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Chapter 5: Fire in Western Forest Ecosystems

Understory Fire Regimes

Major Vegetation Types

Major forest types that are characterized by nonlethal understory fire regimes include those where ponderosa pine or Jeffrey pine has been a major component either as a fire-maintained seral type or as the self-perpetuating climax (table 5-1). This includes extensive areas throughout the Western United States from northern Mexico to southern British Columbia, Canada (Little 1971). Also, sizeable areas of open woodlands dominated by Oregon white oak, California black oak, blue oak, or Digger pine were characterized by frequent understory fires largely due to deliberate burning by Native Americans (Boyd 1986; Lewis 1973). These occurred in relatively dry areas west of the Cascades and Sierra Nevada from the southwest corner of British Columbia to southern California. Recent studies suggest that large areas of the redwood forest in coastal northern California were characterized by frequent understory fires resulting from burning by Native Americans (Brown and Swetnam 1994; Duncan 1992; Finney and Martin 1989; Greenlee and Langenheim 1990).

Additionally, portions of other forest types may also have had understory fire regimes. For example, some areas of interior Douglas-fir near the drought-caused lower timberline in the higher valleys of the Rocky Mountains may have been maintained in open condition in understory fire regimes (Arno and Gruell 1983; Arno and Hammerly 1984). Nevertheless, most of this type is best represented by the mixed regime.

Fire Regime Characteristics

Fires were frequent, with mean intervals between 5 and 30 years in most areas (Kilgore 1987; Martin 1982) in the ponderosa pine type and at similar intervals in the redwood type; fires occurred even more frequently in some of the oak-prairie communities. At one extreme, fire intervals averaged 1 to 2 years in an area of northern Arizona and no more than 10 years throughout the Southwestern ponderosa pine type due to abundant lightning activity (Dieterich 1980). Conversely, near the cold limits of the ponderosa pine type in western Montana, mean fire intervals averaged between 25 and 50 years (Arno and others 1995b). Relatively short mean intervals occurred where many ignitions were made by Native Americans, while longer

Table 5-1—Occurrence and frequency of presettlement fire regime types by Forest and Range Environmental Study (FRES) ecosystems, Kuchler potential natural vegetation classes (1975 map codes), and Society of American Foresters (SAF) cover types. Occurrence is an approximation of the proportion of a vegetation class represented by a fire regime type. Frequency is shown as fire interval classes defined by Hardy and others (1998) followed by a range in fire intervals where data are sufficient. The range is based on study data with extreme values disregarded. The vegetation classifications are aligned to show equivalents; however, some corresponding Kuchler and SAF types may not be shown.

			Fire regime types						
			Understory		Mixed		Stand-replacement		
FRES	Kuchler	SAF	Occur[a]	Freq[b]	Occur	Freq	Occur	Freq	Nonfire
Coastal[c] Douglas-fir 20	Cedar-hemlock-Douglas-fir K022	Douglas-fir-w. hemlock 230			M	2: 40-150	M	3	
	Mosaic of above and Oregon oak woods K028	Pacific Douglas-fir 229			M	2: 40-150	M	3: 200-500	
		Red alder 221							
	Calif. Mixed evergreen K029	Douglas-fir-tanoak-Pacific madrone 234			M	1			
Redwood 27	Redwood K006	Redwood 23	M	1: 5-25	m	2			
Hemlock-Sitka spruce 24	Spruce-cedar-hemlock K001	Sitka spruce 223			m	2	M	3	m
		W. hemlock 224					M	3	
		W. hemlock-Sitka spruce 225					M	3	
		W. redcedar-w. hemlock 228					M	3	
W. hardwoods 28	Oregon oakwoods K026	Oregon white oak 233	M	1					
	California oakwoods K030	Blue oak-digger pine 250	M	1					
		Canyon live oak 249			M	1,2			
		California coast live oak 255			M	1,2			
Coastal[c] fir-spruce 23	Silver fir-Douglas-fir K003	True fir-hemlock 226					M	3	m
	Fir-hemlock K004	Mountain hemlock 205					M	2,3	m
Inland forests									
Ponderosa pine 21	W. ponderosa pine K011	Pacific ponderosa pine 245	M	1: 5-30	m	2			
	Pine-Douglas-fir K018	Pacific ponderosa-Douglas-fir 244	M	1: 5-30	m	2			
	Mixed conifer K005	Sierra Nevada mixed conifer 243	M	1: 5-30	m	2			
		Jeffrey pine 247	M	1: 5-30	m	2			
		California black oak 246	M	1: 5-30	m	2			
	Arizona pine K019	Interior ponderosa pine 237	M	1: 1-25	m	2			
	E. ponderosa K016	Interior ponderosa pine 237			M	2			
	Black Hills pine K017	Interior ponderosa pine 237	m	1	M	2	M	2	
Interior[c] Douglas-fir 20	Douglas-fir K012	Interior Douglas-fir 210	m	1,2	M	2: 25-100			
Larch 25	Grand fir-Douglas-fir K014	W. larch 212			M	2: 25-200	M	2,3	
		Grand fir 213			m	2	M	2,3	
W. white pine 22	Cedar-hemlock-pine K013	W. white pine 215			M	2: 50-200	M	3: 130-300	

(con.)

Table 5-1—Con.

			Fire regime types						
			Understory		Mixed		Stand-replacement		
FRES	**Kuchler**	**SAF**	**Occur[a]**	**Freq[b]**	**Occur**	**Freq**	**Occur**	**Freq**	**Nonfire**
Lodgepole pine 26	Lodgepole pine-subalpine K008	California mixed subalpine 256			M	2			
Rocky Mountain lodgepole pine [c] 26	W. spruce-fir K015	Lodgepole pine 218			M	2: 25-75	M	2,3: 100-300	
	W. spruce-fir K015	Whitebark pine 208			M	2: 50-200	M	3: 150-300	
Interior [c] fir-spruce 23	W. spruce-fir K015	Engelmann spruce-subalpine fir 206					M	2,3: 100-400	m
	Spruce-fir-Douglas-fir K020	White fir 211			M	2	M	2,3	
		Blue spruce 216			M	2	M	2,3	
W. aspen [c] 28	W. spruce-fir K015	Aspen 217			m	2	M	2	

[a]M: major, occupies >25% of vegetation class; m: minor, occupies <25% of vegetation class.
[b]Classes are 1: <35 year, 2: 35 to 200 years, 3: >200 years.
[c]Added subdivision of FRES.

intervals occurred on similar forest sites that were more remote from aboriginal occupation. For example, in a western Montana study the mean fire interval from 10 heavily used areas was 9 years while the mean interval from 10 remote areas on similar sites was 18 years (Barrett and Arno 1982).

In the Southwestern ponderosa pine type, major fire seasons occur after snow melt (April and May) and in mid-summer just before the monsoon rains begin, and a secondary season exists in the fall. In most other areas the main lightning fire season is summer; whereas Indian burning apparently occurred to some extent in spring, summer, and fall (Barrett and Arno 1982; Gruell 1985a, 1985b). Low-intensity surface fires were characteristic and may have been quite large where dry forests and adjacent grasslands were extensive—for example, on the gentle topography of high plateaus in northern Arizona and New Mexico. In contrast, in rugged mountainous topography, the understory fire regime was often confined to small areas of dry sites on south-facing slopes (Arno 1980). The adjacent moist sites supported other, denser forest types, which burned less often and in mixed or stand-replacement fire regimes. When stand-replacement fires burned the adjacent moist types in 1889 and 1910 in the Northern Rocky Mountains, the dry forest types still burned primarily in a nonlethal manner. See chapter 6 for additional information about the Southwestern ponderosa pine type.

Fuels

During periods of high fire frequency, fuels were primarily herbaceous material and forest floor litter. After fire suppression became effective, forest floor duff and live fuels such as shrubs and conifer regeneration accumulated. Measurements in recent decades (Brown 1970; Brown and Bevins 1986; Sackett 1979) show that litter typically ranges from 0.6 to 1.4 tons/acre (1.3 to 3.1 t/ha) and the entire forest floor of litter and duff averages about 12 tons/acre (27 t/ha) in both Arizona and Northern Rocky Mountain areas. Forest floor quantities as high as 40 tons/acre (90 t/ha) have been measured (Harrington 1987b). During periods of frequent fire, forest floor quantities would typically range from 1 to 4 tons/acre (2.2 to 9.0 t/ha). Herbaceous fuels range from practically none in dense stands to as much as 0.5 tons/acre (1.1 t/ha) in open stands on productive sites. In the Black Hills of South Dakota, herbaceous fuel quantities in open stands of ponderosa pine averaged 440 lb/acre (490 kg/ha), which was six times greater than in closed stands (Uresk and Severson 1989). Herbaceous fuel quantities are typically about 400 lb/acre (448 kg/ha).

Frequent low-intensity surface fires perpetuated open stands of trees whose lower branches were killed by fire. With fire suppression, accumulated fuels support higher intensity fire including torching and crowning behavior and longer periods of burnout. The increased burn severity results in greater mortality to plants and soil organisms. Managers can easily overlook the significance of forest floor fuels; the upper layer (litter) and part of the middle (fermentation) layer provide the highly combustible surface fuel for flaming combustion and extreme fire behavior during severe fire weather. The lower part of the fermentation layer and the humus layer make up the ground fuel that generally burns as glowing combustion. A substantial amount of forest floor material can remain after an area is initially burned (Sackett and Haase 1996).

Postfire Plant Communities

Ponderosa Pine/Jeffrey Pine and Ponderosa Pine-Mixed Conifer

Pre-1900 Succession—These semiarid forest types are widespread in the inland portions of western North America. They include pure pine climax types, which are abundant in plateau areas of northern Arizona and New Mexico, central Oregon, and eastern Washington. They also encompass many sites in the inland mountains where pines are seral to more shade-tolerant conifers—interior Douglas-fir, white fir, grand fir, or incense-cedar. Prior to 1900 these pine communities experienced frequent fires as a result of highly combustible leaf litter, an abundance of cured herbaceous vegetation, and a long season of favorable burning weather. Stands had an open, parklike appearance, dominated by large old, fire-resistant trees. Shrubs, understory trees, and downed logs were sparse, as testified to by dozens of historical photographs and narrative accounts (Cooper 1960; Leiberg 1899; Wickman 1992). Travelers often rode horseback or pulled wagons for miles through these forests without the need of cutting trails.

Undergrowth was primarily of fire-resistant grasses and forbs that resprouted after each burn. Shrubs were suppressed by the frequent burning coupled with overstory competition (Gruell and others 1982). In most stands, duff depth probably averaged only about half an inch (Keane and others 1990a). The majority of overstory trees survived each fire, while many of the understory trees were killed. The most fire-resistant species—ponderosa pine, Jeffrey pine, and western larch—were favored. In the large areas of this type where ponderosa pine is seral, it maintained dominance only because of the frequent fires.

In much of the pure ponderosa pine type and in the seral pine type on dry sites, pine regeneration occurred whenever overstory trees died, thereby creating small openings. These open microsites allowed a few seedlings to grow fast enough to gain resistance to survive the next fire (Cooper 1960; White 1985). Thus stands tended to be uneven-aged and often contained some 400 to 600 year old trees (Arno and others 1995b, 1997). Trees were often distributed in small even-aged clumps. When small patches of overstory were killed by fire or bark beetles, subsequent fires consumed these fuel concentrations, locally reducing grass competition and creating mineral soil seedbeds. This favored establishment of ponderosa pine seedlings, allowing a new age class to develop in a micromosaic pattern within a stand (Cooper 1960). These effects helped create an uneven-age stand structure composed of small, relatively even-aged groups (Cooper 1960; Arno and others 1995b).

Mixed-severity fire regimes were characteristic on some of the relatively moist sites and on steep slopes throughout the ponderosa pine type. Variable and mixed regimes were evidently widespread in ponderosa pine communities in the Front Range in Colorado and in the Black Hills of South Dakota and Wyoming, and stand-replacement regimes occurred in some situations in the Black Hills. These are described under the section "Mixed Fire Regimes," later in this chapter.

Post-1900 Succession—Important changes have occurred in these forests since 1900 due to interruption of frequent burning. Nonlethal fire has decreased while lethal fire has increased (fig. 5-1). Reduced fire began in the late 1800s as a result of (1) relocation of Native Americans and disruption of their traditional burning practices; (2) fuel removal by heavy and extensive livestock grazing; (3) disruption of fuel continuity on the landscape due to irrigation, cultivation, and development; and (4) adoption of "fire exclusion" as a management policy. The general result has been development of dense conifer understories, commonly adding 200 to 2,000 small trees per acre beneath old growth stands or thickets of 2,000 to 10,000 small trees per acre where the overstory was removed. Densely overstocked conditions have resulted in slow growth and poor vigor of most trees in a large proportion of the ponderosa pine type where adequate thinning treatments have not been applied. Stand stagnation is accompanied by a sparse representation of nonflowering herbs and shrubs, which reflects a loss of natural biodiversity and of forage for wildlife (Arno and others 1995a). Growth stagnation renders even the dominant trees highly vulnerable to mortality in epidemics of bark beetles, defoliating insects, diseases such as dwarf mistletoe, and various root rots (Biondi 1996; Byler and Zimmer-Grove 1991; Cochran and Barrett 1998). For example, in the 1980s about a million acres of ponderosa pine-fir forests in the Blue Mountains of eastern Oregon suffered heavy mortality from the above agents as a result of overstocking and growth stagnation related to fire exclusion (Mutch and others 1993).

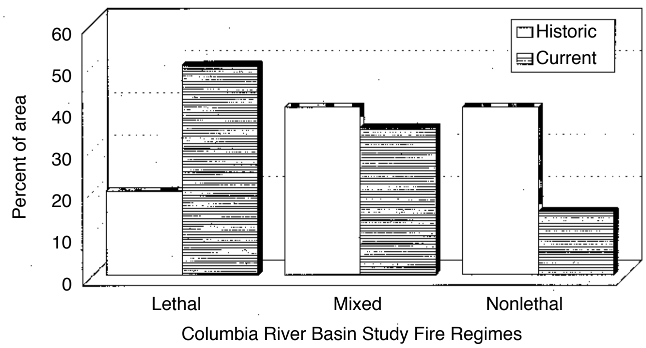

Figure 5-1—Change in fire severity between historic (pre-1900) and current conditions for Forest Service and Bureau of Land Management administered forested potential vegetation groups in the Interior Columbia Basin and portions of the Klamath and Great Basins (Quigley and others 1996).

In many stands, duff mounds 6 to 24 inches deep have accumulated under old growth trees, and burning these mounds may girdle and kill the trees (fig. 5-2). Stands of small, slow-growing pines have also colonized former grasslands (Gruell 1983). Overstory trees have been removed in more than a century of logging, primarily partial cutting, and this has aided development of thickets of small trees. On sites where ponderosa pine is seral, there has been a compositional shift to the shade-tolerant species. These successional changes have resulted in a buildup of understory or ladder fuels that now allow wildfires to burn as stand-replacing crown fires.

A combination of heavy forest floor fuels and dense sapling thickets acting as ladder fuels, coupled with the normally dry climate and frequent lightning- and human-caused ignitions, has resulted in a dramatic increase of severe wildfires in the ponderosa pine type in recent decades (Arno 1996; Williams 1995). For example, approximately 1 million acres (405,000 ha), largely in this type, burned in severe wildfires in central in Idaho between 1986 and 1996 (Barbouletos and others 1998).

Management Considerations—Fires of the past were important to the evolution of ponderosa and Jeffrey pine forests (Keane and others 1990a; Mutch 1970; Weaver 1967). Today, prescribed fire and wildland fire are the obvious and most feasible substitutes for filling the ecological role of historic fires in restoring these wildland ecosystems (fig. 5-3). Many alternatives exist for employing prescribed fire and fuels management treatments to improve forest health and reduce excessive ladder fuels in ponderosa pine and pine-mixed conifer types (Arno 1988). Different prescriptions can be chosen to enhance critical resources or values (Fiedler and others 1996), such as maintenance of old growth in a natural area, encouraging

Figure 5-2—A prescribed burn during October in central Idaho removed duff as thick as the distance between the hands, in this case with little damage to large ponderosa pine trees.

Figure 5-3—Prescribed fire during May is being used to reduce fuel loadings after a retention shelterwood harvest in a ponderosa pine/Douglas-fir forest.

browse and cover on a big game winter range, maintaining forest structure favored by neotropical migrant bird species, northern goshawk, flammulated owl, and other species of concern; protecting homes and watersheds from severe wildfire while maintaining visual screening; or providing a continuous supply of forest products without disruption of esthetics. However, most long-term management goals for wildlands in these forest types can be enhanced by some form of prescribed fire and fuels management.

Many contemporary stands have such an altered stand structure and composition, including a buildup of understory fuels, that it is difficult to restore forest health with prescribed fire alone. Silvicultural cutting and pile-burning or removal of excess small trees may be necessary to allow successful application of prescribed fire and to return to more open structures dominated by vigorous trees of seral species (Arno and others 1995a). Failed attempts to restore more natural stand conditions with prescribed burning alone may result from inappropriate use of fire as a selective thinning tool in dense fire-excluded stands, or from burning too little or too much of the accumulated forest floor fuels. A better approach to the latter problem may be to apply two or even three burns to incrementally reduce loadings (Harrington and Sackett 1990). Once a semblance of the desired stand and fuel conditions have been established, stands can thereafter be maintained more routinely with periodic burning or a combination of cutting and fire treatments. Prescribed fire can be used in wildernesses and natural areas to maintain natural processes.

The advantages of using fire and improvement cuttings to restore and maintain seral, fire-resistant species include: (1) resistance to insect and disease epidemics and severe wildfire; (2) providing continual forest cover for esthetics and wildlife habitat; (3) frequent harvests for timber products; (4) stimulation of forage species; and (5) moderate site disturbances that allow for tree regeneration (Mutch and others 1993). Frequent prescribed fires will not produce heavy screening or hiding cover, which is not sustainable over large areas in these forests. But such fires can help maintain moderate cover and screening indefinitely (Martin and others 1988). Management of a large proportion of the forest in open conditions can help ensure protection of strategically located patches of heavier cover (Camp and others 1996). The frequent disturbance cycles can also produce and maintain large old trees characteristic of pre-1900 forests and of high value for wildlife habitat, esthetics, and selective harvesting for lumber. In other words, the management approach of using a modified selection system and periodic burning can be used to maintain remnant old growth stands and to create future old growth (Fiedler 1996; Fiedler and Cully 1995).

Prescribed fire and wildland fire must be introduced cautiously in stands where leave trees have poor vigor or where tree roots are located in a deep duff layer (Harrington and Sackett 1992). Burning thick forest floor fuel layers can mortally injure roots and boles of old pines that in past centuries survived many fires (Sackett and Haase 1996). Exceptionally poor tree vigor is reflected by growth stagnation over two or more decades in the dominant trees in both second growth and old growth stands. This widespread stand stagnation has resulted from basal area stocking levels often two or more times those of historic conditions (Arno and others 1995b; Biondi 1996; Cochran and Barrett 1998; Habeck 1994). Fire can be highly stressful to trees that are suffering from growth stagnation, and may, for instance, allow bark beetles to inflict major damage to the weakened trees. If vigor of desired leave trees is poor, it may be wise to thin mechanically and allow the leave trees to recover or release somewhat before applying fire, in perhaps 2 years (Fiedler and others 1996).

Options for alleviating the condition of poor vigor or deep duff are not ideal. Managers can simply accept a 20 to 50 percent loss of old growth in a single fuel-reduction burn as being a cost of decades of fuel buildup. Most old growth stands are now more heavily stocked than in pre-1900 times, and some of the trees would probably have been killed by natural fires had suppression not intervened. Alternatively, fuels could be manually removed or raked away and dispersed from around the boles of old growth trees. The use of a burn prescription that reliably removes a portion of the fuel mound around a big tree has not been found. If glowing combustion is able to establish in the deeper mounds, it can continue even with high moisture content of that material and result in total consumption and prolonged heat release.

Improvement cutting, thinning, and understory cutting with whole-tree removal or pile burning may be necessary to achieve open stocking levels that will sustain vigorous tree growth and to reduce ladder fuels (Fiedler and others 1996) (fig. 5-4). Harvesting and thinning should be designed to retain the most vigorous trees. If stems are tall and slender, as in dense second growth stands, it may be necessary to leave clumps of three to five trees for mutual protection against breakage by wet snow and windstorms. The restoration cutting process may require thinning in two to three steps over 15 to 20 years. Spot planting of the desired seral tree species in open burned microsites can be used when shade-tolerant species have taken over (Fiedler and others 1996).

Prescribed fire can be used in a variety of seasons to meet management objectives (Harrington 1991; Kalabokidis and Wakimoto 1992; Kauffman and Martin 1990; Kilgore and Curtis 1987; Martin and Dell

Figure 5-4—(A) An unwanted ponderosa pine-fir stand that resulted from partial cutting of large pines followed by development of fir thickets. (B) Similar stand after the first restoration treatment consisting of thinning to favor remaining pines and jackpot burning.

1978; Weatherspoon 1990). This includes burning in late winter following snowmelt, when understory Douglas-fir or true firs may burn readily and are easily killed because of low foliar moisture content; spring; cloudy-humid days in summer; or autumn. Trees are less susceptible to fire damage when entering dormancy in late summer and fall. Potential for fire damage can be reduced by thinning and whole-tree removal, burning when slash is still green, successive burns starting with damp fuels, and raking duff mounds away from boles of old growth trees. Fire intensity can be reduced by burning at dawn, late evening, or at night. Conversely, to enhance burning in stands where surface fuels are inadequate, such as in fir thickets, thinning can be used to create sufficient loadings of cured slash. Alternatively, waiting for grass fuels to cure in the fall may be effective. If enclaves of dense growth are desired, such as for wildlife habitat, these can be protected from wildfire if buffered within a matrix of treated stands that have light fuel loadings.

During the past decade tens of thousands of acres of the ponderosa pine type have been treated with prescribed fire in central Oregon, northwestern Montana, and parts of Arizona and New Mexico (Kilgore and Curtis 1987; Losensky 1989; Simmerman and Fischer 1990). If these applications can be greatly expanded they could correct some of the severe forest health and wildfire problems that exist in the Inland West (Everett 1994; McLean 1992; Mutch and others 1993).

Redwood

Pre-1940 Succession—Forests where redwood was the most abundant tree covered about 1 million acres in a narrow strip along the coastal fog belt from the extreme southwestern corner of Oregon to Monterey County, California (Roy 1980). It has long been recognized that relatively frequent understory fires were historically a common feature of the redwood forest and that fires seldom killed many of the large redwood trees (Fritz 1931). Redwood is even more fire resistant than coast Douglas-fir, its primary associate, and unlike most conifers in this region, redwood sprouts vigorously from dormant buds when the crown is heavily scorched. Pacific madrone and tanoak, the most abundant hardwoods in the redwood type, are fire susceptible. They resprout when top-killed by fire, but burning probably taxed them physiologically when they were growing beneath an overstory.

Recent advances in dating fire scars on redwood stumps have shown that presettlement (pre-1850) fire intervals averaged between about 5 and 25 years, shorter than previously estimated (Brown and Swetnam 1994; Finney and Martin 1989, 1992). The pattern of frequent fires on fire-scarred tree stumps was traced back to about 1300 A.D. in one study area (Finney and Martin 1989) and to about 800 A.D. in another (Fritz 1931). There is a convergence of evidence from historical journals and archeological and anthropological discoveries that Indian burning was primarily responsible for the frequent fires prior to the mid-1800s (Duncan 1992; Greenlee and Langenheim 1990; Lewis 1973; Stuart 1987). Coincidentally, the redwood forest is located close to interior coastal valleys where detailed journal accounts of Indian burning have been assembled (Boyd 1986, 1999). In the presettlement period, before logging occurred, the frequent fires probably kept understories open and reduced forest floor fuels. Overstories of the tall trees with branch-free lower boles were relatively dense because of high site productivity and redwood's fire resistance.

During the settlement period, in the later 1800s and early 1900s, Anglo-Americans conducted logging that created large quantities of slash. These inhabitants continued a pattern of frequent burning in conjunction with logging and for grazing or other purposes. They also allowed accidental fires to spread.

Post-1940 Succession—Starting in the 1930s and 1940s, land use patterns changed with the implementation of the California Forest Practices Act and with more vigorous fire suppression (Greenlee and Langenheim 1990; Stuart 1987). The number of escaped fires from agricultural or logging activities was reduced greatly; but the effects of this reduction of fires have received little evaluation. It is generally assumed that the long-lived, shade-tolerant redwoods will continue to dominate regardless of removal of underburning. Successional relationships in redwood forest communities (Zinke 1977) suggest that with suppression of underburning, shade-tolerant shrubs, understory hardwoods, and western hemlock will increase as will forest fuels in general. In the extensive parks and preserves where redwood forests are protected from logging, continued exclusion of fire will probably allow fuels to accumulate to levels that support higher intensity wildfires, which can escape suppression. Thus, the removal of underburning may ultimately result in a mixed fire regime where wildfires kill significant portions of the overstory and may induce soil damage on the steep slopes associated with a large portion of the redwood type (Agee 1993; Atzet and Wheeler 1982). Additionally, removal of underburning will probably reduce the abundance of early seral species (including chaparral species) and will allow trees to colonize the small openings and prairies associated with the redwood forest belt (Finney and Martin 1992; Greenlee and Langenheim 1990; Zinke 1977).

Oregon Oak Woodlands

Pre-1850 Succession—Open woodlands dominated by Oregon white oak once occupied the driest climatic areas throughout the Puget Sound-Willamette Valley lowlands and southward in dry valleys behind the coastal mountains to the California border. (Farther south this woodland expands to cover large areas of dry hilly terrain and it is dominated by several species of oak in addition to other hardwood trees; those communities are described under “Western Oaks” in chapter 6.) Oregon white oak dominated in open woodlands and savannas associated with valley grasslands, and isolated small prairies that were surrounded by the extensive coast Douglas-fir forest. Oak woodlands also were associated with droughty sites such as bedrock with shallow soils on the southeast coast of Vancouver Island and in the San Juan archipelago, in the rain shadow of the Olympic Mountains.

Ample evidence from journal accounts and archeological sources shows the extensive oak woodlands of the Willamette and other major valleys persisted as a “fire climax” maintained by frequent aboriginal burning (Agee 1993; Boyd 1986, 1999; Habeck 1961). Prior to the influx of Euro-American settlers in the mid-1840s, the Kalapuyan Indians and other tribes typically set fire to large areas of the Oregon oak woodlands to aid hunting, food plant harvest, and for other purposes (Boyd 1986). Firing was commonly done in September, and many areas were burned at short intervals, perhaps annually in some areas. Similar patterns of frequent burning to maintain valley grasslands, isolated prairies, and open oak woodlands are described from northwestern Washington southward to central California (Lewis 1973; Boyd 1986, 1999), but these practices are well documented only in the Willamette Valley of northwestern Oregon.

Most of these fires must have been characterized by short duration flaming as they quickly consumed grass and litter that had accumulated since the previous burn. The thick-barked oaks survived, but regeneration of all shrubs and trees would have been heavily thinned by frequent burning. Grass flourished. The effect of frequent burning on oak regeneration from sprouts and seedlings is not known, but this species was more successful in establishment than Douglas-fir or other competitors under a regime of frequent burning. Results of experimental burning suggest that heavily burned microsites are favorable for oak seedling establishment (Agee 1993). Also, about half of the 1 to 9 year old seedlings burned in a prescribed fire resprouted and were alive 3 years later.

Post-1850 Succession and Management Considerations—In former oak savannas, fire exclusion has led to an increased density of shrubs and oaks, transforming them into woodlands (Agee 1993). In former oak woodlands, shrubs, Douglas-fir, and other tree species are replacing oaks. Livestock grazing and fire exclusion have been major factors in the successional change that has occurred in Oregon oak woodlands since Euro-American settlement. Logging, clearing, and firewood harvest also have changed many woodlands. Additionally, large areas of oak woodlands have been displaced by agricultural, commercial, industrial, and residential development.

Today, 150 years after Euro-American settlement began, only a general idea of presettlement conditions can be hypothesized for most stands. Much of the remaining undeveloped area in this type will be replaced successionally by the year 2010 unless prescribed fire and other restoration treatments are conducted (Agee 1993). To complicate restoration of oak communities, a variety of introduced herbaceous plants and the shrub Scotch broom are now established. Introduced plants can increase as a result of some treatments. Nevertheless, some strategies of burning carefully coordinated with cutting, seeding of native plants, and other treatments hold some promise (Agee 1993; Sugihara and Reed 1987). Restoration of structural characteristics of the oak communities is an attainable goal (see Agee 1993).

Mixed Fire Regimes

Major Vegetation Types

Major forest types include coast Douglas-fir, redwood, California red fir, interior Douglas-fir, western larch, lodgepole pine, whitebark pine, and ponderosa pine types east of the continental divide in Montana, South Dakota, Wyoming, and Colorado. (There is evidence that a mixed regime may have been important for perpetuation of giant sequoia groves in the Sierra Nevada; Stephenson and others 1991; Swetnam 1993.) These forests are widespread in the upper Great Plains, the mountains of the Western United States, and in the northwest coastal regions, extending into southern British Columbia (fig. 1-2). In large portions of their distributions, some of these forest types are also characterized by stand-replacement fire regimes in large portions of their distributions, evidently as a result of differences in climate or topography. An example of this contrast is the larch-lodgepole pine forest in Glacier National Park, Montana, where the northern portion was under a mixed fire regime while the southern portion had a stand-replacement fire regime (Barrett and others 1991). A similar contrast is provided by lodgepole pine types in southwestern Alberta as described by Tande (1979) and Hawkes (1980).

Fire Regime Characteristics

Fires were variable in frequency and severity, and perhaps because these situations are difficult to characterize in simple terms, they have been largely overlooked in previous fire regime classifications (Brown 1995). Mean fire intervals were generally longer than those of understory fire regimes and shorter than those in stand-replacement fire regimes. However, some individual fire intervals were short (<30 years), while the maximum intervals could be quite long (>100 years). Our mixed category covers the spectrum of fire regimes between nonlethal regimes and those where stand-replacement fires were typical.

As described in chapter 1, mixed fire regimes may consist of a combination of understory and stand-replacement fires. Examples are the seral ponderosa pine-western larch forests in western Montana that burned in replacement fires at long intervals (150 to 400+ years) with nonlethal underburns at short intervals (20 to 30 year averages) in between (Arno and others 1995b, 1997).

Mixed severity fire regimes may also be characterized by fires that killed a large proportion of fire-susceptible species in the overstory (such as western hemlock, subalpine fir), but spared many of the fire-resistant trees (such as redwood, Douglas-fir, larch, ponderosa pine). These fires tended to burn in a fine-grained pattern of different severities, including patches where most of the moderately susceptible trees (such as California red fir, white fir, lodgepole pine) survived. Any given location within a mixed fire regime could experience some stand-replacement fires and some nonlethal fires along with a number of fires that burned at mixed severities.

Evidence of mixed severity fire in ponderosa pine is suggested in two landscape photocomparisons of central Montana from the 1880s to 1980 (Gruell 1983, plates 32 and 43). Relatively long fire intervals and mixed burning also occurred in ponderosa pine in the Colorado Front Range (Laven and others 1980) and in the Black Hills of South Dakota (Brown and Sieg 1996; Shinneman and Baker 1997). The mixed fire regime is reported to have been common in mixed-conifer forests of northern Idaho (Zack and Morgan 1994; Smith and Fischer 1997) and western Montana (Arno 1980).

Pre-1900 fires often covered large areas. The uneven burning pattern in mixed fire regimes was probably enhanced by mosaic patterns of stand structure and fuels resulting from previous mixed burning. Thus, past burn mosaics tended to increase the probability that subsequent fires would also burn in a mixed pattern. Complex mountainous topography also contributed to variable fuels and burning conditions, which favored nonuniform fire behavior.

Fuels

During the presettlement period fuels were probably quite variable spatially and temporally. At a given time, some segments of the vegetative mosaic would be patches of postfire regeneration that had arisen where the last fire killed much of the overstory. Fuel loadings in these patches might increase dramatically as dead trees and limbs fell into a developing patch of saplings. If these regenerated patches burned again, the resulting "double burn" might be an area cleared of most living and dead fuel and thereafter more likely to support nonlethal underburning in the next fire. In the presettlement period a given fire could burn day and night for 2 to 3 months under a great variety of weather conditions in a hodgepodge of different vegetation and fuel structures. Reburning might occur later in the same fire event. This could result in an intricate pattern of different fire effects on the landscape. Such complex burning patterns are difficult to imagine in modern stands where 60 to 100 years of fire exclusion have allowed most of the landscape mosaic to age and advance successionally. Patches of late-successional forests with accumulations of dead and living fuels have coalesced, increasing the likelihood of fires of unusual size and severity (Barrett and others 1991).

The ranges in fuel loadings observed in vegetation types characterized by mixed and stand-replacement fire regimes exhibit considerable overlap. Fuel loadings vary widely within broad vegetation classes due to stand history and site productivity. Dead woody fuels accumulate on the ground often in a haphazard manner due to irregular occurrence of natural mortality factors such as fire, insects, disease, tree suppression, and wind and snow damage. However, the greatest fuel loadings tend to occur on the most productive sites, which are predominately stand-replacement fire regimes. For example, in the Northern Rocky Mountains downed woody fuel loadings ranged from an average of about 10 tons/acre (22 t/ha) on low productivity (30 cu ft/acre/yr) sites to about 30 tons/acre (67 t/ha) on high productivity (90 cu ft/acre/yr) sites (Brown and See 1981).

Average fuel loadings determined from extensive forest surveys in the Northern Rocky Mountain National Forests (Brown and Bevins 1986; Brown and See 1981) indicate that quantities of duff and downed woody material differ between mixed and stand-replacement fire regimes (table 5-2). For example, total woody fuel loadings for the spruce-fir and cedar-hemlock types, which are stand-replacement regimes, averaged about 30 tons/acre. It averaged about 17 tons/acre in Douglas-fir and lodgepole pine types, which are characterized by mixed and stand-replacement regimes. Variability within stands and cover types was considerable. Fuel loading distributions for forest floor and all classes of downed woody material were highly skewed, with long right-handed tails. The ratios of medians-to-means averaged close to 0.6 (Brown and Bevins 1986). These statistics indicated that fuels were not uniformly distributed but concentrated in scattered patches.

Downed woody fuels greater than a 1 inch diameter are considered coarse woody debris, which has

Table 5-2—Average loadings of forest floor and downed woody fuel by diameter class for randomly located sample points in Northern Rocky Mountain forest types: Douglas-fir (DF), Lodgepole Pine (LP), Larch/grand fir (L/GF), Spruce/fir (S/F), and Cedar/hemlock (C/H).

	USDA Forest Service forest survey cover types				
Fuel	**DF**	**LP**	**L/GF**	**S/F**	**C/H**
	tons/acre				
Litter	0.56	0.35	0.66	0.52	0.85
Duff	13.0	16.0	21.8	25.4	25.4
Woody					
0 to ¼ inch	.18	.22	.22	.12	.30
¼ to 1 inch	1.0	1.0	1.3	1.0	1.3
1 to 3 inches	1.8	2.1	2.3	1.9	2.7
3+ inches	12.9	14.4	17.7	23.8	29.4
Total woody	15.9	17.7	21.5	26.8	33.7

important implications for managing biodiversity and nutrient potentials. Based on a survey of coarse woody debris knowledge (Harmon and others 1986) quantities of downed woody material are considerably higher in Cascade Mountains and coastal forests than in the Northern Rocky Mountains. Loadings of coarse woody debris ranged from 60 to 300 tons/acre (130 to 670 t/ha) in Sitka spruce and western hemlock of coastal British Columbia and from 60 to 240 tons/acre (130 to 540 t/ha) in the Douglas-fir type of the Cascade Mountains.

Postfire Plant Communities

Coast Douglas-fir and Douglas-fir/Hardwoods

Pre-1900 Succession—These humid maritime forests are extensive at low and middle elevations west of the crest of the Cascades and British Columbia Coast Range from northern California to southern British Columbia. Fire history studies (see Agee 1993) indicate that mixed fire regimes were common in the Douglas-fir type south from west-central Oregon; drier areas of the Douglas-fir type farther north; and in the Douglas-fir/hardwood types of northwestern California and southwestern Oregon (Wills and Stuart 1994) (fig. 5-5). Conversely, the cooler, wetter, more northerly portions of the coast Douglas-fir type tended to be associated with stand-replacing fire regimes. Mixed fire regimes were probably also associated with some areas of the redwood type, perhaps on steep terrain and in areas relatively remote from Native American use.

Mixed fire regimes favored development of stands dominated by large old, fire-resistant trees, such as coast Douglas-fir—and, where present, redwood. These regimes were characterized by patchy nonuniform burning (Morrison and Swanson 1990; Teensma 1987; Wills and Stuart 1994). Overall, most of the fire-susceptible trees (notably western hemlock) were killed while many of the resistant trees survived. Occasional nonlethal understory fires and stand-replacement fires also occurred. Effects of burning included removing understory conifers and ladder fuels, preventing successional replacement by shade-tolerant trees, and creating openings of all sizes that allowed regeneration of seral undergrowth (including berry-producing shrubs), hardwood trees (such as red alder, bigleaf maple, bitter cherry), Douglas-fir and a few other seral conifers (such as western white pine and shore pine).

In northwestern California and southwestern Oregon, dry Douglas-fir/hardwood types burned rather frequently and supported a variety of seral shrubs, including *Ceanothus* spp. as well as hardwood trees that typically resprout after fire—including tan oak, madrone, canyon live oak, and chinquapin (Agee 1993; Husari and Hawk 1993; Wills and Stuart 1994). A remarkable feature of the mixed fire regimes in dry sites was the prevalence of large (>6 feet in diameter), old Douglas-fir that had survived numerous fires. Although forests associated with this fire regime type are extensive and important for a variety of ecological values, little is known about landscape patterns and successional patterns associated with the presettlement fires. The existence of this mixed fire regime as a widespread type was documented only recently (Agee 1993; Means 1980; Morrison and Swanson 1990).

Post-1900 Succession—Better knowledge of the ecological role and importance of fire in these mixed fire regimes is needed (Kauffman 1990). Although major ecological changes in these forests due to clearcutting and short-rotation forest management have been recognized, other significant changes have also occurred as a result of interruption of the mixed fire regime (Agee 1990). Effects of fire exclusion are

Figure 5-5—Coastal Douglas-fir in a dry area of northwestern Washington, with scars from two different historic fires.

conspicuous in dry site coastal Douglas-fir communities which burned rather frequently, for example, those in southwestern Oregon (Agee 1991; Means 1982) and in the Puget Sound lowlands (Agee and Dunwiddie 1984; Boyd 1986). Such effects include loss of early seral shrub species, advanced successional development, increased stand density, and increased mortality. In older logged areas it is common to find dense second growth Douglas-fir and hemlock that are stagnating and succumbing to root rot, whereas the original stands consisted of large Douglas-fir in moderately open stands that had survived for several centuries in the presence of repeated fires.

Management Considerations—These forest types have high value for recreation, esthetics, endangered species habitat, and timber production. It is generally recognized that fire had an important role in creating these forests. A century ago Gifford Pinchot, Forester for the U.S. Department of Agriculture, argued for research into the ecological role of fire in these forests, but his call went largely unheeded (Pinchot 1899). Most fire research in these vegetation types has been related to burning of clearcuts (Kauffman 1990), and provides knowledge that is of limited value for modern ecological application. Other ecological aspects of these forests have been studied in detail at the H. J. Andrews Experimental Forest in west-central Oregon (Franklin and Others 1981; Teensma 1987) and in some redwood ecosystems (Zinke 1977). Major forest preservation efforts have focused on these forests, but ironically have generally accepted the continued exclusion of fire as consistent with maintenance of ecological values.

California Red Fir and Sierra/Cascade Lodgepole Pine

Pre-1900 Succession—These are high elevation forests characteristic of the southern Cascades, Klamath Mountains (in northwestern California), and the Sierra Nevada. Fire history studies conducted thus far suggest a variable or mixed fire regime.

The following summary of fire history in California red fir forests is paraphrased from Husari and Hawk (1993) with additional information from Taylor (1993). Estimates of natural fire frequency in California red fir range from 21 to 65 years (Taylor 1993; Taylor and Halpern 1991). Analysis of lightning fire occurrence in Yosemite National Park shows that, on a per acre basis, the California red fir forest type there experiences more lightning ignitions than any other vegetation type, but the fires are mostly small (van Wagtendonk 1986). This is probably attributable to lower overall productivity on these sites, a compact duff layer, a short fire season, and generally cool, moist conditions. The California red fir forest shows structural evidence of a combination of large intense fires, small fires and fires of mixed severity (Taylor 1993). This variety of fire characteristics has led to landscape diversity in California red fir forests (Agee 1989).

Agee (1993) and Chappell and Agee (1996) describe variable and mixed fire regimes in lodgepole pine forests of southern Oregon. Average fire intervals are estimated to be 60 to 80 years. Mountain pine beetle epidemics can result in an accumulation of heavy fuels, which in turn supports stand-replacement fire. Stands with moderate quantities of older downed logs and open space between tree canopies often experience smoldering fires ("cigarette burns") that spread primarily through decayed logs on the forest floor. Southward, in the California red fir-lodgepole pine-mixed conifer subalpine forest of California, small patchy fires are the norm (Parsons 1980). This is due in part to an abundance of broken topography, rock, bare mineral soil, and sparse fuels that hamper fire spread.

Post-1900 Succession—Suppression of the mixed, patchy fires in these high-elevation forests may eventually result in a landscape mosaic consisting largely of contiguous old stands with comparatively heavy loadings of dead trees (standing and fallen) and canopy fuels. This is probably the basis for Husari and Hawk's (1993) projection that in the future these forests will be characterized by infrequent high-intensity, stand-replacing fires.

Management Considerations—Intensive tree harvesting can be used to break up continuous heavy fuel loadings that might result in large, severe fires. Laacke and Fiske (1983) state that most silvicultural treatments have been designed to produce even-aged stands. Clearcutting offers the opportunity to control the spread of dwarf mistletoe and root disease, which are often a concern in this type. Recent interest in perpetual retention of some tree cover on high-elevation forest sites and in designing treatments consistent with historical disturbances will probably encourage attempts at uneven-aged silviculture or retention shelterwood. California red fir is a shade-tolerant species, which conceptually makes it appropriate to consider for uneven-aged silvicultural systems. Concern about root disease and dwarf mistletoe has worked against consideration of uneven-aged systems, but use of underburning might serve some function in controlling these pathogens (Koonce and Roth 1980; Petersen and Mohr 1985). Fire history and experience burning in white fir types (Petersen and Mohr 1985; Weatherspoon 1990) suggest that understory burning might be useful in some California red fir/lodgepole forests.

Interior Douglas-fir, Larch, Rocky Mountain Lodgepole Pine

Pre-1900 Succession—A broad range of mid-elevation mountain forests dominated by interior Douglas-fir, western larch, or Rocky Mountain lodgepole pine were characterized by mixed fire regimes. These occurred from central British Columbia (Strang and Parminter 1980) and Jasper National Park, Alberta (Tande 1979), southward at least to western Wyoming (Arno 1981; Loope and Gruell 1973). They were abundant and diverse in western and central Montana (Arno 1980; Barrett and others 1991, Arno and Gruell 1983). Mixed fire regimes allowed an open overstory of mature Douglas-fir and larch to survive many fires. Small trees and associated less fire-resistant species were heavily thinned by moderate-intensity burning. Additionally, some nonlethal underburns occurred in lodgepole pine stands having light fuels. Occasional stand-replacing fires were also part of the mixture making up this fire regime.

Effects of these variable fires often included maintaining a fine grained forest community mosaic on much of the landscape—as is illustrated by maps in Tande (1979), Barrett and others (1991), and Arno and others (1993) (fig. 5-6). Elements of this mosaic were small stands dominated by various age structures of seral coniferous species and seral hardwoods such as Scouler willow and aspen. Some stands experienced nonlethal underburns that maintained open understories by killing saplings and fire sensitive species. Others experienced patchy fire mortality that gave rise to patchy tree regeneration including seral species. Occasional large stand-replacement fires may have

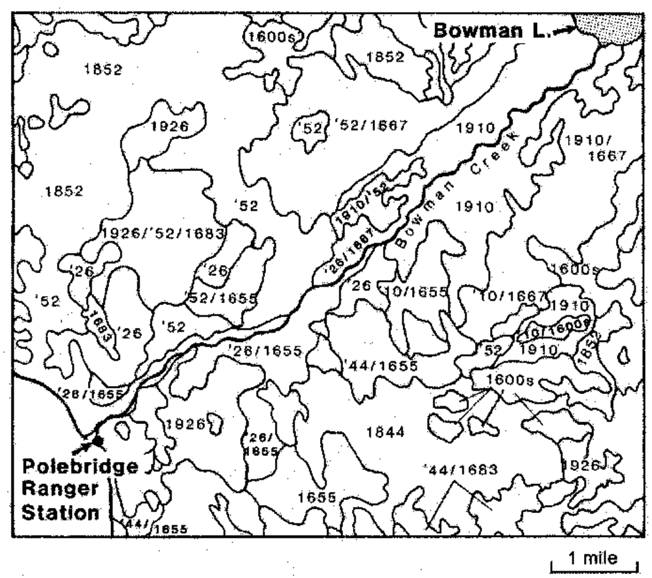

Figure 5-6—This mosaic of age-classes resulted from a mixed-severity fire regime in Glacier National Park, Montana. Dates indicate fire years that resulted in establishment of seral western larch and lodgepole pine age classes. In addition, some low-intensity underburns were detected in fire scars, but they did not thin the stand enough to allow new age classes to become established (from Barrett and others 1991).

reduced the spatial diversity, but the varying distribution of seed sources and sprouting shrubs in the preburn mosaic probably enhanced variability in postburn vegetation. A fire effect near the lower forest boundary was to maintain seral grasslands, shrublands, and aspen groves by periodically removing most of the invading young Douglas-fir or lodgepole pine (Arno and Gruell 1986; Patten 1963; Strang and Parminter 1980).

Post-1900 Succession—With a reduction in fire activity due to livestock grazing (removing fine fuels) and fire exclusion policies, young conifer stands have invaded former grasslands within or below the forest zone. The trees are densely stocked and subject to extreme drought stress. They often have poor vigor and are susceptible to western spruce budworm or other insect or disease attacks and to stand replacing fires. Productivity of seral herbs, shrubs, and aspen declines dramatically in the continuing absence of fire.

Stands within the forest zone may have undergone significant changes in recent decades. As a result of fire exclusion, the trees in most stands within the landscape mosaic have become older, and often have a buildup of down woody or ladder fuels. Recent wildfires have burned as larger stand-replacement fires than those detected in fire history studies (Arno and others 1993; Barrett and others 1991).

Management Considerations—Fire exclusion may move these communities toward a long-interval stand-replacement fire regime. This could decrease vegetation diversity on the landscape and may reduce values for wildlife habitat, watershed protection, and esthetics. Numerous alternatives exist for simulating more natural landscape structure and disturbance regimes using silvicultural cuttings and prescribed fire (Arno and Fischer 1995; Arno and others 2000; Brown 1989; Gruell and others 1986).

Whitebark Pine

Pre-1900 Succession—The whitebark pine type occurs near the highest elevations of forest growth from southern British Columbia south to western Wyoming in the Rocky Mountains and along the Cascades to northern California. In the drier mountain ranges and on rocky sites with sparse fuel, whitebark pine is characterized by a mixed fire regime, whereas in moist and more productive areas it is perpetuated by a stand-replacement fire regime. The mixed fire regime has been noted in whitebark pine stands in the Selway-Bitterroot Wilderness and nearby areas of central Idaho and western Montana (Barrett and Arno 1991; Murray 1996). Prior to 1900 these forests experienced a range of fire intensities from nonlethal underburns to large (but usually patchy) stand-replacement fires. Rugged terrain, including extensive rocklands and cool-moist north slopes hampered the spread of fires and resulted in a variable burn pattern.

Whitebark pine is a seral species on all but the harshest sites and is replaced successionally by subalpine fir, Engelmann spruce, or mountain hemlock (fig. 5-7). These species were readily killed in low-intensity fires, whereas whitebark pine often survived. Epidemics of mountain pine beetle periodically killed many of the older whitebark pines. Fuels created by beetle kills and successional ladder fuels contributed to patchy torching or stand-replacement burning. Underburns had a thinning effect that removed many of the competing fir, while more intense fires created open areas favorable for whitebark pine regeneration. This species' seeds are harvested and cached often in burned areas by Clarks Nutcrackers (*Nucifraga columbiana*). Many seed caches are not retrieved, so pines regenerate (Tomback 1982). Whitebark pine is hardier than its competitors and functions as a pioneer species on high-elevation burns.

Post-1900 Succession—Fire exclusion may have been particularly effective in many areas of the whitebark pine type where rugged terrain provides natural fire breaks. To cover large areas of the type, which is restricted to high ridges, fires had to burn across broad valleys. Many of the latter are now under forest management, agriculture, suburban or other development that prevents fire spread. Large wilderness areas and National Parks sometimes allow wildland fires with limited suppression as a substitute for natural fires. However, even the most successful natural fire program in a large wilderness has had a lower level of success in returning fire to whitebark pine than to other forest types (Brown and others 1994, 1995). Major fires in the whitebark pine type are confined largely to late summer in especially dry years, when prescribed natural fires usually are not allowed.

To complicate matters, white pine blister rust (*Cronartium ribicola*), an introduced disease, is killing cone-bearing limbs and entire trees of whitebark pine in about half of the species' natural range (Arno and Hoff 1990). A small percentage of the trees has some resistance, but without ample sites upon which to regenerate, resistant strains cannot develop and multiply.

Management Considerations—Fires may be more critical for whitebark pine's survival now that blister rust has inflicted heavy mortality across large areas of the Northwestern United States. Evidence from mortality observations (Kendall and Arno 1990), permanent plots (Keane and Arno 1993), and ecological process modeling (Keane and others 1990b) suggests that unless active management is carried out on a landscape scale, whitebark pine will continue to decline in a large part of its range and may virtually

Figure 5-7—Whitebark pine regenerating on a 26-year-old burn (foreground). In contrast, the old, unburned forest (background) consists of subalpine fir, Engelmann spruce, and dead whitebark pine snags.

disappear in some areas. Use of wildland fires in wilderness, prescribed fires, release cuttings to favor the pine over its competitors, and aiding the propagation of natural rust resistance are the most obvious alternatives. These measures are now being tested at several sites in Idaho and Montana by Robert Keane, Rocky Mountain Research Station, Missoula, Montana.

Ponderosa Pine

Pre-1900 Succession—Some ponderosa pine forests were historically characterized by mixed fire regimes, although the extent and ecological relationships of these mixed regimes are yet to be determined. It appears that mixed regimes were commonly associated with ponderosa pine growing east of the Continental Divide, and also with some forests west of the Divide, especially those on steep slopes and on relatively moist sites. The most compelling evidence for a large area of mixed fire regime comes from the Black Hills of South Dakota (Brown and Sieg 1996; Gartner and Thompson 1973; Shinneman and Baker 1997) and the Front Range of the Rocky Mountains in Colorado (Kaufmann 1998; Laven and others 1980). Many of the ponderosa pine stands in the Black Hills and nearby areas of northeastern Wyoming and southeastern Montana develop dense patches of pine regeneration after fire, which become thickets of small stagnant trees, susceptible to stand-replacing fire. Intervening areas with more open stocking presumably were more likely to underburn in the frequent fires of the presettlement era. Factors contributing to a mixed fire regime in ponderosa pine probably include relatively moist sites that tended to produce pine thickets soon after a fire, areas frequently exposed to high winds during the burning season, steep topography, and stands killed by bark beetle epidemics.

Post-1900 Succession—In the Black Hills, northeastern Wyoming, and southeastern and central Montana, fire exclusion coupled with livestock grazing has resulted in an expansion of ponderosa pine from its presettlement habitat on rocky ridges and other poor sites into the adjacent grassy plains. This invasion may involve over a million acres (Gartner and Thompson 1973; Gruell 1983), but no data are available. The stands on the ridges have also thickened with ingrowth of younger trees. Dense stands greatly reduce production of native grasses and forbs and diminished forage values for livestock and wildlife (Gartner and Thompson 1973). Thousands of homes are now located in these dense pine stands, and many are threatened annually by wildfires. Nearly 50 homes burned in a central Montana wildfire in 1984, and over

100 burned in 1991 in ponderosa pine woodlands near Spokane, Washington.

Management Considerations—The dense stands of small ponderosa pines that have expanded into grasslands in the upper Great Plains are at high risk of severe wildfire and have diminished forage values. Breaking up the continuity of these stands using silvicultural cuttings and prescribed fire treatments would allow more effective control of fire. It may be possible to thin some of these stands commercially while retaining the largest and healthiest trees. Prescribed burning in conjunction with cutting could reduce fuel loadings and stimulate forage (Gartner and Thompson 1973; Kilgore and Curtis 1987). Initial burning should be done with care not to injure leave trees (see discussion of ponderosa pine in the section "Understory Fire Regimes").

There may be objections to converting dense stands to open-growing ones, especially doing so on a landscape scale (Shinneman and Baker 1997). Patchy even-aged cuttings and prescribed burns are one alternative that could be used to simulate historical mixed regime patterns (Franklin and Forman 1987). Allowing dense forests on public lands to be killed by insect epidemics that encourage severe wildfires may be the eventual result of inaction. This latter alternative could be made less hazardous to adjacent lands if fuels management were carried out around the borders of such areas (Scott 1998).

Stand-Replacement Fire Regimes

Major Vegetation Types

Major forest types include coast Douglas-fir, true fir/hemlock, interior true fir/Douglas-fir/larch, Rocky Mountain lodgepole pine, white pine/western redcedar/hemlock, spruce/fir/whitebark pine, and aspen. Several minor forest types are also characterized by stand-replacement fires. These forests are widespread in wetter forest regions of the Northwestern United States and Western Canada and in subalpine forests associated with the major mountain ranges. Some of the same compositional types are also characterized by mixed fire regimes in large portions of their distributions. Differences in regional climate, fuels, and local topography can influence the resulting fire regime (for example, see Barrett and others 1991).

Fire Regime Characteristics

Stand-replacing fires kill most overstory trees, although the pattern of these fires on the landscape varies with topography, fuels, and burning conditions. Sometimes extensive areas burn uniformly in stand-replacing fire events, especially in wind-driven crown fires (Anderson 1968). However, a major proportion of stand-replacement is caused by lethal surface fire, as was the case with much of the 1988 Yellowstone Area fires. Lethal surface fire was responsible for about 60 percent (versus 40 percent in crown fire) of the stand-replacement burning in the Selway-Bitterroot Wilderness under the prescribed natural fire program (Brown and others 1995). Under different conditions, a complex landscape mosaic of replacement burning from crown fire and lethal surface fire is interwoven with areas of lighter burning or no burning. For instance, patchy burning patterns may be accentuated by rugged mountainous topography containing contrasting site types, microclimates, and vegetation. These mosaic elements represent diverse burning environments and the result is that stand-replacement burning is restricted to certain landscape elements. For example, in one area of northern Idaho, stand-replacement fires were associated with a mid-slope "thermal belt" on southern and western exposures while other slopes tended to burn in mixed severity fires (Arno and Davis 1980). Superimposed on the site mosaic is a fuels mosaic linked to the pattern of past fires. On gentle topography and more uniform landscapes, such as high plateaus, stand-replacement fires tend to be more uniform or at least to burn in large-scale patches.

Stand-replacement fires generally occur at long average intervals (table 5-1), ranging from about 70 years in some lower elevation Rocky Mountain lodgepole pine forests subject to extreme winds, to 300 to 400 years in some inland subalpine types, and over 500 years in some moist coastal mountain forests. Often the range of actual intervals is broad since the fires themselves depend on combinations of chance factors such as drought, ignitions, and high winds. Such combinations occur sporadically. In coastal forest types having long fire intervals, such as coast Douglas-fir and true fir-mountain hemlock, it appears that exceptional drought and perhaps an unusual abundance of lightning ignitions were linked to major fires (Agee 1993). The great length of intervals and findings of substantial climatic changes during the last few thousand years suggest that fire intervals varied with climatic changes (Johnson and others 1994).

The irregular timing of stand-replacement fire is heightened in several forest types by their propensity to support double or triple burns in the aftermath of an initial fire. For instance, the Yacolt fire (1902) of southwestern Washington and the Tillamook fire (1933) of northwestern Oregon reburned numerous times (Gray and Franklin 1997; Pyne 1982). A history of occasional replacement fires followed by severe reburns also is common in the Clearwater drainage of northern Idaho (Barrett 1982; Wellner 1970).

In the Rocky Mountain lodgepole pine type, fuel buildup is an important factor in length of fire intervals (Brown 1975; Romme 1982). Mean fire intervals in this type range from a low of about 70 years in productive lower elevation lodgepole pine forests in high wind environments on the east slope of the Rockies—for example, at Waterton Lakes National Park, Alberta; Glacier National Park, Montana; and perhaps in the Red Lodge area northeast of Yellowstone National Park. At the other extreme, mean fire intervals on unproductive sites such as the high-elevation rhyolite plateaus in Yellowstone National Park are 300 to 400 years (Millspaugh and Whitlock 1995; Romme 1982). The majority of studies in this type has found mean fire intervals between 100 and 250 years (Agee 1993; S. W. Barrett 1994; Hawks 1980; Kilgore 1987).

Fuels

Unlike understory and mixed fire regimes, fuels play a critical role in limiting the spread of fire in stand-replacement fire regimes. Accumulation of duff and down woody fuels increases the persistence of burning. This is important for keeping fire smoldering on a site until a wind event occurs (Brown and See 1981). Typically a certain level of fuel is required to allow fire to spread. This may be the result of dead and down fuels—from insect epidemics, windstorms, or a previous fire—or of extensive ladder fuels (fig. 5-8). In contrast, stands with few down or ladder fuels often fail to support fire (Brown 1975; Despain 1990). In lodgepole pine, dead and down woody fuel loadings of 15 to 20 tons/acre (34 to 45 t/ha) are generally near the lower threshold of what will support a stand-replacement through moderate-intensity surface fire (Fischer 1981). Ladder fuels and heavier loadings of down and dead woody fuels contribute to torching, and with winds a running crown fire may evolve.

In cover types supporting large trees such as Douglas-fir/hemlock and western white pine, large woody fuel loadings typically are 40 to 50 tons/acre (90 to 110 t/ha) and duff about 30 tons/acre (67 t/ha) (Keane and others 1997). In smaller tree cover types such as lodgepole pine and spruce/fir, large woody fuels typically are 15 to 20 tons/acre and duff about 15 to 30 tons/acre. However, the range in loadings may be considerably greater as reported for Kananaskis Provincial Park, Alberta (Hawkes 1979), where downed woody fuels ranged from 4 to 63 tons/acre (9 to 141 t/ha) and duff from 8 to 58 tons/acre (18 to 130 t/ha).

Figure 5-8—Downfall of mountain pine beetle killed lodgepole pine results in an accumulation of large downed woody fuels that increases the likelihood of stand-replacement fire.

Postfire Plant Communities

Coast Douglas-fir

Pre-1900 Succession—These humid maritime forests are extensive at lower and middle elevations west of the Cascades and British Columbia Coast Range. The cooler, wetter, and more northerly portions of the coastal Douglas-fir type (generally associated with the mountains of western Washington and southwestern British Columbia) burned in stand-replacement fires at long intervals, averaging 200 to several hundred years (Agee 1993). The range of pre-1900 fire intervals on a given site is unknown because in most cases only the most recent interval can be calculated due to decay of the previous stand. Long and others (1998) described fire intervals over the last 9,000 years, and Impara (1997) reports on the spatial patterns of historical fires in the Oregon Coast Range.

Western hemlock is the potential climax dominant tree in most of this type, but seral Douglas-fir, which arose after replacement fires during the last several hundred years, is the actual dominant. The greater size and longevity of Douglas-fir allows it to persist in considerable quantities for 700 to 1,000 years between major stand-opening disturbances such as fire or severe blowdowns (Agee 1993). Scattered individual Douglas-fir survived fires and served as seed sources in the burn. Seeds of this species may also survive and mature in the crowns of some trees whose foliage was killed (but not consumed) by a late-summer fire. The seeds are also wind-dispersed from unburned stands. Douglas-fir seedlings grow readily on burned seedbeds and outcompete other conifers in the postburn environment.

Often red alder becomes abundant and temporarily outgrows Douglas-fir in a recent burn. However, the fir grows up beneath and displaces alder within a few decades, benefitting from soil nitrogen fixed by symbiotic organisms associated with alder roots. Numerous other seral conifers (western white pine, shore pine, grand fir, and Sitka spruce) and hardwood species (bigleaf maple, mountain ash, cascara, and others), as well as seral shrubs (salmonberry, huckleberries) and herbaceous plants, appear in the postburn environment, greatly enriching the biological diversity of these forests (Fonda and Bliss 1969; Franklin and Dyrness 1973; Hemstrom and Franklin 1982; Huff 1984; Yamaguchi 1986).

Post-1900 Succession—Due to the great length of natural fire intervals it would seem unlikely that significant successional changes have occurred in most of these forests as a result of attempts to exclude fire during this century. Large areas of these forests have been clearcut in recent decades, sometimes followed by broadcast burning. This has given rise to large areas of early seral communities dominated by native flora, often with planted Douglas-fir, which might offset a shortage of early seral communities resulting from natural fires. However, natural burns and clearcuts differ ecologically, for example, in seedbed preparation, in providing residual large woody debris, and in having an overstory of dead trees (Kauffman 1990). Hansen and others (1991) point out that young communities arising after fires are rich in structural complexity and in species composition, but are the rarest successional state, much rarer in today's landscapes than is old growth. Although millions of acres have been set aside as reserves for old growth Douglas-fir, there are no measures for perpetuating these communities through the use of prescribed fire, and if present fire suppression policies succeed, young postfire communities will continue to be rare.

Management Considerations—Until the 1990s these forests were usually managed by clearcutting, site preparation, and growing even-aged stands at rotations (50 to 100 years) much shorter than those of presettlement fire intervals. This management approach failed to consider perpetuation of many ecological functions in these forests (Kauffman 1990). The need to develop more ecologically-based management strategies gave rise to concepts of "new forestry" treatments (Franklin and others 1986; Gillis 1990; Hopwood 1991). Most of these leave patches of overstory and understory trees after harvesting to increase structural diversity of the new stand and the "biological legacies" of large woody debris. In this structural respect, these treated stands are simulating the early seral community following a natural fire. However, many of the proposed treatments avoid actually utilizing fire due to a desire to limit smoke, increase woody residues on the site, avoid the operational difficulties in burning, and reduce treatment costs (Means and others 1996). Douglas-fir can be regenerated in heavily logged areas without burning. It is apparently assumed that the other effects of fire are expendable, for example, in soil nutrition and maintenance of diverse fire-dependent undergrowth species (Agee 1993; Kauffman 1990). However, there is little scientific basis for such an assumption. A more rigorous evaluation of the consequences of various management alternatives, including use and avoidance of burning, is needed for this ecological type.

Coastal True Fir-Mountain Hemlock

Pre-1900 Succession—These high-elevation maritime forests are found along and west of the crest of the Cascades (north of Crater Lake, Oregon) and the British Columbia Coast Range. Principal tree species are Pacific silver fir, mountain hemlock, western hemlock, and noble fir. This type is a cooler and wetter environment than the coastal Douglas-fir type that borders it at lower elevations and on warmer aspects. Annual precipitation is commonly >100 inches and a deep snowpack accumulates in winter and persists into early summer.

The principal tree species are fire-sensitive and seldom survive surface fires. Thus, fires were typically of the stand-replacement type, although scattered Douglas-fir found in this type often survived. Fire return intervals were evidently between about 125 and 600 years (Agee 1993). Shorter intervals (<200 years) were associated with drier environments where the type is confined to north-facing slopes and is surrounded by drier types. Fires in this type usually occur under conditions of severe summer drought accompanied by strong east (foehn) winds. Major blowdowns also initiate regeneration cycles and can contribute large amounts of fuels in this type.

Postfire stands often go through a shrub-dominated stage—commonly including early seral communities of mountain huckleberry (Agee 1993; Franklin and Dyrness 1973). A variety of early seral conifers becomes established in burns (noble fir, Douglas-fir, subalpine fir, Alaska-cedar, lodgepole pine, and western white pine). Eventually the shade-tolerant Pacific silver fir, mountain hemlock, and western hemlock become dominant.

Post-1900 Succession—The long intervals between stand-replacement fires and the remote location of much of this forest type suggest that fire suppression would have had a minor effect upon it, but no detailed evaluation of this question has been made.

Management Considerations—Few fire management programs that plan for wildland fire use exist in the National Parks and wilderness areas in this forest type. Where fires occurred in the past, they often resulted in shrubfield/open conifer stands. These persistent open, "old burn" communities have been an important component of wildlife habitat and natural diversity. Use of prescribed fire is limited in this type because fire generally burns only under extreme weather conditions. Because the principal tree species are readily killed by fire, any burning in standing trees increases loadings of dead and down fuels. Mechanical fuel manipulation (tree harvesting or removal of dead woody fuel) is necessary for creating fuel reduction zones to contain wildfires (Agee 1993).

Interior True Fir–Douglas-fir–Western Larch

Pre-1900 Succession—This is a diverse group of forests that have a stand-replacement fire regime and are dispersed throughout much of the Interior West, usually at middle elevations in the mountains. Principal tree species are white fir and grand fir (potential climax), interior Douglas-fir (seral or climax), and larch, lodgepole pine, and aspen (early seral associates). These forests commonly develop dense stands with accumulations of ladder fuels and they often occupy steep slopes on cool aspects. The forest floor fuels are primarily a compact duff layer that does not support low intensity surface fires. However, when down woody or ladder fuels accumulate and severe burning conditions arise, they can support a stand-replacing surface or crown fire. Such fires occurred at intervals averaging between 70 and 200 years. Similar compositional types in other geographic areas or on different topographic situations are associated with mixed fire regimes. The relative amounts of these types in mixed and stand-replacement fire regimes is unknown (Brown and others 1994). Also, the factors that determine whether one of these forests will have a mixed or stand-replacement regime is not known, but lack of receptiveness of surface fuels to burning, characteristically dense stands, steep slopes, and frequent strong winds probably favor the stand-replacement fire regime. For example, one area in the stand-replacement regime is on the eastern slope of the Continental Divide in Montana where dense Douglas-fir stands develop in an environment featuring severe winds (Gruell 1983).

Relatively frequent stand-replacement fires kept much of the landscape in open areas (seral grasslands or shrublands) and favored seral shrub species (such as serviceberry, willow, and bitterbrush) and aspen. Such plant communities are important forage for wildlife.

Post-1900 Succession—Photocomparison and fire history studies suggest that fire exclusion has allowed a greater proportion of these inland forests on the landscape to develop as dense stands. The spatial continuity of these stands may allow insect and disease epidemics and stand-replacement fires to become larger than in the past (Arno and Brown 1991; Byler and Zimmer-Grove 1991; Gruell 1983) (fig. 5-1). At the same time seral grassland species, shrubs, aspen, and seral conifers are being replaced by thickets of shade-tolerant conifers.

Management Considerations—This major forest cover type is divided into mixed and stand-replacement fire regimes, but the environmental characteristics linked to each fire regime type are poorly known. Knowledge of these characteristics would help land managers determine where stand-replacement fire is probable, which might help in setting priorities for management of fuels to confine potentially severe wildland fires. It should be possible to reduce frequency and extent of stand-replacement fires using a variety of fuel-reduction treatments. Prescribed fire in activity fuels (slash) can be useful in fuels reduction and in obtaining other desirable fire effects such as stimulation of wildlife forage. It may be possible to use fire for fuels reduction and habitat improvement for ungulates by felling a few trees per acre to create enough fine slash fuels to allow a prescribed fire to move through the stand. This is promising in Douglas-fir stands because of this species resistance to low intensity fire.

Rocky Mountain Lodgepole Pine

Pre-1900 Succession—This is a major type at middle to high elevations in the more continental mountain climatic areas of the Inland West, from the Yukon Territory, Canada, to southern Colorado. In parts of this geographic distribution, lodgepole pine forests burned in a mixed fire regime, primarily where fine surface fuels and dry climate allowed lower intensity fires to occur. Much of the lodgepole pine type, however, is resistant to burning except when there is an accumulation of down woody, ladder, and crown fuels. When fuel loadings are sufficient to support fire, it becomes a stand-replacing surface or crown fire.

Brown (1975) illustrated how fuel loadings are indirectly linked to stand age (fig. 5-9). Young dense stands containing ladder fuels of associated spruce and fir and accumulated downfall from a former, beetle-killed or fire-killed overstory have high potential to support a stand-replacement fire. Conversely, young pole-size stands of pure lodgepole pine (with sparse lower limbs) arising after a burn that removed most large fuels, have low potential to support fire. When a lodgepole pine stand becomes mature or overmature, tree growth and vigor declines markedly, and likelihood of a mountain pine beetle epidemic increases. Such epidemics kill many trees that begin falling in a few years, and within 10 to 15 years large amounts of dead woody fuels accumulate that greatly adds to the potential of stand-replacement fire. Dwarf mistletoe also builds up with stand age and adds highly flammable witches-brooms to the tree crowns. Stand-replacement fire destroys the dwarf mistletoe, except in surviving patches, and removes potential for mountain pine beetle until a mature stand has again developed.

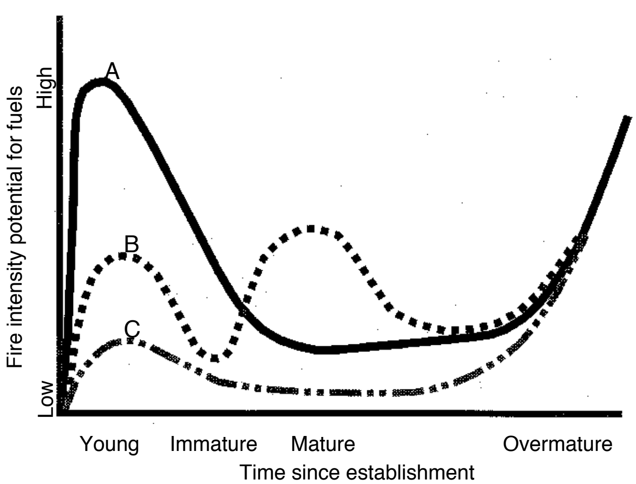

Figure 5-9—Fuel cycles and fire intensity potential in a lodgepole pine stand-replacement fire regime (Brown 1975).

Post-1900 Succession—Some studies indicate that attempts to exclude fire have had relatively little effect in this fire regime (Barrett and others 1991; Johnson and others 1990; Kilgore 1987). Certainly numerous fires have been successfully suppressed while quite small or while they were in adjacent, different fire regime types; but this is presumably offset by additional ignitions from large numbers of human-caused fires. The possibility exists that suppression could have appreciable effects in some geographic areas, especially where units of this type are small, isolated, and surrounded by other kinds of forest or vegetation where fires have been largely excluded. In the southern Canadian Rockies a decline in fire frequency in largely stand-replacement fire regime types was attributed at least partially to prevention and suppression of human-caused fires (Achuff and others 1996). However, in some geographic areas, the proportion of area burned by lethal seveity has increased (fig. 5-1).

Management Considerations—As illustrated by the political uproar regarding the Yellowstone Area fires of 1988, this forest type represents a challenge for fire management (Christensen and others 1989; Wakimoto 1989). Ecologists, land managers, and many environmental activists recognize the importance and inevitability of large stand-replacement fires. In contrast, such fires are often viewed as an unnecessary inconvenience or as a disaster by those who are unaware of the natural role of wildland fire.

Fires are critical to maintenance of biological diversity in this type. Many early seral species, including herbs, shrubs, and aspen, depend on occasional fires to remain as components of the lodgepole pine type (Habeck and Mutch 1973; Kay 1993). Black-backed Woodpeckers, many invertebrates, herbivores, small mammals, birds, and even some aquatic organisms depend upon fires for creation of seral communities, snag patches, and beneficial nutrient cycling (Agee 1993; Despain 1990).

Stand-replacement fire regimes in lodgepole pine forests can be influenced by management actions. For example, fuel breaks can be developed near critical property boundaries and to protect resorts and other facilities (Anderson and Brown 1988; Kalabokidis and Omi 1998; Schmidt and Wakimoto 1988). Wildland fire use programs coupled with prescribed stand-replacement fires could help develop landscape fuel mosaics that limit the ultimate size of wildfires (Weber and Taylor 1992; Zimmerman and others 1990).

Clearcutting and broadcast burning have long been a common timber management treatment in this type. If fine fuel consumption is complete, most of the seed source in the slash will be destroyed. Seeds from open-coned pines at the edge of units are often wind-distributed about 200 feet into clearcuts in sufficient quantities for forest regeneration (Lotan and Critchfield 1990). Leaving some cone-bearing trees standing throughout the burn can provide seed source as well as light shade and snags for wildlife. In salvage logging of fire-killed stands, it is important to leave ample dead trees for a variety of wildlife species.

There is increasing interest in planning for patches of trees to survive broadcast burning, to provide structural diversity in the post-treatment community (Arno and Harrington 1998; Hardy and others 2000). Underburning in a lodgepole pine shelterwood cut, although difficult, may be possible if slash fuels are light and moved away from the base of leave trees.

Western White Pine-Cedar-Hemlock

Pre-1900 Succession—This forest type is centered in northern Idaho and the interior wet zone of southeastern British Columbia (Krajina 1965; Shiplett and Neuenschwander 1994). It also extends into northeastern Washington and northwestern Montana. It occupies a "climatic peninsula" (Daubenmire 1969) or inland extension of Pacific maritime climate between about 46 and 53 °N latitude. This is the only area of the Rocky Mountain system where western white pine, western redcedar, western hemlock, and numerous other maritime associates (trees and undergrowth) are found. In this area the inland maritime species form the dominant vegetation mixed with Inland Rocky Mountain species such as ponderosa pine, interior Douglas-fir, Engelmann spruce, western larch, and whitebark pine.

Traditionally this type has been considered to mainly represent a stand-replacement fire regime, but detailed fire history studies are few (Smith and Fischer 1997). The most characteristic, large, and influential fires were stand-replacing, and because of scarcity of information, the type is discussed only in this section. Nevertheless two recent studies (Barrett 1993; Zack and Morgan 1994) as well as earlier observations (Arno 1980; Arno and Davis 1980; Marshall 1928) indicate that substantial areas of the type were also exposed to a mixed fire regime. Evidence of underburning is often found in valley bottoms, on gentle slopes on dry aspects, and on ridgetops. Surviving trees were primarily western white pine, western larch, and large western redcedars. Underburns may have been important locally in perpetuating a dominance by large trees of these species. Conditions associated with underburning have not been described, but underburning has occurred in recent wildland fires in these forests (Brown and others 1994).

The stand-replacement fires characteristic of the western white pine-cedar-hemlock type occurred at intervals of 130 to 300 years associated with severe drought, which commonly occurred for a short period during mid- or late-summer. Because of the productive growing conditions, ladder fuels can develop rapidly in young stands. Moreover, large woody fuels are created in abundance by fires and by insect and disease epidemics. Two or three decades after a stand-replacement fire, most of the dead trees have fallen and become heavy down fuels. This, coupled with a dense stand of small trees and tall shrubs, may constitute a fuelbed that allows severe burning in a second fire, known as a "double burn" (Wellner 1970). When fire occurs under conditions of extreme drought accompanied by strong winds, stand-replacement fires are likely in many natural fuel configurations. If large accumulations of down woody fuel (>25 tons/acre) are present, stand-replacement fires can occur under extreme drought without strong winds or steep slopes (Fischer 1981).

Past stand-replacement fires allowed seral fire-dependent species to dominate most pre-1900 stands. The major early seral tree dominants were western white pine, western larch, and lodgepole pine, but were accompanied by lesser amounts of interior Douglas-fir, grand fir, Engelmann spruce, paper birch, and ponderosa pine. Including the everpresent western redcedar and western hemlock, these disturbance communities were diverse. Luxuriant seral shrub and herbaceous plant growth added to this diversity, as described by Larsen (1929), Daubenmire and Daubenmire (1968), and Cooper and others (1991). Occasional fires allowed a variety of seral shrubs to thrive, including redstem and evergreen ceanothus, currants, red elderberry, Scouler willow, serviceberry, mountain maple, American mountain-ash, bittercherry, and chokecherry. After a double burn, shrubfields would persist for decades (Barrett 1982; Wellner 1970). Shiplett and Neuenschwander (1994) classify five common successional scenarios in these forests. These are (1) a relatively rapid succession to the redcedar-hemlock climax, (2) a prolonged domination by a mix of seral tree species as a result of disturbances, (3) a shrubfield resulting from multiple burns, (4) a sere influenced by scattered larch relicts that survived fires, and (5) lodgepole pine dominance throughout fire cycles on less productive sites with relatively frequent burns.

Post-1900 Succession and Management Considerations—Clearcut logging has to a considerable extent replaced fire as the principal stand-replacing disturbance in this forest type. Often the logging is followed by broadcast burning or dozer scarification and piling of large woody residues, which are then burned. Like stand-replacement fire, clearcutting favors establishment of early seral tree species. Unlike fire, clearcutting does not leave a snag forest to moderate the microclimate and provide large quantities of woody debris and future fuels. Recently, environmental concerns have been raised about cumulative impacts of road building and logging, including soil disturbance, erosion, loss of water quality, aesthetic impacts, loss of wildlife habitat, and smoke production from prescribed fire. These concerns have encouraged substitution of partial cutting or of no cutting at all accompanied by fire suppression. These approaches contrast strongly with natural fire in their effects on vegetation and may result in epidemic forest mortality resulting from root diseases and bark beetles (Byler and Zimmer-Grove 1991).

A high percentage of western white pine has been killed in the last 50 years as a result of white pine blister rust, an introduced disease. White pine has a low level of natural rust resistance, and resistant genotypes are available for use in reforestation. However, this species requires fire or logging with site preparation to make sites available for regeneration and successful establishment.

Relatively rapid change is characteristic of the vegetation in this highly productive forest type. In the past, fire was the principal agent initiating new cycles of change. Heavy logging and site preparation was to a limited extent a replacement for fire, but had some undesirable impacts. In revising management to reduce those impacts it is important to consider strategies and treatments that provide the beneficial effects associated with fire in these ecosystems (Smith and Fischer 1997).

Spruce-Fir-Whitebark Pine

Pre-1900 Succession—This type makes up the highest elevations of forest growth in the Rocky Mountains and other interior ranges of Western North America from central British Columbia to central Oregon and western Wyoming. Southward in the Rocky Mountains to New Mexico, beyond the range of whitebark pine, the ecologically similar limber pine is often associated with the spruce and fir. In northern British Columbia, the high-elevation spruce-fir forest merges with the white spruce and black spruce boreal types discussed in chapter 3.

In drier regions of the Interior West and locally on drier topographic sites is a mixed severity fire regime characterized by an abundance of whitebark pine (see the section “Mixed Fire Regimes” in this chapter). In contrast, the spruce-fir-whitebark pine type has variable amounts of whitebark pine or none at all, but is characterized by stand-replacement fires generally at intervals of 100 to 400 years. For example, in the most detailed study of this type so far, in the Bob Marshall Wilderness Complex in Montana, Keane and others (1994) found mainly stand-replacement fires at intervals of 54 to 400+ years in 110 sample stands distributed across a 1.5-million-acre (607,000 ha) area. In the Southern Rocky Mountains, spruce is often the dominant subalpine forest cover and other major disturbances—spruce beetle epidemics, extensive snow avalanches, and areas of wind-thrown forest—interact with stand-replacement fires in complex temporal and spatial patterns (Baker and Veblen 1990; Veblen and others 1994). In the wettest spruce-fir microsites, such as naturally subirrigated basins, fire occurs rarely and is not the prevalent factor controlling successional cycles that it is in most of Western North America.

Pre-1900 fires added structural and compositional diversity to the spruce-fir-whitebark pine forest. Burned areas often remained unforested for extended periods due to the harsh microclimate (Arno and Hammerly 1984). In extreme cases regenerating conifers take on a shrublike (krummholz) form for 50 years or longer. Often whitebark pine is able to become established first in a high-elevation burn due to its superior climatic hardiness and its advantage of having seeds planted in small caches by the Clark’s Nutcracker (Arno and Hoff 1990).

Post-1900 Succession—Little is known about possible human-induced changes in successional patterns throughout this high-elevation type. Logging has occurred in some sizeable areas of the type and has to a limited extent been a substitute for stand-replacement fire. In other areas fire suppression may have effectively reduced the landscape component made up of young postfire communities. For example, Gruell (1980) published many photographs taken at subalpine sites in northwestern Wyoming in the late 1800s and early 1900s and compared them with modern retakes. Most of these comparisons show that mature forest is noticeably more extensive today. Presumably the slow postfire recovery period resulted in large areas being unforested at any given time.

Whitebark pine has suffered a major setback since the early 1900s due to heavy mortality from mountain pine beetle and blister rust (Keane and Arno 1993). The introduced blister rust particularly reduces the amount of whitebark pine seed source available for regeneration. In some areas large outbreaks of spruce bark beetle and root rot in subalpine fir have also resulted in heavy loadings of large woody fuels, which will support future stand-replacement fires (Veblen and others 1994).

Management Considerations—In smaller wilderness areas and parks it is hard to plan for stand-replacement fires from lightning ignitions due to the problem of confining fires within area boundaries. Data presented by Brown and others (1994) suggest that maintaining natural fire cycles in these high-elevation forests is difficult because the forests only burn when fire danger elsewhere is unacceptably high as a result of extreme drought. Traditional timber harvesting coupled with broadcast burning is now less likely to occur because of environmental concerns about road building, watershed impacts, and obtaining prompt tree regeneration. Concerns regarding fire management options are generally similar to those expressed in high-elevation lodgepole pine types. In some cases prescribed fires might be used to maintain natural fire cycles. Cutting to provide slash fuels could allow prescribed burning to be done when wildfire hazard is moderately low.

Aspen

For discussions about aspen, see chapter 3, "Fire in Northern Ecosystems."

Regimes Where Fire is Rare

In some forest types, which collectively cover only a small fraction of the forested land in Western North America, fire is so unusual or exceptionally infrequent that it exerts little selective influence on vegetation development. Certain stands and topographic situations within the subalpine spruce-fir type seldom burn and their successional cycles are initiated primarily by beetle epidemics or windthrow. In British Columbia, Hawkes (1997) reported fire cycles of 800 to 2,000 years on cool wet sites occupied by the spruce-fir type. The only major forest type of Western North America where fire is not a primary disturbance agent is Sitka spruce-western hemlock. This type is generally confined to the wettest lowland sites along the immediate Pacific Ocean coastal strip and in alluvial bottoms of coastal valleys from southern Oregon to southern British Columbia. Northward, in central British Columbia and southeastern and south-central Alaska, it expands to cover most of the narrow, low elevation coastal forest zone (Arno and Hammerly 1984). Fires of appreciable extent are unusual in this type due to the prevalence of moist conditions year-round (Agee 1993). Windfall is a more prevalent disturbance creating new stands. On the Alaskan coast most fires are human-caused and occur during rare droughts (Noste 1969). Lightning fires are rare; nevertheless, the historic role of fire is not fully resolved. For example, Harris and Farr (1974) report four episodes of extensive fires in southeastern Alaska between about 1660 and 1830.