Port Orford cedar, tanoak and other hardwoods appear to maintain their status with or without fire (Atzet *et al.* 1996, Sawyer & Keeler-Wolf 1995).

There are no data available from the Klamath-Siskiyou region to shed light on the historic extent of fires in western hemlock forests. Agee (1993) suggests that fire sizes are limited by periods of fire-prone weather, which average several days or weeks before being naturally suppressed by onshore marine airflow and/or precipitation. Some very large, stand replacing crown fires have undoubtedly occurred in the past, such as the 1868 event that burned roughly from Yachats, Oregon in the north to the mouth of the Klamath River in California. This fire event was believed to have burned all summer, spreading inland as far as 50 kilometers in some areas (Cooper 1939). Whether lightning or humans were the cause of these fires is unknown, but they most likely occurred during a relatively rare, prolonged period of extreme fire weather in late summer and fall.

Foothill and Lower Montane Forests

Oak Woodlands

Oak-dominated woodlands and open forests occupy a variety of low-elevation sites in the Klamath Mountains, including ridgetops (e.g. the "bald hills" of the western subregion), river canyons, foothills of inland valleys and droughty sites with shallow, rocky soils scattered through the interior forests below 3,000 feet (Sawyer & Keeler-Wolf 1995, Sawyer & Thornburgh 1977b). Forest structure varies from open savannahs with grass understories to closed-canopy stands with a minor conifer component (Agee 1993, Thilenius 1968, Whittaker 1961). In terms of dominant tree species, three major types of oak woodlands have been recognized in the region: Oregon white oak (*Quercus garryana*), California black oak (*Quercus kelloggii*), and canyon live oak (*Quercus crysolepis*; Sawyer & Keeler-Wolf 1995, Atzet *et al.* 1992).

Although these woodland types may differ in terms of species composition and structure, they all occur in areas that are physiologically marginal for tree growth, because of water limitations caused by low rainfall and/or thin, droughty soils (Minore 1979). Oak stands are generally more common in the southern and eastern portions of the Klamath-Siskiyou region, where annual precipitation is less than 40 inches and dry-season rainfall is less than 6 inches (Atzet *et al.* 1992). Whittaker (1960) described oak woodlands dominated by an overstory of *Quercus kelloggii* and *Q. garryana* as the driest forested association in his transect across the Siskiyou Mountains. The three major oak woodland types show similarities not only in some climatic and edaphic factors but also in characteristics of the fire regime and ecological interactions with fire.

Information on the fire ecology of oak woodlands in the Klamath Mountains is very limited. Evidence of fires from fire scars on trees is often lacking, and because oak woodlands are not commonly used for timber production, they have received less study than other forest types. Because oaks regenerate from both seedlings and sprouts, stand development patterns are not easily interpreted. Most oaks, with relatively thick corky bark and the ability to basal sprout, are well-adapted to frequent fires. Regeneration of oak seedlings may be associated with microsites of bare soil created by fire (Agee 1993 and references cited therein).

In one of the very few studies on fire and oak woodlands in the Klamath-Siskiyou region (the Bald Hills area of Redwood National Park), Sugihara & Reed (1987) found evidence of burning since 1875 and documented eight fires since 1917 in one Oregon white oak stand which translates into a mean FRI of approximately 8 years. This study likely underestimates the actual fire return interval, because frequent low-intensity fires would not always be recorded on trees. Most of the evidence that suggests frequent burning comes from historical accounts of Native American subsistence patterns. Extrapolation from historical information suggests that average fire return intervals in oak woodlands were typically less than 5 years, with the most heavily used sites burning almost every year (Lewis 1993, Sugihara & Reed 1987).

Fires set regularly by Native Americans are thought to play an important part in sustaining the character of many oak woodlands (Lewis 1993, Sugihara *et al.* 1987, Boyd 1986). The myriad reasons why Native Americans burned, and the sophistication of their practices, are topics that lie beyond the scope of this report. Most early historical accounts of settlers traveling through oak woodlands note evidence of fire, suggesting frequent burning (LaLande & Pullen 1999). Low intensity fires on average every few years kept conifers from invading and allowed for easy acorn gathering (Thilenius 1968, Habeck 1961). Extent of the fires is also unknown but may have been substantial given the dry conditions and abundance of fine fuels created by dense understory of grasses and forbs (particularly in the Oregon white oak type; Agee 1993).

Oak woodlands growing on unproductive sites, such as canyon live oak stands found in major river canyons, likely exhibit a different fire regime from those associated with more productive sites. Soils on steep canyon slopes in the western and eastern subregions are often very dry, rocky and shallow, preventing establishment by most shrubs and trees. As a result, fuel accumulation occurs rather slowly and is often discontinuous (Casey Stewman, Humboldt State

University, pers. communication, Skinner 1995b, Minnich 1980). Although few data are available, fire frequency in these unproductive types may be lower than what has generally been suggested for oak woodlands (e.g. median FRI of 11 years, with a range of 3 – 55 years; unpublished data cited in Skinner & Chang 1996). Oak stands occupying unproductive sites are also less likely to be invaded by conifers, and may have changed relatively little due to fire suppression (Casey Stewman, Humboldt State University, pers. communication).

Douglas-fir/Hardwood

Douglas-fir/hardwood forests include a number of types where Douglas-fir shares dominance with one or more sclerophyllous broad-leaved hardwoods, of which tanoak is most common (Sawyer & Keeler-Wolf 1995, Bingham & Sawyer 1992, Franklin & Dyrness 1973). As effective moisture decreases, the dominant hardwood species gradually shifts from tanoak to Pacific madrone (*Arbutus menziesii*) to California black oak and Oregon white oak to canyon live oak, with giant chinquapin (*Chrysolepis chrysophylla*) on cooler sites (Agee 1993, Sawyer 1980). Conifers other than Douglas-fir, including ponderosa pine (*Pinus ponderosa*), sugar pine (*Pinus lambertiana*) and incense cedar (*Calocedrus decurrens*), may occur in low to moderate densities.

Douglas-fir/hardwood forests are the most widespread type in the Klamath-Siskiyou region, extending over millions of hectares, primarily in the western subregion (Atzet *et al.* 1992, Sawyer *et al.* 1977). The type occupies a broad elevational band beginning just inland of the redwood and western hemlock forests near sea level and extending east up to approximately 4,000 feet, where it grades into more mesic mid-montane Douglas-fir (without hardwoods) and then white fir forests (Sawyer *et al.* 1977, Sawyer 1980). Relatively xeric, unproductive sites support a higher proportion of sclerophyllous hardwoods and lower density of conifers (McDonald & Tappeiner 1996, Thornburgh 1982).

The fire regime of Douglas-fir/hardwood forests is considered by Agee (1993) as one of the most variable in the Pacific Northwest, "prevent[ing] generalizations about fire and its ecological effects". Both historic and contemporary fires have included intense stand-replacing conflagrations, mixed severity fires, and low intensity underburns, often within the same fire perimeter. As flames encounter different fuel conditions and weather (e.g. cooler, more humid nights vs. drier, warmer days), the intensity of fire and effects on vegetation vary in complex spatial and temporal patterns. The result is a patchy mosaic of mostly multi-aged stands across the landscape, with each patch exhibiting different tree densities, ages and species (Wills & Stuart 1994, Agee 1993).

Douglas-fir/hardwood forests experience a high number of lightning ignitions, and are typically continuous with other forests from which fires may easily spread (Agee 1993). July and August are the months of greatest lightning activity, but September has a higher proportion of total fire ignitions (Agee & Flewelling 1983). Native American ignitions probably supplemented lightning in specific portions of the landscape where fire was used to clear travel corridors or maintain populations of plants used for food (e.g. tanoak, hazel) and basketry (e.g. beargrass; Boyd 1986, Lewis 1973). Once started, fires in these forests can spread across very large areas, depending on weather, fuels, topography and other factors. The exceptionally large 1987 fires affected tens of thousands of hectares of Douglas-fir/hardwood forests, but even larger fire events are known from the historic record (Agee 1993, Atzet & Wheeler 1982, Morris 1934).

Considerable variability in fire frequencies has been reported in the literature for Douglas-fir/hardwood forests, with modal return intervals ranging from 3 to 90 years across the region (Tables 1 and 2). In the Salmon River watershed of northwest California, Wills & Stuart (1994) found mean fire return intervals of 13-22 years, but with high variability (3 – 71 years). Several other studies report mean or median FRIs in the range of 10-30 years, with shorter intervals associated with more exposed sites and drier types (e.g. Douglas-fir/canyon live oak) found further east (White *et al.* in press, Atzet *et al.* 1996, Atzet & Martin 1992, Agee 1991a, Adams & Sawyer 1980). Fire-free periods over 50 years have been documented in the pre-settlement era, allowing fire-sensitive young conifers to reach a size that is relatively fire resistant. Keeler-Wolf (1990, 1985) described extensive old-growth Douglas-fir/hardwood stands on cool, mesic sites in the Marble Mountains that have not burned for more than 150 years.

Evidence suggests that the intensity of fires encompassed a wide range of fire severity with many fires, or large portions of them, burning at low to moderate severity (Agee 1993). Even intense stand-replacing fires are characterized by a high degree of patchiness in this forest type (Wills & Stuart 1994, Wright & Bailey 1982). Severely burned areas may account for only 15-20% of the total area burned (Atzet & Martin 1992, Adams & Sawyer 1980). The high variability of fire intensity and frequency in these forests creates multiple developmental pathways, that at maturity converge on the modal type with an open Douglas-fir overstory and more continuous understory of hardwoods (Thornburgh 1982, Sawyer *et al.* 1977).

The patterns of fire effects in these forests reflect variable fire severities and ability of the different species to take advantage of post-fire conditions. Young Douglas-fir are generally killed by fire, but become highly fire resistant with increasing age (Agee 1993). The hardwood species are thin-barked and often top-killed by low and moderate intensity fires, but aggressively resprout. The sprouting ability of hardwoods provides a definite advantage (as an early post-fire occupier of) on burned sites. The following four scenarios span the range of fire interactions with stand development in Douglas-fir/hardwood forests (adapted from Agee 1993, Thornburgh 1982):

1) In the absence of fire, importance of hardwoods (especially tanoak) will increase but stand will remain co-dominated by long-lived Douglas-fir. Species composition may remain somewhat stable over many decades (Hunter 1997, Jimerson 1990).
2) Low-intensity fires thin small Douglas-fir and create variable-sized gaps that allow for additional regeneration. Some hardwoods are top-killed but resprout. Successive fires of this type separated by decades result in stands with multiple age classes and fine grained patchiness, similar to what has been documented in mixed conifer forests of the Sierra Nevada (Fites-Kauffman 1997, Bonnicksen & Stone 1981)
3) After a moderate fire, the site will be co-dominated by hardwood sprouts and scattered large Douglas-fir produce numerous seedlings. The hardwoods will grow more quickly at first, but eventually Douglas-fir will overtop them.
4) After a more severe fire, there may be few surviving young Douglas-fir. The stand will be dominated by hardwoods or shrubs for decades until Douglas-fir invades from adjacent stands. Post-fire colonization by conifers can be spread over up to 50 years following fire (Agee 1991a, Means 1982).

It can be seen from this how fire frequency and intensity interact to produce a landscape with high spatial heterogeneity in the Douglas-fir/hardwood forest type.

Ponderosa Pine/Douglas-fir

Dry, relatively open forests of ponderosa pine and Douglas-fir are found intermingled with oak woodlands and mixed conifer forests in the lower montane zone (1,500 – 3,500 feet) of the eastern and central Klamath Mountains (Waring 1969, Whittaker 1960). While both species are typically present, ponderosa pine dominates xeric sites and slopes with south- or west aspects, whereas Douglas-fir is more important on mesic sites. Annual precipitation is less than 70 cm (30 in) but soils are often deep (Atzet & Wheeler 1982). Many authors have included this forest as a variant of the mixed conifer type, but it is differentiated by the absence of white fir and greater importance of oaks (usually *Quercus kelloggii* and/or *Q. garryana*) as secondary associates (Sawyer & Keeler-Wolf 1995). Other conifers that may be present, generally in low numbers, include incense cedar, western juniper (*Juniperus occidentalis*), knobcone pine (*Pinus attenuata*) and sugar pine (Sawyer & Keeler-Wolf 1995, Eyre 1980).

Generally the fire regime of the ponderosa pine/Douglas-fir forest type is characterized by frequent fires of low to moderate intensity. Skinner & Chang (1996) report a median fire return interval of 11 years for ponderosa pine/mixed conifer forest (with a range of 3 – 55 years), and Taylor & Skinner (1994) estimates the mean FRI for a ponderosa pine/Douglas-fir forest in the north-central Klamath Mountains as 10 years (no range is given). In the Sierra Nevada, where this type is more widespread, Skinner & Chang (1996) report historical FRIs were commonly less than 10 years. Frequent fires are likely a function of the prolonged dry season, abundance of surface fuels in the form of conifer needles, herbaceous vegetation and oak leaves (Rothermel 1983), and the regular use of fire by Native Americans to manage this forest type (Lewis 1993, Boyd 1986).

Historically, low intensity surface fires were the norm in the ponderosa pine/Douglas-fir forest type, with occasional flare-ups occurring in shrub patches (Chang 1996, Skinner & Chang 1996). Although little data are available from the Klamath-Siskiyou region, crown fires were apparently rare (Husari 1980). These understory fires thinned saplings, maintained relatively open understories and created occasional openings for pine and oak seedling establishment in more intensely burned patches where fuel loads are locally higher (Chang 1996, Agee 1993, Rundel *et al.* 1977). Thick bark, deep roots, and low-flammability crown structures help mature pines and oaks to survive most fires (Kauffman 1990). In the absence of fire, they will eventually be crowded out by the more shade tolerant Douglas-fir (Weatherspoon *et al.* 1992, Biswell 1989).

The fire season is relatively long in comparison with most other forest types in the Klamath-Siskiyou region, extending from early June on the driest sites (e.g. southerly aspects) to early October. Some fires were probably ignited by lightning, but Indian burning was also significant (LaLande & Pullen 1999, Lewis 1990). Little is known of the spatial extent of fires in this forest, but data from other regions suggests small to moderate sized events, with occasional large fires (Agee 1990). Small openings allow for the regeneration of shade-intolerant pines and oaks, which thereafter are occasionally missed by or survive fires until they become fire-resistant (Husari & Hawk 1994). Hence, the landscape pattern is often characterized by even-aged groups in a fine scale, uneven-aged mosaic (Agee 1990, Wright & Bailey 1982).

Mid-Montane Forests

White Fir

The white fir forest type is the most environmentally variable and one of the most common in the Klamath-Siskiyou region (Atzet & Wheeler 1982, Franklin & Dyrness 1973). It is most commonly found at intermediate elevations (4,000 – 6,000 feet), particularly in the western subregion, where it grades into Douglas-fir/hardwood and Shasta red fir forest at its lower and upper limits, respectively. White fir (*Abies concolor*) is the major tree species, often forming pure or nearly pure stands. The most common secondary associates are Douglas-fir, sugar pine and incense cedar, but most conifer species in the region may be present in small numbers. The climatic environment is generally cooler (but not necessarily moister) than the Douglas-fir/hardwood type, and is the lowest zone where significant winter snow accumulation occurs.

Four studies have been conducted in the Klamath-Siskiyou region that describe one or more characteristics of the fire regime in white fir forests. Agee (1991) found a mean fire return interval of 43 years in a white fir/Douglas-fir community and a 61-64 year mean FRI for a more mesic white fir/herb type, suggesting a decrease in fire frequency with increasing elevation and/or moisture. Using different methodologies in widely separate study areas, Atzet & Martin (1992), Thornburgh (1995) and Taylor & Skinner (1994) all estimated modal FRIs in white fir of 25-29 years. Unfortunately, none of these studies reported a range of variability associated with these values.

The most comprehensive analysis of fire patterns in white fir forests has been conducted by Stuart & Salazar (in press). Based on data collected from numerous sites across the Six Rivers National Forest, they calculated a mean FRI of 39 years, but with a very wide range (12 –161 years). No correlation was found in their study between fire frequency and distance from the ocean, elevation or latitude. Because white fir is highly susceptible to fire damage (especially when young), frequent fires favor sugar pine, ponderosa pine and other more fire-resistant conifer species (Thornburgh 1995, Atzet & Wheeler 1982).

The intensity and severity of fires in white fir forests are both most often described as low to moderate, with patches of high severity (Agee 1993, 1991, Stuart & Salazar in press). In comparison with Douglas-fir/hardwood and mixed conifer forests, fires in white fir generally spread more slowly and begin at lower intensity, a result of the tightly packed litter layer and dense canopies that shelter fire from the wind and direct rays of the sun (Husari & McKelvey 1996). As fire size increases under favorable combinations of topography, fuels and weather, fire intensity generally increases and becomes more variable.

Multiple age classes are often present in white fir forests where fires causing partial mortality have occurred, thereby allowing for initiation of subsequent cohorts (Stuart & Salazar in press). However, large, stand-replacing events are not uncommon in this type, particularly after an extended fire-free period when fuel accumulations are high. Such intense fires occur when lightning ignitions overlap with extreme fire weather (Talbert 1996, Gripp 1976). In a study of vegetation effects from the 1987 fires in the Marble Mountains, Thornburgh (1995) found a patchy mosaic of fire severity, and noted that severity was correlated with successional status. Young, even-aged white fir stands mostly experienced high intensity fire, whereas old-growth stands were underburned with little overstory mortality.

Little work has been done to investigate seasonality and spatial extent of fires in white fir. It can be inferred from climatic conditions that most fires burned in late summer to fall; fires initiated in summer might slowly burn across the landscape until extinguished by autumn rains. White fir forests probably have a shorter fire season than lower elevation types; in comparison with Douglas-fir, white fir produces shorter needles and reduced depth of surface fuels. Older white fir stands also form a cooler, damper microclimate, that may impede fire spread (Atzet & Wheeler 1982).

Agee (1991) reported fire sizes from 86 to 576 ha around Oregon Caves National Monument, and found that many fires stopped at the lower boundary of the more mesic white fir type, presumably due to higher cover in the herb layer and lower fuel moistures.

Although individual fires may have burned in a relatively homogeneous fashion, over time the combination of multiple fires burning at low, moderate and occasional high intensity resulted in a patchy mosaic of stand structures and composition across the landscape. Fire played a role not only in shaping the overall landscape mosaic but also in creating a diversity of individual patch types as a reflection of variability in fire frequency and severity at the same site (Stuart & Salazar in press, Agee 1991). Unburned patches were often left within burned areas, where fuel profile was discontinuous or where fire burned during cool weather or at night. Studies conducted in white fir forests in the southern Cascades generally show a similar pattern of fire (Table 1).

Mixed Conifer

Mixed forests of white fir, Douglas-fir, sugar pine, ponderosa pine and incense cedar typify mid-elevations in the eastern subregion of the Klamath Mountains (Sawyer & Thornburgh 1977). They are essentially a northern extension of the well-known Sierran montane or mixed conifer forest (Sawyer & Keeler-Wolf 1995, Fites 1993, Rundel *et al.* 1977), and in the eastern Klamaths are generally located on slopes and ridges between 3,500 and 5,500 feet elevation, above ponderosa pine – Douglas-fir forests and oak woodlands. White fir often dominates the species mix on north aspects and higher elevations, whereas ponderosa pine is most important at lower elevations and on south slopes. California black oak, canyon live oak, and bush chinquapin (*Castanopsis chrysophylla*) may be present, as well as Shasta red fir (*Abies magnifica* var. *shastensis*) at the highest elevations. Some authors consider this type as a subset of white fir forests, but their regional location and fire regime are considerably different.

The fire regime of mixed conifer forests has mostly been described as one of relatively frequent, spatially variable fires of low and moderate severity, with occasional small patches of high-severity fires (Skinner & Chang 1996, Agee 1993). Median FRIs for areas of mixed conifer forest in the Klamath Mountains were reported by Agee (1991) to have been 13 years (with a range of 3 – 57 years), by Skinner (1994) as 17 years (with a range of 7 - 50 years), and by Skinner (in press) as 7 - 13 years with a range of 4 - 64 years (Table 1). The sites represented by these studies are geographically distributed from the central Siskiyou Mountains near the OR-CA state line to the Scott Mountains along the Shasta-Trinity Divide, covering a variety of elevations and topographic positions. Medians and ranges of mixed conifer FRIs in the southern Cascades appear to be slightly lower and less variable than those in the eastern Klamaths (Table 1).

It is important to note the medians and range of FRIs in this forest type (up to 50-65 years in length) are considerably shorter than those reported for mid-montane forests more commonly associated with the western Klamath subregion (e.g. white fir, Douglas-fir types). Shorter return intervals and more consistency in the fire frequency probably allows for continued co-dominance of shade-intolerant ponderosa pine and sugar pine. However, the occasional longer interval is sufficient to allow for young white fir and Douglas-fir to reach a size that is resistant to low-severity fire (Agee 1993). Thus, the temporal variation in fire patterns is likely to influence the variation in species composition of the mixed conifer forest over the landscape (Agee 1993).

Fire intensities appear to have been mostly low to moderate in mixed conifer forests of the eastern Klamaths, generally thinning the forest according to species susceptibility to fire, tree size and density. Under severe fire weather or in a stand that had experienced a longer fire-free interval, small to intermediate-sized patches (tens to hundreds of hectares) of high intensity fire probably occurred within a matrix of low intensity. Following the 1987 fires, Weatherspoon & Skinner (1995) found only small, widely dispersed patches of high-severity fire in unmanaged mixed conifer forests in the Trinity Mountains near Hayfork. Fire severity generally increases with increasing elevations, and was probably more variable on moist sites than on drier sites (Caprio & Swetnam 1995, Toth *et al.* 1994, McNeil & Zobel 1980).

There exists very little data on the spatial extent and landscape pattern for mixed conifer forests in the Klamath-Siskiyou region. However, some careful inferences can be made from studies conducted in similar forests of the southern Cascades and Sierra Nevada. In these adjacent regions, clumped aggregations of large trees, often of several species, exists at a fine scale (Stephenson *et al.* 1991, Bonnicksen & Stone 1981). Thomas & Agee (1986), for example, found clumped distributions of ponderosa pine, sugar pine and white fir in old-growth stands at Crater Lake National Park. The source of the clumping is not clear, but may be associated with good seed years, presence or absence of fire in a young patch, and competitive relationships between the species (Agee 1993). The northerly aspects most likely had different species composition from and greater tree densities than the southerly aspects, as well as different scales of tree aggregation or stand clumpiness.

Upper Montane and Subalpine Forests

The upper montane and subalpine zones include several different forest types in the Klamath Mountains, of which Shasta red fir (upper montane) and mountain hemlock (subalpine) are the most common and well-known. These forests are often found on upper slopes, high ridges and the tops of peaks in the western and eastern subregions (Sawyer & Thornburgh 1977). Subalpine areas are prone to frequent lightning strikes (van Wagtendonk 1991), but ignite spreading fires only under specific conditions. This is due to the shortness of the fire season, the compactness and/or discontinuous nature of fuel beds, and the relatively common natural fuel breaks (meadows, rock outcrops, etc.) that occur here.

Shasta Red Fir

Forests dominated by Shasta red fir represent the upper montane zone in the Klamath Mountains (Sawyer & Thornburgh 1977, Franklin & Dyrness 1973). Generally found between 6,000 and 8,000 feet in this region, the type is closely allied with red fir forests of the California Cascade Range and Sierra Nevada (Rundel *et al.* 1977). Forests in the *Abies magnifica* zone often form nearly pure stands, except in ecotonal areas, where a wide variety of associated conifers, including mountain hemlock (*Tsuga mertensiana*), western white pine (*Pinus monticola*), lodgepole pine (*Pinus contorta* var. *murrayana*) and white fir may be present (Sawyer & Thornburgh 1977). They generally occupy cool sites with a substantial winter snowpack (six feet or more; Waring 1969). In the western subregion (Siskiyou Mountains north of the Klamath River), noble fir (*Abies procera*) replaces Shasta red fir but is nearly indistinguishable without mature cones. The taxonomic status of the two taxa remains unclear (Sawyer & Thornburgh 1977).

The fire history of red fir forests is not well known, at least in part because of the difficulty in accurately characterizing past fires; fire scars can be grown over, the species tends to rot after being scarred, and evidence of a fire is often obscured by the low intensity of some fire events (Agee 1993). However, red fir forests are most often described as exhibiting a moderate fire regime, with fire frequencies and intensities fairly similar to those dominated by *Abies concolor*. The only reported estimate of mean fire return interval from the Klamath Mountains is 40 years (Atzet & Martin 1992), but this value was derived from age class analysis rather than direct evidence of fire. However it may be possible to infer at least some characteristics of the fire regime in red fir forests from studies conducted in the southern Cascades.

At Swain Mountain in northeastern California, Taylor & Halpern (1991) found a mean FRI of 40-42 years on 0.5 to 1.0 ha plots, with a highly variable range of 5-65 years. Using larger sample areas of 3.0 and 400 ha in the same study area, Taylor (1993) reported FRIs of 16-19 and 13 years (range 1-57 years). At Crater Lake National Park, McNeil & Zobel (1980) and Chappell & Agee (1996) calculated mean FRIs of 20 and 45 years, respectively, with fire-free intervals ranging from 8 to 157 years. These studies suggest that fires are a moderately frequent disturbance in red fir forests, but considerable variability exists both temporally and spatially. Skinner & Chang (1996) suggested that the high variability in FRIs from site to site may be primarily associated with local variation in fuel loads in red fir stands. Higher elevation areas appear to have less frequent fires because biomass accumulates more slowly and weather conditions that will carry a fire occur less often (Weatherspoon *et al.* 1992).

Available evidence suggests that fires burning in red fir forests span the complete range of intensities, resulting in patches of low to high-severity effects. High spatial variability of fire in the red fir type is exemplified by the 1978 Crater Peak Fire in Crater Lake National Park, where severity levels were distributed evenly in total area and interspersion (29% low, 32% moderate, and 34% high-severity, 5% non-forest; Chappell & Agee 1996). The proportional distribution of severity classes appears to vary considerably from fire to fire, with old-growth stands being least likely to burn at high-severity (Chappell & Agee 1996). In some areas of the Klamath-Siskiyou region, red fir stands that burn infrequently or at low intensity serve as refugia for endemic or relictual conifers that are fire sensitive, including Brewer spruce (*Picea breweriana*), Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*; Sawyer & Thornburgh 1970, 1977).

The spatial extent of fires in red fir forests range from small (a few hectares) to large (up to thousands of ha), leading to a complex landscape pattern of varying patch sizes and tree ages (Chappell & Agee 1996). At Crater Lake, numerous natural fires in this zone reached an estimated 200 ha in size (Agee 1993). Fire sizes estimated from fire scars, age classes and other patterns of tree-ring variation in the Caribou Wilderness near Lassen National Park ranged from 22 ha to 1,067 ha, with a median size of 101 ha. Small fires appeared to have been mostly low-severity, whereas larger burns had considerable portions affected by moderate to high-severity fire (Taylor 1995).

The high spatial and temporal variability of fires in red fir forests creates numerous options for vegetation establishment, composition and survival. For example in the southern Cascades, Chappell & Agee (1996) found that red fir forest development in a recently burned patch depends on 1) fire severity, 2) patch size and 3) the presence or absence of lodgepole pine as a prominent pre-fire stand component. Low-severity fires generally consume surface fuels, expose mineral soil, and thin patches of seedlings and saplings, whereas large high-severity patches are more likely to become dominated by shrub and herb communities, which can persist for an indefinite period until red fir is able to regenerate (Taylor 1993). Repeated fires could maintain shrubfields for a longer time or favor establishment of shade-intolerant species. The result is a dynamic, complex pattern of species, age classes and patches over the landscape.

Mountain Hemlock

Forests dominated by mountain hemlock represent the highest distinct forest zone in the Klamath Mountains. The type occurs sporadically on cool, north-facing cirque-like topography at elevations above 5,000 feet, and in continuous stands on all types of topography above 7,000 feet, sometimes delimiting timberline (Sawyer & Keeler-Wolf 1995, Atzet *et al.* 1992). Mountain hemlock is well-adapted to the cold, moist climates found at these elevations, and typically dominates both the overstory and understory. Shasta red fir, western white pine, Brewer spruce and lodgepole pine are the most common associates. At the highest elevations where mountain hemlock extends to timberline, it mixes with whitebark pine (*Pinus albicaulis*) and foxtail pine (*Pinus balfouriana*). Prolonged winter snowpack is characteristic of these forests, with maximum depths of 7-8 m possible in the wettest locations. The short growing season and typically cold/moist environmental conditions have significant effects on the fire regime in these forests.

Very little is known about the long-term patterns of fire in subalpine forests of the Klamath Mountains. Mountain hemlock and most other subalpine conifers are not well-adapted to resist fire, so few fire-scarred trees survive to provide a record of past events. Although these areas receive a high proportion of lightning, environmental conditions are generally not conducive to fire ignition or spread. The fires that do occur probably are ignited late in the growing season (August – September), when fuel and foliar moistures are low. Studies in whitebark pine forests, where fire-scarred trees are available, have found that fires occurred throughout the short growing season, but the largest fires occurred late in the season (Agee 1993). Unusual spring fires burning through the canopies of stands with snow on the ground have been reported in subalpine forests of the Oregon and Washington Cascades (Huff & Agee 1991).

Only two published studies include any information on fire frequency and severity in mountain hemlock forests, and these are based on a coarse analysis of tree age classes rather than dendrochronological techniques. Atzet & Martin (1992) report a mean fire-free period of 115 years in mountain hemlock in the Siskiyou Mountains of southwest Oregon, the longest of any forest type in the Klamath-Siskiyou region. Using a similar methodology in the same area, White *et al.* (in press) calculated mean FRIs of only 12 – 36 years for mountain hemlock forests, with the most frequent intervals in the driest plant association. These data, however, are somewhat suspect because they are based on analysis of tree cohorts rather than direct evidence of fire.

Although no data are presented, the Siskiyou National Forest reported FRIs of 100 - 300 years for the mountain hemlock series in southwest Oregon (USDA Forest Service 1995).

In other regions of the Pacific Northwest (e.g. Cascades, Olympics), fires in mountain hemlock forests are generally infrequent and older forests predominate (Agee 1993). For example, Dickman & Cook (1989) found that at least half of their 18,000 ha study area in the central Oregon Cascades had burned over in the last 500 years, suggesting that fire events are infrequent. In contrast, unpublished data cited by White *et al.* (in press) from the southern Oregon Cascades indicate much shorter FRIs of 13 – 64 years. Given the Klamath-Siskiyou region's complex topography, vegetation mosaic and long dry season, fire return intervals are likely to be highly variable and shorter than those reported for more northerly regions (T. Atzet, Siskiyou National Forest, pers. communication).

When fires do occur in mountain hemlock forests, substantial tree mortality (high-severity effects) is often the result, because of the lack of fire resistance of the major tree species. Lower intensity fires may occur in mountain hemlock forests, as fire scars are often present in these stands (Agee 1993, Atzet & Martin 1992). White *et al.* (in press) suggested that a significant proportion of fires were of a moderately low surface fire intensity, since residual mountain hemlock apparently survived. The scarring might be associated with the type of log-to-log burning pattern observed in other subalpine forest types (Taylor & Fonda 1990, Agee 1981). South-facing slopes are likely to burn more intensely than north-facing slopes (Agee & Smith 1984). Open stands near timberline dominated by whitebark pine, foxtail pine are thought to rarely ever burn (Morgan & Bunting 1990).

Little information exists on the size of fires in mountain hemlock forests. Areal estimates are obscured by the fact that these forests are rarely contiguous over large areas, often grading into meadows, rock outcrops and other non-forested areas (Sawyer & Thornburgh 1977, Franklin & Dyrness 1973). It can be inferred that natural fuel discontinuities may not allow fire spread to the next forest patch, thereby restricting them to small size (Agee & Smith 1984). Agee (1993) suggests that the size distribution of fires in this zone approaches a negative exponential pattern (many small fires, few large ones). Large crown fires, perhaps separated by centuries, will burn under unusual climatic conditions (e.g. strong winds, drought) regardless of the fuel situation (Agee 1993), and may account for the dominant forest age class in any given landscape (Agee 1993, Dickman & Cook 1989).

Forests of Riparian Areas and Ultramafic Soils

Jeffrey Pine

Areas of ultramafic rocks and soils (e.g. serpentine, peridotite) display distinctive vegetative differences in comparison with surrounding landscapes and are varied in the forest types they support (Coleman & Kruckeberg 1999, Kruckeberg 1984, Sawyer & Thornburgh 1977). Forests on the most extreme sites in the Klamath-Siskiyou region are most often dominated by open, often pure stands of Jeffrey pine (Sawyer & Keeler-Wolf 1995, Whittaker 1960). Many other conifers with some tolerance for ultramafic parent material may occasionally be found in small numbers, including western white pine, incense cedar, sugar pine, knobcone pine and lodgepole pine. These forests are characterized by a well-developed understory of dense grasses and scattered shrubs; *Arctostaphylos canescens*, *A. viscida*, *Rhamnus californica*, *Quercus vaccinifolia*, and *Ceanothus cuneatus* are common shrub species.

Jeffrey pine forests are found across a wide range of elevations and topographic positions in the Klamath Mountains, but are perhaps most extensive on the Josephine ophiolite in Del Norte and Josephine Counties, of the western subregion. In the eastern Klamaths, the type is occasionally found off ultramafic soils on rocky slopes and ridges. Sites with less extreme serpentine influence support a modified form of the mixed conifer forest, where Jeffrey pine shares dominance with the other conifers typical of this type in open stands (Sawyer & Keeler-Wolf 1995). Port Orford cedar is often the dominant or co-dominant species on ultramafic soils near the coast, where abundant moisture moderates soil conditions (Atzet *et al.* 1992). The flora associated with these forests is unusual, including numerous rare and endemic species (Kruckeberg 1984).

Similar to many other forests in the Klamath-Siskiyou region, very little research has investigated fire history in the Jeffrey pine type. According to Atzet & Wheeler (1982), “fire infrequently occurs in this series”, but no data are presented. The only available reports of fire frequency were based on analysis of tree age classes and can be considered only rough estimates. According to Atzet & Martin (1992), FRIs in the Jeffrey pine series average 50 years across southwest Oregon. Using similar methods, White *et al.* (in press) estimate considerably shorter FRIs for the same area, averaging 7 – 25 years. Neither of these studies reported a range of variability for estimated fire return intervals. Areas located closer to the coast (e.g. Del Norte County) may burn less frequently due to a shorter fire season and fewer lightning ignitions than inland sites (Stuart & Salazar, in press).

Stand density and fuel loads in these forests are generally limited by their low productivity associated with ultramafic parent material. As a result, most fires were probably low intensity and similar in nature to those associated with open ponderosa pine forests that are found in the eastern Klamath subregion on dry, low elevation sites (Simpson 1980, Sawyer & Thornburgh 1977). The dense understory of grasses and shrubs, together with pine needles, creates a flashy fuel load that encourages frequent, widespread burning (Agee 1993). Even in low-severity fire regimes, however, intense fires may sometimes occur, possibly due to longer than normal fire return intervals that allow litter and understory fuels to accumulate, or due to very unusual fire weather, such as strong winds. Even-aged Jeffrey pine stands have been identified at Pine Flat Mountain in Del Norte County, suggesting a stand replacement fire (Duebendorfer 1987).

Little is known about the seasonality or spatial extent of individual fires in Jeffrey pine forests. Most fires probably occur in late summer and early fall, similar to most other forest types in the region. Large fires have been reported for ponderosa pine forests in other regions of the Pacific Northwest (Agee 1993, Biswell 1989), but it is unclear whether similar patterns apply to Jeffrey pine in the Klamath-Siskiyou region. Areas of bare serpentine rock and other discontinuities in surface fuel may commonly may act as barriers to fire spread, thereby restricting fires to a small size. What extent fires play in influencing stand dynamics, relative to soil effects and other environmental factors, is also unknown. More research is clearly needed on the long-term fire regime of Jeffrey pine forests.

Riparian Areas

Riparian areas are defined as the zones of transition from the terrestrial uplands to aquatic habitats, and support plant communities associated with high availability of water throughout the growing season (Naiman *et al.* 1993). They are found in essentially all forest types. Though riparian areas occupy a very small proportion of the forest landscape, they are generally the most productive sites and have a disproportionate importance for fish and wildlife (Kondolf *et al.* 1996, FEMAT 1994, Naiman *et al.* 1993). Riparian forests in the Klamath Mountains are often dominated by species that are relatively uncommon in upland settings, including Port Orford cedar, Pacific yew (*Taxus brevifolia*), black cottonwood (*Populus trichocarpa*), mountain alder (*Alnus rhombifolia*), bigleaf maple and other deciduous hardwoods. Because of cooler air temperatures and valley-bottom locations, riparian areas often represent the down-canyon extension of a higher elevation forest type (Franklin & Dyrness 1973).

Fire history studies specific to riparian areas in the western U.S. are generally rare. Some inferences can be drawn from the information that is available, but these are based on little empirical evidence and may not reflect specific fire regimes or landscape conditions in the Klamath Mountains. Determining fire return intervals may be complicated by the presence of tree wounds from ice flows (Filip *et al.* 1989) and the short life span of most riparian hardwood species. However it is generally recognized that most western riparian areas burn at a significantly reduced frequency – up to several times longer – than adjacent uplands (Skinner & Chang 1996, Arno 1996, Agee 1993).

Skinner (in press) reported median FRIs from 16 – 42 years (with a range of 5 – 71 years) for four riparian areas within enriched mixed conifer forests of the eastern Klamath subregion north of Lake Shasta. These values were consistently longer (at least double) and more variable than those from adjacent upland forests, even for riparian areas that were only a few feet wide. A significant proportion fires burned on only one side of a stream, suggesting that riparian areas often act as barriers to fire spread and thereby influence landscape patterns far beyond their immediate vicinity (Skinner in press). Most of these fires were of low and moderate intensity, inferred from the presence of numerous fire-scarred conifers.

The lower temperatures, moister air and less flammable vegetation combine to reduce fire intensities in riparian areas. Low intensity ground fires in riparian areas often topkill shrubs and some deciduous trees, such as willows and cottonwoods, but most of these species resprout and soil stability is not impaired (Kauffman 1990). Most conifers easily survive such fires, and fire-sensitive species like Pacific yew and Engelmann spruce often do so by growing in wetter microsites. Infrequent stand-replacing fires do occur, particularly in steep headwater areas where a wind-driven channeling effect occurs (Agee 1994, Skinner in press).

Although direct evidence is limited, the landscape position and size of riparian areas appear to be important determinants of the fire regime for a particular site. In mixed conifer forests of the northern Sierra Nevada, Fites-Kauffman (1997) found that FRIs in riparian zones associated with small, intermittent streams in upper slope locations were fairly similar to adjacent upland areas. In contrast, FRIs for riparian areas associated with large perennial streams in valley bottoms were considerably longer than those of similar upland areas. Evidence of frequent fires in steep upper reaches of intermittent streams was also reported by Taylor & Skinner (1998) in their landscape-level fire history study in the Klamath Mountains. Small, narrow riparian areas are likely to experience more frequent and higher intensity fires than large, broad riparian areas, and those in drier areas will probably burn more frequently than those in wetter areas.

IV. THE HUMAN INFLUENCE ON FIRE REGIMES

In this section we evaluate the influence of human activities on fire regimes in the Klamath-Siskiyou region, summarize the available fire history data from the 20th century, examine various theories and supporting evidence on how today's fire regimes may differ from historic conditions and interpret the ecological significance of these changes for biodiversity conservation and ecosystem management. The information presented here was gleaned from a diversity of sources, including the anthropological literature, general historical accounts, agency fire records, and findings reported by researchers working in other regions. While this information provides valuable insights into the recent past, it is important to recognize the sources suffer from being: 1) anecdotal (e.g. accounts of a few early inhabitants); 2) incomplete and less reliable the further back in time you go (e.g. official records of past fires); or 3) based on indirect information that is subject to varying interpretations. This body of evidence does not provide clear, unequivocal answers; as a result, there will always be some uncertainty about how things used to be (Swetnam *et al.* 1999, Skinner 1997).

Native Americans

It is well established that the substantial Native American populations that inhabited the Klamath Mountains region prior to the arrival of European settlers had well-developed traditions of intentional burning that undoubtedly had significant influence on vegetation patterns. Fire was commonly used by the Shasta, Takelma, Karuk, Tolowa and other tribes for a variety of reasons: to maintain open stands of oaks, aid in the collection of insects, fungi and acorns, clear areas for travel, and to improve habitat for favored plants and game animals (LaLande & Pullen 1999, Anderson & Moratto 1996, McDonald 1979). According to Leiberg (1900), most Indian-set fires occurred in the fall and were "small and circumscribed" but of frequent occurrence. Readers seeking a more detailed discussion of Native American burning practices in the Klamath-Siskiyou region, which is beyond the scope of this assessment, are directed to LaLande & Pullen (1999), Pullen (1996), LaLande (1991, 1995) and Lewis (1990).

While most environmental historians and ecologists generally acknowledge the important role of Native American fires in the Klamath-Siskiyou region as elsewhere along the Pacific coast, there remains some debate over the extent of burning and the degree to which it influenced regional fire regimes across the landscape. The ambiguity results from our inability to separate out the cultural component of historic fire regimes, and the confounding effects associated with changes in climate over the last several thousand years (Millar & Woolfenden 1999b, Swetnam *et al.* 1999). The influence of Indian fire also likely varied considerably over time in response to changing population densities and resource demands (Russell 1997).

Although Native Americans used fire and therefore influenced vegetation patterns, they did not occupy all areas or all ecosystems, nor impose broad-scale and intense impacts on all the area they did occupy (Vale 1998, Delcourt & Delcourt 1997, Swetnam & Baisan 1996, Cermak & Lague 1993). Indian-set fires likely had considerably more influence in some forest types than others. Multiple lines of evidence from the Klamath-Siskiyou region, as elsewhere in the

California and Oregon, indicates that anthropogenic fire was a major force in establishing and maintaining the character of lower-elevation grasslands, chaparral, oak woodlands and ponderosa pine forests, particularly when located immediately around settlements and in areas used more intensely to obtain resources (LaLande & Pullen 1999, Sugihara *et al.* 1987, Barrett & Arno 1982). In general, fires were ignited more frequently at lower elevations and decreased as elevation increased (Anderson & Moratto 1996, LaLande 1995).

Outside of oak and pine-dominated forests, little convincing evidence exists that aboriginal ignitions were ecologically significant across large landscapes. As stated by LaLande & Pullen (1999), "Within the vast mid-elevation, mixed conifer and mixed evergreen forests [comprising the largest vegetation types in the Klamaths], the extent of anthropogenic fire likely was limited and localized – i.e. confined to creating scattered, small openings. Aside from these localities, lightning-caused fire probably deserves more of the credit for the formerly open, park-like stands of most mid-elevation, mixed conifer stands". While further investigations may shed light on the relative importance of Native American burning, at present the case for widespread influence in conifer-dominated forests in the Klamath-Siskiyou region is not convincing.

European Settlement

Beginning in the early 1820's and continuing into the early part of the 20th century, the influence of Indian burning declined dramatically across most of the Klamath-Siskiyou region as native peoples were either exterminated or moved onto reservations. The relatively stable areas of land burned on a regular basis in specific localities was replaced by a set of accidental and land use fires ignited by white settlers (LaLande 1980, 1995, McKinley & Frank 1995). The primary reasons for historic-era burning that have been documented include: to remove vegetative obstacles for mineral prospecting or for easier travel, to drive game, enhance forage for livestock, and to clear land for agriculture (Atzet *et al.* 1988, Martin *et al.* 1981, LaLande 1980, 1995, McDonald 1979, Brown 1960). Typically the intent was to burn off as much vegetation as possible. Many fires also were initiated accidentally from campfires "which the settlers rarely took the time or trouble to extinguish when breaking camp" (Leiberg 1900).

Fires lit by whites during the settlement era (approximately 1850-1920) were significantly different at least in terms of seasonality and intensity from those previously lit by Native Americans. Historical accounts indicate that settler-ignited fires were generally larger in extent and burned at higher intensity than Indian fires, and most often occurred during the hot, dry summer as opposed to spring or fall. Leiberg (1900) states that fires were "more numerous and devastated much larger areas in the early days of settlement than they did before". The Ashland Tidings complained in 1896 that "every year forest fires become more and more of a nuisance" (LaLande 1995).

Settler fires also affected a broader range of vegetation types than those lit by Indians, and may have more greatly influenced the region's mid-elevation conifer forests. Early accounts of the southwest Oregon landscape commonly include references to human-caused forest fires and their effects. In his description of the Rogue River National Forest in southwest Oregon, Leiberg (1900) states that "Fires have widely ravaged the region. There is not a single forested township either on the westside or eastside of the range in which the timber is not more or less fire marked". Atzet *et al.* (1988) has suggested that many of the region's even-aged 70-170 year old forest stands were initiated by human-ignited fires during this period.

Intentional fires set by whites continued to be a significant influence – particularly in the more heavily settled portions of the Klamath-Siskiyou region – up through the 1930's. Many settlers held unfavorable opinions of the Forest Service's practice of fighting fires, and continued to burn for many years after a policy of fire suppression was formalized (LaLande 1995). In 1931, an excerpt from a Siskiyou National Forest diary notes that " …the Curry County Reporter, a Gold Beach newspaper, was still advocating burning of the forest" (Talbert 1996). Not until 1939 did the Rogue River National Forest report that forest-wide, "most incendiary burning has been eliminated or brought under control" (McKinley & Frank 1995).

Fire Suppression

After many years of using fire to promote livestock grazing and clear vegetation, organized fire suppression was initiated in 1906 with the creation of the federal forest reserves, later to become the U.S. national forest system. Although a matter of public policy, relatively little energy was actually directed toward putting out fires on federal lands in the early decades of the 20th century, mainly because the manpower available for fighting fires was hopelessly inadequate. The typical forest reserve was comprised of a million acres with a staff of eight personnel, including clerks (McKinley & Frank 1995). Individual rangers were responsible for fire detection and control on hundreds of thousands of acres of remote, mountainous forest land. As a result, many fires grew to considerable size before even being detected. Once discovered, lack of effective means of communication often delayed report to the headquarters office. After report of a fire was received, lack of roads and trails made it difficult and often impossible to get an adequate fire-fighting force together with the necessary tools and supplies to the scene. As a result, fires often burned uncontrollably until they either burned themselves out or were extinguished by the weather (White & Huhtala 1997, Davies & Frank 1992, Show & Kotok 1924, Ringland 1916, Burns 1911).

The ineffectiveness of these early fire-fighting efforts was made worse by the fact that numerous lightning-caused fires were often burning at the same time, which "made it impossible for the small force of rangers and guards to cope with the situation successfully" (Burns 1911). Fire-fighting efforts were primarily directed at the most accessible and heavily settled areas to protect human life and private property, with little or no resources directed to control fires burning in more remote areas (Davies & Frank 1992, Morford 1984, Cooper 1939). Given these limitations, it's unlikely that fire suppression was an important factor influencing the character of vegetation across large portions of the Klamath Mountains until at least the 1940's. This date is corroborated by several fire history studies that have documented surface fires burning uninterrupted into the middle of the 20th century (Taylor & Skinner 1997, 1998, Wills & Stuart 1984).

Fire suppression efficiency in the Klamath-Siskiyou region improved dramatically in the 1940's, the time period that is generally recognized as the beginning of the modern era of fire suppression (Pyne 1982). The ability to influence the role of fire greatly improved during this period for two reasons. First, a rapidly expanding road transportation system on federal lands allowed for relatively quick access to previously remote and isolated areas. Secondly, major advances in fire-fighting technology, including lighter chain saws, versatile vehicles for transportation, and aerial fire-fighting support played a major role in increasing effectiveness (Husari & McKelvey 1996, Pyne 1996, Walstad 1992), Efficiency further increased soon afterwards when airtankers, fire retardant and helicopters became part of the fire-fighting arsenal in the 1950's (Atzet & Wheeler 1982).

While significant gains have been made in the success of suppression efforts, lightning fires that start in remote areas and steep topography of the Klamath Mountains continue to present a very difficult control problem, particularly when multiple starts occur at the same time (McKelvey & Busse 1996, USDA Forest Service 1994, Morford 1984). Under favorable weather conditions, wildfires continue to grow to large size, a recent example being the 49,000 hectare Big Bar Fire complex that occurred in 1999 on the Shasta-Trinity and Six Rivers National Forests (USDA Forest Service 1999). According to Morford's study of fire history in Siskiyou County, California (1984), "A study of the action to control many of the individual fires causes one to ask if any progress has been made in the fire-fighting activity and methods in the last 40 years. In spite of dozers, tank trucks, helicopters and airtankers, fires continue to become large, doing great damage to the natural resources".

Logging

In addition to fire suppression, logging is the other major human activity that has likely influenced fire regimes in the Klamath Mountains. Although evidence of logging is very conspicuous in today's landscape, this region lagged considerably behind the nearby Cascades and Coast Ranges in developing its timber resources, especially on federal lands (Walstad 1992). The steep, rugged terrain was an impediment to early harvesting technologies, and the timber was considered of inferior quality, too scattered and inaccessible to warrant much attention (McKinley & Frank 1995, LaLande 1995, Hayes 1959). As a result, large-scale logging on federal forestlands of northwest California and southwest Oregon did not begin until after World War II, when increasing demand for lumber and dwindling timber supplies on private lands made logging on federal lands more economically attractive (McDonald 1979, Minore 1978, Hayes 1959).

Construction of an extensive network of roads, along with technological advances such as lightweight chainsaws and yarding systems, made logging possible in areas previously considered unprofitable or inaccessible (Walstad 1992). Early logging programs of the national forests were quite modest, with most volume removed through selective "high grading" of mature ponderosa pine and sugar pine from the most accessible areas (e.g. LaLande 1995). Beginning around 1950, selective cutting was gradually replaced with clearcutting small forest blocks in staggered settings, broadcast burning and replanting. In the following years, both clearcutting's permitted acreages and number of desirable tree species gradually expanded until by the late 1960's, even-aged logging became standard practice on all Forest Service and BLM lands throughout the region. Accelerated rates of logging continued through the 1980's, until concern about the northern spotted owl and other wildlife species reduced harvest levels (FEMAT 1993).

In the relatively brief period of fifty years, even-aged logging and reforestation practices have converted many thousands of hectares of late-successional forests in the Klamath-Siskiyou region into tree plantations. Considerable evidence exists that this change has increased susceptibility of the region's forests to the effects of fire and perhaps altered fire regimes, at both stand and landscape scales (Perry 1995b, Aber *et al.* 2000). Plantations have been known for decades to be more susceptible to fire effects than unmanaged older forests (Buck 1934, Morris 1941, Cowlin *et al.* 1942, Sapsis & Brandow 1997). The increased susceptibility of plantations to fire is in part due to their high tree stocking levels and uniformly dense canopies, structures which lead to hotter, more severe fires (Key 2000). In the Klamath-Siskiyou region, clearcut areas at low- and mid-elevations are often dominated for many years by sprouting hardwoods (e.g. tanoak, Pacific madrone), which are known to be highly flammable (Key 2000, McDonald & Tappeiner 1996, Tappeiner *et al.* 1992).

In addition to changes in stand structure, increased fire severity in plantations is also the result of: 1) creation of a warmer, windier and drier microclimate (Weatherspoon 1996, Rothermel 1983, Countryman 1955), and 2) large volumes of branches, windthrown trees and other dead woody material that is often concentrated on the ground surface after timber harvest (van Wagtendonk 1996, Huff *et al.* 1995, Wilson & Dell 1971). This "logging slash" material can pose a significant fire hazard for 10-40 years after logging, depending on characteristics of the site and rates of decomposition (Lehmkuhl *et al.* 1995). Another logging-related factor increasing fire risk has been the construction of a dense network of logging roads which encompasses much of federal forestlands. Road access generally increases the potential for human-caused ignitions, particularly during hot, dry conditions (USDA Forest Service 2000, Aber *et al.* 2000, FSEE 1999).

The increased fire hazard associated with logging is supported by anecdotal evidence from recent large wildfires where the highest burn intensities have been correlated with intensively managed areas. For example, 65% of managed conifer stands experienced high tree mortality in the 1987 Silver Fire on the Siskiyou National Forest, whereas the large majority of unmanaged older forests escaped with less than 25% of trees being killed (Perry 1994, 1995, USDA Forest Service 1988). On the Klamath National Forest, plantations affected by the 1987 fires "were uniformly destroyed with few exceptions…the vast majority suffered complete mortality" (USDA Forest Service 1994). Weatherspoon & Skinner (1995) analyzed 1987 fire effects on the Shasta-Trinity National Forest and found the least damage in unmanaged older forests, with significantly greater mortality in partially cut stands, particularly in those that had not received post-logging fuel treatment.

Given that managed stands appear to be more prone to high-severity fires, a critical threshold may be reached where fire regimes may be influenced at the larger landscape scale. A recent example of this in the Klamath-Siskiyou region may be the 11,000 hectare Dillon Fire that occurred in 1994 on the Klamath National Forest (USDA Forest Service 1995). Detailed analysis of this fire by Key (2000) found that: 1) clearcuts and plantations burned with higher intensity than unmanaged stands and 2) intense fire behavior in plantations in turn led to increased fire intensity in neighboring unmanaged forests. These findings suggest that the presence of highly flammable plantations not only increased fire intensity but also helped spread the Dillon Fire over a larger area than may have otherwise occurred. Landscape patterns similar to those affected by the Dillon Fire are located throughout the Klamath-Siskiyou region. Once older forests are embedded within a matrix of flammable even-aged stands, "the potential exists for a self-reinforcing cycle of catastrophic fires" (Perry 1995b).

V. ANALYSIS OF 20th CENTURY FIRE HISTORY

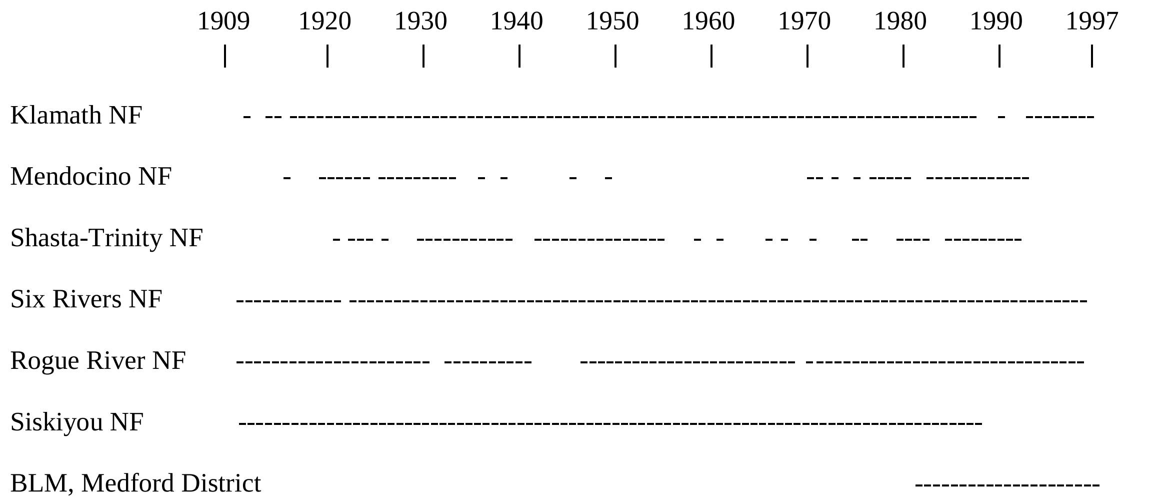
The current popular and frequenty repeated hypothesis about fires in the Klamath Mountains is that – as a result of fire suppression and other human activities – large fires are occurring more frequently and are larger and more intense than they were in the past (Atzet *et al.*

1988, USDA Forest Service 1994, 1995, 1996, 1998b, Brookes 1996). This position is predicated on assertions, that, because of fire suppression: 1) the number of fires in the region has declined over time, 2) fires are substantially larger today than in the past, and 3) large, intense fires are the result of unnaturally high levels of fuel accumulation. However, none of these assertions have been supported with empirical data from the Klamath Mountains or by analysis demonstrating that a change in fire frequency, size or severity has occurred from historic to present. If this hypothesis is not true, it may lead to inappropriate forest management and adverse impacts to regional biodiversity.

To investigate the potential historical changes in fire regimes in the Klamath Mountains, we conducted some rudimentary analysis using the California Statewide Fire History Database. Developed and maintained by the California Department of Forestry (CDF), this database is a compilation of information on fire size, date of occurrence, cause and spatial location for all recorded events throughout the state of California dating back to the early 20th century (CA Dept. of Forestry 1999). We used fire history information beginning as early as 1909 and extending to 1997 for the Klamath, Shasta-Trinity, Six Rivers and Mendocino National Forests. We also obtained all available information from annual fire reports for the Siskiyou and Rogue River National Forests and the Medford District BLM in southwest Oregon, which cover the period between 1910 and present.

While these data represent the most complete record of regional fire history currently available, it is important to recognize that it is also incomplete. Multiple year periods of fire data are missing for some forests, most notably the Mendocino NF from 1950 to 1968 and Shasta-Trinity NF from 1908-1920 (Figure 2). Both missing data and years with no fires are potential explanations for these data gaps but could not be determined from the records. But in either case, these data gaps weaken the analysis for these forests. Other problems with the CDF database are that the perimeters of some fires were only roughly approximated, many smaller fires were not recorded, and the accuracy of some records from the first half of the century is also somewhat suspect (CA Dept. of Forestry 1999).

Figure 2. Years of record for fires on federal lands in the Klamath-Siskiyou region (national forests and BLM districts). Gaps in horizontal lines indicate missing data.



Despite these shortcomings, we utilized the CDF Fire History Database to analyze the overall patterns of burned acreage over time, both on national forest lands and for northwest California as a whole. When viewed as a cumulative distribution, the annual acreage burned appears to be quite variable from year to year and showed no significant time trend in size of area over time ($r^2 = 0.05$, $p = 0.22$, Figure 3). However, significantly fewer acres on average burned per year between years 1909-1950 and 1951-1997, suggesting that fire suppression has had some effect in the region. Fire size follows a similar pattern, with mean fire size being significantly larger before 1950 than afterwards (Figure 4). It is potentially noteworthy that variability in fire size is greater during the era of effective fire suppression (1950-present), with many years of small fires intermixed with several years – specifically 1956, 1977, 1987 and 1994 -- with very large fire events.

Figure 3. Yearly area burned on national forests in northwest California between 1909 and 1997, as reported in the CA Fire History Database.

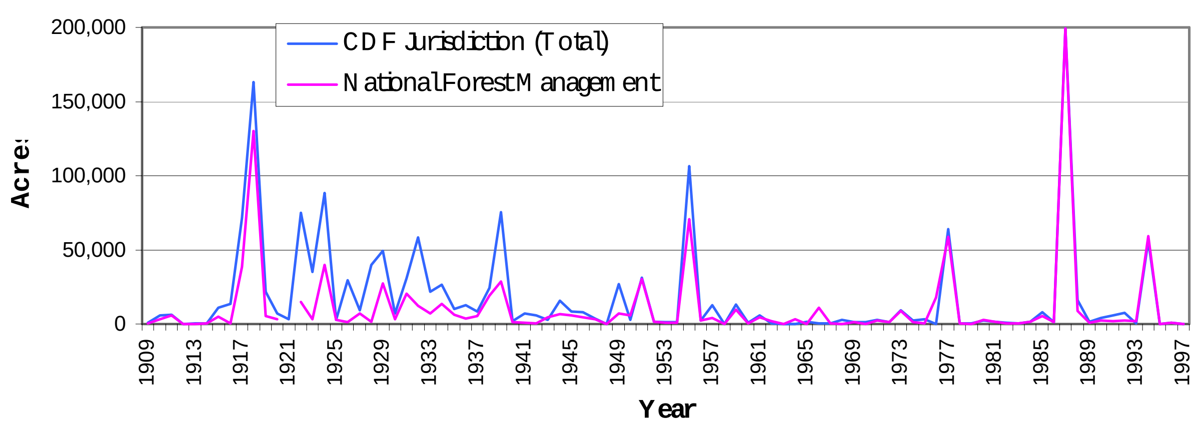


Figure 4. Mean fire size for national forests in northwest California between 1909 and 1997.

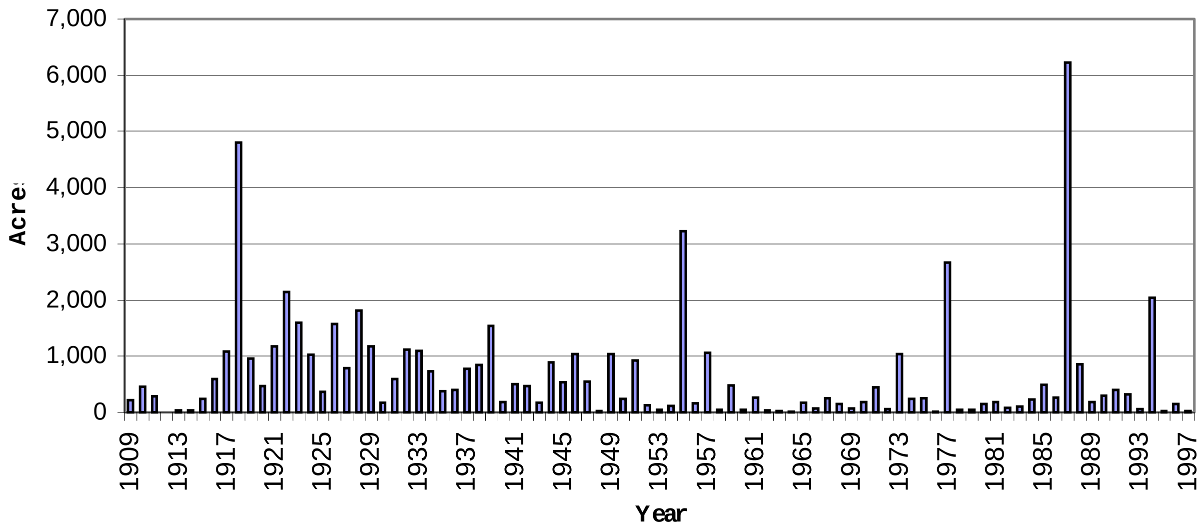
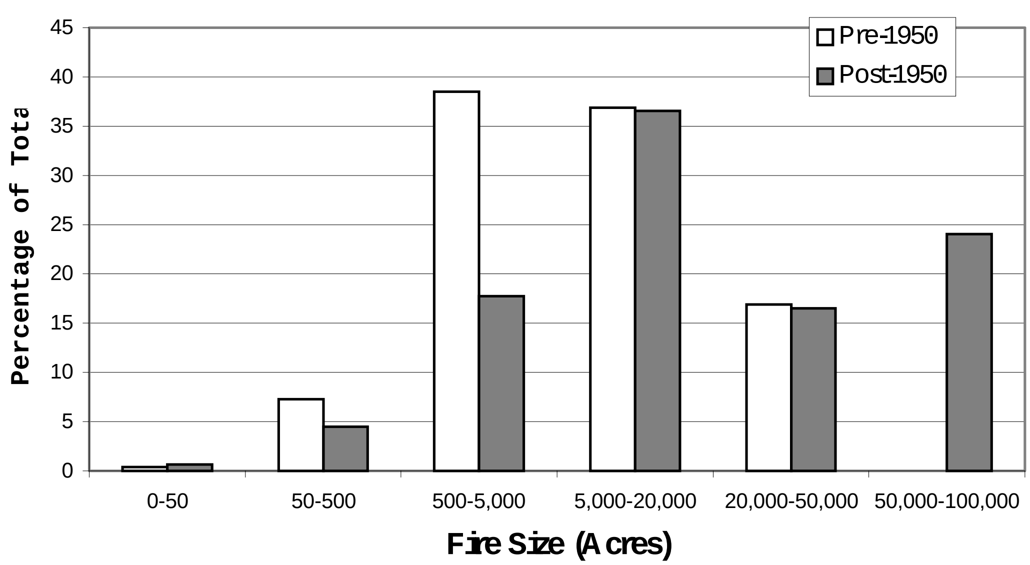


Figure 5. Proportion of total area burned by fires in different size classes, before and after 1950.



The relative changes in fire size before and after 1950 are shown in Figure 5. It appears that the few years that experienced very large fires caused a significant shift in the overall acreage distribution. A greater percentage of area burned in very large fires in the second half of the 1900s, with fewer small to moderate sized fires (e.g. below 5,000 acres). If analyzed at the individual forest level, the mean size of post-1950 fires was significantly larger for the Klamath and Shasta-Trinity
National Forests, but not for the Mendocino and Six Rivers National Forests (Figure 6). However, it is difficult to determine whether these forest-level differences are real or an artifact of gaps or inadequacies in the existing dataset.

Although more total fire events were reported in the first half of the 1900s, there appears to be no significant change over time (Figure 7). Similarly, the relative importance of humans and lightning as ignition sources appears to have remained somewhat constant over the 20th century, with human-caused fires remaining slightly dominant (Figure 8). The larger number of human-caused fires reported before 1940 could be in part a reflection of incendiary fires set by ranchers

Figure 6. Estimated mean fire size for national forests in northwest California for the periods before and after 1950.

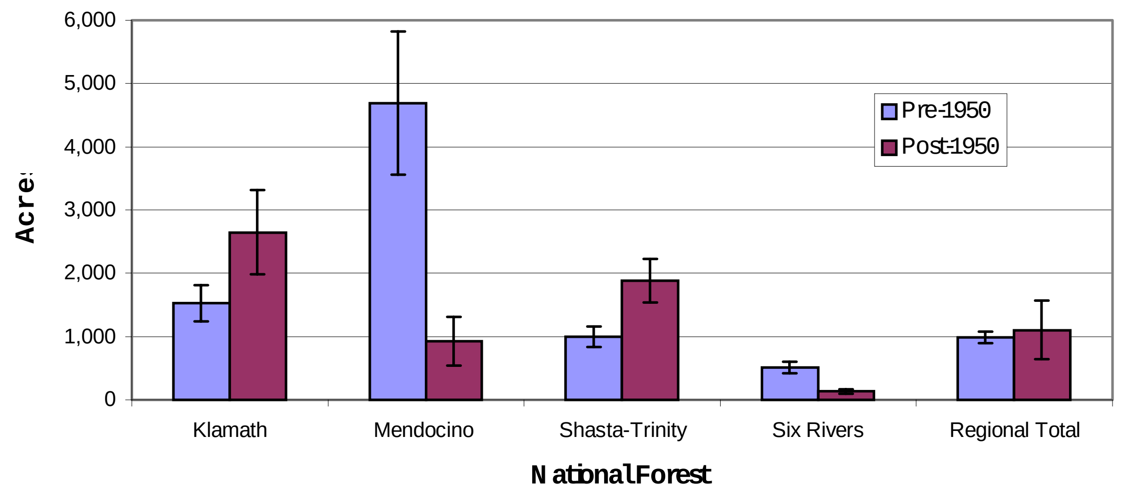
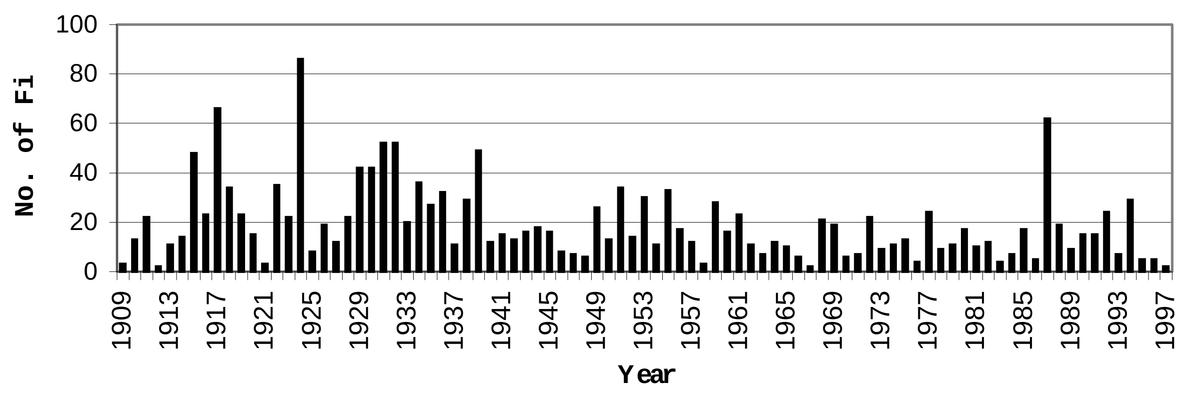
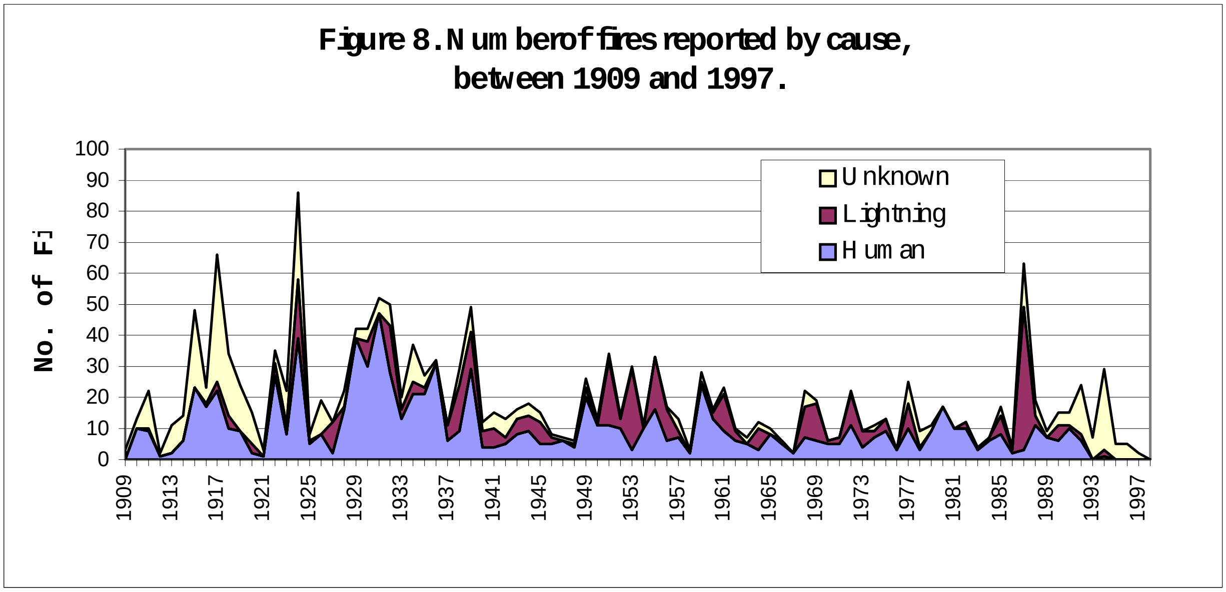


Figure 7. Number of fire events in the CA Fire History Database, 1909-1997.





and others, a common land use practice of that era (LaLande 1995, Atzet & Wheeler 1982). It is possible that public education on fire, which increased dramatically with the "Smokey the Bear" campaign after World War II, has had a measurable impact on the number of human-caused fires.

Interestingly, years that experienced very large fires in the Klamath-Siskiyou region appear to show a higher proportion of lightning ignitions relative to other years. Since the beginning of the modern fire suppression era, there were two years when total area burned exceeded 100,000 acres (Figure 3). These years – 1956 and 1987 – can be characterized as extreme fire years, when an extended period of hot, dry weather corresponded with numerous lightning ignitions. Under these conditions, the demand for fire fighting resources quickly outpaces supply and fires inevitably become large. A similar correlation of years with numerous lightning ignitions with large fire events has been reported in the Sierra Nevada, where "major lightning events coupled with extreme fire weather can overwhelm local suppression resources and grow together into 'complexes' covering large areas" (McKelvey & Busse 1996).

In summary, our initial analysis of 20th century fire history suggests that forests of the Klamath-Siskiyou region have experienced a reduction in both the total amount of area burned and the average fire size since the middle of the 1900s, the beginning of modern fire suppression. However, no clear trends were detected in terms of number of fires or the relative proportion of human- vs. lightning-caused ignitions. Although data are not available on fire intensity, we hypothesize that fire suppression has been somewhat effective at reducing area burned at low and moderate intensities – when fire sizes are likely to be smaller – but not at high intensities when extreme fire conditions typically exist and allow fires grow to large size (McKelvey & Busse 1996, Strauss et al. 1989).

While high-intensity fire may now comprise a larger proportion of total area burned than before 1950, this does not necessarily imply that the size or frequency of large fire events is outside the historic range. Large, intense fires are well-documented in the historic literature for this region (Brown 1960, Cooper 1939, Morris 1934a) and have also been detected by some dendrochronology studies (Stuart & Salazar, in press, van Norman 1998, Agee 1991a). On a larger temporal scale, it simply cannot be determined whether the few large fire events of the recent past are the result of random chance, the effects of human activities, or perhaps a changing climate.

These initial findings parallel in some ways the results of similar studies conducted on federal lands in the Sierra Nevada (Erman & Jones 1996, McKelvey & Busse 1996) and Peninsular Ranges of southern California (Weise *et al.* in press), which found no significant overall trend in acreage burned and great variability in fire size and frequency over the last century. In contrast, significant changes in fire regimes over the historic period have been well-documented in the southwestern U.S. (Swetnam & Baisan 1996, Covington & Moore 1994) and some dry forest types of the eastern Cascades (Everett *et al.* 1997, 2000, Hann *et al.* 1997) and northern Rockies (Arno *et al.* 1995, Smith & Arno 1999). Several lines of evidence strongly suggest that dramatic increases in area burned by large, high-intensity fires over the last several decades in these specific regions and forest types is the direct result of human activities. The important conclusion from this analysis is that patterns of fire in the Klamath Mountains appear to have been much less altered since Euro-American settlement.

VI. KEY FINDINGS AND CONCLUSIONS

Fire ecology and fire history have become increasingly important issues as scientists, land managers and society begin to develop ecosystem-based approaches to federal land management. Understanding the ecological role of fire at the regional and site-specific scale is critical to implementing scientifically sound management plans for federal forests. It is with this in mind that we have aggregated and synthesized here all available information on fire ecology and fire history in the Klamath-Siskiyou region of northwest California and southwest Oregon to determine "what we appear to know". Below are a set of key findings from this review and some qualified insights on the changing role of fire that can be used as a future point of departure for developing ecosystem management plans and forest restoration projects.

Key Findings

- Historic fire regimes in forests of the Klamath Mountains have been and continue to be highly variable in terms of frequency, severity and spatial pattern. This variability in fire regimes is likely a critical aspect of long-term ecosystem dynamics and function, and an important factor contributing to the region's globally outstanding levels of biodiversity. Considerable variation in fire regimes existed at both stand and landscape scales, and created a range of scenarios for vegetation establishment and survival. The wide variation in fire regime attributes (e.g. fire frequency, severity, extent) was probably equally or more important than mean or median values in creating the vegetation mosaics that exist across the landscape.

- In terms of total area, the predominant fire regime was of relatively frequent fires (e.g. mean FRIs of 10-50 years) of mostly low and moderate severity, with varying-sized patches of high severity. This fire regime was predominant in the foothill, lower- and mid-montane forests in both western and eastern subregions of the Klamath Mountains and the Jeffrey pine type on ultramafic soils. Greater variability and a higher proportion of moderate to high severity fire occurred in the cooler and more mesic forests of the coastal, upper montane and subalpine zones and in riparian settings. Old-growth forest characteristics such as large snags and live trees were sustained on many sites for long periods and through many disturbances, thus providing habitat continuity over time.

- Even within a particular forest type, fire severity and effects varied considerably with changes in topography, structural stage, fuel loads and moisture levels, weather, fire behavior in adjacent areas, and chance. Individual fires typically burned for long periods of time under a variety of environmental settings and weather conditions, such that resulting spatial patterns were often highly variable. Many of the more recent large fires in the Klamaths – including some of the 1987 fires, the 1994 Dillon Fire and 1999 Big Bar Fire – continue to exhibit high levels of heterogeneity.

- Euro-American settlement and other land management activities over the last 150 years or so have resulted in significant changes to Klamath-Siskiyou vegetation patterns and their associated fire regimes. Although we lack specific knowledge of Native American burning patterns, their replacement with those of the settlement era was probably ecologically significant. Primary agents of change over the last 50-60 years have been clearcut logging and fire suppression, both of which result in increased fuel loads and less fire-resilient forests.

- Analysis of available fire history data from federal lands in northwest California suggest that some fire parameters have changed over the 20th century while others have not. Total area burned and mean fire size decrease around 1950, suggesting the effects of fire suppression. No clear trends were detected in terms of annual number of fires or the relative proportion of human- vs. lightning-caused ignitions. While large fire events comprise a larger proportion of area burned in the second half of the century, available data does not suggest that the probability or size of large fires has changed.

Changes in Fire Regimes and Forest Conditions

While there is general agreement that human activities have influenced natural fire regimes in the Klamath-Siskiyou region, the extent and specific nature of this influence still remains unclear and somewhat controversial. Most recent debate has focused on the magnitude of change resulting from fire suppression and the extent to which the region's forests are in need of restorative management in order to counteract the effects of suppression. Some resource managers argue that widespread mechanical treatments (e.g. thinning, fuelbreaks, etc.) will be necessary to restore more sustainable forest conditions (e.g. Hardy *et al.* 1999, Atzet 1996, Brookes 1996, USDA Forest Service 1994), whereas others assert that fire ignited by lightning or by people under carefully prescribed conditions may be sufficient to re-establish natural conditions (USDA Forest Service 1999b, Martin & Sapsis 1992, Pickford 1981).

Based on the key findings emerging from this review, we believe that the impact of fire suppression has been far less in the Klamath-Siskiyou region than in many other forested regions of the western U.S., including the Sierra Nevada, the Southwest, and the eastern and southern

Cascades. The primary reasons for this difference are that: 1) fire suppression has been effective over a considerably longer period in these other regions, beginning some time between 1850-1900 rather than ~1950 (Skinner & Chang 1996, Swetnam & Baisan 1996), and 2) fire return intervals are on average longer and more variable in the Klamath Mountains. This is not to say that fire suppression has had no effect here, but the effects in general are more subtle and less widespread than have been documented in other forested regions characterized by frequent, low- and moderate intensity fire regimes.

This review also reveals that the effects of fire suppression have not been uniform across the regional landscape. Changes in forest structure and composition are likely to be most pronounced in those forest types that were previously maintained by frequent, low-intensity fires (e.g. oak woodland, ponderosa pine/Douglas-fir, mixed conifer), whereas those types that burned on a frequency roughly equal to or greater than the period of effective fire suppression (e.g. 50-60 years) may still be within the historic range of variation in terms of fuel loads, stand structure and other ecological attributes. Available fire history data suggests that forest types that can be included within this latter group include coast redwood, western hemlock, white fir, Shasta red fir, mountain hemlock and perhaps the cooler/more mesic Douglas-fir dominated types. Logging has had numerous detrimental effects on these forests, but the fundamental dynamics are relatively little-changed since fire suppression has been effective for less than one natural fire cycle.

In addition, fire suppression has likely been most successful in areas closer to human settlements because protecting private property has always been given priority over other areas, and less so at higher elevations and in remote areas with steep terrain (e.g. wilderness and roadless areas; Frost 1999, Baker 1993). Changes in fire regimes and vegetation are likely to be most dramatic in areas where suppression actions and logging have been concentrated, while effects may be minimal or even absent in other parts of the same landscape (Baker 1993). Even if it is assumed that fire suppression efforts have been successful across the vast majority of the region's federal forestlands, there is uncertainty about whether sufficient time has elapsed to result in significant and widespread changes to the vegetation.

Table 3 compares the most recent fire-free intervals from specific fire history studies conducted in the Klamath-Siskiyou region with reported mean or median fire return intervals. Of the 13 cases for which this comparison can be made, five indicate that one mean fire return interval has been missed, and only two studies reported a statistically significant difference in mean/median FRIs between historic and contemporary periods. This line of evidence suggests that fire suppression has not had a dramatic effect in many Klamath forest types, at least at relatively small spatial scales (e.g. tens to thousands of hectares).

Forest structure and spatial patterns are more likely to have been significantly altered by fire suppression as one moves up from the local to landscape scale. This is because a larger proportion of forest stands now support a relatively dense, multi-storied structure than would occur in the presence of an uninterrupted low- and moderate-intensity fire regime. The cumulative impact has been the development of a more homogeneous forest landscape, where a larger percentage of the landscape is in a stage toward the high end of the range of variability in fire return intervals, fuel loads and stand density (Skinner & Chang 1996, Skinner 1995b). This picture of landscape change, however, becomes more complex when past logging is also considered, which has generally increased fuel loads and created numerous homogeneous stands with reduced resilience to fire.

One qualitative method for comparing relative change across the range of regional forest types is by creating an index that integrates changes resulting from both fire suppression and logging. Table 4 represents an initial attempt at developing such an index of ecosystem change, based on the relative impacts of fire suppression and logging plus some consideration of the rate at which the structure and composition of different forest types change in the absence of fire. Those forest types that are most susceptible to disturbance-mediated shifts in species composition are likely to be most altered from historic conditions. For example when fire is excluded from the eastside mixed conifer zone, dominance shifts relatively rapidly from shade-intolerant species (ponderosa and sugar pine) to shade-tolerants (white fir, incense cedar; Weatherspoon et al. 1992). Species composition in other Klamath forest types – such as Jeffrey pine and Douglas-fir/hardwood – appears to change relatively little during fire-free periods, perhaps because relatively few species are present or dominants are influenced more by soils, moisture and other environmental factors rather than disturbance.

Results of the analysis summarized in Tables 3 and 4 suggest that across the region, forest types of the foothill, lower and mid-montane zones of the eastern Klamaths have likely departed the most from historic conditions. Not surprisingly, these types are similar in terms of their fire ecology and past management to the dry, pine-dominated forests found in other western regions that have undergone dramatic changes in vegetation patterns and fire regimes since Euro-American settlement (e.g. Smith & Arno 1999, Covington & Moore 1994). However, many other forest types – particularly those of coastal and western subregions and middle and upper montane zones – appear to have experienced relatively little overall change in structure and composition over the last century, and may still exhibit fire regimes that are within the historic range of variability. Any ecosystem restoration strategy must recognize these forest-specific differences and focus efforts on those areas that could most benefit from active management.

Lastly, it is important to recognize that the insights offered here represent a poorly developed “state of the art” because we currently have a very incomplete understanding of the role of fire in these forests, how this role has changed over time, and the most effectual means for restoring forests degraded by past management. There are significant risks associated with decisions made in the face of this high level of uncertainty. While ecosystem management plans will be developed in the absence of complete understanding, widespread application of highly intrusive treatments under the auspices of restoration could lead to further damage of the Klamath-Siskiyou region’s forest ecosystems. All in all, we believe it is critical that restoration efforts initially proceed in a patient and incremental fashion, which recognizes the limits of our current knowledge base and incorporates buffers for uncertainty. Investments in research, monitoring and adaptive management will be essential to ensure that we learn from our successes and mistakes.

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