CHAPTER 9

Klamath Mountains Bioregion

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Fires ... have been ground fires, and easily controlled. A trail will sometimes stop them.

R. B. WILSON, 1904

Description of Bioregion

The Klamath Mountains bioregion makes up a major portion of northwestern California continuing into southwestern Oregon to near Roseburg. In California, the bioregion lies primarily between the Northern California Coast bioregion on the west and the southern Cascade Range to the east. The southern boundary is made up of the Northern California Coast Ranges and Northern California Interior Coast Ranges (Miles and Goudey 1997). The very steep and complex terrain of the Klamath Mountains covers approximately 22,500 km^2 (8,690 mi^2), or 6% of California. The bioregion includes the Klamath and Trinity River systems, the headwaters of the Sacramento River, the most extensive exposure of ultramafic rocks in North America (Kruckeberg 1984), and the most diverse conifer forests in North America (Cheng 2004) (Map 9.1).

Physical Geography

The Klamath Mountains have been deeply dissected by the Klamath, McCloud, Sacramento, and Trinity Rivers with no consistent directional trends. Only two sizable alluvial valleys, Scott Valley and Hayfork Valley, occur here (Oakeshott 1971, McKee 1972). Elevations in the Klamath Mountains range from 30 m (100 ft) to 2,755 m (9,038 ft). From north to south, several prominent ranges or ridge systems comprise the Klamath Mountains with Mt. Eddy being the highest peak (Oakeshott 1971, McKee 1972). The crests of these ridge systems are usually between 1,500 m (4,900 ft) and 2,200 m (7,200 ft) (Irwin 1966).

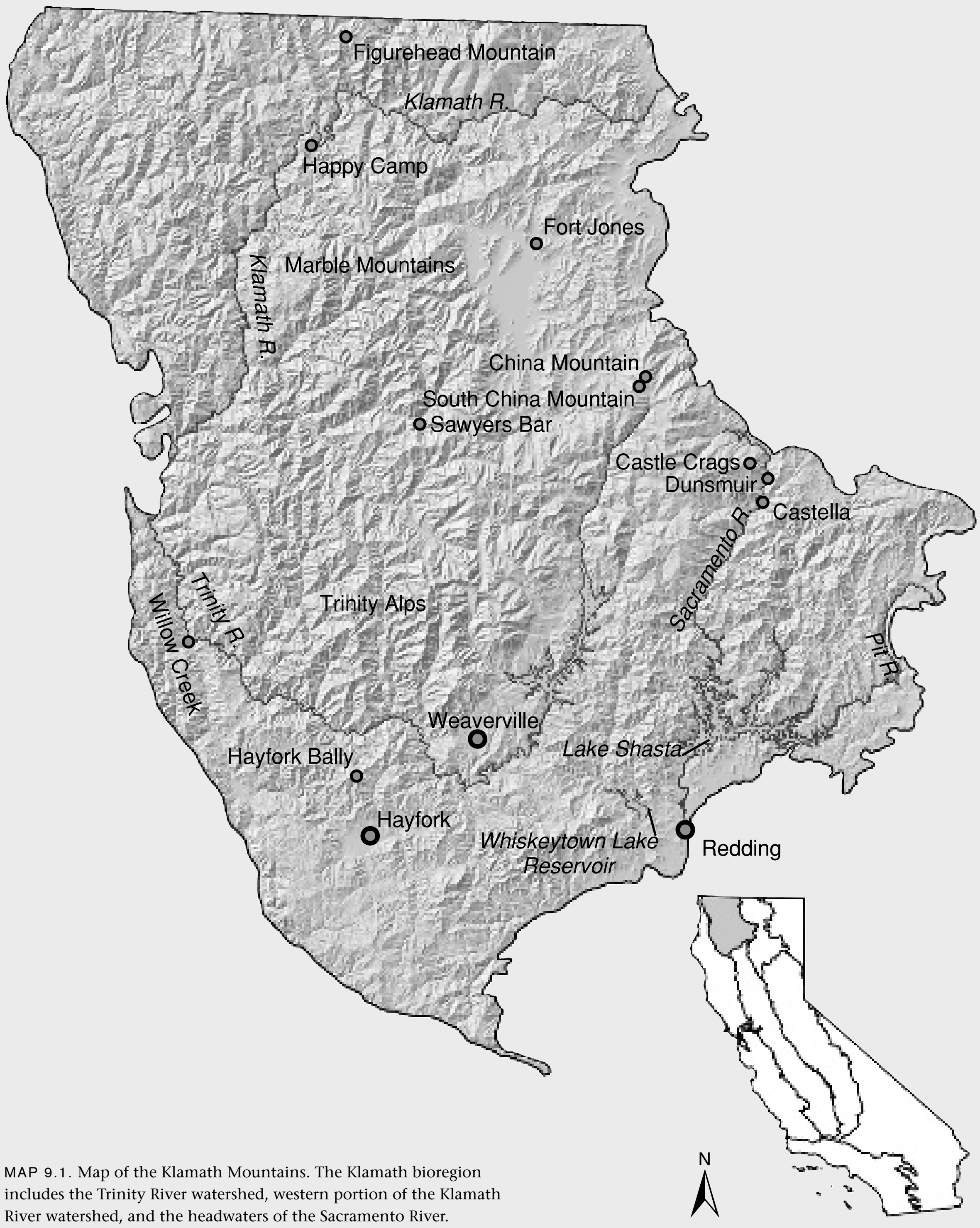
The complexity of the geology and terrain has a strong influence on the structure, composition, and productivity of vegetation in the Klamath Mountains (Whittaker 1960). The topography and vegetation influence fire regimes. Spatial variation in soil productivity combined with steep gradients of elevation and changes in slope aspect across landscapes control the connectivity, structure, and rates of fuel accumulation.

Climatic Patterns

The climate of the Klamath Mountains is mediterranean, characterized by wet, cool winters and dry, warm summers. However, the local expression of this climate regime is remarkably variable due to a strong west to east moisture and temperature gradient caused by proximity to the Pacific Ocean and steep elevation gradients that influence temperature and the spatial pattern of precipitation via orographic effects. The contemporary climatic phase appears to have become established about 3,500–4,000 years ago (West 1985, 1988, 1989, 1990; Mohr et al. 2000).

Table 9.1 shows normal January and July maxima and minima temperatures for Willow Creek (west), Sawyers Bar (central), Dunsmuir (east), and other selected stations from west to east. These data demonstrate the warm temperatures that exist during the long, annual summer drought. These temperature records in the Klamath Mountains are only from valleys or canyon bottoms because no regularly reporting stations are located above 1,000 m (3,280 ft).

Although most precipitation falls between October and April, there is considerable local and regional geographic variation in the amount of annual precipitation. Generally, less precipitation falls in valleys and canyons than in the surrounding uplands with strong gradients over short horizontal distances. Precipitation declines with distance from the coast in both the northern and southern Klamaths. The driest areas occur along the eastern edge of the range adjacent to the Shasta and Sacramento Valleys. However, there is no west to east precipitation gradient in the eastern Klamaths in the watersheds of the Sacramento, McCloud, and Pit Rivers. The high precipitation of the eastern-most Klamaths



MAP 9.1. Map of the Klamath Mountains. The Klamath bioregion includes the Trinity River watershed, western portion of the Klamath River watershed, and the headwaters of the Sacramento River.

TABLE 9.1

Average annual, January, and July precipitation and normal daily January and July maxima and minima temperatures for representative stations (elevations noted) in the Klamath Mountains

	Average Precipitation cm (in)	*Normal Daily Maximum Temperature °C* (°F)	*Normal Daily Minimum Temperature °C* (°F)
Willow Creek (141 m)			
Annual	143.5 (56.5)		
January	24.3 (9.6)	11.1 (52)	1.5 (35)
July	0.4 (0.2)	34.7 (95)	11.5 (53)
Sawyers Bar (659 m)			
Annual	117.6 (46.3)		
January	21.6 (8.5)	9.1 (48)	−2.9 (27)
July	2.3 (0.9)	32.8 (91)	10.9 (52)
Fort Jones (830 m)			
Annual	57.6 (22.3)		
January	10.8 (4.3)	6.6 (44)	−5.1 (23)
July	0.9 (0.4)	32.9(91)	8.6(48)
Weaverville (610 m)			
Annual	101.2 (39.8)		
January	18.8 (7.4)	8.3 (47)	−2.8 (27)
July	0.5 (0.2)	34.2 (94)	9.6 (49)
Whiskeytown (367 m)			
Annual	160.4 (63.1)		
January	30.0 (11.8)	12.0 (54)	2.1 (36)
July	0.7 (0.3)	35.3 (96)	17.4 (63)
Dunsmuir (703 m)			
Annual	163.6 (64.4)		
January	29.7 (11.7)	9.9 (50)	−0.9 (30)
July	0.7 (0.3)	31.8 (89)	12.1 (54)

is probably caused by orographic uplift of moist air masses. The eastern Klamaths are the first major range encountered by southwesterly flowing winds moving northeast across the Sacramento Valley. At higher elevations, most precipitation falls as snow. The average annual early April snowpack depth and water content for high-elevation sites in the Klamath Mountains are shown in Table 9.2.

WEATHER SYSTEMS

Critical fire weather in the Klamath Mountains is generated by conditions of both the California and Pacific Northwest weather types described by Hull et al. (1966). Overall, critical fire weather is associated with any weather condition that creates sustained periods of high-velocity winds with low humidity. In the Klamath Mountains, critical fire weather conditions are created by three different weather patterns described by Hull et al. (1966): (1) Pacific High–Post-Frontal (Post-Frontal), (2) Pacific High–Pre-Frontal (Pre-Frontal), and (3) Subtropical High Aloft (Subtropical High).

Post-Frontal conditions occur when high pressure following the passage of a cold front causes strong winds from the north and northeast. Temperatures rise and humidity declines with these winds. Examples of fires fanned by Post-Frontal conditions occurred in 1999 when the Megram, east of Hoopa, burned more than 57,000 ha (141,000 ac) and the Jones fire, northeast of Redding near Lake Shasta, consumed more than 900 structures while burning more than 10,000 ha (25,000 ac).

Pre-Frontal conditions occur when strong, southwesterly or westerly winds are generated by the dry, southern tail of a rapidly moving cold front. Strong winds are the key here because temperatures usually drop and relative humidity rises as the front passes. These strong winds are able to spread

TABLE 9.2
Average April 1 snowpack data for representative courses ordered from north to south (CCSS 2002)

	Elevation m (ft)	*Snow Depth* cm (in)	*Water Content* cm (in)
Etna Mountain	1,798 (5,900)	190.2 (74.9)	76.2 (30.0)
Sweetwater	1,783 (5,850)	94.2 (37.1)	34.5 (13.6)
Parks Creek	2,042 (6,700)	231.9 (91.3)	92.5 (36.4)
Deadfall Lakes	2,195 (7,200)	174.5 (68.7)	72.6 (28.6)
North Fork Sacramento R	2,103 (6,900)	153.9 (60.6)	59.9 (23.6)
Gray Rock Lakes	1,890 (6,200)	246.6 (53.8)	57.2 (22.5)
Middle Boulder 3	1,890 (6,200)	136.7 (97.1)	103.4 (40.7)
Wolford Cabin	1,875 (6,150)	218.7 (86.1)	91.4 (36.0)
Mumbo Basin	1,737 (5,700)	145.0 (57.1)	59.9 (23.6)
Whalan	1,646 (5,400)	124.5 (49.0)	53.1 (20.9)
Highland Lakes	1,829 (6,000)	172.5 (67.9)	74.9 (29.5)
Slate Creek	1,737 (5,700)	163.6 (64.4)	73.9 (29.1)
Red Rock Mountain	2,042 (6,700)	259.8 (102.3)	111.8 (44.0)
Bear Basin	1,981 (6,500)	197.6 (77.8)	84.8 (33.4)

fires rapidly through heavy fuels such as happened in 2001 when the Oregon fire west of Weaverville burned more than 650 ha (1,600 ac) and 13 homes.

Subtropical High conditions occur when the region is under the influence of descending air from high pressure that causes temperatures to rise and humidity to drop. In the Klamath Mountains, these conditions lead to fires controlled mostly by local topography. Subtropical High conditions also promote the development of strong temperature inversions that inhibit smoke from venting out of the canyons and valley bottoms. The combination of smoke and lack of vertical mixing created by strong inversions, especially following initiation of widespread lightning-caused fires, reduces fire intensity. Under Subtropical High conditions, fires create mainly low- to moderate-severity effects. An example of recent major fire episodes burning under these conditions includes the Hayfork fires in 1987 where 70% of the burned area sustained low- to moderate-severity fire effects (Weatherspoon and Skinner 1995). Fires burning above the inversion layer and immediately after dissipation of the inversion often burn at much higher intensity (Weatherspoon and Skinner 1995).

LIGHTNING

Lightning is common in the Klamath Mountains with 12.8 strikes (range 6.4–26.4)/yr/100 km^2 (33.7 strikes [range 16.8–69.4]/yr/100 mi^2). Lightning-caused fires have accounted for most area burned in recent decades (e.g., 1977, 1987, 1999, and 2002). Lightning may ignite hundreds of fires in a 24-hour period. As a result of the large number of simultaneous fires combined with poor access for fire-suppression forces, steep topography, and extensive strong canyon inversions (see above), widespread lightning events have contributed to situations where fires burn for weeks to months and cover very large areas. For example, widespread lightning during the last week of August in 1987 ignited fires that ultimately burned more than 155,000 ha (380,000 ac). These fires burned until rain and snow extinguished them in November (Biswell 1989). The Biscuit fire, also caused by lightning and burned in both California and Oregon in 2002, burned more than 186,000 ha (450,000 ac).

Lightning occurrence increases with distance from the coast and with increasing elevation (van Wagtendonk and Cayan 2007). It is interesting to note that the two years with the least number of lightning strikes recorded—1987 and 1999—were the same two years with the greatest amount of area burned by lightning-caused fires during the period of lightning strike data (Fig. 9.1).

Though it seems counterintuitive, the number of lightning-caused fires in a region is not necessarily related to the number of lightning strikes. Storms that produce lightning-caused fires are associated with higher instability and higher dew point depression (drier air) than storms that produce the most lightning strikes (Rorig and Ferguson 1999, 2002). Additionally, in both 1987 and 1999, a single storm episode was responsible for nearly all of the area burned by lightning-caused fires.

Ecological Zones

The Klamath Mountains are an area of exceptional floristic diversity and complexity in vegetative patterns (Whittaker 1960, Stebbins and Major 1965). The diverse patterns of climate, topography, and parent materials in the Klamath Mountains create heterogeneous vegetation patterns more complex than that found in the Sierra Nevada or the Cascade

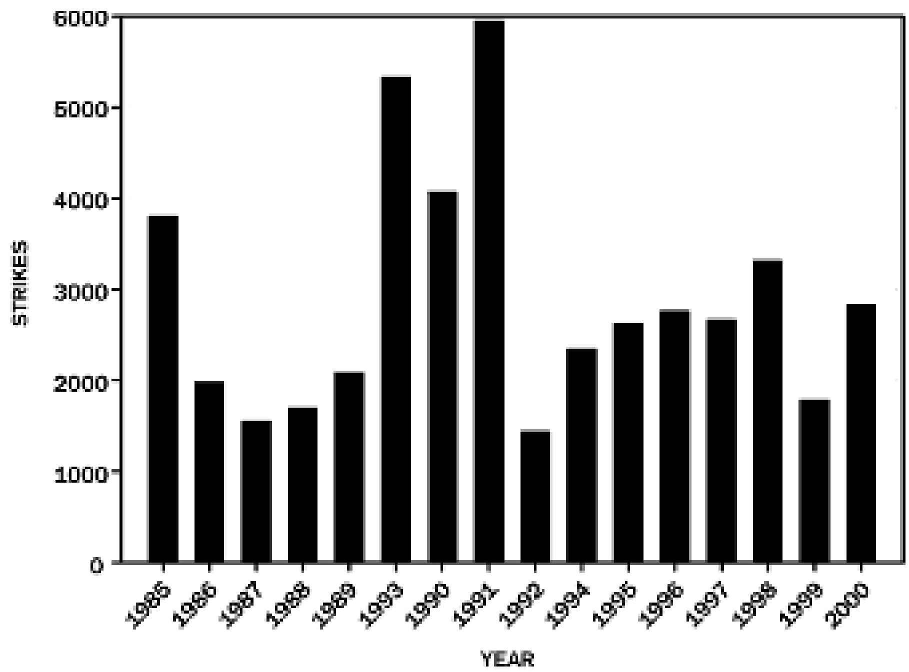


FIGURE 9.1. Variation in number of lightning strikes by year.

Range (Sawyer and Thornburgh 1977). The Klamath Mountains are thought to be of central importance in the long-term evolution and development of western forest vegetation because of this diversity and the mixing of floras from the Cascade/Sierra Nevada axis and the Oregon/California coastal mountains that intersect in the Klamath Mountains (Whittaker 1961, Smith and Sawyer 1988). Vegetation and species diversity generally increases with distance from the coast and species diversity is highest in woodlands with a highly developed herb strata (Whittaker 1960). Conifer forests and woodlands are found in all elevational zones throughout the bioregion.

The rugged, complex topography and resulting intermixing of vegetation in the Klamath Mountains defies a simple classification of ecological zones by elevation. Nevertheless, this chapter discusses three general zones: (1) a diverse lower montane zone of mixed conifer and hardwood forests, woodlands, and shrublands; (2) a mid-upper montane zone where white fir *(Abies concolor)* is abundant and hardwoods are less important; and (3) a subalpine zone where white fir, Douglas-fir *(Pseudotsuga menziesii* var. *menziesii)*, sugar pine *(Pinus lambertiana)*, and ponderosa pine *(Pinus ponderosa)* drop out and are replaced by upper montane and subalpine species such as Shasta red fir *(Abies magnifica* var. *shastensis)*, mountain hemlock *(Tsuga mertensiana)*, western white pine *(Pinus monticola)*, Jeffrey pine *(Pinus jeffreyi)*, whitebark pine *(Pinus albicaulis)*, lodgepole pine *(Pinus contorta* spp. *murrayana)*, foxtail pine *(Pinus balfouriana)*, and curl-leaf mountain-mahogany *(Cercocarpus ledifolius)*.

LOWER MONTANE

The lower- and mid-montane zone is characterized by a very complex and diverse intermixing of vegetation assemblages (Fig. 9.2). This heterogeneity is caused by rugged complex terrain, diverse lithology, and a diversity of fire regimes.

Grasslands are most extensive in the two alluvial valleys (e.g., Scott and Hayfork). Shrublands are found throughout the Klamath Mountains. At lower elevations, shrublands are found on warm or rocky, dry sites and on ultramafic and limestone-derived soils. Species that commonly dominate lower-montane shrublands are whiteleaf *(Arctostaphylos viscida)* and greenleaf manzanitas *(Arctostaphylos patula)*, Brewer oak *(Quercus garryana* var. *breweri)*, and deer brush *(Ceanothus intergerrimus)*. Shrublands also occupy extensive areas around historic mining districts, such as those near Lake Shasta and Whiskeytown Reservoirs where the combination of heavy cutting to support mining and air pollution from smelters drastically reduced site quality and increased soil erosion. The northern-most stands of chamise *(Adenostoma fasciculatum)* are found in the Whiskeytown area. Douglas-fir–dominated and mixed evergreen forests are found throughout this zone.

MID TO UPPER MONTANE

In the western Klamath Mountains are areas on upper slopes and ridgetops locally known as prairies supporting a dense sward of perennial grasses. Grasslands also occur on shallow ultramafic soils and on cemented glacial till, whereas wet montane meadows are scattered throughout the upper-montane and subalpine areas. Shrublands occur at higher elevations on poor sites and where severe fires have removed tree cover. Important shrubs here are tobacco brush *(Ceanothus velutinus* var. *velutinus)*, shrub tan oak *(Lithocarpus densiflorus* var. *echinoides)*, golden *(Chrysolepsis chrysophylla)* and bush chinquapin *(Chrysolepsis sempervirens)*, huckleberry oak *(Quercus vaccinifolia)*, and greenleaf manzanita.

Woodlands dominated or co-dominated by any combination of blue oak *(Quercus douglasii)*, Oregon white oak *(Quercus garryana)*, California black oak *(Quercus kelloggii)*, gray pine

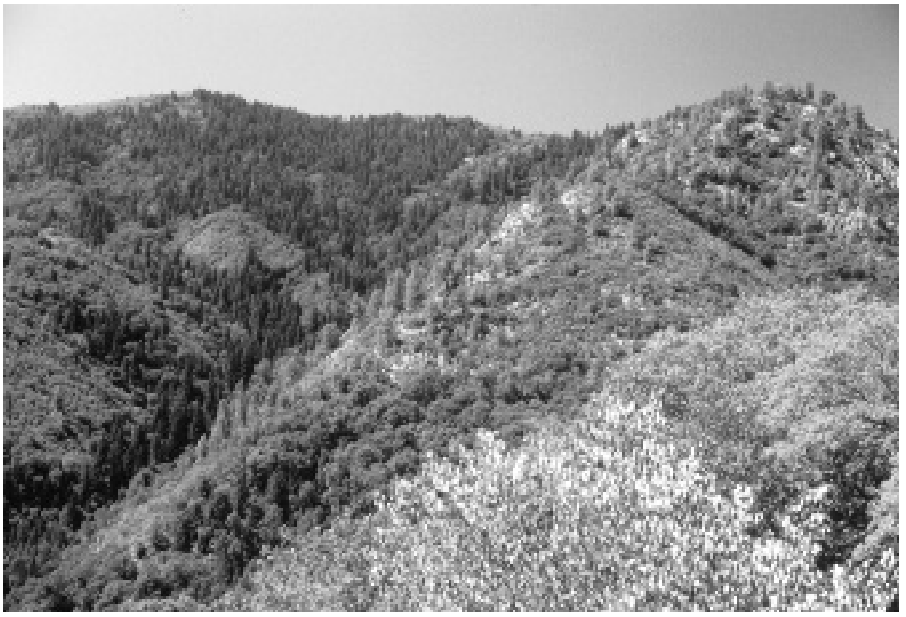


FIGURE 9.2. Lower montane zone. This photo shows the diversity typical of the lower montane zone in the Klamath Mountains. This scene is from the McCloud River Canyon. Left side of photo shows Douglas-fir stands, California black oak stands and Brewer oak intermixed on soils derived from weathered metasediments. Right side of photo shows gray pine woodland, buck brush, and Brewer oak on soils derived from limestone. (Photo by Carl N. Skinner.)

FIGURE 9.3. Mid montane zone. Douglas-fir usually dominates conifer forests in this zone. Jud Creek looking north toward Hayfork Bally. (Photo by Carl Skinner, USDA Forest Service.)

(Pinus sabiniana), or ponderosa pine are found on sites similar to grasslands. Woodlands are also found on steep, dry, south- and west-facing slopes such as those along the Trinity River west of Junction City. Dry woodlands of ponderosa pine, western juniper *(Juniperus occidentalis* ssp. *occidentalis)*, Douglas-fir, Oregon white oak, and incense-cedar *(Calocedrus decurrens)* dominate sites around the Scott and Shasta Valleys. Woodlands are also common on harsh sites in the upper-montane zones where they may be dominated by western white pine, Jeffrey pine, incense-cedar, Shasta red fir, or curl-leaf mountain-mahogany.

The conifer component of montane forests can be quite diverse and up to 17 conifer species have been identified in some watersheds in the north central Klamath Mountains (Keeler-Wolf 1990). However, stands usually have Douglas-fir in combination with any of five other conifer species: sugar pine, ponderosa pine, incense-cedar, Jeffrey pine, and white fir (Fig. 9.3). Areas of ultramafic soils are an exception, however, and instead support stands usually dominated by Jeffrey pine or gray pine. Douglas-fir is the dominant conifer in the western portion of the range. Ponderosa pine becomes an important associate on drier sites and may co-dominate or even dominate sites in the eastern part of the range. White fir is of significant importance throughout except on ultramafics where Jeffrey pine becomes more important. With increasing elevation, white fir generally gives way to Shasta red fir and then mountain hemlock. Western white pine is commonly an important species throughout the upper montane areas.

The hardwood component of Klamath montane forests is equally diverse and distinguishes them from montane forests in the Sierra Nevada and Cascade Range. Hardwoods commonly present in the subcanopy include golden chinquapin, bigleaf maple *(Acer macrophyllum)*, Pacific madrone *(Arbutus menziesii)*, tanoak *(Lithocarpus densiflorus)*, California black oak, and canyon live oak *(Quercus chrysolepis)*. Tanoak and golden chinquapin, dominant hardwoods in the west, are replaced by California black oak in the central and eastern Klamath Mountains.

SUBALPINE

Subalpine woodlands and forests dominate the highest elevations in the Klamath Mountains (Fig. 9.4). There is no upper limit to this zone as trees are able to grow to the tops of the highest peaks (Sawyer and Thornburgh 1977). The alpine character of the higher elevations of the Klamath Mountains is primarily due to shallow soils (Sharp 1960) or soils derived from strongly ultramafic parent materials and not due to low temperatures that prevent forest growth (Sawyer and Thornburgh 1977). Forests in the subalpine zone are generally open, patchy woodlands of widely spaced trees with a discontinuous understory of shrubs and herbs. Extensive bare areas are common (Sawyer and Thornburgh 1977). However, dense stands are found on deeper soils.

Stands on mesic sites are dominated by mountain hemlock, whereas xeric sites are usually occupied by Shasta red fir (Sawyer and Thornburgh 1977, Keeler-Wolf 1990). Woodlands are also common on harsh sites in the upper-montane and subalpine zones where any mixture of western white pine, Jeffrey pine, whitebark pine, foxtail pine, mountain hemlock, or curl-leaf mountain-mahogany may occur.

Overview of Historic Fire Occurrence

Prehistoric Period

Vegetation assemblages have varied considerably over the Holocene, and there have been long periods (thousands of yrs) with assemblages unlike any found today. Contemporary vegetation assemblages coalesced approximately 3,000 to 4,000 years ago when the climate cooled and became moister compared to the previous several millennia (West 1985, 1988, 1989, 1990; Mohr et al. 2000). Because the dominant tree species have potential life spans of 500 to 1,000+ years (Brown 1996, 2002), the current forest assemblages have existed for only a few life spans of the dominant tree species.

Fire regimes have varied over millennia primarily due to variations in climate. The record of fire in the Klamath Mountains covers the post-glacial Holocene and extends back to about 13,000 to 15,000 years B.P. and is preserved as variation in fossil charcoal abundance in lake sediments (West 1985, 1988, 1989, 1990; Mohr et al. 2000; Daniels 2001; Whitlock et al. 2001; Briles 2003). The frequency of fire episodes over this period track variation in precipitation and temperature (Whitlock et al. 2003). Fire episodes were more frequent during warm, dry periods such as the early Holocene and the Medieval Warm Period than in cool, wet periods (Whitlock 2001). Fire regimes characteristic of the pre-settlement period (i.e., 1600 A.D.–1850 A.D.) have been in place for approximately the last 1,000 years (Mohr et al. 2000). The fossil charcoal record indicates that the frequency of fire episodes per century, and millennia, has not been stable over the Holocene. Charcoal influx appears to be more closely related to trends in regional burning reflective of the amount of available biomass rather than to local fire frequency (Whitlock et al. 2004). Importantly, the paleoecological evidence suggests there is only a loose coupling between fire regimes and any particular vegetation assemblage (Whitlock et al. 2003).

Native people of the Klamath Mountains used fire in many ways: (1) to promote production of plants for food (e.g., acorns, berries, roots) and fiber (e.g., basket materials); (2) for ceremonial purposes; and (3) to improve hunting conditions (Lewis 1990, 1993; Pullen 1995). Though native ignitions appear to have been widespread, we do not know the extent of their influence on fire regimes and vegetation at broad scales.

Several fire history studies describe fire regimes in parts of the Klamath Mountains over the last few centuries (Agee 1991; Wills and Stuart 1994; Taylor and Skinner 1997, 1998, 2003; Stuart and Salazar 2000; Skinner 2003a, 2003b; Fry and Stephens 2006). These studies indicate there are two periods with distinctly different fire regimes: (1) the Native American period, which usually includes both the pre-historic and European settlement period, and (2) the fire suppression period. Though there is variation among sites as to when fire suppression became effective, the temporal patterns of fire occurrence in the pre–fire suppression period indicate that most stands experienced at least several fires each century. This suggests a general fire regime of frequent, low- to moderate-intensity fires.

Historic Period

Europeans began to explore the Klamath Mountains by the 1820s (Sullivan 1992, Pullen 1995). Following the 1848 discovery of gold along the Trinity River (Jackson 1964, Hoopes 1971), people of European, Asian, and other non-native cultures began to enter the Klamath Mountains in large numbers and permanently settle the area. Settlers are reported to have set fires to make travel easier, to clear ground for prospecting, to drive game, and to encourage forage production for sheep and cattle (Whittaker 1960). Though settlement is thought to have increased fire frequency and perhaps fire intensity, no increases in fire occurrence during the settlement period are evident in fire scar studies (Agee 1991; Wills and Stuart 1994; Taylor and Skinner 1998, 2003; Stuart and Salazar 2000). It may be that fires caused by settlers, either intentional or accidental, replaced fires ignited by Native Americans as the latter

FIGURE 9.4. A subalpine landscape looking southwest from Mount Eddy toward the Trinity Alps. Most of the trees in the foreground and middle ground are foxtail pines. (Photo by Carl N. Skinner.)

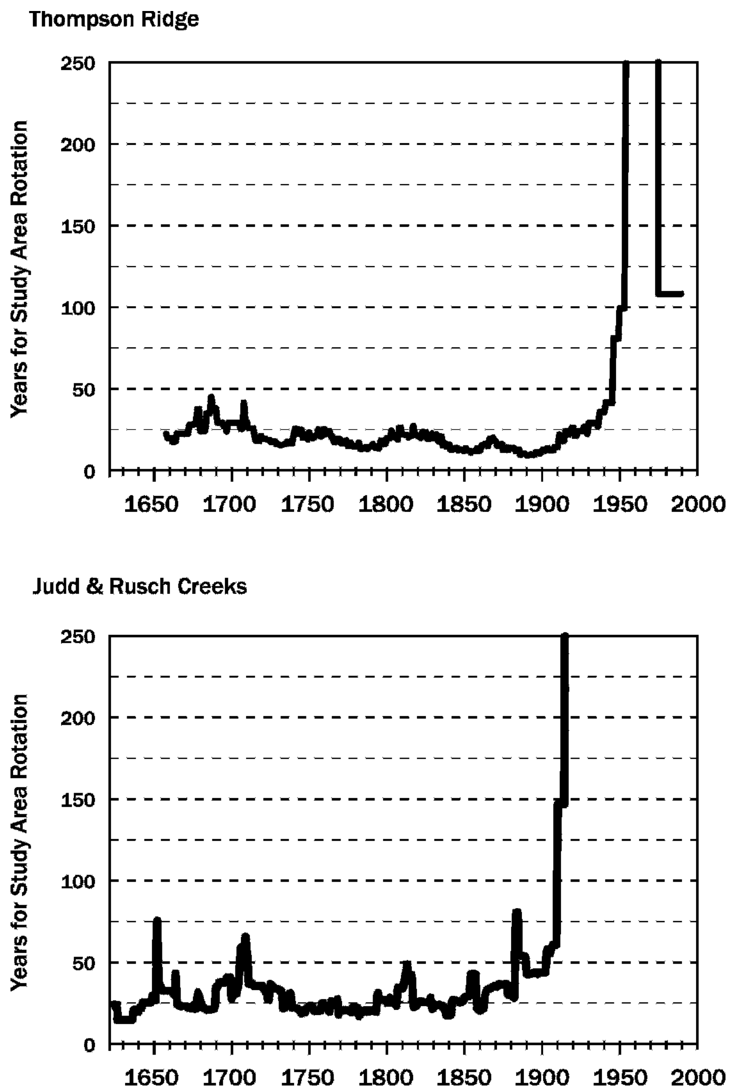


FIGURE 9.5. Charts showing the dramatic increase in fire rotations for two large study areas: Thompson Ridge near Happy Camp (Taylor and Skinner 1998), and Rusch/Jud creek watersheds near Hayfork (Taylor and Skinner 2003).

populations declined. In any case, many areas in the Klamath Mountains experienced a pre-settlement fire regime until fire suppression became effective sometime after establishment of the Forest Reserve system in 1905 (Shrader 1965). Fire suppression had become effective in more-accessible areas by the 1920s (Agee 1991; Stuart and Salazar 2000; Skinner 2003a, 2003b; Taylor and Skinner 2003; Fry and Stephens 2006), whereas fire suppression did not become effective in more remote areas until after 1945 (Wills and Stuart 1994, Taylor and Skinner 1998, Stuart and Salazar 2000).

Current Period

Fire occurrence declined dramatically with the onset of fire suppression. This is illustrated by the steep rise in fire rotation for two large study areas: (1) near Happy Camp (Taylor and Skinner 1998) and (2) near Hayfork (Taylor and Skinner 2003) (Fig. 9.5).

Over the 400 years prior to effective fire suppression, there are no comparable fire-free periods when large landscapes experienced decades without fires simultaneously across the bioregion (Agee 1991; Wills and Stuart 1994; Taylor and Skinner 1998, 2003; Stuart and Salazar 2000; Skinner 2003a, 2003b).

Along with these changes in the fire regimes are changes in landscape vegetation patterns. Before fire suppression, fires of higher spatial complexity created openings of variable size within a matrix of forest that was generally more open than today (Taylor and Skinner 1998). This heterogeneous pattern has been replaced by a more homogenous pattern of smaller openings in a matrix of denser forests (Skinner 1995a). Thus, spatial complexity has been reduced. The ecological consequences of these changes are likely to be regional in scope, but they are not yet well understood. When modern fires burn under relatively stable atmospheric conditions conducive to thermal inversions in the narrow canyons, patterns of severity appear to be similar to historical patterns (Weatherspoon and Skinner 1995, Taylor and Skinner 1998). However, when inversions break and/or strong winds accompanied by low humidity occur, large areas of severe burn are possible such as those of the Megram fire in 1999 (Jimerson and Jones 2003) and the Biscuit fire in 2002 (USDA Forest Service 2003). The extent of the recent high-severity burns appears to be different than historic burning patterns. More area is burning at high intensity, and this is related, in part, to higher quantities and more homogeneous fuels caused by accumulation during the fire-suppression period.

Major Ecological Zones

Fire Regimes

The steep and complex topography of the Klamath Mountains provides for conditions that make it difficult to separate fire regimes by ecological zones. The most widespread fire regime in the Klamath Mountains is found from the lower montane through the mid-montane into the upper montane and it crosses ecological zones. Indeed, the patterns we present run the elevational gradient from the lowest canyon bottoms to nearly 2,000 m (6,250 ft). Generally, the steep, continuous slopes that run from low to higher elevations interact with changes in slope aspect and the dominating influence of the summer drought, to create conditions for frequent, mostly low- and moderate-intensity fires in most ecological zones in the Klamath Mountains. Given the importance of topographical controls on fire regimes in the Klamath Mountains we discuss the fire regimes more generally rather than assign them to specific ecological zones as in other bioregions.

TOPOGRAPHY

The long-term record of fires from intensive studies of fire scars, tree age-classes, and species composition demonstrates that topography strongly influenced Klamath Mountain fire regimes. The spatial pattern of fire occurrence appears to be related to differences in timing of fires from place to place and topographically related differences in fire severity rather than to fire frequency. With the exception of riparian zones (Skinner 2002a, 2003b), only small differences in median fire-return intervals have been found within watersheds of several thousand hectares despite considerable variability in elevation, slope aspect, and tree species composition; and they vary from landscape to landscape following no consistent pattern (Taylor and Skinner 1998, 2003).

Areas of similar timing of fires were found to be of several hundred hectares and were bounded by topographic features (e.g., ridgetops, aspect changes, riparian zones, lithologic units) that affect fuel structure, fuel moisture, and fire spread (Taylor and Skinner 2003). It is likely that the size of areas of similar fire occurrence probably varied from landscape to landscape depending on topographic complexity. Although areas separated by topographic boundaries often had similar fire return interval distributions, they often experienced fires in different years than in adjacent areas. The topographic boundaries between fire occurrence areas were not simple barriers to fire spread, but acted more like filters. In many years these features contained fires, but in other years, especially those that were very dry, fires would spread across boundaries (Taylor and Skinner 2003) (Fig. 9.6).

RIPARIAN ZONES

Few fire history data are available from riparian zones, but available data suggest that fire-return intervals, and possibly fire behavior, are more variable within riparian zones than in adjacent uplands (Skinner 2002a, 2003b). Median fire-return intervals were generally twice as long on riparian sites than on neighboring uplands. However, large differences in the range of fire return intervals were not found between riparian zones and adjacent upland sites (Skinner 2002a, 2003b). It should be noted that these data are from riparian sites adjacent to perennial streams and are probably not representative of riparian areas associated with ephemeral and intermittent streams. Riparian areas associated with ephemeral and intermittent streams dry out over the warm summers and probably have a fire regime similar to the surrounding uplands (Skinner 2002a, 2003b).

Thus, riparian areas along perennial watercourses served as effective barriers to spread of many low-intensity and some moderate-intensity fires and strongly influenced patterns of fire occurrence beyond their immediate vicinity. Consequently, by affecting fire spread, riparian areas are a key topographic feature that also contributes to the structure and dynamics of upland forest landscapes (Skinner 2002a, 2003b; Taylor and Skinner 2003).

FIRE SEVERITY

Patterns of fire severity, an important determinant of stand and landscape structural diversity, have been associated with topographic position in both the pre-fire suppression and contemporary periods (Weatherspoon and Skinner 1995, Taylor and Skinner 1998, Jimerson and Jones 2003). A typical pattern of fire severity is illustrated in Figure 9.7 (Taylor and Skinner 1998). Generally, the upper third of slopes and the ridgetops, especially on south- and west-facing aspects, experience the highest proportion of high-severity burn. In the landscape, this is seen as larger patches of shrubs, young even-aged conifer stands, and stands of knobcone pine *(Pinus attenuata)*. The lower third of slopes and north- and east-facing aspects

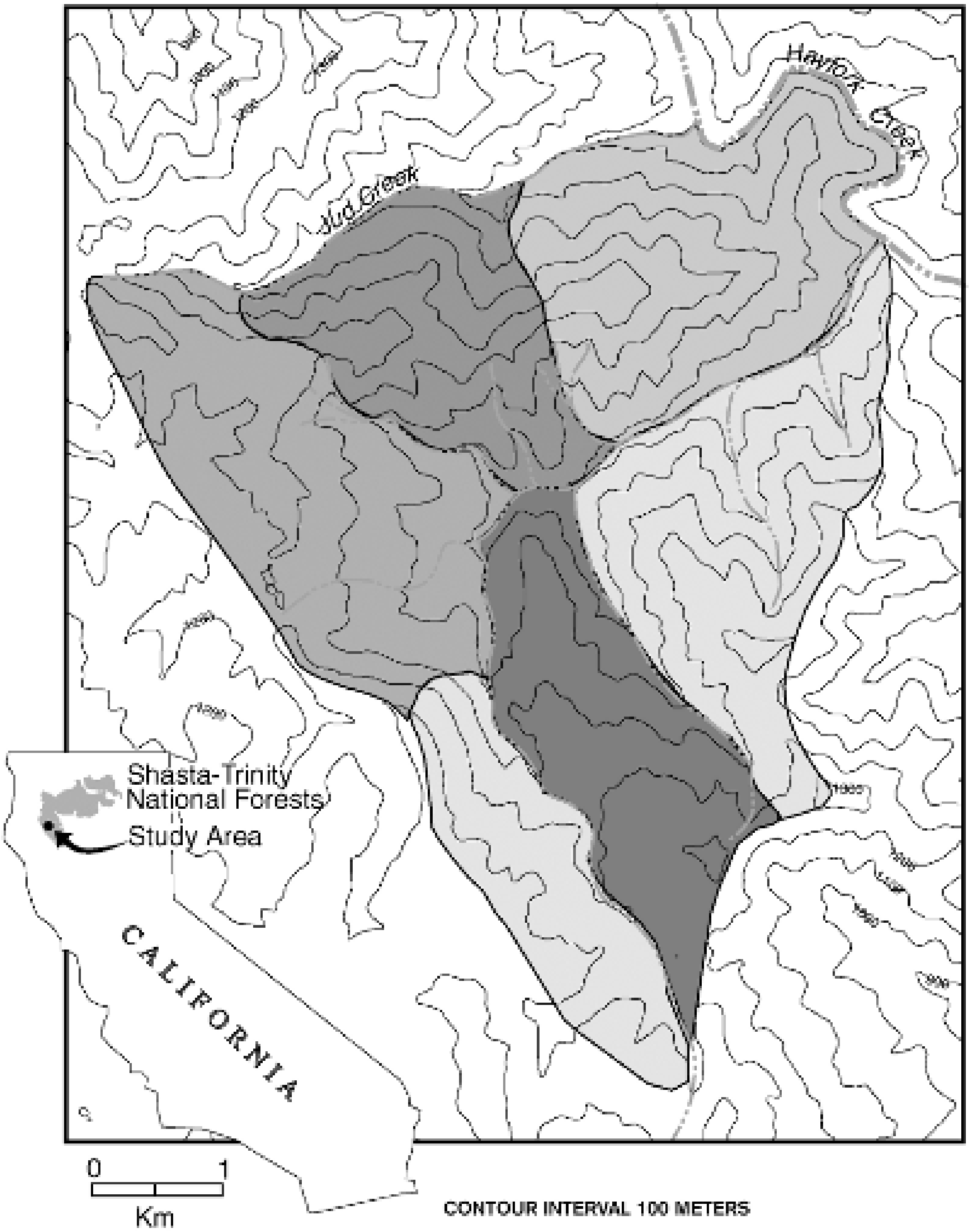


FIGURE 9.6. Map of areas with similar timing of fire occurrence in the Rusch/Jud creek watersheds near Hayfork. This figure illustrates how topographic features limited the spread of fires in most years. Even though fire frequency did not vary significantly from area to area, the year of fire occurrence was often different from one area to its neighbors. (Adapted from Taylor and Skinner 2003.)

experience mainly low-severity fires. Thus, more extensive stands of multi-aged conifers with higher densities of old trees are found in these lower slope positions. Middle slope positions are intermediate between lower and upper slopes in severity pattern. Middle and upper slope positions, especially on south- and west-facing aspects, are more likely to experience higher fire intensities than other slope positions due to differentials in factors that affect fire behavior. The effect of greater drying and heating of fuels on these slopes contributes to greater fire intensity and makes it more likely that these slope positions experience higher-intensity burns (Rothermel 1983). The common occurrence of strong thermal inversions in the steep, narrow

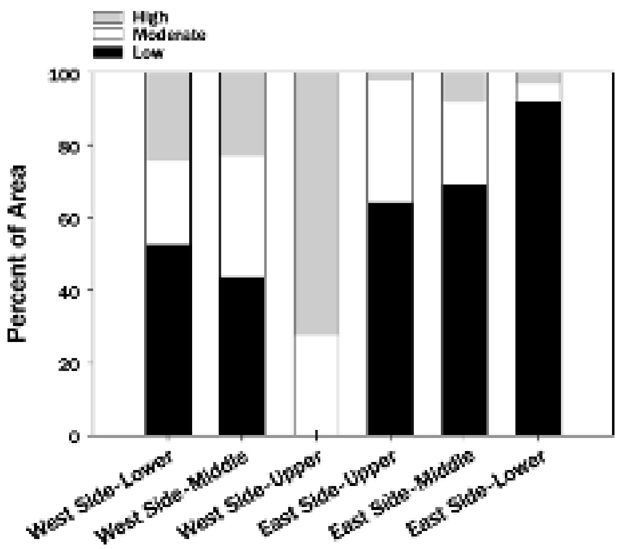


FIGURE 9.7. Chart depicting the distribution of cumulative fire severity patterns on Thompson Ridge near Happy Camp (Taylor and Skinner 1998).

canyons of the Klamath Mountains amplifies differentials in temperature, humidity, and fuel moisture between the canyon bottoms and the ridgetops (Schroeder and Buck 1970). Diurnal patterns of local sun exposure and wind flow combine with slope steepness to affect fire behavior (Schroeder and Buck 1970, Rothermel 1983). Thus, upper slopes would have a greater tendency to support higher-intensity fires running uphill through them in contrast to the tendency for lower slopes to support lower-intensity backing fires. The exposure to wind and solar insulation combines with position on steep slopes to create conditions where upper slopes experience higher-intensity fires more often than do lower slopes. The cumulative effects of the interaction of these factors on landscape patterns are depicted in Figure 9.8 (Sidebar 9.1).

Lower Montane

Tables 9.3 and 9.4 summarizes the fire regime information of common alliances in the lower montane ecological zone of the Klamath Mountains.

FIRE RESPONSES OF IMPORTANT SPECIES

More fire ecology information is available for alliances that include Douglas-fir as an important species than for any other alliances in the Klamath Mountains. Douglas-fir, once mature, is very resistant to low- to moderate-intensity surface fires due to a variety of characteristics. Douglas-fir has very thick bark, a deep rooting habit, high crowns (Agee 1993), short needles, heals fire wounds rapidly, and does not slough bark. In fact, Douglas-fir is the most fire-resistant tree species in the Klamath Mountains. Its common conifer associates, ponderosa, Jeffrey, and sugar pine, are also fire resistant and have thick bark, root deeply, and have high, open crowns. The pines, however, have longer needles and slough bark that forms a less compact litter bed so surface fires are more intense at the base of pine trees. It is not unusual for these three pine species to exhibit open fire wounds *(cat faces)*. In contrast, Douglas-fir rarely maintains open fire wounds. Wounds generally heal rapidly and are bark covered after only a few years. Moreover, Douglas-fir has shorter needles than the pines and does not slough bark so litter beds beneath the trees are compact, which reduces fire intensity at the base of the tree. Thus, Douglas-fir has advantages in this bioregion following occasional extended periods (20–30 years) without fire when Douglas-fir is less likely to incur basal bole damage than the pines.

Canyon live oak, generally considered sensitive to fire, is common in the lower montane zone of the Klamath Mountains. They may be easily top-killed by fire due to a dense canopy and thin bark that makes them highly susceptible to crown scorch and cambium damage. As with most oaks, if the top is killed, canyon live oak sprouts vigorously from the root crown (Tirmenstein 1989).

California black oaks, common throughout lower and mid-montane forests in the Klamath Mountains, have thin bark and are fire sensitive compared with conifer associates (e.g., Douglas-fir, ponderosa pine, sugar pine, white fir) that invade oak stands during long fire-free periods. However, oak litter beds decompose rapidly and usually have low accumulations of fuel so fires that burn in oak litter have a low intensity and rarely damage mature stems. Moreover, California black oak crowns are open and do not usually support crown fires. With regular burning, the understory fuels are light, generally composed of grasses, forbs, scattered shrubs, and oak litter. Additionally, if black oaks are top-killed they sprout vigorously from the root crown and are able to maintain their presence on a site.

Stands with a major component of buck brush *(Ceanothus cuneatus* var. *cuneatus)* are found scattered throughout the lower- to mid-montane zones in the Klamath Mountains on xeric sites with shallow soils on limestone, ultramafic, or granitic bedrock. Often associated with buck brush are the shrubs birch-leaf mountain-mahogany *(Cercocarpus betuloides* var. *betuloides)*, holly-leaf redberry *(Rhamnus ilicifolia)*, California buckeye *(Aesculus californica)*, and the trees California bay *(Umbellularia californica)* and California black oak. It is interesting that buck brush does not sprout but establishes from seed following fires, whereas its associates are all strong sprouters (Table 9.5).

Dense stands of shrubs dominated by Brewer oak are common and often support a diverse association of woody species. Brewer oak–dominated stands are found well into the mid-montane areas. Common associates are deer brush, poison oak *(Toxicodendron diversilobum)*, snowdrop bush *(Styrax officinalis)*, foothill ash *(Fraxinus dipetala)*, birch-leaf mountain-mahogany, wild mock orange *(Philadelphus lewisii)*, redbud *(Cercis occidentalis)*, and California buckeye. All of these species sprout vigorously following fires (Skinner 1995b) (Table 9.5).

FIRE REGIME–PLANT COMMUNITY INTERACTIONS

The fire regimes of forests dominated by Douglas-fir are discussed at length in the section describing the common fire regimes of the Klamath Mountains. As these fire regimes are

FIGURE 9.8. This photo of Figurehead Mountain in the Thompson Creek watershed illustrates how patch size varies with topographic position as a response to variation in fire intensity. The largest patches with mostly young trees are on the upper thirds of the slopes as a response to higher-intensity fires above the inversion. Intermediate patches are in the middle-third slope position. The lower-third slope position has a fine-grain pattern of dense large, old trees indicating fires burned primarily as low-intensity surface fires in these locations (Taylor and Skinner 1998). This photo was taken in 1992—five years after the entire landscape shown had burned in the 1987 fires. (Photo by Carl Skinner, USDA Forest Service.)

TABLE 9.3
Fire regime characteristics—for lower-montane forest and woodlands

Vegetation type	Douglas-fir–dominated	Canyon live oak	California black oak	Oregon oak
Temporal				
Seasonality	Summer–fall	Summer–fall	Summer–fall	Summer–fall
Fire-return interval	Short	Short–Medium	Short	Short
Spatial				
Size	Medium–large	Medium	Medium	Medium–Large
Complexity	Moderate–high	Moderate–high	Low–moderate	Low–moderate
Magnitude				
Intensity	Low–moderate	Low–moderate	Low	Low
Severity	Low–moderate	Low–moderate	Low–moderate	Low–moderate
Fire type	Surface	Surface	Surface	Surface

NOTE: Fire regime terms used in this table are defined in Chapter 4.

not specific to this zone, we do not elaborate on them here. Here we concentrate on alliances more common in this zone than in others.

In the lower- to mid-montane zone, canyon live oaks commonly achieve tree stature and dominate steep, xeric slopes in landscapes that experienced frequent, low- to moderate-intensity fires. Canyon live oaks on these sites sometimes have open cat faces with fire scars evident. However, the fire record is generally undatable due to decay around the wound. Fire scar records collected from ponderosa pines, sugar pines, and Douglas-firs scattered in five canyon live oak stands near Hayfork had median fire-return intervals of 6 to 22 years (Taylor and Skinner 2003). This fire scar record covered the period from the mid 1700s to the last recorded fire in 1926.

Sites where canyon live oak makes up a major portion of the canopy are often rocky, unproductive (Lanspa n.d.), and have sparse, discontinuous surface fuels that do not carry fire well except under more extreme conditions (Skinner and Chang 1996). Slopes with canyon live oak are often so steep that surface fuels collect mainly in draws, small benches, and on the upslope side of trees. Fires on these slopes would likely follow the draws and burn in a discontinuous manner. The fire record comes from trees located near the head of ephemeral draws on the upper third of slopes. The presence of fire scars in the canyon live oaks

TABLE 9.4
Fire regime characteristics—Lower-montane shrublands

Vegetation type	Buck brush	Brewer oak	Whiteleaf manzanita
Temporal			
Seasonality	Summer–fall	Summer–fall	Summer–fall
Fire-return interval	Medium–long	Short–medium	Medium–long
Spatial			
Size	Medium	Small–large	Medium–large
Complexity	Moderate	Moderate–high	Low–high
Magnitude			
Intensity	High	Low–high	Low–high
Severity	High	Moderate–high	Moderate–high
Fire type	Passive-active crown	Surface–passive crown	Surface to active-independent crown

NOTE: Fire regime terms used in this table are defined in Chapter 4.

TABLE 9.5
Fire response types for important species in the lower-montane zone of the Klamath Bioregion

	Type of Fire Response			
	Sprouting	Seeding	Individual	*Species*
Conifer	None	Stimulated (establishment)	Resistant/killed	Douglas-fir, ponderosa pine
	None	Stimulated (seed release)	Resistant/killed	Gray pine
	None	Fire stimulated (seed release)	Killed	Knobcone pine
Hardwood	Fire stimulated	Stimulated (establishment)	Top-killed/survive	California black oak
	Fire stimulated	None known	Top-killed/survive	Brewer oak, tan oak, foothill ash, Oregon ash, Fremont cottonwood, white alder
Shrub	None	Stimulated (germination)	Killed	Whiteleaf manzanita
	Fire stimulated	Stimulated (germination)	Top-killed/survive	Chamise, deer brush, greenleaf manzanita, mahala mat
	Fire stimulated	None	Top-killed/survive	California buckeye, Lemmon's ceanothus, shrub tan oak, birch-leaf mountain-mahogany, wild mock orange, snowdrop bush, poison oak

TABLE 9.6
Fire regime characteristics—Upland forests in mid- to upper-montane zones

Vegetation type	Jeffrey pine	White fir	Shasta red fir	Knobcone pine
Temporal				
Seasonality	Summer–fall	Summer–fall	Late summer–early fall	Late summer-early fall
Fire-return interval	Short	Short–medium	Short–medium	Truncated medium
Spatial				
Size	Small–large	Small–large	Medium	
Complexity	Moderate	Moderate–high	Moderate–high	Low–moderate
Magnitude				
Intensity	Low–moderate	Low–moderate	Low–moderate	Multiple
Severity	Multiple	Multiple	Multiple	Moderate–high
Fire type	Surface	Surface to crown	Surface to crown	Crown

NOTE: Fire regime terms used in this table are defined in Chapter 4.

suggests they were scarred by very light fires that burned in fuel that had collected on the uphill side of the stem.

Stands dominated by California black oak are common throughout lower- and mid-montane areas especially in the central and eastern Klamath Mountains. The highly nutritious acorns of California black oaks were an important food source for the native people of the bioregion. To perpetuate this food source, the native people promoted and maintained California black oak stands by regular burning (Lewis 1993). Since the onset of fire suppression, conifers have invaded many of these stands and they are poised to overtop and replace the oaks on many sites.

California black oak usually suffers the greatest damage when moderate-intensity fires burn in stands that have a significant component of conifers. Greater fuel accumulates under conifers because conifer litter decomposes more slowly than California black oak litter. Moreover, oaks in mixed stands often have lower vigor due to competition from the conifers, and lower-vigor trees are more susceptible to fire damage, especially with the altered fuelbeds. In these mixed stands, conifers often survive fires because they have thicker bark, whereas many oaks may be top-killed. If much of the conifer canopy remains, the oaks then sprout in the shade of the conifers and are often not able to reach the main canopy as they do in an open environment or under other oaks.

Black oak (as well as tan oak and Pacific madrone) seedlings can survive for many years in the shaded understory of conifers. During this time, they are able to develop a large root system with a long taproot with limited top growth. Top growth on the seedlings may die back to the root crown and re-sprout several times waiting to quickly put on height growth following formation of a canopy gap. In this way, California black oaks are able to survive for long periods as isolated trees in relatively dense conifer stands. Additionally, when a high-intensity fire kills much of the conifer overstory, existing oak seedlings are poised to quickly grow and reclaim dominance of the site (McDonald and Tappeiner 2002). Subsequent frequent fires will maintain the oak dominance. An example of this process can be seen near Volmers along Interstate 5 where a severe fire in 1986 killed several hundred hectares of mixed Douglas-fir, ponderosa pine, and sugar pine. The burned area is now dominated by fast-growing California black oak on mesic sites, and knobcone pine on xeric sites.

Extensive stands of California black oaks survived the approximately 12,000 ha (29,600 ac) High Complex near Lake Shasta reservoir in 1999. Even though this fire burned in August and early September, the driest time of the year, the light fuel beds under oak stands supported mostly low-intensity surface fire.

Mid- to Upper Montane

Forests in this zone are differentiated from lower-elevation forests by the increased importance of white fir throughout and Shasta red fir in higher portions and the decreased importance of hardwoods, especially tan oak, giant chinquapin, and California black oak. Specified in this way, the lower extent of the zone varies from approximately 600 m (2,000 ft) in the west to about 1,300 m (4,250 ft) in the eastern portion of the range (Sawyer and Thornburgh 1977). Table 9.6 summarizes the fire regime information for vegetation common in the mid- to upper-montane ecological zone of the Klamath Mountains.

FIRE RESPONSES OF IMPORTANT SPECIES

White fir has thin bark when young, but its bark is not shed and thickens with age, making it more fire tolerant when mature. Shasta red fir is similar but appears to be more sensitive than white fir at all ages.

Port Orford-cedar *(Chamaecyparis lawsoniana)*, commonly associated with mesic conditions on soils derived from ultramafic material, is found in two disjunct areas in the

TABLE 9.7

Fire regime characteristics—riparian forests, wetlands, and upland shrub types in the mid- to upper-montane zone

Vegetation type	Port orford-cedar	California pitcher plant	Ceanothus shrub fields	Greenleaf manzanita
Temporal				
Seasonality	Late summer–fall	Late summer–fall	Summer–fall	Summer–fall
Fire-return interval	Short–medium	Short–medium	Medium–long	Medium–long
Spatial				
Size	Small–medium	Small	Small–large	Small–large
Complexity	Moderate–high	Moderate–high	Low–high	Low–high
Magnitude				
Intensity	Low–high	Low–moderate	Moderate–high	Moderate–high
Severity	Low–high	Low–high	Moderate–high	Moderate–high
Fire type	Surface to crown	Surface	Crown	Crown

Klamath Mountains. The largest stands of Port Orford cedar occur in the western Klamath Mountains, especially in the Siskiyous. Inland, Port Orford cedar stands are primarily found in riparian settings in the Trinity Pluton ultramafic formation (Jimerson et al. 1999), mostly in the Trinity and Sacramento River watersheds. Port Orford cedar stands often include trees more than 300 years old with open, charred wounds (cat faces) indicating they commonly survived low- to moderate-intensity surface fires (Table 9.7).

Knobcone pine, a serotinous cone pine with relatively thin bark, is common in the Klamath Mountains in areas that burn intensely.

Stands dominated by Jeffrey pine are found primarily on soils derived from ultramafic rock and they occur in the lower-montane through the subalpine zones (Sawyer and Thornburgh 1977). Incense-cedar is a common associate with huckleberry oak and California coffeeberry as common understory shrubs. Jeffrey pine is similar to ponderosa pine in that it develops thick bark relatively early in life rendering it resistant to most low- and moderate-intensity fires. Incense-cedar becomes very resistant to low- and moderate-intensity fires as it approaches maturity due to thick, insulating bark and high crowns. Incense-cedar has also been found to withstand high levels of crown scorch (Stephens and Finney 2002).

Important shrub-dominated alliances of the upper-montane Klamath Mountains are greenleaf manzanita, deer brush, tobacco brush, and huckleberry oak. All of the dominant shrubs in these alliances sprout vigorously following fire. Moreover, manzanitas and most *Ceanothus* spp, also establish after fire from long-lived seeds stored in soil seed banks (Tabel 9.8).

FIRE REGIME–PLANT COMMUNITY INTERACTIONS

Most information on fire regimes and fire effects in white fir forests comes from areas on the edges of the Klamath Mountains. On the western edge, Stuart and Salazar (2000) found median fire-return intervals of 40 years in the white fir alliances, and shorter 26- and 15-year median intervals where white fir was found in the Douglas-fir and incense cedar associations. Atzet and Martin (1992) reported a 25-year fire-return interval for white fir, and Agee (1991) found a range from 43 to 64 years from dry to moist white fir forest in the Siskiyous. Thornburgh (1995) reported a 29-year fire-return interval for the centrally located Marble Mountains.

Before the fire suppression era, the severity of most fires was not high, due to the fire tolerance of mature white fir and generally low to moderate fire intensities. Generally, more fires are dated from fire scars than from fire-initiated cohorts of regeneration (Taylor and Skinner 1998, Stuart and Salazar 2000), allowing inference that most fires were underburns. The natural forest structure is patchy, and this structure was maintained by fire. Areas that burn with high severity usually are young stands of pure white fir, open stands of white fir with a shrub understory, or montane chaparral that may contain a few white firs (Thornburgh 1995), and these high-severity patches create coarse scale heterogeneity.

Our understanding of the frequency and extent of high-severity fire and its role in stand and landscape dynamics in the white fir zone is limited. Fire likely interacted with wind to influence dead fuel accumulations. In the Klamaths and in the Cascades to the east, white fir stand structure is often all-aged and sites often have pit and mound topography created by windthrow, suggesting that wind is an important disturbance that creates gaps (Agee 1991, Taylor and Halpern 1991, Taylor and Skinner 2003). Moreover, at these higher elevations, winter snowfall is common, and when followed by high winds, can cause substantial snapping of treetops, as in 1996 in the central Klamath Mountains. Wind-generated stem snap and windthrow were responsible for the high fuel accumulations that generated the higher-severity burn patterns in the 1999

TABLE 9.8
Fire response types for important species in the mid- to upper-montane zone of the Klamath bioregion

	Type of Fire Response			
	Sprouting	Seeding	Individual	*Species*
Conifer	None	Fire stimulated (seed release)	Killed	Knobcone pine
	None	Fire stimulated (establishment)	Resistant/killed	Douglas-fir, ponderosa pine, Jeffrey pine
	None	None	Resistant/killed	Incense cedar, Port Orford-cedar, sugar pine, western white pine, red fir, white fir, western juniper
	None	None	Killed	Brewer's spruce, lodgepole pine
Hardwood	Fire stimulated	None	Top-killed/survive	Bigleaf maple, tanoak, canyon live oak, Pacific dogwood, white alder, Oregon ash, water birch
	Fire stimulated	None	Resistant/top-killed/survive	California black oak, blue oak, Pacific madrone, golden chinquapin
	Fire stimulated	Stimulated (establishment)	Resistant/top-killed/survive	Oregon white oak
	None	None	Killed	Curl-leaf mountain-mahogany
Shrub	Fire stimulated	Stimulated (germination)	Top-killed/survive	Tobacco brush, greenleaf manzanita, mahala mat
	Fire stimulated	None	Top-killed/survive	Bush chinquapin, shrub tanoak, huckleberry oak, California buckeye, wild mock orange, vine maple, mountain maple

Megram fire (Jimerson and Jones 2003). The degree to which higher stand densities and surface fuel accumulations due to fire exclusion stimulated this synergistic effect is not clear.

Forest density in white fir forests has tended to increase with fire suppression, with the shade-tolerant white fir generally showing the largest increases (Stuart and Salazar 2000). Fire-tolerant species such as ponderosa pine, sugar pine, and California black oak are declining and this will most likely continue as long as fire exclusion is effective.

Though Shasta red fir is common throughout the Klamath Mountains in upper montane and subalpine environments (Sawyer and Thornburgh 1977), Shasta red fir has been studied most extensively in the Cascades and more detail will be presented in that chapter (Chapter 10).

In the Klamath Mountains, fire history has been documented in one Shasta red fir stand near Mumbo Lakes. Important associates were western white pine, white fir, Jeffrey pine, and mountain hemlock (Skinner 2003a). Six fire-scarred samples were collected from a 2-ha (5-ac) site within this stand. The fire record extended from 1576 to 1901. The composite median fire-return interval for all samples was 10 years and the median fire-return interval for individual trees ranged from 9 to 30 years. However, there was considerable variation in fire-return intervals with a minimum interval of 2 years from 1698 to 1700 and a maximum of 118 years from 1752 to 1870. No fires were detected after 1901. The fire-free period since 1901 is exceeded only by the 118-year interval.

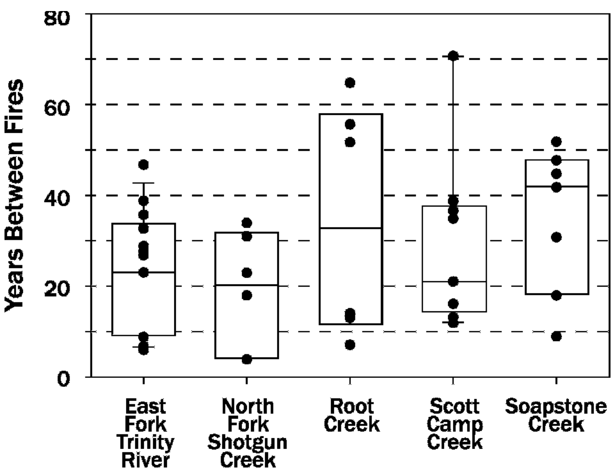


FIGURE 9.9. Port Orford-cedar stand fire intervals. Chart shows distribution of fire-return intervals in inland stands of Port Orford-cedar. (Source: Skinner 2003a).

Though Port Orford-cedar is resistant to low- and moderate-intensity fires, there has been extensive mortality to Port Orford-cedars in stands where high-intensity fires have burned in recent years. For example, in the 1994 Bear fire, mortality was so high in the No Man's Creek drainage (a proposed Research Natural Area) that there was concern that Port Orford-cedar would disappear due to lack of seed source (Creasy and Williams 1994). Since Port Orford-cedar stands are located on mesic, riparian sites and their wood is highly resistant to decay, it is likely these stands are able to produce heavy fuel loadings, especially following longer periods without fire as in the more recent fire suppression era. When these areas finally do burn in the inevitable dry years, high-intensity burns should be expected with accompanying mortality of the Port Orford-cedars.

The previous discussion on the influence of riparian areas on Klamath Mountain fire regimes was based on information from inland sites in the Trinity and Sacramento River watersheds dominated by Port Orford-cedar. These fire-scar data for the inland Port Orford-cedar stands indicate that fires burned with median fire-return intervals of 16 to 42 years (Fig. 9.9). In each case, the median fire-return interval in the Port Orford-cedar stands was at least twice that of forests in the surrounding uplands (Skinner 2003b). Though there was considerable variation in length of fire intervals, the length of time since the last fire (the fire-suppression period) exceeds the longest interval previously recorded in each of the sampled stands.

Knobcone pine in the Klamath Mountains exhibits a unique bimodal geographical distribution related to areas at higher and lower elevations that experience high-intensity fires. As in other bioregions, knobcone pine is found at low elevations intermixed with chaparral as around Lake Shasta and Whiskeytown Lake reservoirs. However, in the Klamath Mountains, knobcone pine is also found in the upper montane zone on upper slopes and ridgetop positions, especially on south- and west-facing slopes. As discussed previously, these are locations that experience more extreme fire weather conditions (e.g., low humidity, high temperature, high winds) than the surrounding landscape.

Jeffrey pine forests are generally thought to have fire regimes similar to ponderosa pine forests—frequent, low- to moderate-intensity fires. However, Jeffrey pine sites often have more variation in fire-return intervals than sites that support ponderosa pine (Skinner and Chang 1996, Taylor 2000, Stephens 2001, Stephens et al. 2003). This variation is probably due to the combination of nutrient-poor soils and shorter growing seasons, especially at higher elevations, which increases variability in fuel production compared with typical ponderosa pine sites.

Fire-scar data from ultramafic sites with Jeffrey pine in the Klamath Mountains are available from 7 sites in the vicinity of Mt. Eddy (Skinner 2003a) and 10 sites near Hayfork (Taylor and Skinner 2003). The median fire-return interval for the Jeffrey pine sites near Mt. Eddy ranged from 8 to 30 years and 8 to 15 years for those near Hayfork. For the sites near Mt. Eddy, the current fire-free periods of 57 to 129 years exceed the 95th percentile pre-fire suppression fire-free interval for 5 of 7 sampled stands. At Hayfork, the current fire-free periods of 68 to 125 years exceed the longest pre-fire suppression intervals recorded on all 10 sites.

Considerable differences in the flammability of shrub stands have been noted. Shrub stands dominated by manzanita, particularly greenleaf and whiteleaf manzanita, burn more readily than stands dominated by ceanothus (either deer brush or tobacco brush) or stands with a significant component of shrub canyon live oak, tan oak, or chinquapin (Weatherspoon and Skinner 1995). Stands dominated by huckleberry oak appear to be similar to those dominated by California-lilac or other oaks (Table 9.8).

The occurrence of montane shrub stands may be associated with either poor edaphic conditions unsuitable for tree growth or high-intensity, stand-replacing fires. Once established, because of the nature of shrub fuels, fires that burn in these communities are more likely to be high-intensity, stand-replacing events.

Thus, where shrub communities established following stand-replacing forest fires, recurring fire plays a key role in the maintenance of these communities by preventing shrub replacement by trees (Wilken 1967, Nagel and Taylor 2005). More information on fire regimes of shrub-dominated alliances can be found in Chapter 10.

The only known herbaceous alliance with fire ecology information in the Klamath Mountains is for the California pitcher plant *(Darlingtonia californica)*. Pitcher plant seeps are common in open habitats saturated with running water, usually on serpentine substrate (Sawyer and Keeler-Wolf 1995). The continuous presence of flowing water through these herbaceous communities would seem to limit opportunities for fires and little is known of their fire ecology (Crane 1990). However, Port Orford-cedar, incense-cedar, western white pine, or Jeffrey pine trees with cat faces, are commonly scattered in and adjacent to the seeps.

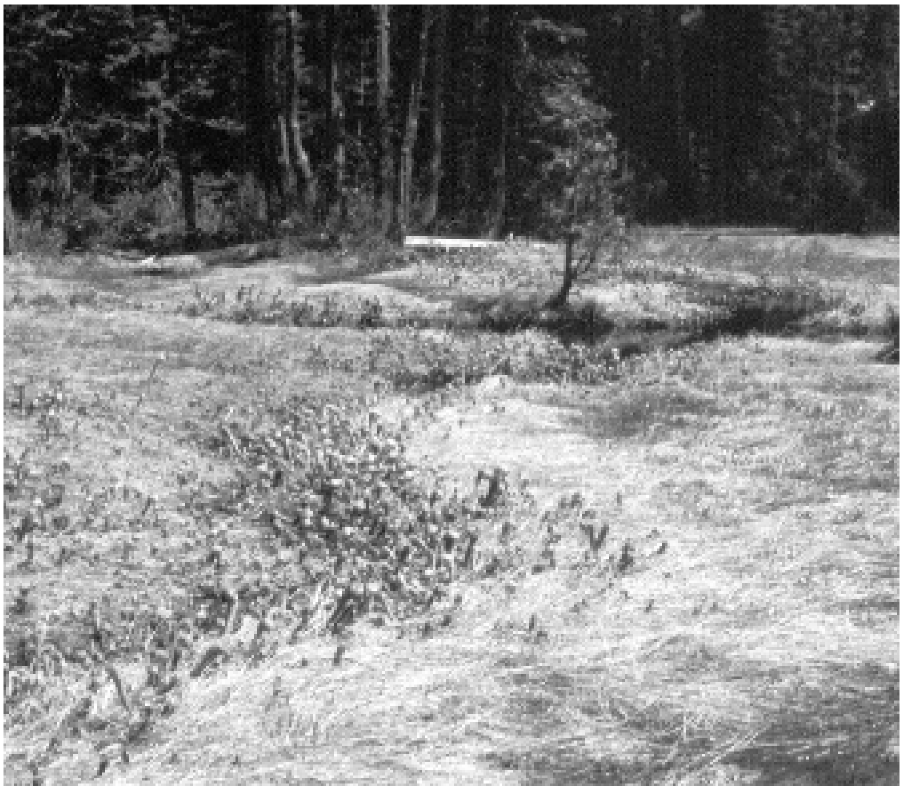


FIGURE 9.10. A pitcher plant seep in September following an early hard frost in the Scott Camp Creek watershed near Castle Lake. (Photo by Carl N. Skinner.)

A prescribed burn in September 1997 in the Cedar Log Flat Research Natural Area on the Siskiyou National Forest was found to spread easily through dead herbaceous material in sedge and pitcher plant seeps under the following conditions: humidity 27%, temperature 20°C–25°C (68°F–77°F), 10-hour fuel moisture 12%, and 100-hour fuel moisture 20% to 26% (Borgias et al. 2001). These are conditions easily achieved, or exceeded, in the summer where pitcher plant is found. Though a decline in pitcher plant cover was detected three years post-fire, unburned controls experienced a similar decline suggesting little effect from the burn (Borgias et al. 2001).

Fire histories from fire-scarred trees in pitcher plant seeps have been documented in the North Fork of Shotgun Creek (NFSC) and Soapstone Creek (SC). Median fire return intervals for these sites were18 years and 42 years, respectively (sites 2 and 5 in Fig. 9.9) (Skinner 2003b), whereas individual tree fire-return intervals ranged from 24 to 73 years at NFSC, and 40 to 140 years at SC. Differences in the length of fire-return intervals in these seeps are probably related to conditions in the surrounding forests. NFSC is located in the upper third of a steep, southeast-facing slope and is surrounded by mixed stands of Jeffrey pine, white fir, incense-cedar, sugar pine, and Douglas-fir. Consequently, it would be expected to have relatively short fire return intervals. On the other hand, SC is near the bottom of a U-shaped canyon on a gentle slope surrounded by mixed stands of Shasta red fir, white fir, western white pine, Jeffrey pine, sugar pine, and Douglas-fir. Thus, SC would be expected to have relatively long fire return intervals. Port Orford-cedar is the most common tree on both sites, however.

Fires burning in these environments probably occur very late in the season when water is low, in very dry years, or possibly after an early frost has killed much of the herbaceous material above ground as in Figure 9.10.

Subalpine

FIRE RESPONSES OF IMPORTANT SPECIES

Most tree species in the subalpine zone, including mountain hemlock, Shasta red fir, whitebark pine, western white pine, foxtail pine, lodgepole pine, and curl-leaf mountain-mahogany have thinner bark than species found at lower elevations and are easily damaged or killed by moderate-intensity fire or the consumption of heavy surface fuels at the base of the tree. Tables 9.9 and 9.10 summarize the fire regime information for vegetation discussed in the subalpine ecological zone of the Klamath Mountains.

FIRE REGIME–PLANT COMMUNITY INTERACTIONS

Landscapes of this zone are a heterogeneous mosaic of stands, rock outcrops, talus, morainal lakes, and riparian areas, so fuels are discontinuous. Moreover, deep snowpacks persist into late June or July in most years, so the fire season is very short. Fuel beds from the short-needled species are compact and promote slow-spreading, mostly smoldering surface fires. Fuel build-up tends to be slow because of the short growing season. Higher-intensity fires that do burn in

TABLE 9.9
Fire response types for important species in the subalpine zone of the Klamath Bioregion

	Type of Fire Response			
	Sprouting	Seeding	Individual	*Species*
Conifer	None	None	Resistant/killed	Red fir, mountain hemlock, Jeffrey pine, foxtail pine, western white pine, whitebark pine
	None	None	Killed	lodgepole pine
Hardwood	None	None	Killed	Curl-leaf mountain-mahogany

TABLE 9.10
Fire regime characteristics—Subalpine

Temporal	
Seasonality	Late summer–fall
Fire-return interval	Short–long
Spatial	
Size	Small–medium
Complexity	Moderate–high
Magnitude	
Intensity	Low
Severity	Multiple
Fire type	Surface

subalpine forests primarily occur in areas of locally heavy fuel accumulations during periods of extreme fire weather.

The only fire history data for the subalpine zone in the Klamath Mountains are from stands on China Mountain (Mohr et al. 2000, Skinner 2003a). Species present in these stands are mountain hemlock, Shasta red fir, whitebark pine, western white pine, foxtail pine, and lodgepole pine.

Fire-scar samples were collected from 14 trees on three 1-ha (2.5-ac) sites in the Crater Creek watershed. Over the period spanned by the fire-scar record (1404–1941), the median fire return intervals for these sites were 11.5, 12, and 13 yrs. However, 44 of 51 fires were detected on only single trees. This suggests that fires in this subalpine basin were mainly low intensity and small. Ranges of individual-tree median fire-return intervals were 9 to 276 years with a grand median of 24.5 years. No fires were detected after 1941.

Management Issues

Managers face several fire-related challenges in the Klamath Mountains but most are similar to those faced by managers in other parts of California and the western United States (e.g., smoke management, heavy fuel accumulations). However, two issues—wildlife habitat and wildland-urban interface—stand out in this bioregion.

Wildlife Habitat

Management objectives often include the desire to maintain forest ecosystems within their historic range of variability (HRV; see, e.g., Swanson et al. 1994, Manley et al. 1995) using ecological processes (FEMAT 1993, USDA-USDI 1994) as a means to sustain a mix of desirable wildlife habitats. Recent studies suggest that vegetation patterns and conditions generated by pre–fire-suppression fire regimes (Taylor and Skinner 1998, 2003) may be advantageous for wildlife species of concern such as the northern spotted owl *(Strix occidentalis caurina)* (Franklin et al. 2000) and several species of butterflies (Huntzinger 2003). Fire suppression has been ubiquitously applied throughout the bioregion. Consequently, there is a need to better understand the role of frequent low- and moderate-intensity fires on development of the forest landscape mosaic from stand to watershed scales (Agee 1998, 2003). This understanding will help managers better assess risks associated with different management alternatives (Attiwill 1994, Mutch and Cook 1996, Arno et al. 1997, Cissel et al. 1999, Arno and Allison-Bunnell 2002, Agee 2003).

More-recent management activities, such as logging and replacement of multi-aged old-growth forests with even-aged forest plantations and continued fire suppression have reduced forest heterogeneity, increased the proportion of even-aged forests, and altered habitat conditions for forest-dwelling species compared to conditions in the pre–fire-suppression landscape (USDAs-USDI 1994). Large wildfires with large proportions of stand-replacing or near-stand-replacing fire have burned in the Klamath Mountains in the last three decades (1977, 1987, 1995, 1996, and 2002). These fires have reduced the extent, in some places dramatically, of multi-aged, old-growth stands. Areas burned by these fires are now occupied by plantations, even-aged hardwood stands, or brushfields and, in some watersheds (e.g., north and south forks of the Salmon River, Chetco River), these vegetation types are now the landscape matrix. Moreover, some areas that burned

SIDEBAR 9.1. DEVELOPMENT OF EVEN-AGED FOREST STANDS

Prior to fire suppression, parts of the forested landscape in the Klamath Mountains were occupied by stands of trees with similar ages, but there is little evidence that they covered large areas (i.e., hundreds–thousands ha) (Atzet and Martin 1992, Agee 1993, Taylor and Skinner 1998, 2003). We believe the origin of even-aged stands is not just the result of punctuated establishment following stand-replacing fire. Certainly, high-severity, stand-replacing fire is the process responsible for the location and extent of some even-aged stands (e.g., Agee 1993; Taylor and Skinner 1998) but two other pathways of even-aged stand development are also possible.

Frequent low- to moderate-severity fires often kill conifer seedlings and occasionally kill dominant trees leading to the development of large forest openings over long periods (i.e., decades to centuries) especially in upper-slope topographic positions. The interruption of these frequent fires with a longer fire-free period, combined with a good seed crop, perhaps associated with cooler and moister conditions, could then trigger establishment of even-aged stands. This pathway appears to be responsible for some of the even-aged stands of white fir or Douglas-fir we observed in forests on Thompson Ridge near Happy Camp (Taylor and Skinner 1998).

Another pathway to even-aged stand development we have observed is associated with fire suppression. In some forest types, punctuated regeneration of fire-sensitive species occurred over wide areas following suppression of fire. For example, young even-aged forests of Douglas-fir now occupy large areas in parts of the Klamath Mountains where frequent fire had originally maintained dominance by black oak. The result of this process has increased the proportion of landscapes occupied by even-aged conifer forests at low to middle elevation.

intensely in 1977 (e.g., Hog fire) burned intensely again in 1987 (e.g., Yellow fire). The 1987 fires also burned large areas of multi-aged, old-growth forest at high intensity. Thus, young even-aged forests that will have high fuel loads as plantations are thinned, and old-growth stands with high fuel loads due to fire suppression, may amplify conditions for even-aged landscape development. Positive feedbacks between management (i.e., fire suppression, plantations), stand conditions in the new even-aged vegetation matrix, and intense fire have the potential to maintain or even expand an even-aged forest matrix that is unusual with respect to the pre-historical period.

Wildland-Urban Interface

With an average of less than 1.2 people/km^2 (3 people/mi^2), the Klamath Mountains have a low human population compared with California as a whole (USCB 2002). Yet, a large proportion of the bioregion is classified as mixed interface (CDF 2002b) because of the dispersed nature of dwellings in small, scattered communities in flammable, wildland vegetation. As a result, several hundred homes have been lost to wildfires that originated in the bioregion in just the last three decades (CDF 2002a). Examples of major suppression efforts in wildland-urban interfaces in the bioregion include fires near Hayfork and Happy Camp (1987), Redding and Lakehead (1999), Weaverville (2001), and Jones Valley (Bear fire) and French Gulch (2004). The Jones fire (1999) alone burned more than 900 structures (CDF 2002a), including nearly 200 homes in and around Redding. The fire problem at the wildland-urban interface will continue to grow as more people move into low-density housing at the edges of communities throughout the bioregion.

Future Directions

There is a critical need to better understand the synergistic relationships between low-, moderate-, and high-intensity fire and pre–fire-suppression vegetation patterns. There is a particular need for quantitative estimates of the proportion of landscapes in different stand types (i.e., old-growth, young even-aged, hardwood) and how they were patterned on the landscape to provide a stronger foundation for applying concepts of historical range of variability to forest management in the Klamath Mountains. There is great potential for fire and landscape ecologists to work with wildlife ecologists to examine wildlife responses to landscape dynamics across a range of spatial and temporal scales.

Hardwoods, especially oaks, provide important habitat elements for many species of wildlife. As a result, managers may use prescribed fire to inhibit conifer encroachment into oak stands as well as to improve acorn crops (Skinner 1995b). Oak woodlands have also been associated with rich vegetation diversity. Yet, their ecology is little studied in these montane forest environments. We need to better understand the ramifications of the potential loss of large areas of hardwoods to conifers for associated vegetative diversity and wildlife habitat.

The temporal and spatial dynamics of large, dead woody material in areas where pre–suppression fire regimes are characterized by frequent, low- to mixed-severity fires is not known but it is probably very different than those identified by current standards and guidelines used by both federal and state agencies. Quantities of large woody material for standards and guidelines were developed from contemporary old-growth forests that had experienced many decades of fire suppression. These quantities of woody material were probably unusually high compared to typical pre–fire-suppression values. Consequently, a management emphasis on meeting or exceeding standards and guidelines for dead woody material has and will increase fire hazard over time and threatens the very habitat the standards and guidelines were designed to improve (Skinner 2002b).

Summary

Primarily due to the annual summer drought and ample winter precipitation, fires were historically frequent and generally of low to moderate and mixed severity in most vegetation assemblages, especially those that cover large portions of the Klamath Mountains. Fire exclusion and other management activities have led to considerable changes in Klamath Mountain ecosystems over the last century. Of all management activities that have contributed to altering ecosystems in the Klamath Mountains, fire suppression has been the most pervasive since it alone has been ubiquitously applied. Though there is much current discussion of the need for restoring fire as an ecological process, or at least creating stand structures that would help reduce the general intensity of fires to more historical levels, there are many competing social/political concerns and objectives (e.g., fine filter approaches to managing wildlife habitat and air quality) that make doing anything problematic (Agee 2003). Regardless of how these controversies are resolved, the ecosystems of the Klamath Mountains will continue to change in response to climate and social/political choices for the use of forest resources and their associated fire-management alternatives.

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