CHAPTER ELEVEN

Klamath Mountains Bioregion

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

WILSON (1904)

Description of the Bioregion

The Klamath Mountains bioregion occupies much of northwestern California continuing into southwestern Oregon. In California, the bioregion lies between the Northern California Coast bioregion on the west and the southern Cascade Range to the east. The southern boundary is the Northern California Coast Ranges and Northern California Interior Coast Ranges (Miles and Goudey 1997). This bioregion covers approximately 22,500 km² (8,690 mi²), or 6% of California. It includes the Klamath and Trinity River systems, the headwaters of the Sacramento River, the most extensive exposure of ultramafic rocks in North America, and some of the most diverse conifer forests in North America (Sawyer 2006) (Map 11.1).

Physical Geography

The Klamath Mountains have been deeply dissected by the Klamath, McCloud, Sacramento, Salmon, and Trinity Rivers with no consistent directional trends. Only two sizable alluvial valleys, Scott and Hayfork, occur here (Oakeshott 1971). Elevations range from 30 m (100 ft) to 2,755 m (9,038 ft). Several prominent ranges or ridge systems comprise the bioregion with Mt. Eddy being the highest peak (Oakeshott 1971). 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 (Whittaker 1960, Sawyer 2006) and thus influence fire regimes. Spatial variation in soil productivity combined with steep gradients of elevation and changes in slope aspect controls the connectivity, structure, and rates of fuel accumulation.

Climate

Climate of the bioregion is Mediterranean. However, the local expression of climate is remarkably variable due to strong west-east moisture and temperature gradients 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 ~3,000 to ~4,000 years ago (Mohr et al. 2000, Briles et al. 2011).

Table 11.1 shows climatic data for selected stations from west to east. Notably, 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).

There is considerable local and regional variation of annual precipitation. Generally, less precipitation falls in valleys and canyons than in the surrounding uplands with strong gradients over short distances. The driest areas occur adjacent to the Shasta and Sacramento Valleys. However, the watersheds of the Sacramento, McCloud, and Pit Rivers in the eastern Klamath Mountains are noted for high annual precipitation. At higher elevations, most precipitation falls as snow. The average annual early April snowpack depth and water content for snow courses are shown in Table 11.2.

WEATHER SYSTEMS

Critical fire weather in the Klamath Mountains is associated with any weather condition that creates sustained periods of high velocity winds with low humidity. Three weather patterns are important (Hull et al. 1966): (1) Pacific High—Postfrontal (Postfrontal), (2) Pacific High—Prefrontal (Prefrontal), and (3) Subtropical High Aloft (Subtropical High).

Postfrontal 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 Postfrontal conditions occurred in 1999 when the Megram fire burned over 57,000 ha (141,000 ac) east of Hoopa and the Jones fire, northeast of Redding near Lake Shasta, consumed over 900 structures while burning over 10,000 ha (25,000 ac).

Prefrontal 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

MAP 11.1 Klamath Mountains bioregion in California.

temperatures usually drop and relative humidity rises. These strong Prefrontal winds are able to spread fires rapidly as happened when the Oregon fire (2001) west of Weaverville burned over 650 ha (1,600 ac) and 13 homes and the Panther fire (2008) south of Happy Camp, already over 20,200 ha (50,000 ac) burned an additional 5,260 ha (13,000 ac) at high severity in a single run.

Subtropical High conditions occur when the region is under the influence of high pressure that causes temperatures to rise and humidity to drop. In this bioregion, these conditions lead to fires controlled mostly by local topography. Subtropical High conditions promote the development of strong temperature inversions that inhibit smoke from venting out of the canyons and valley bottoms (Robock 1988, 1991) leaving only the ridgetops in full sun. Smoke trapped under the thermal inversions, especially following initiation of widespread lightning-caused fires, shades the surface from solar heat, thus amplifying differentials in temperature, humidity, and fuel moisture between the canyon bottoms and the ridgetops (Schroeder and Buck 1970, Robock 1988, 1991, Estes et al. 2017) reducing fire intensity below the inversions. Examples of recent major fire episodes burning under these conditions include the Hayfork fires (1987) where 70% of the burned area sustained low-moderate-severity fire effects (Weatherspoon and Skinner 1995) and the widespread lightning fires of 2008 (Miller et al. 2012a). Fires burning above the inversion layer and immediately after dissipation of the inversion, especially when accompanied by strong winds, can produce large areas of high severity (Weatherspoon and Skinner 1995). Examples of such fires are the Megram fire in 1999 (Jimerson and Jones 2003), the Biscuit fire in 2002 (USDA Forest Service 2003), and the Motion and Panther fires of 2008 (Miller et al. 2012b).

LIGHTNING

Lightning is common in the Klamath Mountains with 12.8 strikes (range 6.4 to 26.4) yr^{-1} 100^{-1} km^{-2} (33.7 strikes [range 16.8 to 69.4] yr^{-1} 100^{-1} mi^{-2}) (van Wagtendonk and Cayan 2008). Lightning-caused fires have accounted for most area burned in recent decades (for example, 1977, 1987, 1999, 2002, 2006, 2008, 2012, and 2014). Indeed, from 1984 to

TABLE 11.1
Average annual, January, and July precipitation and normal daily January and July maxima and minima temperatures for representative stations in the Klamath Mountains

Location—elevation	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)

2008 over 87% of area burned in northwestern California was from lightning-caused fires (Miller et al. 2012a). Lightning may ignite hundreds of fires in a 24-hour period such as on June 21, 2008. The large number of simultaneous ignitions combined with poor access for fire-suppression forces, steep topography, and extensive strong canyon inversions (see above) generate widespread lightning fires that often burn for weeks to months over large areas (e.g., Estes et al. 2017).

For example, on June 21, 2008 lightning ignited widespread fires across northern California following an unusually early and dry spring (Hayasaka and Skinner 2009). These ultimately burned >175,000 ha (>432,000 ac) in the bioregion (Miller et al. 2012b). Many burned until extinguished by rain and snow in the fall (Miller et al. 2012a).

Lightning occurrence increases with distance from the coast and increasing elevation (van Wagtendonk and Cayan 2008). Interestingly, the two years with relatively few lightning strikes recorded—1987 and 1999—were years with some of the greatest amount of area burned by lightning-caused fires during the period of lightning strike data (Fig. 11.1).

Though counterintuitive, the number of lightning-caused fires and total area burned in a region are not necessarily related to the number of lightning strikes. More important than number of strikes is the ratio of ignitions to strikes (Hayasaka and Skinner 2009). Storms producing lightning-caused fires are associated with higher instability and drier air than storms that produce the most lightning strikes (Rorig and Ferguson 1999, 2002). Additionally, in each of 1987, 1999,

TABLE 11.2

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

Course name	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)

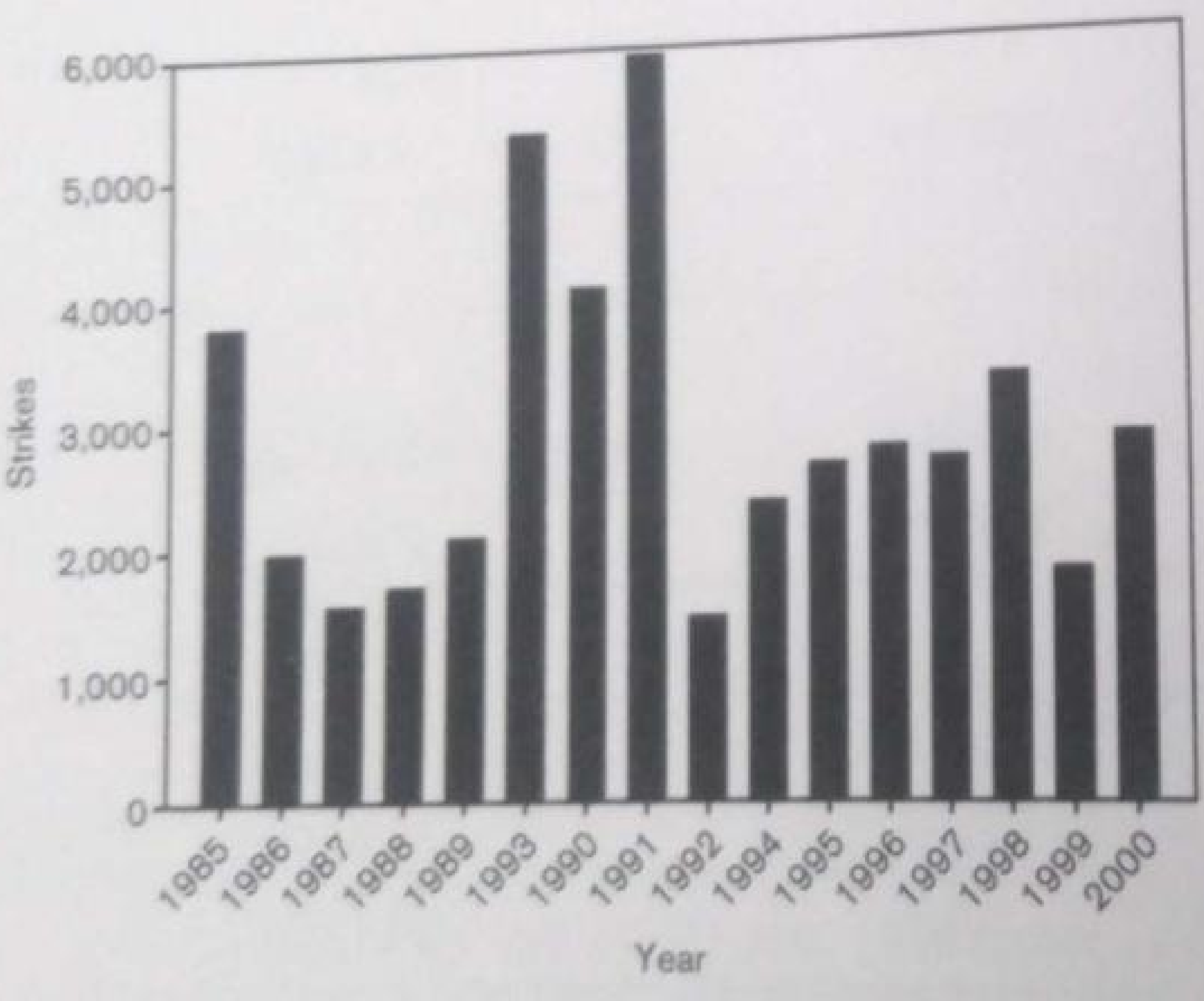

FIGURE 11.1 Variation in number of lightning strikes by year.

2008, and 2012 a single storm episode was responsible for nearly all of the area burned by lightning-caused fires.

The contribution of lightning-caused fires to total area burned has increased from 42% to 87% over the last century while the annual area and sizes of fires have significantly increased (Miller et al. 2012a). Further, the annual area burned appears to have changed over this time from being initially associated with drought to being inversely associated with summer rainfall. As the region receives very little summer rain, this further attests to the importance of thunderstorm characteristics—i.e., are they wet or dry. With improved access for suppression forces in more recent decades, thunderstorms accompanied by rain inhibit fire spread long enough for crews to arrive and suppress them. When little or no rain accompanies thunderstorms, fires ignite easily and quickly spread to become widespread fires that exceed capacity of suppression forces (Miller et al. 2012a).

It appears likely the incidence of lightning fires will increase as climate warms and fire season lengthens (Westerling et al. 2006, Yang et al. 2015). Lengthening fire seasons are characterized by earlier onset to spring warming and later fall cooling. Thus, fires can more easily ignite and spread earlier in the year and burn over a longer period of the year with increased drying of fuels (Yang et al. 2015). The widespread outbreak of lightning-caused fires in 2008 were set up by the early, dry spring (Hayasaka and Skinner 2009) which may become more common under a warming climate (Yang et al. 2015).

FIRE CLIMATE

To date, no studies have found a consistent association of fire activity with the El Niño Southern Oscillation (ENSO). This appears largely due to the location of the bioregion in the pivot zone (40–45°N) of the north/south dipole pattern of ENSO (Dettinger et al. 1998, Wise 2010). Resulting in the fire climate in this bioregion acting like the Southwest in some years and the Northwest in others. Examples are the droughts in the El Niños of 1965–1966 and 1991–1992 (Northwest pattern) and the extremely wet years of the strong El Niños of 1982–1983 and 1997–1998 (Southwest pattern).

Years with widespread and larger fires are usually dryer and warmer than the norm (Trouet et al. 2006, Taylor et al. 2008, Trouet et al. 2009). Trouet et al. (2009) found that these anomalous warm/dry years are associated with positive phases of both the Pacific North American Pattern (PNA) and the Pacific Decadal Oscillation (PDO). The development of a positive PNA + PDO produces persistent high-pressure ridges along the Pacific Coast in winter (Wallace and Gutzler 1981, Mantua et al. 1997) which reduces the amount and alters timing of annual precipitation (Trouet and Taylor 2010) contributing to fire seasons beginning earlier and being generally warmer, dryer, and longer (Trouet et al. 2009).

Ecological Zones

The Klamath Mountains have exceptional floristic diversity and complexity in vegetative patterns (Whittaker 1960, Sawyer 2006). The diverse patterns of climate, topography, and parent materials create heterogeneous vegetation patterns more complex than found in the Sierra Nevada or the Cascade Range (Sawyer and Thornburgh 1977, Sawyer 2006). The bioregion is thought to be of central importance in the 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 here (Whittaker 1961, Sawyer 2006). Vegetation and species diversity generally increases with distance from the coast and species diversity is highest in woodlands with highly developed herb strata (Whittaker 1960). Conifer forests and woodlands are found in all elevational zones throughout the bioregion (Sawyer 2006).

The rugged, complex topography and resulting intermixing of vegetation in this bioregion defies a simple classification of ecological zones by elevation (Sawyer 2006). Nevertheless, this chapter will discuss 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 (*P. ponderosa*) drop out and are replaced by upper montane and subalpine species such as Shasta red fir (*A. magnifica* var. *shastensis*), mountain hemlock (*Tsuga mertensiana*), western white pine (*P. monticola*), Jeffrey pine (*P. jeffreyi*), whitebark pine (*P. albicaulis*), lodgepole pine (*P. contorta* subsp. *murrayana*), foxtail pine (*P. balfouriana* subsp. *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. 11.2). 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 (Scott and Hayfork). Shrublands are found throughout the Klamath Mountains. Lower elevation 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 manzanita (*Arctostaphylos viscida*), greenleaf manzanita (*A. patula*), Brewer oak (*Quercus garryana* var. *breweri*), and deer brush (*Ceanothus integerrimus*). Shrublands also occupy extensive areas around historic mining districts (e.g., near Lake Shasta and Whiskeytown Reservoirs) where the combination of heavy cutting to support mining and air pollution from smelters caused drastic soil erosion and reduced site quality. 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 dense perennial grasses. Grasslands also occur on shallow ultramafic soils and on cemented glacial till, while wet montane meadows are scattered throughout the upper montane and subalpine areas. Shrublands occur at higher elevations on poor sites and where severe fires inhibit or have removed tree cover. Important shrubs here are tobacco brush (known locally as snowbrush) (*Ceanothus velutinus*), shrub tanoak (*Notholithocarpus densiflorus* var. *echinoides*), giant chinquapin (*Chrysolepis chrysophylla*), bush chinquapin (*C. sempervirens*), huckleberry oak (*Quercus vacciniifolia*), and greenleaf manzanita.

Woodlands dominated by any combination of blue oak (*Q. douglasii*), Oregon oak (*Q. garryana*), California black oak (*Q. kelloggii*), gray pine (*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*), Douglas-fir, Oregon oak, and incense cedar 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 (*Calocedrus decurrens*), Shasta red fir, or curl-leaf mountain-mahogany.

The montane conifer forests can be quite diverse with up to 17 conifer species have been identified in some watersheds in the north central Klamath Mountains (Keeler-Wolf 1990). However, stands typically have Douglas-fir in combination with any of five other conifer species: sugar pine, ponderosa pine, incense cedar, Jeffrey pine, and white fir (Fig. 11.3). Areas of ultramafic soils are an exception to this vegetation pattern, and stands here are usually dominated by Jeffrey pine or gray pine. Douglas-fir is the dominant conifer in the western portion of the bioregion. Ponderosa pine becomes an important associate on drier sites and may codominate or even dominate sites in the eastern part of the bioregion. White fir is of significant importance throughout except on ultramafics where Jeffrey pine is 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 other bioregions. Hardwoods commonly present in the subcanopy include: giant chinquapin, big-leaf maple (*Acer macrophyllum*), Pacific madrone (*Arbutus menziesii*), tanoak (*N. densiflorus* var. *densiflorus*), California black oak, and canyon live oak (*Q. chrysolepis*). Tanoak and giant chinquapin, dominant hardwoods in the west, are replaced by California black oak in the central and eastern Klamath Mountains.

Several species of fire sensitive conifers (Brewer spruce (*Picea breweriana*), Engelmann spruce (*P. engelmannii*), subalpine fir (*Abies lasiocarpa*)) are found in scattered, disjunct, and

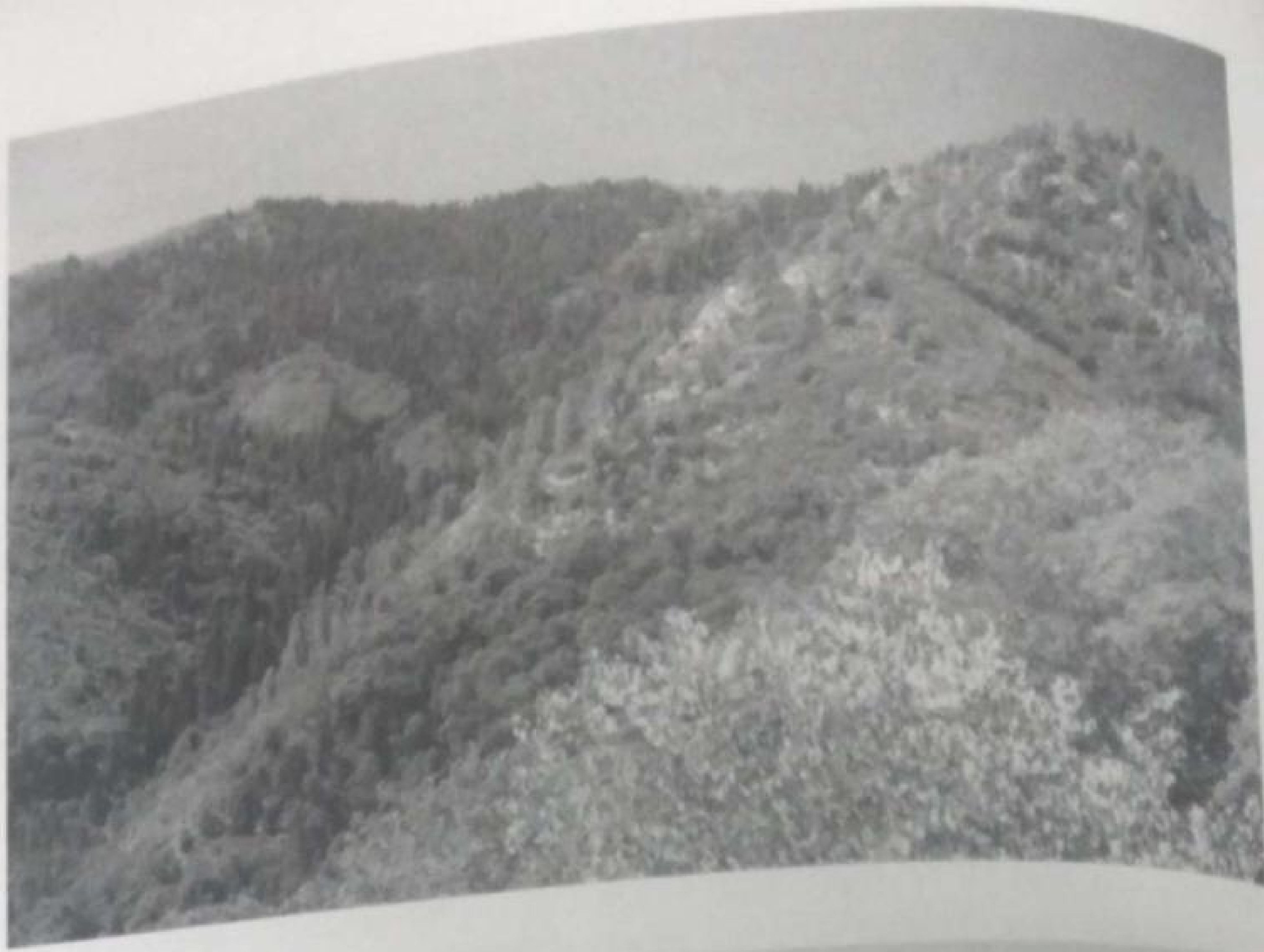

FIGURE 11.2 Lower montane zone. Photo from the McCloud River canyon shows the diversity typical of the lower montane zone. Left side of photo shows Douglas-fir stands, California black oak stands, and Brewer oak intermixed on soils derived from weathered metasediments. Right side of photo shows gray pine woodland, buck brush, and Brewer oak on soils derived from limestone (photo credits: Carl Skinner, USDA Forest Service).

FIGURE 11.3 Mid-montane zone. Douglas-fir usually dominates conifer forests in this zone. Jud Creek looking north toward Hayfork Bally (photo credits: Carl Skinner, USDA Forest Service).

isolated locations that are fireless refugia or places that escape fire for long periods (Sawyer and Thornburgh 1977, Thornburgh 1990, Ledig et al. 2005). These species are sometimes found in watersheds that support a high diversity of conifer species such as the Sugar Creek Research Natural Area (Cheng 2004, Sawyer 2006, Agee 2007).

SUBALPINE

Subalpine woodlands and forests dominate the highest elevations in the Klamath Mountains (Fig. 11.4). 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, Sawyer 2006). The alpine character of the higher elevations 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, occasionally dense stands can be found on deeper soils.

Stands on mesic sites are dominated by mountain hemlock while 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.

Historic Fire Occurrence

Holocene Fire, Vegetation, and Climate History

Our understanding of the prehistoric vegetation and fire regimes come primarily from pollen and charcoal preserved in the sediments of lakes occupying cirques or landslide depressions with some records extending into the last ice age

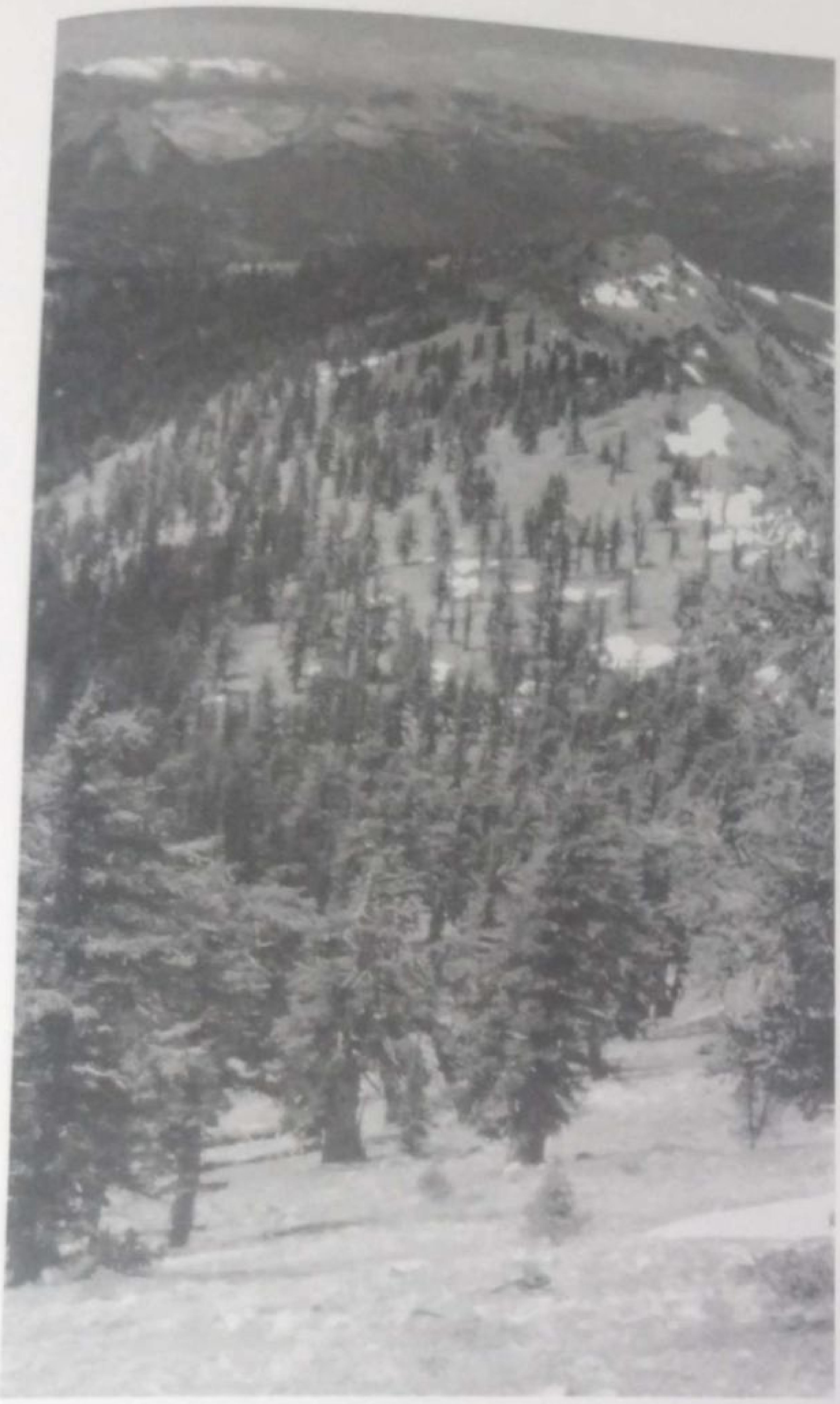

FIGURE 11.4 Subalpine landscape looking toward the Trinity Alps from Mount Eddy. Most trees in the foreground and middle ground are foxtail pines (photo credits: Carl Skinner, USDA Forest Service).

(>20 ka [20,000 years before present]; West 1990, Mohr et al. 2000, Daniels et al. 2005, Briles et al. 2005, 2008, 2011). Besides the slow variations in climate related to the seasonal cycle of insolation and long-term droughts significantly influencing vegetation and fire regimes, nonclimatic factors also have shaped the region's vegetation and fire history. For example, lags in plant response to climate change among sites have been attributed to a forest's relative distance from the coast and the penetration of the coast fog zone (Briles et al. 2008). Local topographic gradients have also influenced the density of forest cover and through time accounted for sharp gradients in vegetation and fire patterns. Additionally, the geology and specifically nutrient limitations and lower moisture due to increased evapotranspiration of ultramafic substrates in the bioregion have had a strong influence on forest composition and structure through time (Briles et al. 2011).

Eight published pollen and charcoal records are available from the Klamath bioregion, mostly from montane and subalpine forests. Bolan Lake (1,637 m elevation [5,371 ft]) and Sanger Lake (1,547 m [5,075 ft]) occur in the Siskiyou Mountains, and their watersheds are underlain by diorite substrates (Briles et al. 2005, 2008). Campbell Lake (1,750 m [1,741 ft]) in the Marble Mountains lies on metamorphic substrates, and Taylor Lake (1,979 m [6,493 ft]) in the Russian Mountains is located on granodiorite substrates (Briles et al. 2011). Bluff Lake (1,926 m [1,819 ft]), Crater Lake (2,288 m [7,507 ft]), Mumbo Lake (1,860 m [6,102 ft]), and Cedar Lake (1,742 m [5,715 ft]) are located on the extensive Trinity Ultramafic Sheet (Mohr et al. 2000, Daniels et al. 2005, Briles et al. 2011).

The pollen and charcoal records document major plant community and fire regime changes since the last glacial period (Fig. 11.5). The glacial period was characterized by cold dry conditions due to significantly lower summer insolation than today. The Bolan Lake record between ~17 and 15 ka suggests that Klamath forests were initially open with sagebrush, grasses, and scattered white pines (Haploxylon pines) and mountain hemlock (Briles et al. 2005). Only the highest peaks in the Klamath Mountains support similar plant communities today. Fire activity was very low and fires did not burn much biomass.

As summer insolation increased in the late-glacial period, warm mesic conditions prevailed between 15 and 11.5 ka, conifers including white pines, fir (*Abies* spp.), and mountain hemlock increased their ranges upslope while forests on nonultramafic substrates became more closed throughout the bioregion. However, forests in the central bioregion on ultramafic substrates remained open and supported primarily yellow pines (Diploxylon pines) likely Jeffrey pine. Fires occurred infrequently at all locations during the late-glacial period. Although forests became more closed on nonultramafic locations, fire activity was low, suggesting cool moist conditions limited ignition and fire spread.

A period of warm dry conditions occurred from 11.5 to 7 ka as summer insolation increased and drought became more intense. Forests on nonultramafic substrates transitioned to an open forest of xerophytic species including white pines, cedars, shrub oaks, and roses, and on ultramafic substrates, open forests were dominated by yellow pines, cedars, and shrub oaks. Douglas-fir and mountain hemlock were limited by dry conditions in the central bioregion and absent completely on ultramafic substrates. They were also significantly reduced in abundance in the Siskiyou Mountains. At all sites, fire occurrence was the highest during the early Holocene.

Summer radiation declined after 7 ka through present, and conditions became cooler and wetter. During this period, firs replaced white pines as the dominant tree species on nonultramafic soils through the Klamath Mountains, and Douglas-fir became more abundant in the Siskiyous. Forests on nonultramafic soils were generally closed. On ultramafic substrates, yellow pines and firs increased, while shrub oaks and cedars declined, but forests remained open. Fire frequency decreased after 7 ka, but was higher than during the late-glacial period.

The modern vegetation developed at approximately 3–4 ka as summers cooled and became moister due to declining summer radiation. Douglas-fir increased in the Siskiyous after 2 ka and dominated the forests along with firs, and increased to low levels on nonultramafic soils and remained nonexistent on ultramafic sites in central forests. Mountain hemlock, which was significantly reduced at all locations after 11.5 ka, increased in abundance after 4 ka (and especially after 2 ka) except on ultramafic substrates. It was particularly sensitive to submillennial climate variations, decreasing in abundance during the Medieval Climate Anomaly and increasing during the Little Ice Age. In central forests on ultramafic substrates, yellow pines increased while shrub oaks declined during the last 4 ka.

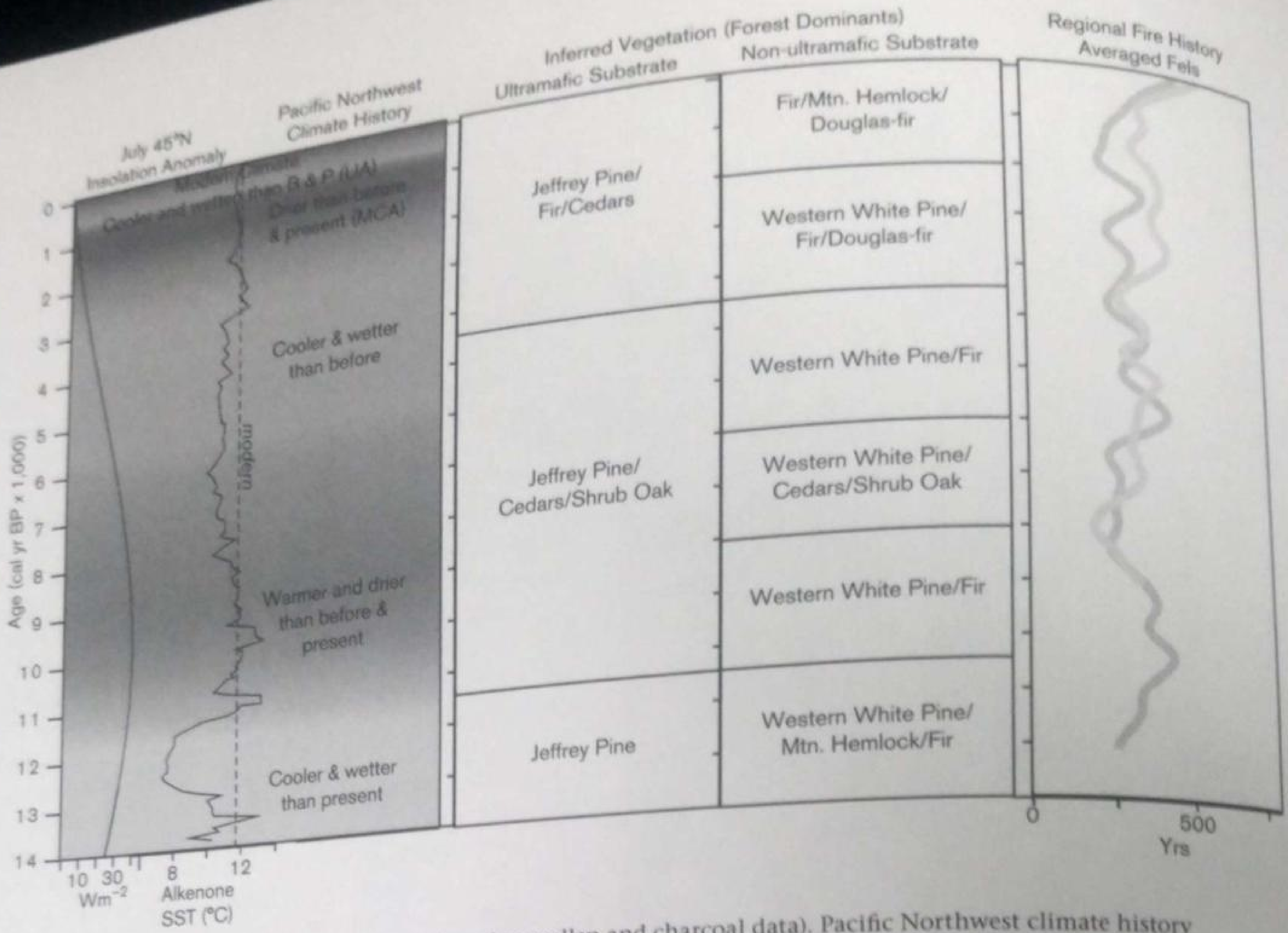

FIGURE 11.5 Climate, vegetation, and fire history (based on pollen and charcoal data). Pacific Northwest climate history summarized based on July 45°N insolation anomaly, alkenone d18O-derived sea surface temperatures from ODP 1019, and modeled climate (Alder and Hostetler 2015, Bartlein et al. 1998, Barron et al. 2003). LIA = Little Ice Age; MCA = Medieval Climatic Anomaly.

Fire activity in the last 4 ka remained moderately high on nonultramafic sites, but declined on ultramafic substrates possibly due to decline in the shrub oak understory that helps to carry fires. At all locations, fire activity decreased to unprecedented low levels after 1 ka, likely due to a combination of cool moist conditions during the Little Ice Age followed by fire suppression in recent times.

In summary, vegetation and fire regimes have continually changed in the Klamath Mountains since the last ice age and have been significantly influenced by slow variations in summer insolation and substrate differences. Past climate change has resulted in elevational adjustments in plant species, with important conifer species, such as Douglas-fir and mountain hemlock, showing particular sensitivity to warm/dry conditions. Climate has been the dominant driver of fires in the montane and subalpine Klamath forests, except on ultramafic substrates when understory shrubs were sparse.

Fire History Reconstructions of the Last 500 Years

Several fire history studies describe fire regimes of the Klamath Mountains over the last few centuries (Agee 1991, Wills and Stuart 1994, Taylor and Skinner 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 prehistoric and European settlement periods, and (2) the fire-suppression period. Native people of the bioregion used fire in many ways: (1) to promote production of plants for food and fiber; (2) for ceremonial purposes; and (3) to improve hunting conditions (Long et al. 2016). Though ignitions by natives appear to have been widespread, the extent of their influence on fire regimes and vegetation is not known. Though there is variation among sites in when fire suppression became effective, before fire suppression began it appears most stands experienced at least several fires each century. This suggests a general fire regime of frequent, low-moderate-intensity fires.

Historic

Europeans began to explore the bioregion by the 1820s (Sullivan 1992). Following the 1848 discovery of gold along the Trinity River (Jackson 1964, Hoopes 1971) nonnative people began to enter the bioregion 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). However, 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, Fry and Stephens 2006). It may be that fires caused by settlers, either intentional or accidental, replaced fires ignited by Native Americans as the latter populations declined (Taylor et al. 2016). One study found that fire frequency in the Whiskeytown mining district declined following influx of miners in the mid-1800s (Fry and Stephens 2006). Fires went from frequent and local to less frequent and more extensive. This was similar to findings by Skinner et al. (2009) in the North Coast Range where they suggested it may be due to a decline in Native American burning accompanied by diminished herbaceous fuels from livestock grazing. In any case, many areas in the Klamath Mountains did not experience a major change in the 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), while it did not become effective in more remote areas until after 1945 (Wills and Stuart 1994, Taylor and Skinner 1998, Stuart and Salazar 2000).

Twentieth-Century Fire Activity

Fire occurrence declined dramatically with onset of fire suppression. Over the 400 years preceding 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, Stuart and Salazar 2000, Taylor and Skinner 1998, 2003, Skinner 2003a, 2003b, Fry and Stephens 2006).

These changes in the fire regimes are accompanied by 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). The ecological consequences of these changes are likely to be regional in scope but are not yet well understood.

The annual maximum fire size and total area burned have been increasing since the onset of fire suppression in the early twentieth century even as number of fires has declined (Miller et al. 2012a). When modern fires burn under relatively stable atmospheric conditions conducive to thermal inversions in narrow canyons as described above, patterns of severity appear to be similar to historical patterns (Weatherspoon and Skinner 1995, Taylor and Skinner 1998, Miller et al. 2012a).

Although there is no clear trend in overall proportion of high-severity burn area, the size of fires and the size of high-severity burn patches have been increasing over the last several decades—the larger the fire, the larger the maximum high-severity burn patches (Miller et al. 2012a). The extent of the recent high-severity burn patches appears to exceed historic patch size patterns (Skinner 1995a, Taylor and Skinner 1998). We suggest this is related, in part, to higher quantities and more continuous, homogeneous fuels caused by accumulation during the fire-suppression period.

Fire severity, though counterintuitive, is inversely associated with the total area burned in a year—greater area burned is associated with lower proportion of high severity (Miller et al. 2012a). This is largely a result of lightning-caused fires accounting for most area burned and having a lower proportion of high-severity than human-caused fires. The large lightning-caused fires are generally in rugged, remote landscapes where fires burn for weeks to months under variable and often less than severe conditions. In contrast, human-caused fires are generally near communities and travel corridors that provide better access. Such human-caused fires escape mostly under very severe burning conditions. Since they do not come in swarms of ignitions like lightning, human-caused fires are usually isolated events and get sufficient resources to be contained quickly when weather and burning conditions moderate. Thus, much of the area burned by human-caused fires burns under severe conditions leads to greater proportions of high severity (Miller et al. 2012a).

Major Ecological Zones

Fire Regimes

The steep and complex topography of the Klamath Mountains makes it difficult to separate fire regimes by ecological zones. The most widespread fire regime in the bioregion is found from the lower 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 summer drought, to create conditions for frequent mostly low- and moderate-intensity fires in most ecological zones of the bioregion. Given the importance of topographical controls on fire regimes, we will discuss the fire regimes more generally rather than assign them to specific ecological zones as in other bioregions.

The Klamath Mountains are often described as characterized by complex, mixed-severity fire regimes (Halofsky et al. 2011, Perry et al. 2011). Thus, this bioregion generally had neither completely low-intensity, surface-fire regimes nor totally stand-replacement, crown-fire regimes (Halofsky et al. 2011, Perry et al. 2011). Yet, to be useful this label (mixed severity) needs to be accompanied by specific descriptors (e.g., patch scales, proportions of severity levels) as by itself it is simply stating that burned patches lie somewhere on the gradient between being mostly alive to mostly dead. Importantly, though fires were largely quite heterogeneous, the central tendency for fire effects was to generally fall on the end of the gradient with mostly low-moderate-severity surface fires with variation influenced by topography resulting in a complex mosaic of fire effects (Taylor and Skinner 1998, Halofsky et al. 2011, Perry et al. 2011). This interpretation of the fire regime is largely supported by tree-ring derived fire histories (Wills and Stuart 1994, Stuart and Salazar 2000, Taylor and Skinner 1998, 2003, Skinner 2003a, 2003b, Fry and Stephens 2006).

TOPOGRAPHY

Topography strongly influences Klamath Mountain fire regimes. The long-term record of fire occurrence suggests spatial patterns were related to differences in timing of fires from place to place and differences in fire severity rather than fire frequency. With the exception of riparian zones (Skinner 2003b), only small differences in median Fire Return Intervals (FRIs) have been found within watersheds of several thousand hectares despite considerable variability in elevation, slope aspect, and species composition (Taylor and Skinner 1998, 2003).

Areas that burned with similar timing were found to be of several hundred hectares and bounded by topographic fea-

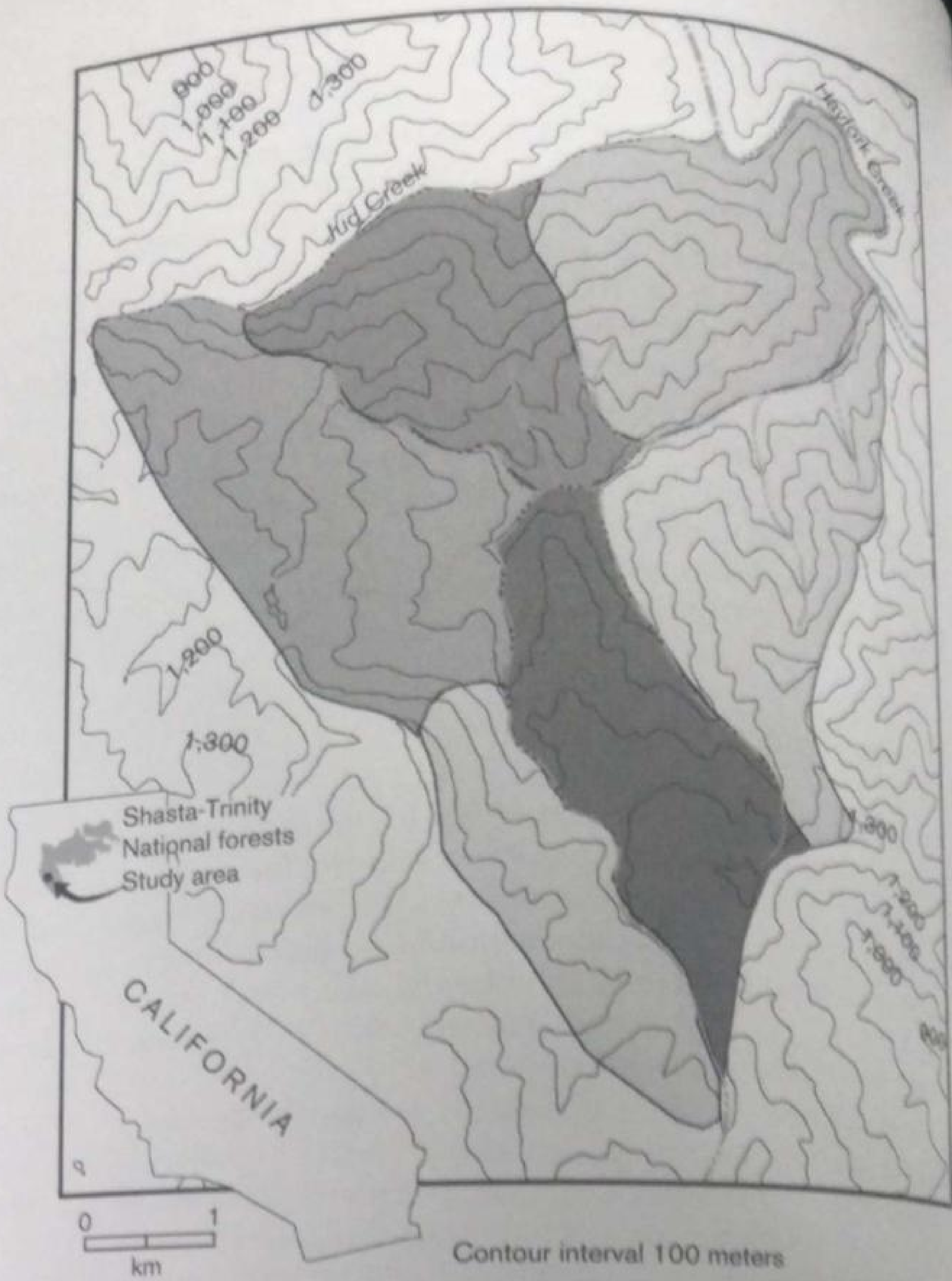

FIGURE 11.6 Map of FOAs in the Rusch/Jud creek watersheds near Hayfork. Figure illustrates how topographic features limited the spread of fires in most years. Though fire frequency did not vary significantly from area to area, the year of fire occurrence was often different from neighboring FOAs (adapted from Taylor and Skinner 2003).

tures (e.g., ridgetops, aspect changes, riparian zones, lithologic units) that affect fuel structure, fuel moisture, and fire spread (Taylor and Skinner 2003). We refer to such areas as Fire-Occurrence Areas (FOA). It is likely that the sizes of FOAs vary from landscape to landscape depending upon topographic complexity and are more localized than what is implied by the term fireshed. Although FOAs separated by topographic boundaries commonly had similar FRI distributions, they often experienced fires in different years—thus, different timing of fires.

These topographic boundaries between FOAs were not simple barriers to fire spread, but acted more like filters. In many years these features contained fires within the FOAs, but in others, especially unusually dry years such as 1829 or more recently 2008, fires would spread across boundaries and burn large portions of the greater landscape (Taylor and Skinner 2003) (Fig. 11.6). Thus, although nearby FOAs may each experience frequent fires, topographic factors set them up to generally burn in different years contributing to landscape heterogeneity.

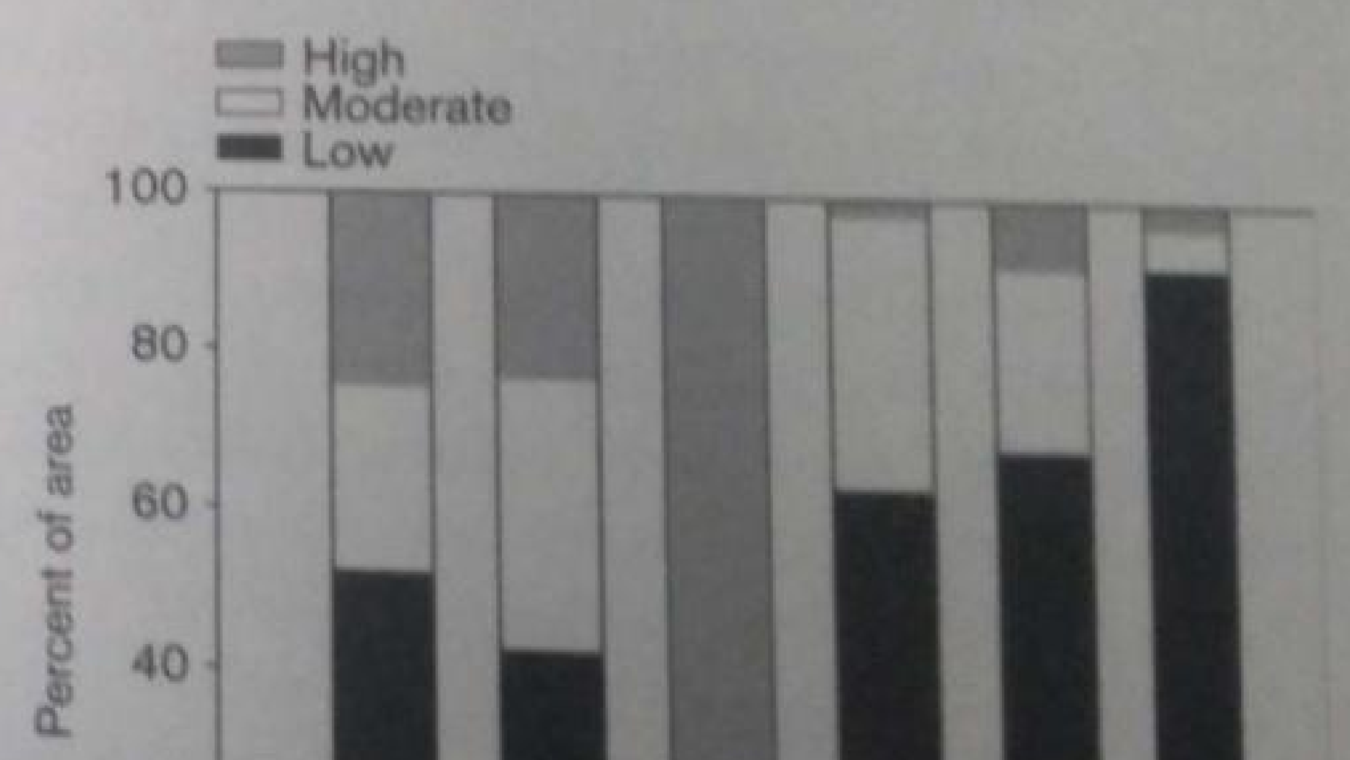

FIGURE 11.7 Chart depicting the distribution of cumulative fire severity patterns on Thompson Ridge near Happy Camp (Taylor and Skinner 1998).

FIRE SEVERITY

Patterns of fire severity, an important determinant of stand and landscape structural diversity, have been associated with topographic position in both the prefire-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 Fig. 11.7. Generally, the upper third of slopes and the ridgetops, especially south- and west-facing aspects, experience the highest proportion of high-severity burn. This is seen as larger patches of shrubs, young even-aged conifer stands, or stands of knobcone pine

FIGURE 11.8 Photo of Figurehead Mountain in the Thompson Creek watershed illustrates how patch size varies with topographic position in response to variation in fire intensity. The largest patches of high severity are on the upper thirds of the slopes, intermediate patches are in the middle third slope position, with the lower third slope position exhibiting a fine grain pattern dominated by large, old trees indicating fires burned primarily as low-intensity surface fires in these locations (Taylor and Skinner 1998). Photo taken in 1992, five years after entire landscape burned in the 1987 fires (photo credits: Carl Skinner, USDA Forest Service).

(*Pinus attenuata*). The lower third of slopes and north- and east-facing aspects experience mainly low-severity fires. Thus, more extensive stands of multiaged conifers with higher densities of old trees are found in these lower slope positions. Severity patterns of middle slope positions are intermediate between the other two positions.

Mid- 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 factors that affect fire behavior. These slopes generally experience greater drying and heating of fuels which contributes to greater fire intensity and makes it more likely to experience higher-intensity burns (Rothermel 1983). The common occurrence of strong thermal inversions that trap smoke in the steep, narrow canyons amplify differentials in temperature, humidity, and fuel moisture and thus differentials in fire behavior between the canyon bottoms and the ridgetops (Schroeder and Buck 1970, Robock 1988, 1991). 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 tend to support higher-intensity fires running uphill through them compared to the tendency for lower slopes to support lower-intensity backing fires. Exposure to wind and solar insulation combine 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 Fig. 11.8.

It is important to note that this interpretation/description of severity patterns assumes that relatively even-aged cohorts of regeneration are exclusively the result of gaps and openings created by a preceding fire (Taylor and Skinner 1998). Other pathways to such patches exist (Brown 2006, Brown et al. 2008) with two likely being important in this bioregion. First scenario: when a climatic anomaly (e.g., cool/wet period) induced a hiatus in fire occurrence, even for only an additional decade or so, that provided sufficient time for enough regeneration to grow sufficiently to survive subsequent fires (Brown 2006). This would be especially so if the climatic anomaly was accompanied by a good seed crop resulting in abundant tree recruitment. Second scenario: the abundant regeneration documented throughout the western United States that originated coincidently with the onset of the fire-suppression era. This widespread, synchronous recruitment that regenerated in gaps or openings was simply the result of fire exclusion rather than a preceding high-severity fire. It is likely that many of these gaps and openings were created and maintained by chronic, frequent, low-moderate-severity fires. Thus, our description of the historical proportion high-severity patterns in Klamath Mountains landscapes is likely inflated, and possibly greatly so in some landscapes.

RIPARIAN ZONES

Few fire history data are available from riparian zones, but available data suggest that FRIs, and possibly fire behavior, are more variable within riparian zones than in adjacent uplands (Skinner 2003b). Median FRIs were generally twice as long on riparian sites as on neighboring uplands. However, the range of FRIs did not differ between riparian zone and adjacent upland sites (Skinner 2003b). Importantly, these data are from riparian sites adjacent to perennial streams and not ephemeral or 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 2003b). Additionally, the later types of streams are more likely to be above the smoke inversions where the streams initiate. Thus, they would tend to burn more severely than the perennial streams located lower in the watersheds that would be more shaded by the persistent smoke inversions.

Riparian areas along perennial watercourses often served as effective barriers to low-intensity and some moderate-intensity fires and strongly influenced patterns of fire occurrence beyond their immediate vicinity. The ability to be effective barriers would be enhanced by the effects of shading from inversion-trapped smoke. Consequently, by affecting fire spread, riparian areas are a key topographic feature that not only constitute a unique habitat, but also contribute to the structure and dynamics of upland forest landscapes (Skinner 2003b, Taylor and Skinner 2003).

Lower Montane

Fire regime information of common forest, woodland, and shrubland alliances of the Klamath Mountains is summarized in Appendix 1. Generally, before the fire-suppression era, mostly low-moderate-intensity surface fires characterized forest and woodland area fire regimes while mostly high-intensity crown fires were characteristic of shrubland fire regimes.

FIRE RESPONSES OF IMPORTANT SPECIES

More fire ecology information is available for alliances with Douglas-fir an important species than any others in this bioregion. Douglas-fir, once mature, is very resistant to low-moderate-intensity surface fires due to a variety of characteristics. When mature, 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 pines are also fire resistant as they too have thick bark, root deeply, and have high, open crowns. The pines, however, have longer needles and slough bark which forms a less compact litter bed that is better aerated 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 (commonly referred to as 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 become more compact reducing fire intensity at the base of the tree. Thus, Douglas-fir has advantages in this bioregion following occasional extended periods (20 years to 30 years) without fire when Douglas-fir is less likely than the pines to incur basal bole damage.

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 dense canopy and thin bark that makes them highly susceptible to crown scorch and cambium damage. As most oaks, if the top is killed, canyon live oak sprouts vigorously from the root crown (Tollefson 2008).

California black oaks, common throughout lower and mid-montane forests in the bioregion, have thin bark and are fire sensitive compared to the conifer associates that invade oak stands during longer fire-free periods. The size and shape of California black oak leaves provide for a well-aerated litter bed that can burn rapidly (Engber and Varner 2012). However, oak litter beds decompose rapidly contributing to low accumulations of fuel so fires that burn in oak litter are low intensity compared to fires in pine litter and rarely damage mature stems. Moreover, California black oak crowns are open and rarely 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 (Cocking et al. 2012).

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 birch-leaf mountain-mahogany (*Cercocarpus betuloides* var. *betuloides*), hollyleaf 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 that germinates following fires, while its associates are all strong sprouters.

Dense stands of shrubs dominated by Brewer oak (*Quercus garryana* var. *breweri*) are common and often support a diverse association of woody species. Brewer oak stands are found well into the mid-montane areas. Common associates are deer brush (*C. integerrimus*), poison oak (*Toxicodendron diversilobum*), snowdrop bush (*Styrax redivivus*), California ash (*Fraxinus dipetala*), birch-leaf mountain-mahogany, wild mock orange (*Philadelphus lewisii*), redbud (*Cercis occidentalis*), and California buckeye. Brewer oak is generally more flammable than other shrub oaks and other shrub associates. The leaf morphology creates a less compact more flammable litter bed than its associates (Engber and Varner 2012). Thus, where Brewer oak is a major component of shrubfields, it is usually the primary carrier of fire. All of these species sprout vigorously following fires (Skinner 1995b).

FIRE REGIME–PLANT COMMUNITY INTERACTIONS

The fire regimes of forests dominated by Douglas-fir were discussed at length in the section describing the common fire regimes of the Klamath Mountains and so are not repeated here. Here we concentrate on alliances more common in this zone than in others. Fire responses of important species in the lower montane zone are presented in Table 11.3.

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-moderate-intensity fires. Canyon live oaks on these sites sometimes have open wounds with fire scars evident. However, the fire record is generally undatable due to decay. Fire-scar records collected from ponderosa pines, sugar pines, and Douglas-firs scattered in five canyon live oak stands near Hayfork had median FRIs of 6 years to 22 years (Taylor and Skinner 2003).

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 (Skinner and Chang 1996). Canyon live oak is less flammable than California black oak due to small leaf size producing compact litter beds (Engber and Varner 2012). Slopes with canyon live oak are often so steep that surface fuels collect mainly in draws, on small benches, and the upslope side of trees. Fires on these slopes would likely follow the draws and burn in a discontinuous manner. The fire-scar 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 suggest they were scarred by very light fires that burned in fuel that collected on the uphill side of the stem.

Stands dominated by California black oak (CBO) are common throughout lower and mid-montane areas especially in the central and eastern Klamath Mountains. Their highly nutritious acorns were an important food source for the native people of the bioregion. In order to perpetuate this food source, the native people promoted and maintained CBO stands by regular burning (Long et al. 2016). The cultural use of regular fire to manage CBO was promoted by the

TABLE 11-3
Fire responses of important species in the Lower Montane Zone of the Klamath Bioregion

	Type of fire response			
Lifeform	Sprouting	Seeding	Individual	Species
Conifer	None	Stimulated (establishment)	Resistant/killed	Douglas-fir, ponderosa pine
	None	Stimulated (seed release)	Resistant/killed	Gray pine
	None	Fire stimulate (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, tanoak, foothill ash, Oregon ash, Fremont cottonwood, white alder
Shrub	None	Fire stimulated	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, California storax, poison oak

species having the more flammable foliage among oaks in the bioregion due to leaf morphology (Engber and Varner 2012). Since the onset of fire suppression, conifers have invaded many of these stands and are poised to overtop and replace the oaks on many sites.

California black oak usually suffers the greatest fire damage when moderate-intensity fires burn in stands that have a significant component of conifers. Greater fuel accumulates under conifers due to slower decomposition. Moreover, CBO in mixed stands often have lower vigor due to competition from the conifers, making the trees more susceptible to fire damage. Conifers often survive fires in these mixed stands because they have thicker bark while many CBO may be top-killed. Where much of the conifer canopy remains, the oaks then sprout in the shade of the conifers and are unlikely to reach the main canopy as they would in an open environment or under other oaks.

Where conifers have overtopped CBO and begun to dominate the stands, low-moderate-intensity fires often enhance the process of succession to conifers by damaging the older, now weakened, understory oaks. Once stands have succeeded to conifer dominance, a high-intensity fire can kill the conifers outright while only top-killing the oaks. After such fires, CBO can sprout from root crowns to quickly regain dominance (Cocking et al. 2012). Though this will allow the area to return oak-dominance, it will take many decades before CBO develop the large, mature condition necessary to produce significant acorn crops, denning sites, and other important habitat qualities (Long et al. 2016).

California black oak (as well as tanoak 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 resprout several times waiting to quickly put on height growth following formation of a canopy gap. Thusly, CBO are able to survive for long periods as isolated trees in relatively dense conifer stands. Then, when a high-intensity fire kills much of the conifer overstory, existing CBO seedlings can quickly grow and reclaim dominance of the site (McDonald and Tappeiner 2002). An example can be seen near Volmers along Interstate 5 where a severe fire in 1986 killed several hundred hectares of mixed-conifer forest. 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 ~12,000 ha (29,600 ac) High Complex in 1999. Even though this fire burned in the driest time of the year, August and early September, the light fuelbeds 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. Specified in this way, the lower extent of

TABLE 11.4

Fire response of important species in the mid- to upper montane zones of the Klamath Bioregion

	Type of fire response			
Lifeform	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	Big-leaf maple, tanoak, canyon live oak, Pacific dogwood, white alder, Oregon ash, western birch
	Fire stimulated	None	Resistant/top-killed/survive	California black oak, blue oak, Pacific madrone, giant chinquapin
	Fire stimulated	Stimulated (establishment)	Resistant/top-killed/survive	Oregon oak
Shrub	None	None	Killed	Curl-leaf mountain-mahogany
	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

the zone varies from approximately 600 m (2,000 ft) in the west to ~1,300 m (4,250 ft) in the eastern portion of the range (Sawyer and Thornburgh 1977). The fire regime information for vegetation alliances common in this part of the bioregion is summarized in Appendix 1.

FIRE RESPONSES OF IMPORTANT SPECIES

Fire responses for important species in the mid- to upper montane ecological zone are presented in Table 11.4.

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

Port Orford cedar (POC) (*Chamaecyparis lawsoniana*), commonly associated with mesic conditions on soils derived from ultramafic material, is found in two disjunct areas of the bioregion. The largest stands of POC occur in the western Klamath Mountains, especially in the Siskiyous. Inland, POC 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. POC stands often include trees over 300 years of age with open, charred wounds indicating they survived low-moderate-intensity surface fires.

Stands dominated by Jeffrey pine are found primarily on soils derived from ultramafic rock and they occur from the lower montane through the subalpine zones (Sawyer and Thornburgh 1977). Incense cedar is a common associate with huckleberry oak (*Quercus vaccinifolia*) and California coffeeberry (*Frangula californica*) 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 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 (*Arctostaphylos* spp.) and most California-lilacs (*Ceanothus* spp.) also establish after fire from long-lived seeds stored in soil seed banks (Knapp et al. 2012).

Most information on fire regimes and fire effects in white fir forests comes from the edges of the Klamath Mountains. On the western edge, Stuart and Salazar (2000) found median FRIs 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 FRI for white fir, and Agee (1991) found a range from 43 years to 64 years from dry to moist white fir forest in the Siskiyous. Thornburgh (1995) reported a 29-year FRI for the centrally located Marble Mountains.

Before the fire-suppression era, the modal 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 fir (Thornburgh 1995) and these 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 Cascade Range, 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. Wind in 1996 generated stem snap and windthrow that created the high fuel accumulations producing the higher-severity burn patterns in the 1999 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, and the shade-tolerant white fir generally shows the largest increases (Stuart and Salazar 2000). Fire-tolerant species such as ponderosa pine, sugar pine, and California black oak are declining and this should continue as long as fire exclusion is effective.

In the Klamath Mountains, fire history has been documented in only one Shasta red fir stand near Mumbo Lakes (Whitlock et al. 2004). The composite median FRI was 10 years and the median FRI for individual trees ranged from 9 years to 30 years. No fires were detected after 1901. Though Shasta red fir is common throughout this bioregion in upper montane and subalpine environments (Sawyer and Thornburgh 1977), Shasta red fir has been studied most extensively in the Cascades so more detail is presented in chapter 12.

Though Port Orford cedar is resistant to low- and moderate-intensity fires, extensive mortality to POC has occurred in stands where high-intensity fires have burned in recent years. For example, high mortality in the No Mans Creek drainage (a proposed Research Natural Area) from the Bear Fire (1994) led to concern that POC would disappear locally due to lack of seed source (Creasy and Williams 1994). Since POC stands are located on mesic, riparian sites and their wood is highly resistant to decay, these stands can produce heavy fuel loadings, especially following unusually long periods without fire. When such areas finally burn in inevitably dry years, high-intensity burns should be expected with accompanying mortality of the Port Orford cedars.

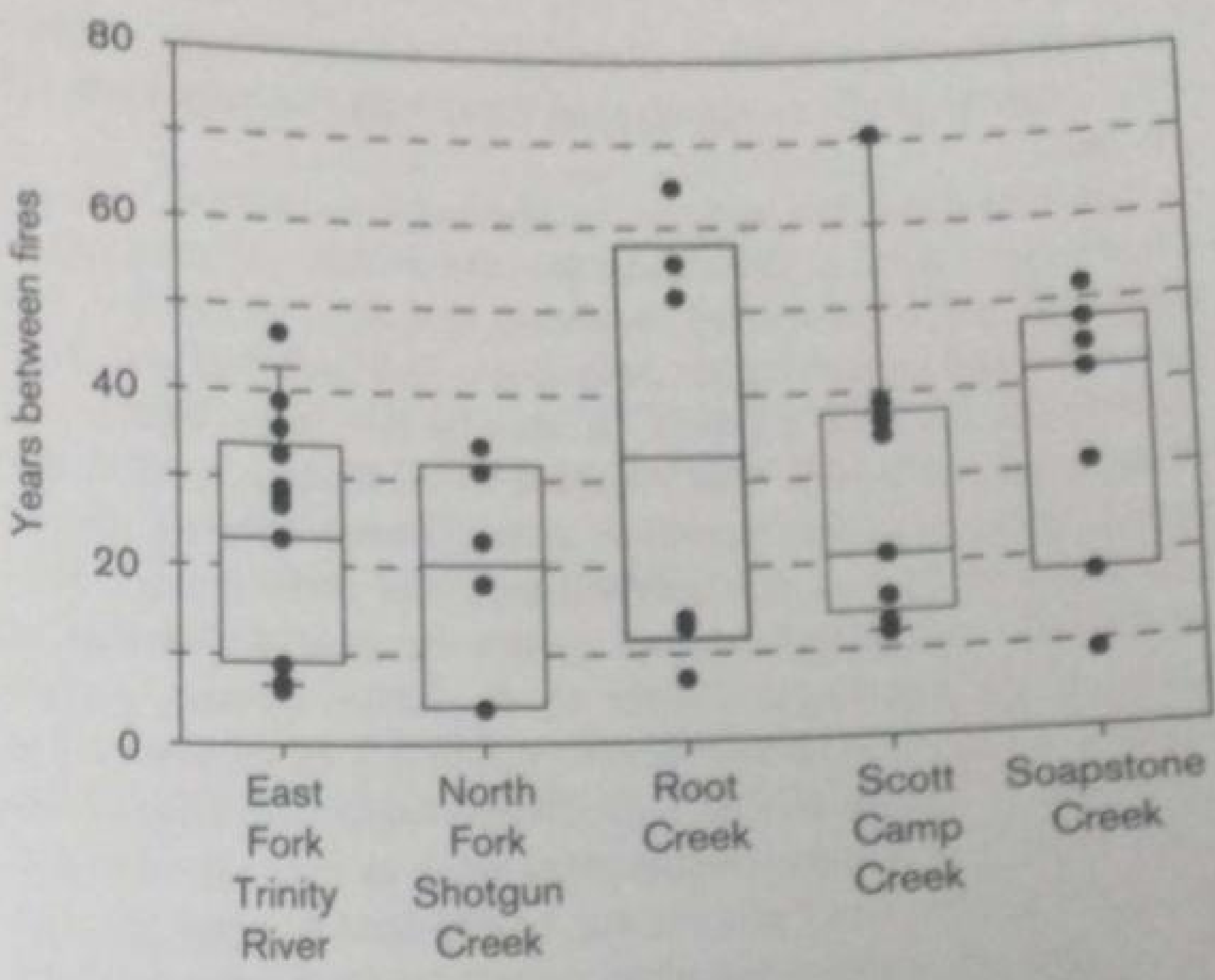

FIGURE 11.9 Distribution of FRIs in inland stands of Port Orford cedar (Skinner 2003a).

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 POC. These fire-scar data for the inland POC stands indicate that fires burned with median FRIs of 16 years to 42 years (Fig. 11.9). In each case, the median FRI in the POC 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 time since the last fire (the fire-suppression period) exceeds the longest interval previously recorded in each of the sampled stands.

Knobcone pine in this bioregion exhibits a unique bimodal geographical distribution in higher and lower elevation areas 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 this bioregion, knobcone pine is also found in the upper montane zone on upper slopes and ridgetop positions, especially on south- and west-facing slopes that tend to burn more severely than the surrounding landscape. An example can be seen in Fig. 11.8 where much of the severely burned upper slope is occupied by knobcone pine.

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

Fire-scar data from ultramafic sites with Jeffrey pine are available from seven sites in the vicinity of Mt. Eddy (Skinner 2003a) and 10 sites near Hayfork (Taylor and Skinner 2003). The median FRI for the sites near Mt. Eddy ranged from 8 years to 30 years and 8 years 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 prefire-suppression fire-free interval for five of seven sampled stands. At

Hayfork, the current fire-free periods of 68 to 125 years exceed the longest prefire-suppression intervals recorded on all 10 sites.

The fire sensitive species in the region—Brewer spruce, Engelmann spruce, subalpine fir—are at risk of being extirpated from their scattered locations by high-severity fire. For example, the entire Rock Creek Butte Research Natural Area (RCBRNA) burned severely in one of the large lightning-caused fires of 2008. This resulted in all Brewer spruce, the target species of the research natural area (Cheng 2004), being killed by the fire leaving no local seed source. This effectively extirpated Brewer spruce from RCBRNA due to inability to regenerate (Cole et al. 2010). Brewer spruce appears to be able to regenerate under a tree overstory but may have problems in open conditions especially after severe fires. Thus, a warming climate may work to make it more difficult for young trees to become established in open patches of severe burn even when there is a local seed source nearby (Ledig et al. 2012).

The occurrence of montane shrub stands may be associated with either edaphic conditions unsuitable for tree growth or high-intensity fires. Once established, because of the nature of shrub fuels, fires that burn in these communities are more likely to be high-intensity events. Thus, where shrub communities become established, recurring fire plays a key role in the maintenance of these communities by inhibiting succession from shrubs to trees (Nagel and Taylor 2005, Lauvaux et al. 2016). More information on fire regimes of shrub-dominated alliances can be found in chapter 12.

The only known herbaceous alliance with fire ecology information in the bioregion is the California pitcher plant (*Darlingtonia californica*). Pitcher plant seeps are common in open habitats saturated with flowing water, usually on ultramafic 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 cedars, incense cedars, western white pines, or Jeffrey pines with charred catfaces are commonly scattered in and adjacent to the seeps.

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 conditions easily achieved, or exceeded, in the summer where pitcher plant is found. Only limited effects of the burn were detected three years post-burn (Borgias et al. 2001).

Fire histories from fire-scarred trees in pitcher plant seeps have been documented in two tributaries to the Sacramento River. Median fire return intervals for these sites were 18 and 42 years, respectively (sites 2 and 5 in Fig. 11.9) (Skinner 2003b). Differences in the length of FRI in these seeps are probably related to conditions in the surrounding forests. One is located in the upper third of a steep, southeast-facing slope surrounded by mixed stands of Jeffrey pine, white fir, incense cedar, sugar pine, and Douglas-fir. Consequently, it would be expected to have shorter FRIs. The other 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, it would be expected to have longer FRIs. 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 aboveground as in Fig. 11.10.

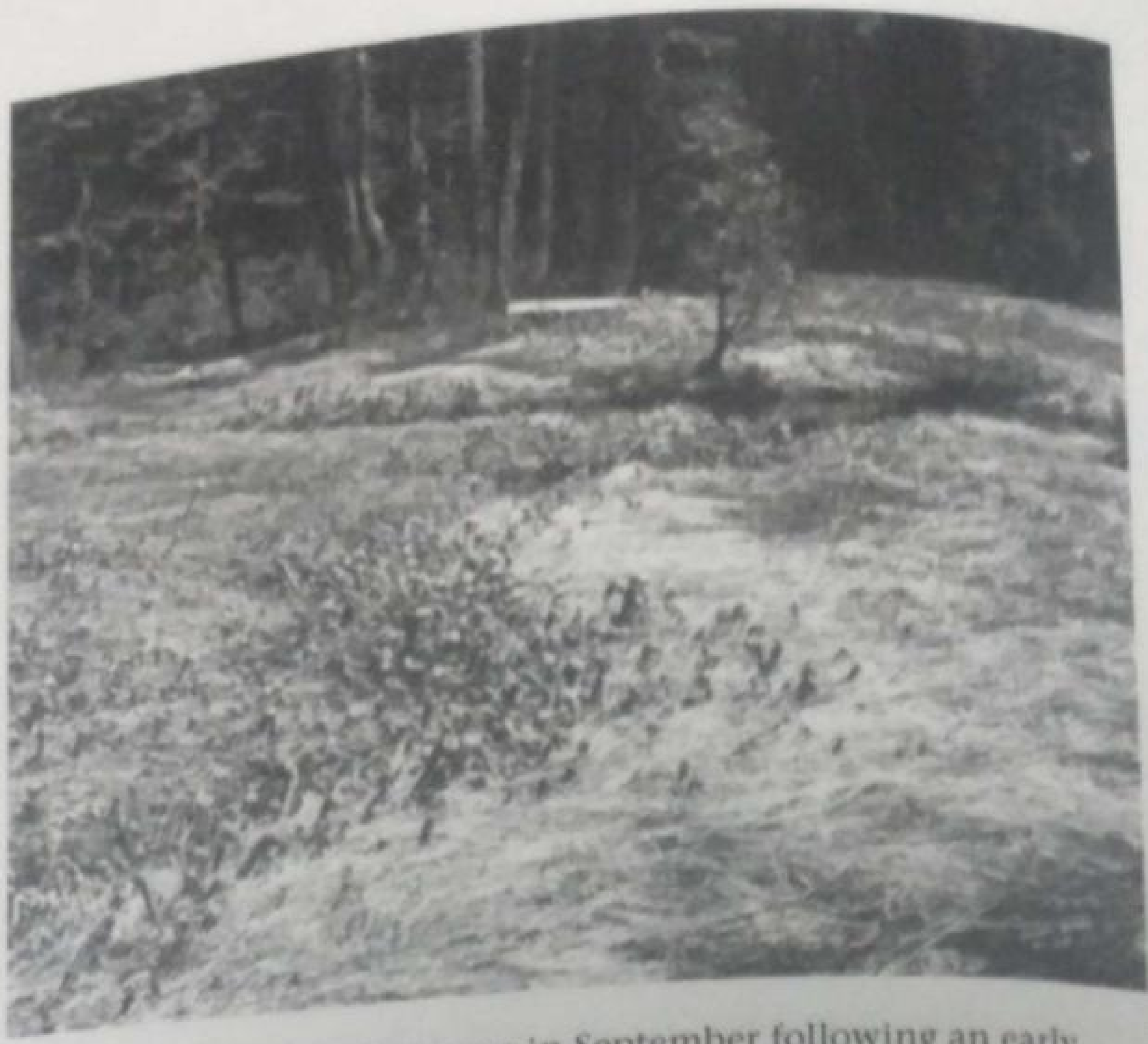

FIGURE 11.10 Pitcher plant seep in September following an early hard frost in the Scott Camp Creek watershed near Castle Lake (photo credits: Carl Skinner, USDA Forest Service).

Subalpine

FIRE RESPONSES OF IMPORTANT SPECIES

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 of 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 (Table 11.5). Appendix 1 summarizes the fire regime information for vegetation discussed in the subalpine ecological zone.

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 snow packs generally persist into late June or July so the fire season is very short. Fuelbeds from the short-needled species are compact and promote slow spreading, mostly smoldering surface fires. Fuel buildup tends to be slow because of the short growing season. Higher-intensity fires that burn in 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 to 1941), the median fire return intervals for these sites were 11.5, 12, and 13 years. However, 44 of 51 fires were detected on only single trees.

TABLE 11.5
Fire response of important species in the subalpine zone of the Klamath Bioregion

Lifeform	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

Thus, fires in this subalpine basin were mainly low intensity and small. Ranges of individual-tree median FRIs were 9 years 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 with several issues—wildlife habitat, wildland-urban interface, and smoke—standing out in this bioregion.

Wildlife Habitat

Management objectives often include the desire to maintain resilient forest ecosystems similar to that of their Historic Range of Variability (HRV) (e.g., Swanson et al. 1994, Long et al. 2014a) using ecological processes (FEMAT 1993, USDA-USDI 1994, Long et al. 2014b) in order to sustain a mix of desirable wildlife habitats. Recent studies suggest that vegetation patterns and conditions generated by prefire-suppression fire regimes (Taylor and Skinner 1998, 2003) may be advantageous for wildlife species of concern such as the northern spotted owl (Franklin et al. 2000, Agee 2007) and several species of butterflies (Huntzinger 2003). Of all management activities, fire suppression alone has been ubiquitously applied throughout the bioregion. Consequently, there is a need to better understand the role of frequent low- and moderate-severity and mixed-severity fires on development of the forest landscape mosaic (Agee 1998, 2003, Perry et al. 2011). This understanding will help managers better assess risks associated with different management alternatives (e.g., Agee 2003, Hessburg et al. 2016).

More recent management activities such as logging, replacement of multiaged 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 the prefire-suppression landscape (USDA-USDI 1994). Large wildfires with large patches of high severity have burned in the Klamath Mountains in the last several decades (1977, 1987, 1995, 1996, 2002, 2008, 2012, 2014, 2017). These fires have reduced the extent, in some places dramatically, of multiaged, old-growth stands. Indeed, wildfire, among all causes, is responsible for the largest portion of loss of nesting and roosting habitat for the northern spotted owl, especially in reserves, since implementation of the Northwest Forest Plan (Davis and Dugger 2011). Areas burned by these fires become occupied by plantations, even-aged hardwood stands, or brushfields, and, in some watersheds (e.g., north and south forks of the Salmon River), these vegetation types are now the landscape matrix. Moreover, some large areas that burned intensely in 1977 burned intensely again in 1987, while large areas that burned intensely in 1987 did so again in 2008 (Perry et al. 2011).

The increasing size of high-severity patches results in reduced structural heterogeneity across landscapes. 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 initiate and expand persistent broad scale changes from forest to shrubland (Coppoletta et al. 2016, Lauvaux et al. 2016).

Forests in the lower- and mid-montane zone that historically burned at low to moderate severity are now particularly susceptible to high-severity fire because of high surface and canopy fuel loads from fire suppression (Taylor and Skinner 2003). A shift to larger patches of high-severity fire can induce a vegetation switch if fire effects or climate change favor postfire establishment of different species (Collins and Roller 2013, Lauvaux et al. 2016). High fire severity in lower and mid-montane forests initiates a period of dominance by fire-dependent shrubs (montane chaparral) that establish from sprouts or buried seedbank (Knapp et al. 2012). Montane chaparral impedes tree seedling establishment and growth, and shrubs can dominate severely burned sites capable of supporting trees for decades or even a century or more (Coppoletta et al. 2016, Lauvaux et al. 2016). Consequently, postfire rates of forest development following severe fire can be slow and may be further exacerbated by interactions with subsequent fire.

Accumulating evidence indicates that fire initiated montane chaparral exhibits self-reinforcing fire behavior with shrublands often burning severely again in subsequent fires (Perry et al. 2011, Lauvaux et al. 2016). Similar self-reinforcing severe fire effects have been observed where plantations were established in the footprint of severe fires to facilitate rapid forest development and then burned severely again in subsequent fires before reaching maturity (Thompson et al. 2007, Thompson and Spies 2010). Old shrubfields that converted to forest during the fire-suppression period have also been observed to burn severely again suggesting that shrubfields may impart a long-term ecological memory of fire effects in a landscape (Taylor et al. 2013, Coppoletta et al., 2016, Lauvaux et al. 2016).

A warming climate with more extreme fire weather (e.g., Lenihan et al. 2008, Collins 2014) and large areas burning with high severity may increase the likelihood of vegetation shifts. Interactions between fire, vegetation, and climate change could lead to a "landscape trap" where a vegetation switch and with positive feedback processes maintain the new vegetation regime across entire landscapes (Lindenmayer et al. 2011, Coppoletta et al. 2016, Lauvaux et al. 2016). This would have significant implications for the type and heterogeneity of habitat for forest-dwelling species in these ecosystems.

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 2002a) because of the dispersed nature of dwellings in small, scattered communities in flammable, wildland vegetation. As a result, hundreds of homes have been lost to wildfires that originated in the bioregion in just the last several decades (CDF 2002b). Examples of major suppression efforts in WUIs in the bioregion include fires near Hayfork and Happy Camp (1987), Redding and Lakehead (1999), Weaverville (2001), Jones Valley and French Gulch (2004), and Orleans (2008, 2013). The Jones fire (1999) alone burned over 900 structures (CDF 2002b) 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.

Smoke

Most people living in the Klamath Mountains reside in the lower reaches of canyons where smoke collects under the thermal inversions. The periodic outbreaks of widespread fires in this bioregion create profound smoke episodes that can go on for weeks to months leading to health problems for susceptible people (Mott et al. 2002) and impairment of visibility inconveniencing tourists and businesses that rely on tourism. As a result of these effects, smoke is regulated and managed as primarily a human health hazard and secondarily as a nuisance. Smoke is discussed in this regard in chapter 23.

Historically, the presence of smoke was pervasive though varying from year to year and the clear vistas expected and desired today are largely an artifact of fire suppression. Yet, smoke is rarely discussed in a context of being part of the ecological process of fire. Further, though it is generally recognized that there is a fire deficit today, this is usually not accompanied by a recognition of a corresponding smoke deficit (although see Stephens et al. 2007, Lake and Long 2014). Smoke has always been a major part of the ecosystem in the productive, summer dry forests of this bioregion. The continuous record of charcoal from lake sediment data attests to the persistent presence of smoke (Whitlock et al. 2004, Briles et al. 2011). Indeed, before fire suppression became the rule, rather than having clear vistas of the mountains in the summer, C. Hart Merriam, chief of the Biological Survey, noted in 1899, ". . . few see more than the immediate foreground and a haze of smoke that even the strongest glass cannot penetrate (Agee 2007)." If "pristine" means original and unaltered then pristine summer skies would have been characterized by considerable smoke and haze from the many fires that would be burning in most years (Stephens et al. 2007).

Rarely discussed are the benefits of smoke. Though a number of benefits have been noted (Lake and Long 2014), we limit our discussion to the potential affect of smoke on maintenance of cooler stream water temperature (Mahlum et al. 2011, Lake and Long 2014).

Stream temperature measurements acquired during ongoing fires in the Klamath Mountains (F. Lake, Forest Service, Pacific Southwest Research Station, Redding, California, USA, pers. comm.) and in the Rocky Mountains (Mahlum et al. 2011) often remain either unchanged or lower than in areas outside of the influence of smoke. It appears the cooling under the thermal inversions not only dampens fire behavior reducing fire severity to vegetation, but may also promote cooler stream water temperatures. It is hypothesized that before fire suppression, smoke trapped in canyons would be a common occurrence, especially in late summer during warm, dry years. Typically streamflow would be low during these warm/dry periods and in the absence of smoke, water temperatures could become elevated and stressful to cool water fish and other aquatic life. Having smoke a common occurrence during these periods would help to keep streamwater temperature lower and less stressful to aquatic life. It may be too that reduction of solar radiation and cooling would lower the need for water by vegetation, reducing transpiration, leaving more water available for streamflow.

Because the degree of stream warming in a landscape following fire is largely due to the level and pattern of fire severity across the watershed (Gresswell 1999, Rieman et al. 2003), we hypothesize that a more indirect, yet longer lasting effect of smoke dampening fire behavior would likely be less area burned severely resulting in more vegetative shading along riparian areas during periods without smoke. Halofsky and Hibbs (2008) found that the fire severity in the riparian zone along fish bearing streams, measured as basal area mortality, was most strongly associated with fire severity in adjacent uplands. Amaranthus et al. (1989) found that though some headwater riparian areas that burned severely had considerable water temperature increases after the Silver fire (1987), less than 5% of headwater riparian zones in their study area had burned severely, while considerable shading remained along lower reaches with net effect of maintaining cool temperatures in the lower reaches. From this it is reasonable to surmise that smoke, by reducing fire intensity and resulting fire severity on the lower slopes of canyons in presuppression times, helped to promote cooler stream temperatures both during and indirectly long after fires and continues to do so today.

Future Directions

There is a critical need to better understand the synergistic relationships between low-, moderate-, and high-intensity fire and prefire-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, etc.) and how they were patterned on the landscape to provide a stronger foundation for applying concepts of historical range of variability to forest management. 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 (Long et al. 2016). 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 presuppression fire regimes were characterized by frequent, low-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. Current standards and guidelines were generally 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 prefire-suppression values. Consequently, a management emphasis on meeting or exceeding current 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 protect (Skinner 2002, Knapp 2015).

Managing Wildfire

In 2009, recognizing the increasing wildland fire problem, Congress enacted the FLAME Act, which mandated a national cohesive wildland fire management strategy. Its vision was to safely and effectively extinguish fire, when needed; use fire where allowable; manage our natural resources, and as a nation, live with wildland fire (Wildland Fire Leadership Council 2014). Implementing this vision in the Klamath Mountains requires a comprehensive change in current policy. Indeed, current policies relying primarily on fuels treatments and fire suppression will continue to create an increasing backlog of area outside of historical range of variation (North et al. 2012). Large wildfires that burn for weeks to months dominated by mostly low- and moderate-severity effects have become common over the last several decades in this bioregion. The results of these long-burning fires demonstrate that the bioregion is well set up to benefit from a planned, purposeful use of managed wildfire. We believe this can be successfully accomplished by pursuing two general types of strategies: strategies for remote backcountry areas and strategies for front country areas. They are linked because the success or failure of one will affect the other.

In backcountry areas, including wilderness, more active management of wildland fire, not simply fire suppression, would better support achieving wilderness and broader management goals. In many wilderness areas, annual area burned by natural fires remains far below historical estimates (Parsons and Landres 1998). This is true even in the remote and rugged Klamath Mountains (Miller et al. 2012a), and in the face of large fires of the past few decades, where fire-suppression efforts involve long-term commitments of resources, overhead teams, and expenditures (Lewis 2006). Aggressive fire suppression can also compromise firefighter safety, as happened in 2008 on the Iron 44 fire with a helicopter crash that killed nine people and occurred 15 miles into the Trinity Alps wilderness with no structures at risk. Consideration needs to be given to managing all wildland fire, both natural and human-caused, with an appropriate management response. An example of this was the 2005 Woolley fire in the Marble Mountain wilderness. The source of ignition could not be confirmed, but it was managed primarily with monitoring of fire behavior and effects, with minimal suppression action (Lewis 2006).

The probability of success for this strategy depends on a much more aggressive fuel reduction strategy in and around communities. This would provide for firesafe communities that could better coexist with fire in the broader landscape. Due to the complexity of ownership and responsibility for fire protection, partnerships involving local, tribal, state, and Federal entities are needed to plan the appropriate mix of fuel reduction strategies (Harling 2014a). Leadership can come from local nonprofit groups such as the Watershed Research and Training Center, located in Hayfork, the Mid-Klamath Watershed Council located in Orleans, or national groups such as The Nature Conservancy. Prescribed fire can play a much larger role than it has in the past, but locally it faces the same impediments as in most of northern California: narrow burn windows, regulations, lack of adequate personnel, and environmental laws (Quinn-Davidson and Varner 2012). On the Salmon River, where prescribed fire has been used to create firesafe zones around the community, local residents are now advocating for backcountry wildfires to burn around them to clear away fuels created by earlier burns and reduce the threat of future fires moving into the community (Harling 2014b). Where no structures are present, prescribed fire can be used to manage fuels at the boundary of the front and backcountry (Agee 1996).

Mechanical and manual fuel reduction can be used where topography is gentle and access is present. Near Weaverville, understory clearing along Highway 3 has created a linear zone where wildfire behavior will be reduced, making suppression efforts more effective. Such treatments can be followed by light prescribed fires to further reduce remaining undesired residues and for maintenance. A new biomass cogeneration facility in Weaverville will have the capability to accept clean thinning residues created from fuel reduction treatments, although its 5 megawatt output will primarily be fueled by mill residues (North State Resources 2014). Utilizing a cogeneration facility will reduce the impacts created by smoke if such residues had to be pile burned.

The lessons of the last several decades indicate that the complex, rugged, and often remote terrain of the bioregion precludes treatment of sufficient area with either mechanical treatments or prescribed fire, either alone or in combination, without incorporating managing wildfires to accomplish goals of creating firesafe communities while restoring fire resilient forest landscapes (North et al. 2012, 2014).

The Warming Climate

Long-term fire histories suggest that fire has been an important part of Klamath ecosystems since their evolution, and that climate has been the primary driver of fire occurrence, both directly and through changes in vegetation. At millennial scales severe fires are associated with periods of fir-dominated forest in high-elevation locations, but fire frequency was highest during times when the forest structure was relatively open and conditions warmer and drier than today. Another observation is that while fire history is similar on ultramafic and nonultramafic sites, the consequences were quite different. Ultramafic sites have shown little change in vegetation over the last 10,000 years with only subtle shifts in pine and oak, whereas nonultramafic sites showed more dynamic responses. Conservation planners and resource managers should consider that nonultramafic regions may likely experience far greater change in vegetation with projected climate change than ultramafic sites, despite the high level of endemism in the latter ecosystems. Future shifts on nonultramafic substrates will be hindered by the altered landscapes and in some cases human intervention may be needed to assure plant establishment in the new environment. Economically important species, such as Douglas-fir, and species that are at their ecological limits, such as mountain hemlock, or endemics, such as Brewers spruce, will require special monitoring under warmer future conditions.

Summary

Primarily due to the annual summer drought and ample winter precipitation, fires were historically frequent and generally of low-moderate and mixed severity in most vegetation assemblages, especially those that cover large portions of the bioregion. 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 altered ecosystems in the bioregion, 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 (for example, 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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