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CHAPTER 6

PREHISTORIC BURNING IN THE PACIFIC NORTHWEST: HUMAN VERSUS CLIMATIC INFLUENCES

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When Europeans first arrived in the Pacific Northwest, the region was occupied by several indigenous cultural groups that were adapted in diverse ways to a wide range of environments. The archaeological record indicates that these lifeways developed early in the Holocene in response to the environmental complexity of the region, and that prehistoric activities were probably not substantially different from those at the time of European contact (Aikens 1993). Throughout the Holocene (the last 11,000 years), changes in environment that occurred seasonally, annually, and on longer time scales affected the availability and utilization of resources, including the plants and animals that existed in the region, and these resources, in turn, influenced human land-use patterns. But what of the reverse? To what extent did early peoples change the environment, not only through their possible role in faunal extinctions (sensu Martin 1984), but also through their alteration of the vegetation and significant ecological processes? Was the vegetation encountered by Euro-Americans a reflection of conditions determined by climate and natural disturbance alone or was it highly modified by humans? Denevan (1992) and others (Pyne 1982, 2000; Chase 1987; Butzer 1990; Cronon 1995; Flores 1997; Williams 2000) argue that North America was widely disturbed by human activity prior to the time of Euro-American exploration. In their view, a desire for wilderness preservation has led to denial of this human imprint and a false belief that landscapes at the time of European contact were pristine (Denevan 1992). Others maintain that much of North America, especially in the western United States, was not significantly altered by prehistoric peoples, and the vegetation at the time of European contact was more natural than humanized (Vale, chapter 1 of this volume). In this chapter, we consider the evidence of human alteration in the Pacific Northwest, where paleoecological, archeological, and historical data are available to describe the relations between humans and their environment.

The Pacific Northwest was apparently fairly populated at the time of Spanish exploration in the 1770s, and estimates of population size along the Northwest coast from southeastern Alaska to northern California vary from 200,000 (Boyd 1990) to 102,000 (minimum estimate of Ubelaker 1988). Regardless of the exact number, population centers were largest along the coast and western valleys, with about 35,000–40,000 people on the Pacific slope of Oregon and Washington and about 16,000 in the Willamette Valley (Boyd 1990). Populations east of the Cascade Range were smaller because resources were scarce and geographically isolated. Interior basins of the Pacific Northwest may have supported up to several hundred people in large salmon-fishing encampments, but less than a few dozen people in individual remote settlements (Aikens 1993).

Native Americans prior to European contact undoubtedly disturbed vegetation in the vicinity of permanent settlements and seasonal encampments, and fishing, hunting, and gathering activities inevitably had some ecological impact as well. The issue of most intense debate with respect to the "pristine myth," however, is the scale of environmental alteration caused by human use of fire. Did anthropogenic burning occur to the extent that it created new vegetation types? For example, were low-elevation savanna and woodland created by deliberate burning practices or were they a consequence of climate, soils, and natural (i.e., nonanthropogenic) disturbances? To address these questions requires information on the activities of Native Americans, and a means of separating the impact of human-set fires on prehistoric vegetation from that caused by a natural disturbance regime.

Today, lightning fires in the Pacific Northwest start in summer and early fall during convectional storms associated with interior high-pressure cells. Because of strong easterlies, fires often spread from east to west (Agee 1993). For example, the large Tillamook Fire of 1933, which burned large tracts of the Coast Range, was started in the western edge of the Willamette Valley and moved westward into the Coast Range (Oregon Department of Forestry 1970). The highest number of light-

TABLE 6.1. Fire return intervals for the Pacific Northwest based on dendrochronological methods for the last few centuries (from Agee 1993 and references therein).

	Oregon			*Washington*		
Forest Type	*Area in type (1,000 ha)*	*Fire cycle (yr)*	*Area burned per year (1,000 ha)*	*Area in type (1,000 ha)*	*Fire cycle (yr)*	*Area burned per year (1,000 ha)*
Cedar/spruce/hemlock	292	400	0.7	1,291	937	1.4
Douglas fir	4,444	150	29.6	3,068	217	14.1
Mixed conifer	399	30	13.3	504	50	10.1
Lodgepole pine	757	80	9.4	211	110	1.9
Woodland	1,001	25	40.0	12	25	0.5
Subalpine	1,075	800	1.2	935	500	1.9
Ponderosa pine	3,142	15	209.4	1,438	15	95.8
Other	2,397	133	18.0	1,949	298	6.5

ning strikes today occurs at middle and high elevations in the Cascade Range, in the mountains of eastern Oregon and Washington, and the Klamath region, but, in Oregon, strikes are recorded in all counties (Oregon Department of Forestry 1997).

Modern estimates of fire return intervals for Oregon and Washington are based on forest-cover types and definitions drawn from the first regional forest surveys of the region. On average, Oregon has more dry forests, which burn more frequently than those in Washington, where it is cooler and moister (Agee 1993). The mean fire frequency, based on tree-ring and documentary evidence, varies considerably among forest types (Table 6.1). Ponderosa pine forests burn almost every decade, and the fires are generally of low severity, while subalpine and coastal forests may burn once in a millennium, and the fires tend to be stand-replacing events.

Information on prehistoric vegetation comes from pollen and plant macrofossil records collected from lakes and natural wetlands and from plant assemblages preserved in packrat (*Neotoma*) middens. A network of paleovegetation sites (Figure 6.1) is available from the Pacific Northwest, and, despite some gaps in coverage, the climate and vegetation history of the region is fairly well known for the last 20,000 years (see reviews by Heusser 1977, 1983; Baker 1983; Mehringer 1985; Barnosky et al. 1987; Whitlock 1992; Thompson et al. 1993). The chronology for paleoecological records comes from radiocarbon dating of organic sediment or individual plant remains. Because radiocarbon years depart from

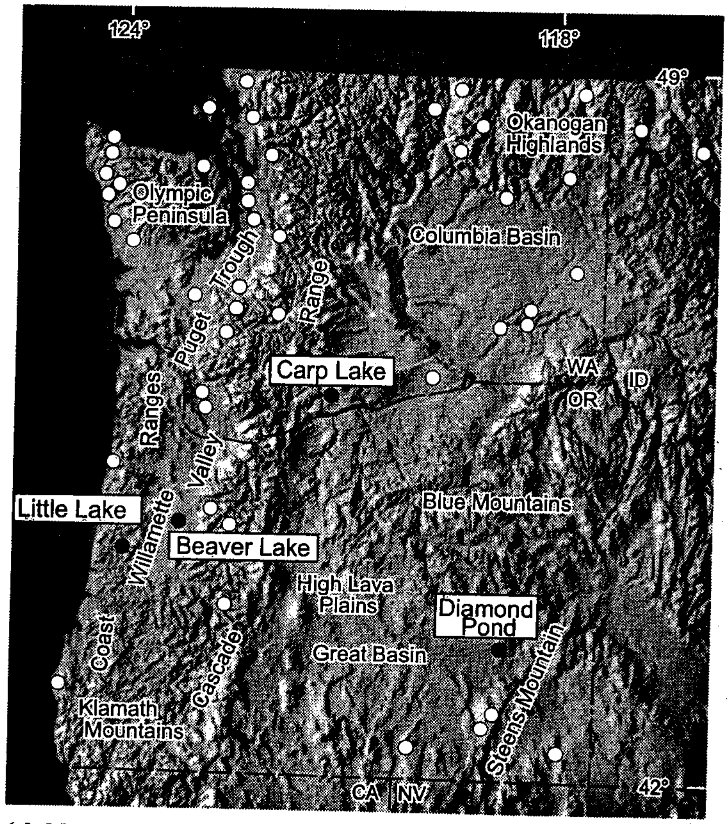

Figure 6.1. Map of geographic regions referred to in text. Open circles show the location of radiocarbon-dated pollen records that have been published in the region. The black circles refer to the sites with high-resolution charcoal data.

calendar years in the early and middle Holocene, it is necessary to convert a radiocarbon-based chronology to calendar years using calibration tables (Stuiver and Reimer 1993; Stuiver et al. 1998). All ages presented in this chapter as "years ago" are radiocarbon dates converted to calendar years.

Two types of records provide prehistoric fire reconstructions: dendrochronological data and lake-sediment data. Dendrochronological records are based on fire-scarred tree-rings as well as the age of forest stands that colonize areas of high-severity fires. Tree rings preserve the scars of low-severity ground fires that do not kill the trees, and from these data it is possible to know exactly where and in what year such fires occurred. Stand-age analysis is used to map the size and age of stand-replacement fires, particularly in boreal and montane forests, where infrequent large fires of high severity characterize the fire regime. Successively younger fires, however, erase the evidence of older fires in stand-age analysis, and, as with fire-scar methods, the reconstruction period is as old as the oldest living trees. Few dendrochronological studies extend beyond the last 500 years, and, in the Pacific Northwest, the longest reliable chronologies span the last 600 years (Agee 1993).

Fire history on longer time scales is obtained from fire proxy preserved in lake-sediment records (see Whitlock and Larsen, in press, for discussion of methods). Particles of charcoal, introduced to a lake during and shortly after a fire, provide information on past fires. Recent refinements have been made in the study of past fires based on charcoal records from laminated and nonlaminated lake sediments (Patterson et al. 1987; Clark 1990; Millspaugh and Whitlock 1995; Clark and Royal 1996; Long et al. 1998). By selecting a site carefully, constraining the size of the charcoal particles examined, and discriminating between the local and extralocal components of the charcoal record, it is possible to reconstruct variations in local fire frequency with fair confidence. The interpretation of the charcoal data is based on calibration studies following recent and historic fires (Whitlock and Millspaugh 1996; Clark et al. 1998; Ohlson and Tryterud 2000; Gardner and Whitlock, in review). Charcoal particles more than 100 microns in size are tallied in contiguous 1-cm-long core intervals, and layers with abundant charcoal (charcoal peaks) are assumed to represent a fire "event." An event is defined as one or more fires occurring during the deposition of that core interval. Depending on the sedimentation rate, a fire event can be dated with decadal precision, although sometimes the peak spans a few centimeters of the core and thus is the equivalent of a few decades of sediment deposition. High-resolution charcoal analysis is time-consuming, and only a few such records are currently available from the Pacific Northwest (Long et al. 1998; Pearl 1999; Mohr et al. 2000). Less detailed charcoal records have been described from the Puget Trough (Sugita and Tsukada 1982; Cwynar 1987) and Cascade Range (Dunwiddie 1986).

Climate and Vegetation Changes Since the Last Ice Age

In the last 20,000 years, the Earth system has undergone a shift from glacial conditions to the present interglacial period, the Holocene (the last 11,000 years). These climatic changes profoundly affected ecosystems as species adjusted their ranges and abundance. Fire regimes were also altered, and it is likely that fire was the proximal cause of many of the vegetation changes. The end of the glacial period is also the time when humans spread across North America. The archeological record in the Pacific Northwest extends back about 11,000 years in the interior region (Aikens and Jenkins 1994) and 10,000 years along the coast (Suttles and Ames 1997).

Environmental changes occurring on millennial time scales were governed by large-scale changes in the climate system that affected western North America (Thompson et al. 1993). One control was the declining influence of North American ice sheets on the climate after 16,000 years ago. The presence of an ice sheet prior to that time steepened the latitudinal temperature gradient south of its margin and shifted the jet stream south of its present position. The Pacific Northwest, as a result, was relatively cold and dry in full-glacial time, and the American Southwest was more humid. As the ice sheets wasted, temperatures warmed, the jet stream shifted northward, and the climate of the Pacific Northwest became warmer and wetter.

Another important control of climate relates to changes in the seasonal cycle of insolation caused by slow variations in the timing of perihelion (when Earth is closest to the sun) and in the amount of tilt of Earth's axis (Kutzbach and Guetter 1986). Between about 14,000 and 7,000 years ago, perihelion was in July and the tilt of Earth's axis was greater than at present. As a result, summer insolation was 8.5 percent greater and 10 percent less in winter in the Pacific Northwest during the early Holocene (about 11,000–7,800 years ago). Greater-than-present insolation led directly to increased summer temperatures and drought. Indirectly, it gave rise to a strengthening of the eastern Pacific subtropical high in the Pacific Northwest, which further intensified summer drought. Paleoclimatic reconstructions suggest that annual precipitation west of the Cascade Range was 40–50 percent less than today and annual temperature was 1–3°C higher. In the Great Basin, increased insolation may have led to stronger-than-present monsoonal circulation and thus wetter summers in the early Holocene. In the middle Holocene (some 7,800–4,400 years ago), summer insolation was less than before and the effects of drought and monsoonal precipitation were attenuated. Summers became cooler and wetter across most of the Pacific Northwest, except in the Great Basin, where the climate became more arid (with the loss of summer precipitation). As the seasonal cycle of insolation approached modern values in the late Holocene (the last 4,400 years), the entire region became cooler than before and the modern climate regime was established.

Paleoecological records indicate that these large-scale climate changes were responsible for major reorganizations of vegetation in the last 20,000 years. The summary of the vegetation history that follows is based on Whitlock (1992, and references therein), as well as new pollen records from the Puget Trough (McLachlan and Brubaker 1995), Oregon Coast Range (Worona and Whitlock 1995; Grigg and Whitlock 1998), Cascade Range (Sea and Whitlock 1995), and Willamette Valley

(Pearl 1999). During the late-glacial period, when the Cordilleran ice sheet and alpine glaciers were receding, the climate was cooler and wetter than today, but warmer than during full-glacial time. In the northern Puget Trough and Olympic Peninsula, lodgepole pine (*Pinus contorta*) forest, rather than tundra, colonized newly deglaciated substrates, suggesting that the climate was relatively warm by 16,000 years ago. Lodgepole pine was joined by Sitka spruce (*Picea sitchensis*), Douglas fir (*Pseudotsuga menziesii*), and hemlock (*Tsuga*), forming a closed forest by 13,000 years ago. A mixture of high- and low-elevation taxa that has no modern counterpart appeared in the southern Puget Trough during the late-glacial period, replacing earlier subalpine parkland communities. As the climate warmed, montane species were forced to higher elevations, and Douglas fir, red alder (*Alnus rubra*), and oak (*Quercus*) prevailed in the lowlands. In the Oregon Coast Range, Douglas fir and red alder were present as early as 16,000 years ago, supplanting forests of mountain hemlock (*Tsuga mertensiana*) and spruce. The southwestern Columbia Basin supported steppe and areas of spruce parkland as a result of cool dry conditions in both full- and late-glacial time. Farther north in the Okanogan region, steppe or tundra with pine (presumably whitebark pine [*Pinus albicaulis*] and western white pine [*P. monticola*]), fir (*Abies*), and spruce were present.

During the early Holocene (some 11,000–7,800 years ago), drought- and disturbance-adapted species became widespread as a result of summers that were warmer and drier than present. Douglas fir, red alder, and bracken (*Pteridium aquilinum*) were abundant within coastal forests, and these taxa along with prairie species were more extensive in the Puget Trough and Willamette Valley. In the mountains, warmer summers shifted the position of upper treeline above its present position. East of the Cascade Range, cold steppe was replaced by temperate steppe, and the forest/steppe ecotone lay above and north of its present range. In the Great Basin, cool and moist conditions allowed for the expansion of sagebrush (*Artemisia*) and at higher elevations for increased pine and juniper (*Juniperus*) (Mehringer 1985).

In the middle and late Holocene (7,800 years ago to present), lower summer temperatures and greater effective moisture everywhere except in the Great Basin shifted the vegetation toward more mesophytic and fire-sensitive species. Forests became closed, and upper and lower treelines shifted to lower elevations. West of the Cascades, increased moisture in the middle Holocene allowed western red cedar (*Thuja plicata*), Oregon ash (*Fraxinus latifolia*), and big-leaf maple (*Acer macrophyllum*) to expand their ranges. Western hemlock (*Tsuga heterophylla*) and Sitka spruce became more abundant in coastal rain forests in the last 4,400 years. Prairies in the Puget Trough and Willamette Valley shrank in size, and oak and Douglas fir were less abundant than in the early Holocene.

Western hemlock and western red cedar also expanded in the Puget Trough. In the Cascade Range, upper treeline shifted downslope to its present elevation.

In eastern Washington, steppe communities were replaced by ponderosa pine parkland in the early and middle Holocene. This transition occurred quite early in the eastern Cascade Range (9,400 to 7,800 years ago) and somewhat later in the Okanogan region (after 4,400 years ago). In the last 4,000 years, low-elevation pine forests have been invaded by mesophytic conifers, including Douglas fir, fir, hemlock, and spruce, and along the Columbia Gorge by Oregon white oak. In the Great Basin, the driest period occurred between 7,000 and 6,200 years ago, when summer precipitation decreased but temperatures were higher than at present. Between 6,200 and 1,950 years ago, the climate was cool and wet, allowing for the expansion of juniper woodland at low elevations. Generally moist conditions have occurred during the last 1,950 years, with the exception of dry periods between 700 and 500 years ago (Wigand 1987).

This relation between past climate and vegetation in the Pacific Northwest provides a means of assessing the natural variations in fire occurrence on long time scales. West of the Cascade Range, where the climate is mesic, one would expect that periods of drier climate would have higher-than-present fire frequencies, and consequently more fire- and drought-adapted taxa in the vegetation. Regardless of the source of ignition—humans or lightning—a dry climate would promote fires by drying fuels. Conversely, when the climate was wet, the low availability of dry fuel would have reduced the possibility of fire spread no matter what the ignition opportunities. In arid regions east of the Cascade Range, the relation between climate and fire is more complex, because climate variability, in addition to particular climate conditions, would be a factor. Fires would have occurred soon after wet periods or during a short drought within an overall wet period, when grasses produced enough fine fuel to carry fire. Prolonged dry periods would have been relatively fire free, because of the lack of fuel productivity. Of course, the vegetation effects on fire go beyond fuel. For example, some forest ecosystems favor species that have adaptations for maintaining a particular fire regime, such as thick bark or serotinous cones. Anomalous fire regimes, not predicted or explained as a result of prevailing climate or vegetation conditions, would point to human agencies.

Fire, Climate, and Human Activity: Case Studies

The prairie and savanna of the Willamette Valley, the juniper woodland of the Great Basin, and the ponderosa pine forest of the eastern Cascades and Blue Mountains are regions where it has been proposed that indigenous peoples regularly set fires (see Boyd 1999b). Likewise, the changes in vegetation that have occurred in the twentieth century have been ascribed to the elimination of native burning practices and the attendant expansion of forest in the absence of fire. These assertions can be tested to some degree, because paleoecological data are available from these regions to reconstruct the climate, vegetation, and fire history. Archaeologic and ethnographic records and historical journals provide an understanding of indigenous cultures and the use of fire prior to and at the time of Euro-American settlement. However, these materials are often sketchy and subject to different interpretations.

The Willamette Valley of Western Oregon

Changes in the Willamette Valley since Euro-American settlement are widely attributed to the elimination of fire and changes in land use activity in the last 150 years. Comparison of the vegetation in the 1850s with that of the present indicates that the density of tree and shrub cover has increased, and 88 percent of prairie and savanna has been lost (from 688,604 ha to 83,476 ha; Hulse et al. 1998). The vegetation and fire regime at present contrasts greatly with the conditions that existed in the valley in prehistoric times and which were witnessed by early Euro-American visitors. At the time of European contact, the Willamette Valley was occupied by a series of small independent groups within the Kalapuya language group (Zenk 1990). The prehistoric record extends human activities back about 8,000 years (Beckham et al. 1981), and it is thought that prehistoric and historic economies were based on a diverse range of wild foods, including river fish, roots, and seeds, as well as deer (*Odocoileus* spp.), elk (*Cervus*), small mammals, and wildfowl. Societies were highly mobile, ranging seasonally to occupy riparian forest, savanna and woodland, and forest. People occupied open or simple structures in summer and permanent structures that housed several families in winter. Down river of the Willamette Falls, salmon (*Oncorhyncus* spp.) were a large component of the economy, but above the falls and beyond extensive salmon runs, camas was an important food source (Boyd 1986). Hunting sites in the Cascades and Coast Range, attributed to valley groups, attest to seasonal use of the forests (Aikens 1993).

Prehistoric Records of Burning

Information on prehistoric fires comes from dendrochronological records as well as pollen and charcoal records from the Willamette Valley and adjacent mountains. Many of the oldest trees in the Cascades and Coast Range were established following one or more large fires in the

1500s and early 1600s (Hemstrom and Franklin 1982; Morrison and Swanson 1990; Impara 1997; Weisberg 1998; Berkley 2000). Some fires occurred in the early 1800s, when Kalapuya populations were declining and before Euro-American settlement (Weisberg 1998; Morrison and Swanson 1990); therefore, natural ignitions seem to be the likely source. Data from the foothills of the Cascade Range and Coast Range suggest fires occurred along the valley margin in the middle and late 1700s prior to direct Euro-American influence (Berkley 2000). Fires are also widely registered in the middle and late 1800s and early 1900s, and these burns have been ascribed to logging, mining, and road-building activities of early settlers (Burke 1979; Teensma 1987; Impara 1997; Berkley 2000). Some of the nineteenth-century fires were surprisingly large: the Silverton fire in 1865 affected 400,000 ha in the Cascades and Willamette Valley, and the Yaquina fire of 1853 burned 119,800 ha in the Coast Range. The Tillamook fire of 1933 covered 97,200 ha in the Willamette Valley and Coast Range (Loy et al. 1976). Impara (1997) estimates that 50–70 percent of the old-growth forest of the Coast Range was decimated by Euro-American burning. Settlement activities also led to localized increases in fire frequencies in the mixed-conifer forests of the southern Cascades (Taylor 1993), Klamath Mountain region (Agee 1991), and Sierra Nevada (Skinner and Chang 1996). Fire occurrence has decreased in all these regions during the last 80 years as suppression efforts have become more effective.

A charcoal record of prehistoric fire activity from Little Lake in the Coast Range indicates that the mean fire return interval was 110 years in the early Holocene, when Douglas fir, red alder, and oak were present (Long et al. 1998). By late Holocene time, the mean fire interval had lengthened to 230 years, and fire-sensitive species like Sitka spruce and western hemlock were more common in the forest (Figure 6.2). These long-term trends in fire occurrence in the Coast Range agree with data from the Puget Trough and suggest a widespread response to Holocene climate changes.

Beaver Lake, located in an abandoned meander of the Willamette Valley, is another site where high-resolution charcoal analysis has been undertaken (Pearl 1999). Land surveys in the 1850s show that the lake was surrounded by willow and ash thicket, topographic depressions near the lake supported riparian forest and wet meadows, and nearby upland vegetation was covered by woodland and savanna. The pollen data suggest that wet forest and meadows first appeared ca. 7,000 years ago as a response to cooling and increased moisture. Charcoal levels at Beaver Lake were low until some 4,100 years ago, when they increased dramatically. The interval of highest charcoal occurred between 2,900 and 600 years ago, after which charcoal levels were again low. Two aspects of this

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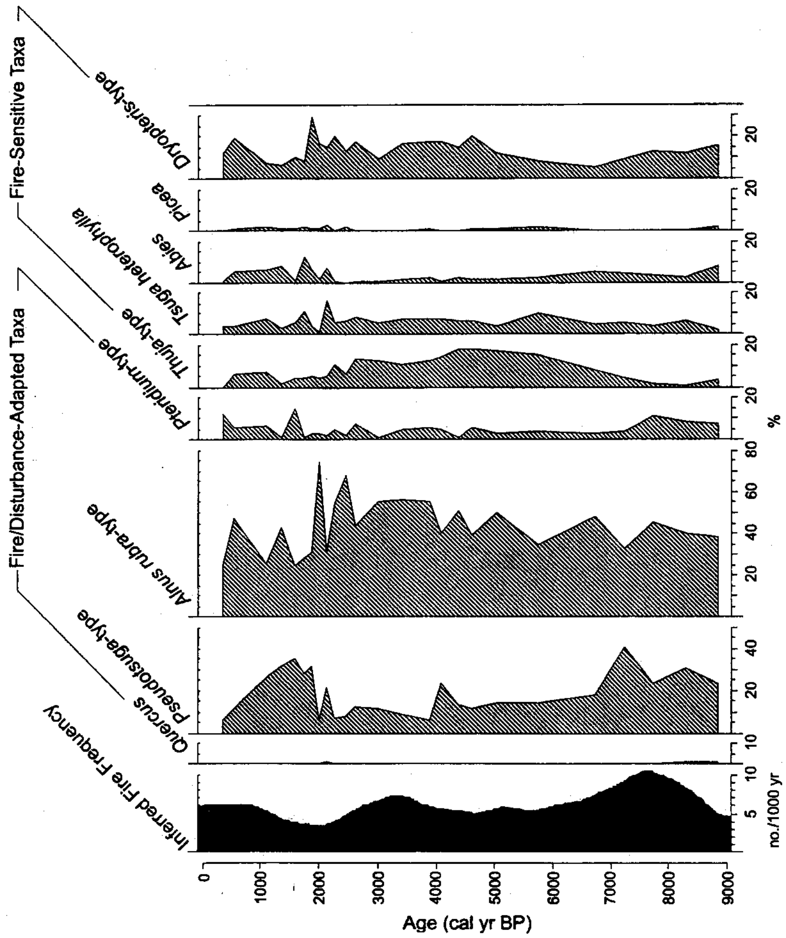

Figure 6.2. Inferred fire frequency and pollen percentages of selected taxa from Little Lake in the Oregon Coast Range (Long et al. 1998). Note the highest fire frequency occurs during periods when fire- and disturbance-adapted species are best represented.

period of abundant charcoal are puzzling. First, the pollen record from Beaver Lake does not indicate any changes in upland vegetation during the period of high charcoal. The fires may have been local and not representative of regional fire frequencies, or they may have occurred in the late summer and fall and thus did not alter the composition of the vegetation. Second, the fire period comes at a time when the climate was shifting to cool, wet conditions in the late Holocene. This juxtaposition of high fire activity during a cool wet period may be evidence of deliberate burning to maintain open vegetation, but it is not obvious why the Kalapuya would have abandoned the effort about 600 years ago, when populations were supposed to have been at their largest (Boyd 1990). The decrease in fires 600 years ago at Beaver Lake may represent (1) an abandonment of the local area for unknown reasons; (2) a decrease in human populations due to disease, starvation, or other factors prior to direct European contact (Ramenofsky 1987; Ubelaker 1988); or (3) the onset of cooler, wetter conditions in the Little Ice Age and a decline in flammability (ca. A.D. 1650–1890; Graumlich and Brubaker 1986; Graumlich 1987). In summary, the Beaver Lake record suggests high fire incidence coincident with Kalapuya occupation, but provides no obvious explanation for decreased burning in the last 600 years. Uncertainties in the timing and interpretation of the record will only be resolved with additional data.

Some have argued that natural ignitions in the valley were not frequent enough in prehistoric time to maintain the fire regime necessary for prairie and savanna (Morris 1936; Johannessen et al. 1971). Lightning strikes are uncommon at present and generally do not occur in summer or early fall when fuels are driest. Moreover, fires in the valley today are actively fought and landscape fragmentation reduces their ability to spread. It is difficult to assess the frequency of natural ignitions in the past, because it would have varied as a component of the climate system. Lightning ignitions were probably more abundant in times of strong convectional activity, such as the early Holocene when monsoonal circulation was enhanced, which is consistent with the charcoal evidence of more fires in the early Holocene at several sites.

Euro-American Journal Descriptions of Burning

Early ethnographers did not gather information on Kalapuya burning practices, and the archaeological record provides few insights. The evidence for burning comes primarily from the accounts of early trappers, explorers, and settlers in the nineteenth century (see Knox 2000 for more detailed discussion of this literature). Contact with the Kalapuya was relatively brief, beginning in 1812 and ending in 1856, when they and other coastal peoples were moved to reservations (Beckham 1990). As early as 1812, Stuart (1995) mentions the decimation of native populations as a result of a smallpox outbreak at the confluence of the Willamette and Columbia Rivers. After 1831, malaria reduced the Kalapuya populations (Boyd 1975, 1986, 1990), and their numbers dropped from some 16,000 at the time of European contact to between 1,175 (Boyd 1990) and 600 (Wilkes 1926) by 1841.

The earliest journals written between 1812 and 1825 (e.g., Douglas 1959; Henry 1992; Seton 1993; Stuart 1995) do not mention native use of fire, either to control or maintain their ecosystem. Most of the accounts were written during June, July, August, and September, and a few were written during winter and spring trips when evidence of fires might have been less obvious. However, as the valley is generally snow-free, burned land would have been visible. Journals from 1826 to 1830 contain some references to fire, but reports of native burning increase after 1840, with expanding Euro-American settlement of the valley. Journals written prior to 1831 (the first year of the malaria outbreak) are probably the most accurate descriptions of Native American burning practices prior to Euro-American settlement. This assertion is based on the fact that hunters and trappers solicited the aid of native peoples, and their relation with the Kalapuya was frequently one of mutual respect and sharing. After 1840, settlers, and missionaries often described indigenous people as ignorant, incompetent, and prone to thievery (e.g., Minto 1900; Riggs 1900; O'Hara 1911). Settlers also altered the ecosystems upon which the Kalapuya depended by farming and by introducing nonnative animals. Pigs, for example, severely damaged camas fields early on (Palmer 1966), and cattle replaced wild game, which had all but disappeared by 1840. Native plant communities were lost as a result of landscape fragmentation, agriculture, intense grazing by cattle and sheep, and the introduction of exotic plants (Hulse et al. 1998).

The most-cited description of the Willamette Valley prior to the 1840s comes from David Douglas, a Scottish botanist who collected plants for the Royal Horticultural Society. He traveled down the Willamette Valley from Fort Vancouver in 1825 and 1826, with members of the Hudson's Bay Company. Douglas's journals are exceptional in their detailed descriptions of the landscape and vegetation, and his perceptions of native peoples seem relatively unprejudiced. Douglas encountered burned areas, some of which were from quite small fires, whereas others were from large conflagrations affecting both his party and the Kalapuya. A careful examination of the Douglas journals, taking his entries in context and chronological sequence, and comparing them with journals written by other members of his expedition, helps to distinguish between prescribed burns set by the Kalapuya and larger, uncontrolled wildfires.

Douglas visited the north end of the valley in 1825, but he undoubtedly spoke with trappers who had traveled farther south. The 1825 journal has no mention of fires, nor does it provide first-person accounts of fires. On an August trip, Douglas was about 25 miles above the falls on the Willamette River in an area of riparian forest and wooded upland (Personal Communication, E. Alverson, 2001). He described a tobacco plantation, which has been cited as one reason for burning by the Kalapuya (Boyd 1986, 1999a). The account suggests the use of fire in wooded areas, but not widespread burning, as Douglas comments on the small acreage that is actually burned:

> 8/19—Towards afternoon left in a small canoe with one Canadian and two Indians . . . on a visit to the Multnomah River. . . . The beaver is now scarce; none alive came under my notice. I was much gratified in viewing the deserted lodges and dams. . . . Collected the following plants . . . *Nicotiana pulverulenta*. . . . I have seen only one plant before, in the Hand of an Indian two months since at the Great Falls of the Columbia. . . . The natives cultivate it here and although I made diligent search for it, it never came under my notice until now. They do not cultivate it near their camps or lodges, lest it should be taken for use before maturity. An open place in the wood is chosen where there is dead wood, which they burn and sow the seed in the ashes. Fortunately I met with one of the little plantations and supplied myself with seeds and specimens without delay. (Douglas 1959:140–141)

The 1826 journey of Douglas can be reconstructed with respect to geography and vegetation with fair confidence (Table 6.2, Figure 6.3). The vegetation shown in Figure 6.3 is based on 1850 General Land Office surveys prior to extensive land-use change (Hulse et al. 1998), and the vegetation distribution was probably similar to that encountered by Douglas. From September 20 to 26, Douglas described the journey from Fort Vancouver to meet Alexander McLeod, Chief Trapper for the

TABLE 6.2. Location and distance traveled, vegetation, and fire observations made by David Douglas during the 1826 journey through the Willamette Valley (see Figure 6.3 for vegetation and geographic location).

Date	*Location, Distance traveled*	*Vegetation circa 1850*[1]	*Burned ground noted*[2]
September 20	Lower valley, 5 miles	Closed forest: upland	No
September 21	Lower valley (at falls)	Closed forest: upland	No
September 22–26	Lower valley, none	Savanna	No
September 27	Lower valley, 5 miles	Woodland and shrubland	Yes
September 28	Lower valley, ~7 miles	Woodland and shrubland	No
September 29	Lower valley, 13 miles	Prairie	No
September 30	Mid-valley, ~10 miles	Savanna	Yes
October 1	Mid-valley, 18 miles	Savanna	Yes
October 2	Mid-valley, 21 miles	Savanna	Yes
October 3	Mid-valley, 9 miles	Prairie	No
October 4	Upper valley, 24 miles	Prairie	Yes
October 5	Upper valley, 19 miles	Savanna	Yes
October 6	Coastal foothills, 16 miles	Woodland and shrubland	Yes
October 7	Coastal foothills, 7 miles	Closed forest: upland	No
October 8	Coastal foothills, 8 miles	Closed forest: upland	Yes

[1]Based on 1850 Land Ordinance Survey (after Hulse et al. 1998).
[2]From David Douglas's 1826 journal entries (Douglas 1959).

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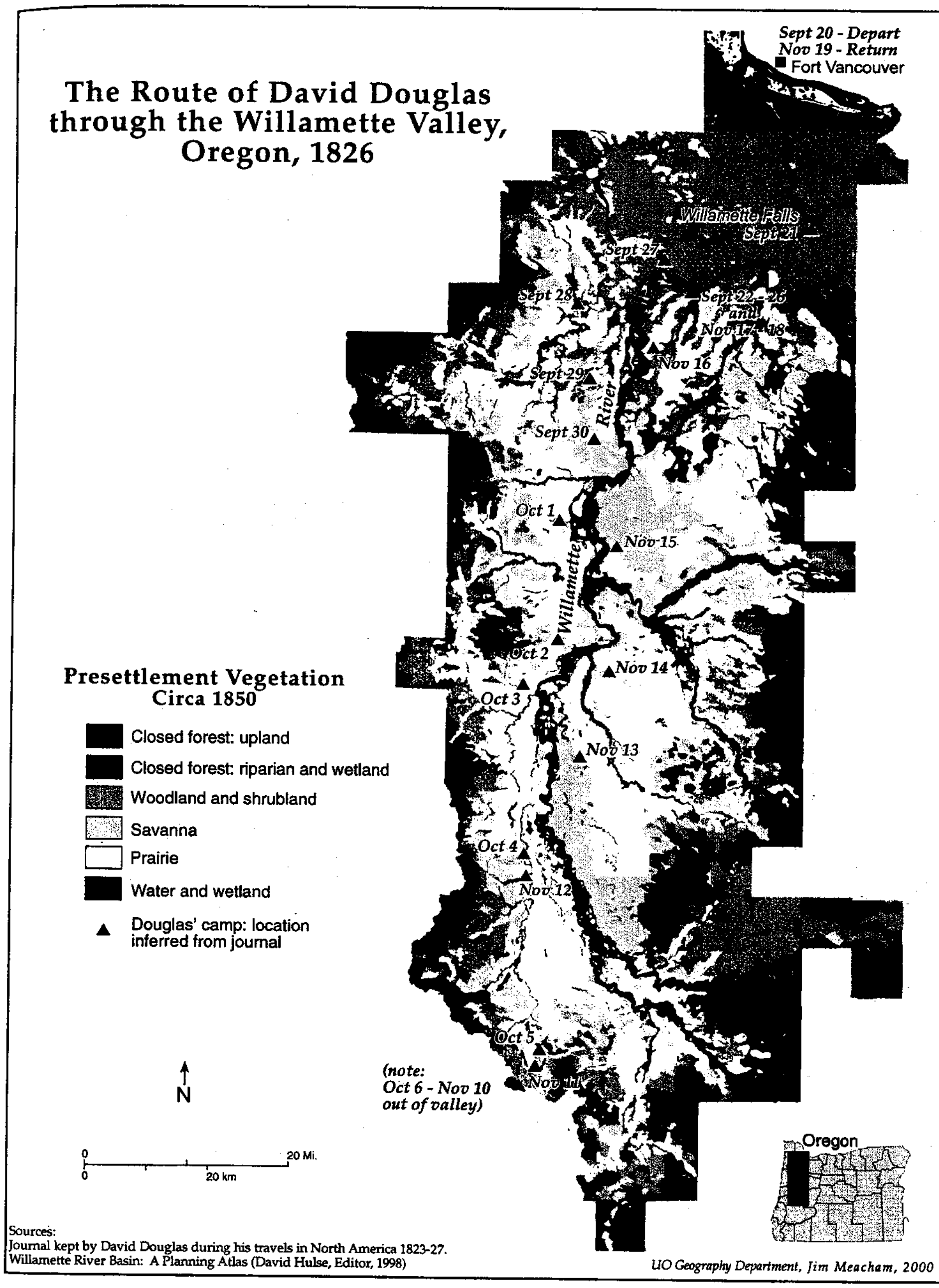

Figure 6.3. The location of David Douglas's camps as he traveled through the Willamette Valley in the fall of 1826. The base map shows the presettlement vegetation ca. 1850, based on surveys of the General Land Office.

Hudson Bay Company and leader of the expedition. McLeod's encampment was near or on the open grassland known as French Prairie. Douglas noted warm weather, heavy dews, and a search for some horses that McLeod had left above the falls on a previous trip; he did not mention fire or burned ground. On September 27, Douglas was west of the Willamette River, between present-day Wilsonville and Newberg, in the same woodland vegetation that had characterized the journey thus far. He detailed landscape conditions, including the effects of a recent fire:

> 9/27—Country undulating: soil rich, light with beautiful solitary oaks and pines interspersed through it and must have a fine effect, but being all burned and not a single blade of grass except on the margins of rivulets to be seen. . . . Marched today five miles. (Douglas 1959:213)

The next day, the group turned south and probably crossed the North Yamhill River. The woodland opened and prairie was possibly evident, but the vegetation did not change significantly. Douglas wrote:

> 9/28—Mr McLeod returned shortly after dusk last night and brought with him one of the Indian guides from the coast south of the country inhabited by the Killimuks. All unfortunate in the chase, and although nine small deer were seen in a group, yet by their keeping in the thickets near the small stream a few miles from our encampment, prevented the hunter from approaching them. Morning pleasant but chilly with heavy dew. Thermometer 41°. Started at eight o'clock, keeping a south-west course. . . . Camped on the south side of the Yamhill River, a small stream about twenty-five yards wide; channel for the greater part mud and sand. Two hundred yards below where we forded are fine cascades 7 feet high. Country much the same as yesterday; fine rich soil; oaks more abundant, and pines scarcer and more diminutive in growth. . . . Picked up a species of *Donia* . . . and . . . *Phlox*, both in rich light dry loam in open woods. . . . Hunters out in search of deer and not yet come home. I expect a fine fall, as seventeen shots were heard in various directions in the woods. (Douglas 1959:213–214)

The September 28 entry notes similar country to that of the previous day, which is probably a reference to the topography and vegetation. The burned area observed on September 27 was apparently small, because the group traveled only 5 miles and made no further mention of it. On September 29, they proceeded southwest, moving between woodland

and savanna. Again, burned vegetation seemed absent and there is no mention of fire, even though the company traveled a fair distance, probably reaching the Eola Hills:

> 9/29—Morning dull and cloudy . . . hunters returned with a very large fine doe. Started at nine and kept a south-west course, and camped not far from the point of a low hill . . . Heavy rain for the remainder of the day and the greater part of the night. Country not different from yesterday. Traveled about thirteen miles. Nothing new came under my notice. (Douglas 1959:214)

On September 30, the company moved into open savanna. The effects of fire reappear in Douglas's comments:

> 9/30—Cloudy until noon, after-part of the day clear and fine with a fanning westerly wind. In the morning dried some of my things which got wet the preceding day. Started at nine and continued our route in a southerly direction, on the opposite side of the hill from where we were yesterday. Most parts of the country burned; only on little patches in the valleys and on the flats near the low hills that verdure to be seen. Some of the Natives tell me it is done for the purpose of urging the deer to frequent certain parts to feed, which they leave unburned and of course are easily killed. Others say that it is done in order that they might better find honey and grasshoppers, which both serve as articles of winter food. (Douglas 1959:214)

Douglas's passages dated September 27, 28, and 30 are widely cited as evidence that the Kalapuya extensively burned the valley (Johannessen et al. 1971; Towle 1982; Boyd 1986, 1999a). However, the full entries for September 28 and September 29, with no mention of fire, are often overlooked. It seems likely that the fires Douglas described on September 27 and 30 were neither contiguous nor part of a single event.

On October 1 the company marched 18 miles and camped on a small stream that entered the Willamette River; the stream could have been Rickreall Creek, Ash Creek, or the Luckiamute River. The distance and description correspond well with the terrain of the Eola Hills. Again, they encountered a burned landscape:

> 10/1—Heavy dew during the night; clear and pleasant during the day, with a refreshing westerly wind . . . continued our route. Had to make a circuitous turn east of south, south, and south-west to avoid two deep ravines that were

> impassable for the horses. Walked the greater part of the day, but found nothing new. On my way observed some trees of Arbutus laurifolia, 15 inches to 2 feet in diameter, 30 to 45 feet high, much higher than any I saw last year on the Columbia; fruit nearly ripe; soil deep rich black loam, near springs, and on the gravelly bottom. Passed at noon some Indians digging the roots of Phalangium Quamash in one of the low plains. Bulbs much larger than any I have seen. . . . Camped at four on the banks of a small stream which falls into the Multnomah three miles to the east. . . . In the dusk I walked out with my gun. I had not gone more than half a mile from the camp when I observed a very large waspnest, which had been attached to a tree, lying on the plain where the ground was perfectly bare and the herbage burned, taken there by the bear (Douglas 1959:214–215)

The following day Douglas recorded a possible source of ignition, lightning. Food for the horses was scarce:

> 10/2—Morning, heavy dew and chilly; clear and fine during the day; sheet lightning in the evening. . . . At noon passed two deep gullies which gave much trouble, the banks being thickly covered with brushwood, willow, dogwood, and low alder. Course nearly due south, inclining to the west. Country same as yesterday, rich, but not a vestige of green herbage; all burned except in the deep ravines. Covered with *Pterius aquilina, Solidago,* and a strong species of *Carduus.* On the elevated grounds where the soil is a deep rich loam, 3 to 7 feet thick on a clay bottom, some of the oaks measure 18 to 24 feet in circumference, but rarely exceeding 30 feet of trunk in height. On the less fertile places, on a gravelly dry bottom, where the trees are scrubby and small, a curious species of *Viscum,* with ovate leaves, is found abundantly. . . . As no place could be found suitable for fodder for the horses, we had to travel till four o'clock, when we camped at a low point of land near a woody rivulet. Marched twenty-one miles. My feet tonight are very painful and my toes cut with the burned stumps of a strong species of *Arundo* and *Spiraea tomentosa.* (Douglas 1959:215)

A recent fire may explain this lack of fodder, but October is generally dry in this region and grass would have been scarce in any event. From

October 4 to 6, the group was in the upper valley and beginning their ascent into the Umpqua Mountains. Douglas noted very warm weather and burned ground:

> 10/4—The morning being cloudy and overcast, we did not start so soon. As it cleared up about ten, the horses were saddled and we proceeded on our route in a southerly direction. Passed in the course of the day three small streams, which all fall into the Multnomah ten miles below this place. As no place could be found fit for camping we were obliged to go until five o'clock, when we put up on the south side of a muddy stream, banks covered with Fraxinus. No deer killed this day, although several were seen. Nothing particular occurred. Marched twenty-four miles; somewhat fatigued. (Douglas 1959:216)

From October 8 to 25, the company was out of the valley. Several references are made to tremendous storms and lightning, and the lack of food in the Umpqua region. The return trip from the upper valley to Fort Vancouver took approximately 8 days. Douglas described the onset of rain and lightning, and the lack of food in camp, but he made no further reference to fire:

> 10/8—Morning cool and pleasant; day clear and warm. Thermometer in the shade 82°; much sheet lightning in the evening, wind westerly. . . . No deer killed and had the last fragments cooked for supper, which gave us all but a scanty meal. . . . We are just living from hand to mouth. All the hunters observe that the animals are very scarce and those shy in consequence of the country being burned. (Douglas 1959:217)

> 10/25—Last night was one of the most dreadful I ever witnessed. The rain, driven by wind, rendered it impossible for me to keep any fire . . . every ten or fifteen minutes immense trees falling producing a crash as if the earth were cleaving asunder, which with the thunder peal on peal before the echo of the former died away, and the lightning in zigzag and forked flashes. . . . My poor horses were unable to endure the violence of the storm without craving of my protection, which they did by hanging their heads over me and neighing. (Douglas 1959:229)

While waiting for Douglas to arrive at French Prairie in September, Alexander McLeod, the leader of the expedition, made a few references to fire in his journal:

> 9/18—The country is much overrun by fire, in many places we had some difficulty to pass our horses owing to their alarm caused by the devouring element. (McLeod 1961:175–176)

> 9/19—We had very sultry weather, accompanied by a fresh breeze. Continued on our route at 4 P.M. put up at the appointed Rendezvous: we had to swim our horses over the Willamette to the east shore, the opposite shore being burned and destitute of Grass. The report of fire arms brought a couple of Indians to us with a canoe which proved of service to us to drive our horses over the Channel. We are led to understand that some of the freemen are in this neighborhood. (McLeod 1961:176)

Traveling south with Douglas, McLeod refers to the occurrence of a recent fire and its negative impact on available game for themselves and the Native Americans in the area:

> 9/30—We saw some Indians in quest of game: like ourselves they meet with little success in consequence of fire having scared the animals. (McLeod 1961:179)

Reading two journals from members on the same expedition allows for a comparison of events. Douglas was new to the area, whereas McLeod had traveled through the valley on numerous occasions for the Hudson Bay Company. Douglas stated the fire was deliberately set by the natives to attract deer to the area. McLeod noted the difficulty the Kalapuya encountered because of the recent fire. Using Table 6.2 and Figure 6.3, the party can be positioned in the savanna vegetation zone, which may have been maintained by periodic fires. However, the McLeod entry raises questions as to whether the Kalapuya set this particular fire, as they seem unprepared for the lack of game in the area. On October 2, McLeod substantiated Douglas's remark concerning the storms and lightning:

> 10/2—Fine weather. Met frequent lightning in the course of the day suffered much inconvenience from excessive heat which tended much to harass our poor horses. Pasture is rarely found in the course of this day none has been seen, altho' we travelled good twenty miles and had to put up along a small river that our horses might have the pickings along the margin of the woods, elsewhere the fire destroyed all the Grass. (McLeod 1961:179)

From the journals of Douglas and McLeod, two types of fire emerge: small, possibly prescribed burns used in tobacco cultivation, and larger, unexpected conflagrations, possibly ignited by lightning, which depleted hunting resources for both Douglas's party and the Kalapuya.

John Work (1923), an employee of the Hudson Bay Company, traveled from Fort Vancouver to the Umpqua River in 1834. When the company reached present-day Monroe, Work wrote the much-cited entries of July 1 and 2 in his journal describing the native peoples setting fire to the grassland:

> 7/1—Three other Indians passed us but made a very short stay and appeared to be much afraid of something. Parts of the plain gravelly and soil poor, herbage getting dry and the ground has an arid appearance; on the lower spots grass luxuriant. (Work 1923:264)
>
> 7/2—The Indians set fire to the dry grass on the neighboring hill, but none of them came near us. The plain is also on fire on the opposite side of the Willamet. (Work 1923:264)

However, the next entry suggests that the fires served as a means of protection for the Kalapuya against the Umpqua:

> 7/3—Ten of them visited the camp and traded their beaver. These Indians are much alarmed lest they be attacked by the Umquahs . . . that nation have threatened to come to war upon them. . . . As we were coming on we found a party of 32 men all armed and ready for war, supposing that a party of Umquahs were coming upon them. (Work 1923:264)

And, on July 5 and 6, Work was approximately 40 miles above the falls and still recounted the anticipation of conflict:

> 7/5—These people are preparing to go to war. (Work 1923:266)
>
> 7/6—They are all armed and prepared for an attack. (Work 1923:266)

Samuel Clarke confirmed the use of fire for protection when he interviewed residents of the Grand Ronde Reservation in the 1880s. Clarke (1905) wrote that burning was used to sight hostile war parties from a distance.

In summary, the reliability of journals as a source of information on indigenous burning practices depends on the time that they were written, the full context of the journal, and the perspectives of the writer and the reader (Knox 2000). Also, by examining single entries from a journal, a biased view of the history for a region may emerge. Only by researching numerous journals, letters, and other papers does the complexity of Kalapuya history at the time of European contact begin to emerge. Early observations must be considered in light of the fact that the Kalapuya were decimated by infectious introduced diseases and their way of life was threatened at the time of even the earliest journals. Only a few of the journals mention the large numbers of Native Americans dying of disease, often by a sentence or single paragraph (e.g., Parker 1840; Wilkes 1926), yet evidence of death must have been pervasive. The early journal accounts that describe fire do not present a picture of broadcast burning to maintain open conditions, although large fires are noted in prairie and savanna areas. Only David Douglas and John Work associate fires with the Kalapuya prior to the 1840s, and the extent of burning from both accounts seems limited.

Juniper Woodland of Eastern Oregon

Western juniper (*Juniper occidentalis*) grows at low and middle elevations (760–1,400 m elevation) in the northern Great Basin and forms the driest forest zone (less than 20 cm annual precipitation) in the Pacific Northwest (Franklin and Dyrness 1973). The fire regime within juniper woodland is determined by the availability of fine fuels in the form of grass, which allows fire to spread. Ground fires remove litter and tree seedlings, enabling grass to resprout, but established juniper trees are fairly fire resistant and can live to be several hundred years old (Burns and Honkala 1990). A fire interval of 30 to 40 years is sufficient to keep juniper from invading sagebrush-grassland communities (Miller and Rose 1995). In the absence of fire, juniper seedlings establish and the woodland becomes more closed. Sagebrush (*Artemisia tridentata*) also replaces perennial bunchgrasses, converting grassland to shrub steppe. Wet periods tend to promote the growth of grass and frequent fires, which in turn limit the ability of juniper and sagebrush to spread. People of the northern Paiute language group occupied the Great Basin at the time of European contact. Current research suggests that prehistoric and historic population densities were never high, and societies were mobile enough to take advantage of the scarce resources (Aikens and Jenkins 1994). Historic accounts highlight the exploitation of mammals, fish, insects, and plants by small family groups during most of the year and the yearly gathering of larger groups at root-processing camps, salmon fisheries, and seed gathering sites (Aikens 1993). Shinn (1980) suggests that fires were regularly set by native groups in historic time for purposes of signaling, hunting, and collecting insects, and Euro-Americans describe burned expanses of prairie that were attributed to Native

Americans. Trapper Peter Skene Ogden, for example, reported in 1826 that the southern Blue Mountains were "overrun by fire" and blamed the fires on native peoples (Langston 1995).

The relationship among fire, grass, and western juniper in prehistoric times is suggested by pollen and charcoal records, particularly those from Diamond Pond in southeastern Oregon, and from plant macrofossils contained in ancient packrat middens (Figure 6.4; Mehringer and Wigand 1990). These data indicate that the period of maximum aridity

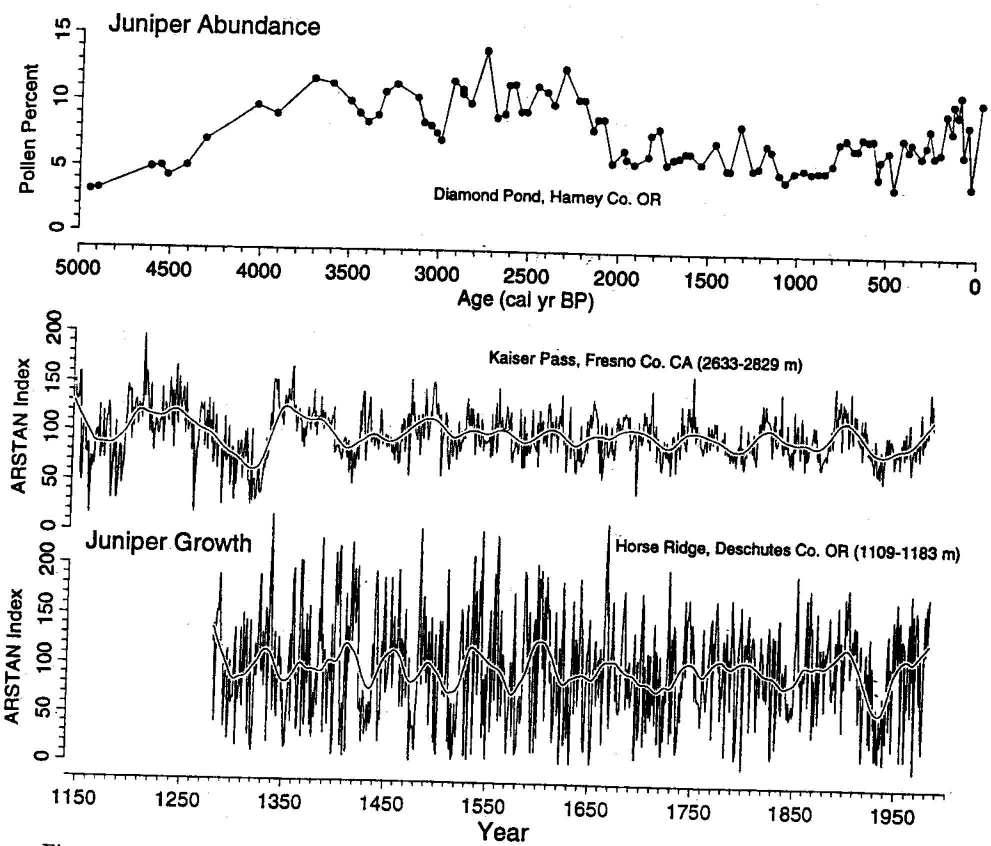

Figure 6.4. Prehistoric and historic juniper expansion. The record of juniper pollen abundance from Diamond Pond (Mehringer and Wigand 1990) shows that juniper pollen was abundant between 4,500 and 2,100 years ago, then present in low amounts from 2,100 to 500 years ago. In the last 500 years, juniper pollen abundance has increased steadily, with the exception of a period of low percentages in the early twentieth century. Growth records of western juniper from the last millennium are available from Kaiser Pass, Calif. (Graumlich 1991), and Horse Ridge, Ore. (Holmes, Adams, and Fritts 1986). The index is high during high growth years. Both records suggest a period of favorable growth since the 1930s, which is consistent with its historic expansion.

occurred between some 7,800 and 4,400 years ago, which is late compared with the rest of the Pacific Northwest (as discussed previously). The archaeological record is sparse during the dry period, probably because populations were focused on wetland and lacustrine resources (Aikens 1983). Wet conditions returned during the Neopluvial period (about 4,400 to 2,000 years ago), and the renewed abundance of upland resources may have allowed populations to become more widely distributed (Aikens 1983).

Pollen and packrat-midden records from Diamond Pond and vicinity describe the vegetation response to a series of climate changes during and since the Neopluvial period (Figure 6.4). With increased moisture after 4,400 years ago, western juniper extended its elevational range downslope by 150 m, and grass was more abundant than sagebrush in the basins (Wigand 1987; Mehringer and Wigand 1990; Miller and Wigand 1994). Between about 2,000 and 1,000–800 years ago, the climate became warmer and drier, and the lower limit of juniper retreated upslope. In the last 1,000 years the climate has become wetter, allowing juniper and grass to expand downslope again (although there was a notable dry period and range contraction from 700 to 500 years ago). The expansion of juniper in the last few centuries has been accompanied by increased sagebrush, not grass, according to the pollen data. The combination of juniper and sagebrush implies greater winter precipitation than before and a reduction in summer precipitation (which would favor sagebrush over grass). Miller and Wigand (1994) note that the "re-expansion of Great Basin woodlands was just getting underway when Europeans first entered the area."

The Diamond Pond record contains little charcoal in sediments dating between 6,200 and 3,700 years ago, which is consistent with a model of few fires when juniper and grass levels were low and sagebrush was abundant. Charcoal values increased in the record about 3,700 years ago and remained generally high until about 1,100 years ago. The increase in fire occurrence coincides with the shift in vegetation towards more juniper and grass in the Neopluvial period. The most recent expansion of juniper woodland, beginning some 1,000 years ago, occurred during a period of few fires.

Dendroclimatological records from eastern Oregon span the last 700 years and indicate several periods of moist conditions that favored juniper growth, including an interval from A.D. 1650 to 1900 that coincides with the Little Ice Age. When the data are filtered to show only interannual and decadal variations, the tree-ring data indicate rapid growth during the 1880s and 1890s, which were some of the wettest years on record, and slow growth during the 1930s, which were among the driest (Figure 6.4) (Garfin and Hughes 1996). Increased precipitation and warm winters must be part of the explanation for the expansion of juniper and decrease in grass in the last 500 years. Decades since 1930 are anomalous compared with other wet periods, however, because of the absence of fires.

Miller and Rose (1995) analyzed the stand ages of western juniper communities and concluded that open stands were present on Steens Mountain from the 1700s to the 1880s. The first increase in tree densities occurred in the late 1800s, and a relatively steady rate of juniper establishment was maintained until the 1950s. Juniper populations increased at a geometric rate after the 1960s. Miller and Rose (1995) speculate that climate change, reduced fire frequencies, and grazing in the late 1800s were the primary factors for juniper expansion. They note that the mild wet winters of the 1880s, following the Little Ice Age, probably promoted vigorous tree growth. The late nineteenth century was also a time of intensive livestock grazing (Burkhart and Tisdale 1976), and the incipient decrease in native bunchgrass eliminated the fuel source that once allowed fire to spread across the landscape. Concurrently the increase in sagebrush provided more safe sites for juniper seedlings. Decreases in Paiute populations during the 1870s may also have been a factor, but their relocation to reservations precedes the greatest expansion of juniper by nearly 90 years. It seems that Euro-American activities and climate change so obvious in this century are more directly responsible for the changes in forest cover.

Ponderosa Pine Forests of the Eastern Cascade Range and Blue Mountains

Ponderosa pine forests form a vegetation zone from 1,450 to 2,000 m elevation in the Oregon Cascades and 900 to 1,500 m elevation in the Blue Mountains (Franklin and Dyrness 1973). The zone lies between mixed communities of Douglas fir, grand fir, pine, and other mesic taxa at higher elevations and juniper woodland and sagebrush steppe at lower elevations. Dendrochronological studies suggest that these forests historically experienced short fire return intervals on the order of decades or less and that fires scarred but often did not kill mature trees (Agee 1993). The extent of individual fires in ponderosa pine forest is not well documented in the Pacific Northwest, but many studies suggest that they were often small and scattered as a result of the discontinuous pattern of fuels (Bork 1985; Agee 1993; Heyerdahl 1997). In areas of frequent fires, the understory was regularly cleared of fuel, and thick-barked, fire-resistant pine trees remained. Where fires were infrequent, the buildup of understory fuels shifted the disturbance regime toward stand-replacement fires, and mesic fire-sensitive species—such as grand fir and Douglas fir and multiple-age stands of ponderosa pine—fill in the understory (Agee 1993). The resiliency of these forests is now of great concern to forest managers, because fire exclusion practices in the late twentieth century have allowed fuels to build up and increase the likelihood of high-intensity burns. Rather than maintaining the forests with low-intensity ground fires, the concern is that the current regime will prove lethal for this forest type.

The open structure of many ponderosa pine forests at the time of Euro-American settlement has been attributed to the effects of frequent fire, and burning by Native Americans may have been one source. The Cascade forests were visited by native peoples from both the Plateau and the Great Basin and also by Inland Valley and Klamath Lake people in historic times (Zucker 1983), and archaeological data extend human occupation to at least early Holocene time (Aikens 1993). Population densities were probably low and consisted of seasonal hunting and gathering groups. Burning may have been used to facilitate travel and hunting and promote the production of grass and berries. Reports of Native American–set fires are mentioned in the journal accounts of early trappers, missionaries, and settlers traveling through and around the Blue Mountains and Northern Rockies (see Gruell 1985; Langston 1995; Barrett and Arno 1999). Whether the observed fires were deliberately set as a means of opening the understory, caused by lightning ignitions, or represent fires escaped from adjacent grassland is not clear from most descriptions.

Tree-ring records confirm that fires in ponderosa pine forests have been controlled by variations in climate on interannual and decadal time scales. Forest ecologists have also described complex linkages between fire, insect outbreaks, and nutrient cycling in these forests (e.g., Mutch et al. 1993). For example, beetle-kill trees increase the likelihood of severe fire, and tree mortality, in turn, introduces nutrients to the soils and allows for seed germination and seedling establishment. Heyerdahl (1997) examined 300 years of tree-ring data from the Blue Mountains and discovered 65 separate fire years at her sites. Xeric forests, dominated by ponderosa pine and juniper, burned more frequently than mesic forests of pine, Douglas fir, fir, and larch, but in extreme drought years both forest types were affected. Xeric forests displayed considerable variation in the size and severity of past fires, depending on local site conditions. The fire-history reconstructions showed strong correlations between drought years and big fire years. The area burned on decadal time scales for the last 300 years also tracked decadal precipitation well. These data are among the strongest and most significant fire-climate relations shown for the Pacific Northwest. A decline in fire occurrence, beginning in the 1880s, was attributed primarily to the effects of grazing but also to variations in climate and insect outbreaks (Heyerdahl 1997). A fire-history study in ponderosa pine forests in the eastern Cascade Range also found a decrease in fire occurrence, which was attributed to grazing and suppression activities in the twentieth century (Bork 1985).

Paleoecological records place the establishment of modern ponderosa pine forest in the middle and late Holocene, following a period of expanded steppe. At Carp Lake near Goldendale, Washington, pollen data suggest that pine forests colonized the region about 7,700 years ago and persisted for the next 3,200 years. The climate became cooler and wetter some 4,400 years ago and allowed Douglas fir, fir, and western hemlock to establish near Carp Lake (Whitlock and Bartlein 1997). Fires were probably more frequent during early Holocene and middle Holocene periods, when the climate was drier than the late Holocene. Unfortunately, charcoal data are not yet available from Carp Lake or other sites in the ponderosa pine forest to allow for reconstruction of the fire history more precisely, but the linkages between vegetation change and climate are well documented. Human impacts on forest composition would have to be discerned on top of those caused by climate.

Native American burning was likely responsible for the open stand structure in ponderosa pine forests in particular localities. Barrett and Arno (1982, 1999) conducted interviews with thirty-one Salish and Kootenai and twenty-seven descendents of early pioneers in northwestern Montana to gather information on human-set fires in ponderosa pine forests during historic times. However, the value of these interviews might be questioned, because no information was provided on the background of the interviewees (were they Salish, Kootenai, or others?), and any account as of 1980 is at least 120 years removed from the critical period. Barrett and Arno (1999) also note that descendants of settlers had more detailed recollections of native burning practices than did native descendants, which raises concerns about possible biases in the data. Twenty-five of the interviewees had some recollection of deliberate burning, and seven could identify the geographic location of such activities. Tree-ring records were analyzed to compare the fire history near historic Native American settlements with that of comparable sites located in remote settings. In nine of ten comparisons the site heavily used by people showed a higher fire frequency than the remote site; in three of the comparisons the difference was statistically significant. The results suggest that Native Americans had an impact on the structure of ponderosa pine forest near densely populated areas, but the impact of burning activities at a larger spatial scale remains unresolved. If the purpose of native-set fires was to influence game, to improve berry gathering and grazing (after the introduction of horses in the 1700s), and to facilitate travel, camping, and communication, such activities would have been geographically limited in scope. The influence of human-set fires on the character of ponderosa pine forest ecosystem at a regional scale has yet to be demonstrated.

Final Comments

Some very large fires have occurred since Euro-American settlement. The worst fire year on record was 1910, when more than 2 million ha of western national forest lands burned in the northern Rocky Mountains and Pacific Northwest (Swetnam and Betancourt 1998). In the last 12 years, these regions have once again experienced a number of large, stand-replacement fires. Fires in 1994 affected more than 11,460 ha of Oregon state forests (Oregon Department of Forestry 1997) and more than 1.2 million ha in eleven western states (Maciliwain 1994). The fires of 2000 consumed more than 7 million acres (National Interagency Fire Center 2000). Many trees were killed by these events, and, as a consequence, forest management practices and fire policy have come under increasing public scrutiny. The size of recent fires has been attributed to changes in vegetation structure, the accumulation of fuel, and climate over the last 100 years. Changes in vegetation and accumulation of fuel have been attributed to the elimination of Native American burning practices (Barrett and Arno 1982; Pyne 1982), effective fire fighting practices since World War II (Pyne 1982), and high tree mortality from recent infestations by mountain pine beetle and western spruce budworm (Mutch et al. 1993). The climate argument is based on the historic occurrence of severe fires in years of intense drought (Balling et al. 1992). It has also been predicted that large fires will continue to occur in the future with global warming as a result of increased greenhouse gases (Franklin et al. 1991; Romme and Turner 1991; Running and Nemani 1991; Bartlein et al. 1997).

Discussions over the degree to which the prehistoric landscape was pristine or humanized filter into the debate of how best to respond to current large fires. If humans altered ecosystems through their use of fire, then a return to presettlement landscapes (i.e., those that existed prior to European contact) is not possible without instigating burning and fuel reduction through forest thinning. It's not surprising that assigning a large role to prehistoric peoples is a popular concept among those who advocate active management of wilderness and commodity lands today. The argument is that some forests are so altered by fire exclusion that fire alone may not restore them. Zyback (1995), for example, suggests that human-set fires, in prehistoric times, altered every acre of the Pacific Northwest, leaving no vegetation unaffected. The

Northwest Forestry Association, which represents commercial timber interests in the region, states that current forests are unnaturally dense and vulnerable to disease in the absence of fires. Restoring forest health, in their opinion as well as that of others, requires immediate thinning and salvage to emulate the effects of native peoples (Bonnicksen 1989; Wagner and Kay 1993). Others note that western forests are spatially variable and have experienced a wide range of fire conditions in the past and at present. A policy of thinning and prescribed burning may be appropriate in low-elevation ponderosa pine forests, but it is less justifiable in areas that historically sustained large stand-replacing events. Given the economic consequences, it is clear that more is at stake in this debate than an academic interest in prehistoric fire regimes.

On the other hand, it is equally incorrect to portray the region as untouched by human action prior to European contact. Historical and ethnographic accounts suggest that Native Americans used fire in the Willamette Valley and at the lower forest-grassland border to open forest and maintain prairie. The frequency and extent of such burning, however, is not clear. Paleoecological data from the Willamette Valley, northern Great Basin, and eastern Cascades and Blue Mountains suggest that climate, vegetation, and fire regimes were closely interlinked in prehistoric times and climate has been a primary determinant of vegetation composition and disturbance regimes. The extent to which fire-regime variability closely tracks independently derived records of climate variability is a convincing measure of the importance of climate relative to other potential causes of fire-regime variability, known or unknown. The principle of Occam's razor suggests that it is not necessary to invoke more complicated arguments or hypotheses than climate variation to explain the temporal patterns we observe in fire regimes.

As climate and climate variability have changed through time, so too have the vegetation and conditions influencing fire occurrence. Wherever we have data, the record shows that fires were generally extensive when prevailing climate and vegetation fostered suitable fuel and weather conditions and an ignition source. Such periods include the early Holocene in most regions, the late Holocene in the northern Great Basin, the late 1500s, the 1850s, the 1930s, and the late 1980s to 1990s. The fire-history record, when viewed on millennial and centennial time scales, indicates no long-term cycle, because the fire regime has continually changed with climate variations.

These climate-vegetation-fire linkages on short and long time scales are the backdrop against which human perturbations must be assessed. Although we have a basic understanding of how fire frequency has changed with climate and vegetation on Holocene time scales, the archaeological and ethnographic records provide little information about the prehistoric use of fire. A relation between human population size and resource utilization seems obvious, but assessing the role of burning requires information on the particular adaptations of the group, their available technologies, and their population size and density, as well as the characteristics of their environment. Without such information, a direct link between fire and humans will never be established.

The case studies described above show a decline in fire occurrence that started between 1,000 and 500 years ago, which coincides with regional cooling and increased moisture at the end of the Medieval Warm period and beginning of the Little Ice Age. Similarly, increases in fire occurred in the Willamette Valley, northern Great Basin, eastern Cascades, and Blue Mountains in the late nineteenth and twentieth centuries following the Little Ice Age. Certainly, the buildup of biomass during the Little Ice Age may have set the stage for more intense fires of recent times, but these environmental changes pale in comparison to the additive effects of Euro-American settlement. Logging, farming, grazing, mining, and fire elimination in the last century have altered vegetation and fire regimes on a regional scale more than any other event of the last 11,000 years. In contrast, prehistoric peoples locally altered the landscape, but there is no strong evidence that their activities created new vegetation types at a regional scale. Even in the Willamette Valley, where early settlers describe the burning activities of the Kalapuya, these activities alone do not explain the presence of prairie, savanna, and oak woodland. Such biomes developed simultaneously in several parts of the Pacific Northwest, as a result of warm dry conditions and frequent fires in the early Holocene, and became restricted in the middle and late Holocene, when conditions were cooler and wetter. Native peoples may have acted as an ignition source for fires, but the ability of vegetation to burn was undoubtedly determined by fuel and weather conditions.

A greater myth than that of the pristine landscape is the assumption that the forests at the time of Euro-American exploration and settlement are representative of all of prehistory. On the contrary, what early Europeans described was only a snapshot of ecosystem change operating on multiple temporal and spatial scales. It would not be possible to re-create the forests that existed 100, 500, or 1,000 years ago, even if we knew past forest conditions perfectly, or the role of Native American activity precisely. A "snapshot" approach to restoration is untenable because the current set of climate conditions is unique on both centennial and millennial time scales. The paleoecological record argues instead that natural ecosystems are dynamic. They should be managed in ways that allow the possibility of changes in species' range and abundance and the occurrence of large, stand-replacing fires in the face of climate change. History suggests that such changes are inevitable in the face of climate change.

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Literature Cited

Aikens, C. M. 1983. Environmental archaeology in the western United States. Pp. 239–251 in *Late Quaternary environments of the United States*, vol. 2, ed. H. E. Wright, Jr. Minneapolis: University of Minnesota Press.

———. 1993. *Archaeology of Oregon*. U.S. Department of Interior, Bureau of Land Management. BLM/OR/WA/ST-93/16+8100.

Aikens, C. M., and D. L. Jenkins, ed. 1994. *Archaeological researches in the Northern Great Basin: Fort Rock archaeology since Cressman*. University of Oregon anthropological papers 50. Eugene: University of Oregon, Department of Anthropology and State Museum of Anthropology.

Agee, J. K. 1991. Fire history along an elevation gradient in the Siskiyou Mountains, Oregon. *Northwest Science* 65:188–199.

———. 1993. *Fire ecology of Pacific Northwest forests*. Washington, D.C.: Island Press.

Baker, R. G. 1983. Holocene vegetational history of the western United States. Pp. 109–127 in *Late-Quaternary environments of the United States*, vol. 2, ed. H. E. Wright, Jr. Minneapolis: University of Minnesota Press.

Balling, R. C., Jr., G. A. Meyer, and S. G. Wells. 1992. Climate change in Yellowstone National Park: Is the drought related risk of wildfires increasing? *Climatic Change* 22:34–35.

Barnosky, C. W., P. M. Anderson, and P. J. Bartlein. 1987. The northwestern U.S. during deglaciation: Vegetational history and paleoclimatic implications. Pp. 289–321 in *North America and adjacent oceans during the last deglaciation*, ed. W. F. Ruddiman and H. E. Wright, Jr., *The Geology of North America*, vol. K-3. Boulder: Geological Society of America.

Barrett, S. W., and S. F. Arno. 1982. Indian fires as an ecological influence in the northern Rockies. *Journal of Forestry* 80:647–651.

———. 1999. Indian fires in the Northern Rockies; ethnohistory and ecology. Pp. 50–64 in *Indians, fire, and the land in the Pacific Northwest*, ed. R. Boyd. Corvallis: Oregon State University Press.

Bartlein, P. J., K. H. Anderson, P. M. Anderson, M. E. Edwards, C. J. Mock, R. S. Thompson, R. S. Webb, T. Webb III, and C. Whitlock. 1998. Paleoclimate simulations for North America over the past 21,000 years: Features of the simulated climate and comparisons with paleoenvironmental data. *Quaternary Science Reviews* 17:549–585.

Beckham, S. D. 1990. History of western Oregon since 1846. Pp. 180–188 in *Handbook of North American Indians,* vol. 7: *Northwest coast,* ed. W. Suttles. Washington, D.C.: Smithsonian Institution.

Beckham, S. D., R. Minor, and K. A. Toepel. 1981. *Prehistory and history of BLM lands in west central Oregon: A cultural resources overview.* University of Oregon anthropological papers 25. Eugene, Ore.

Berkley, E. 2000. Temporal and spatial variability of fire occurrence in western Oregon, A.D. 1200 to present. Master's thesis, Department of Geography, University of Oregon, Eugene.

Bonnicksen, T. M. 1989. Fire gods and federal policy. *American Forests* 95:14–16, 66–68.

Bork, J. 1985. Fire history in three vegetation types on the east side of the Oregon Cascades. Ph.D. diss., Oregon State University, Corvallis.

Boyd, R. 1975. Another look at the "fever and ague" of Western Oregon. *Ethnohistory* 22:135–154.

———. 1986. Strategies of Indian burning in the Willamette Valley. *Canadian Journal of Anthropology* 5:67–86.

———. 1999a. Strategies of Indian burning in the Willamette Valley. Pp. 94–138 in *Indians, fire, and the land in the Pacific Northwest,* ed. R. Boyd. Corvallis: Oregon State University Press.

———, ed. 1999b. *Indians, fire, and the land in the Pacific Northwest.* Corvallis: Oregon State University Press.

Boyd, R. T. 1990. Demographic history, 1774–1874. Pp. 135–148 in *Handbook of North American Indians,* vol. 7: *Northwest coast,* ed. W. Suttles. Washington, D.C.: Smithsonian Institution.

Burke, C. J. 1979. Historic fires in the central western Cascades, Oregon. Master's thesis, Department of Forest Science, Oregon State University, Corvallis.

Burkhart, J. W., and E. W. Tisdale. 1976. Causes of juniper invasion in southwestern Idaho. *Ecology* 76:482–484.

Burns, R. M., and B. H. Honkala. 1990. *Silvics of North America,* vol. 1: *Conifers.* USDA Forest Service, agricultural handbook 654.

Butzer, K. W. 1990. The Indian legacy in the American landscape. Pp. 27–50 in *The making of the American landscape,* ed. M. P. Conzen. Boston: Unwin Hyman.

Chase, A. 1987. *Playing God in Yellowstone.* San Diego: Harcourt, Brace, Jovanovich.

Clark, J. S. 1990. Fire and climate change during the last 750 years in northwestern Minnesota. *Ecological Monographs* 60:135–159.

Clark, J. S., and P. D. Royall. 1996. Local and regional sediment charcoal evidence for fire regimes in presettlement northeastern North America. *Journal of Ecology* 84:67–80.

Clark, J. S., J. Lynch, B. Stocks, and J. Goldammer. 1998. Relationships between charcoal particles in air and sediments in west-central Siberia. *The Holocene* 8:19–29.

Clarke, S. 1905. *Pioneer Days of Oregon History* 1:89–90.

Cronon, W. 1995. The trouble with wilderness; or getting back to the wrong nature. Pp. 69–90 in *Uncommon ground: Toward reinventing nature,* ed. W. Cronon. New York: W. W. Norton.

Cwynar, L. C. 1987. Fire and the forest history of the North Cascade Range. *Ecology* 68:791–802.

Denevan, W. 1992. The pristine myth: The landscape of the Americas in 1492. *Annals of the Association of American Geographers* 82:369–385.

Douglas, D. 1959. *Journal kept by David Douglas during his travels in North America 1823–1827.* New York: Antiquarian Press.

Dunwiddie, P. W. 1986. A 6000-year record of forest history on Mount Rainier, Washington. *Ecology* 67:58–68.

Flores, D. 1997. The West that was, and the West that can be. *High Country News* 29:6–7.

Franklin, J. F., and Dyrness, C. T. 1973. *Natural vegetation of Oregon and Washington.* General technical report PNW-8. Portland, Ore.: USDA Forest Service, Pacific Northwest Research Station.

Franklin, J. F., F. J. Swanson, M. E. Harmon, D. A. Perry, T. A. Spies, V. H. Dale, A. McKee, W. K. Ferrell, J. E. Means, S. V. Gregory, J. D. Lattin, T. D. Schowalter, and D. Larson. 1991. Effects of global climate change on forests in northwestern North America. *The Northwest Environmental Journal* 7:233–254.

Fritts, H. C. 1976. *Tree rings and climate.* New York: Academic Press.

Gardner, J. J., and C. Whitlock. In review. Charcoal accumulation following a recent fire in the Cascade Range, northwestern USA, and its relevance for fire-history studies. *The Holocene.*

Garfin, G. M., and M. K. Hughes. 1996. *Eastern Oregon divisional precipitation and Palmer Drought Severity Index from Tree-Rings.* Final Report to USDA Forest Service cooperative agreement PNW 90-174.

Graumlich, L. J. 1987. Precipitation variation in the Pacific Northwest (1675–1975) as reconstructed from tree rings. *Annals of the Association of American Geographers* 77:19–29.

———. 1991. Subalpine tree growth, climate, and increasing CO_2 an assessment of recent growth trends. *Ecology* 72:1–11.

Graumlich, L. J., and L. B. Brubaker. 1986. Reconstruction of annual temperature (1590–1979) for Longmire, Washington, derived from tree rings. *Quaternary Research* 25:223–234.

Grigg, L. D., and C. Whitlock. 1998. Late-glacial climate and vegetation changes in western Oregon. *Quaternary Research* 49:287–298.

Gruell, G. 1985. Fire on the early western landscape: An annotated record of wildland fires, 1776–1900. *Northwest Science* 59:97–107.

Hemstrom, M. A., and J. F. Franklin. 1982. Fire and other disturbances of the forests in Mount Rainier National Park. *Quaternary Research* 18:32–51.

Henry, A. 1992. *The journal of Alexander Henry the Younger 1799–1814,* vol. 2, ed. B. M. Gough. Toronto: The Champlain Society.

———. 1977. Quaternary paleontology of the Pacific slope of Washington. *Quaternary Research* 8:282–306.

Heusser, C. J. 1983. Vegetation history of the northwestern United States, including Alaska. Pp. 239–258 in *Late Quaternary environments of the United States*, ed. S. C. Porter. Minneapolis: University of Minnesota Press.

Heyerdahl, E. K. 1997. Spatial and temporal variation in historical fire regimes of the Blue Mountains, Oregon, and Washington: The influence of climate. Ph.D. diss., University of Washington, Seattle.

Holmes, R. L., R. I. C. Adams, and H. C. Fritts. 1986. *Tree-ring chronologies of western North America: California, eastern Oregon, and northern Great Basin.* Chronology series 6. Tucson: Laboratory of Tree-ring Research.

Hulse, D., A. Branscomb, J. G. Duclos, S. Gregory, S. Payne, D. Richey, H. Dearborn, L. Ashkenas, P. Minear, J. Christy, E. Alverson, D. Diethelm, and M. Richmond. 1998. *Willamette River Basin: A planning atlas*, ver. 1.0. Seattle: University of Washington Press.

Impara, P. C. 1997. Spatial and temporal patterns of fire in the forests of the central Oregon Coast Range. Ph.D. diss., Oregon State University, Corvallis.

Johannessen, C. L., W. A. Davenport, A. Millet, and S. McWilliams. 1971. The vegetation of the Willamette Valley. *Annals of the Association of American Geographers* 61:286–302.

Knox, M. A. 2000. Ecological change in the Willamette Valley at the time of Euro-American Contact, ca. 1800–1850. Master's thesis, Department of Geography, University of Oregon, Eugene.

Kutzbach, J. E., and P. J. Guetter. 1986. The influence of changing orbital patterns and surface boundary conditions on climate simulations for the past 18,000 years. *Journal of Atmospheric Sciences* 43:1726–1759.

Langston, N. 1995. *Forest dreams, forest nightmares: The paradox of old growth in the inland West.* Seattle: University of Washington Press.

Leopold, A. S., S. A. Cain, C. M. Cottam, I. N. Gabrielson, and T. L. Kimball. 1963. Wildlife management in the national parks. *Transactions of the North American Wildlife Natural Resource Conference* 28:28–45.

Long, C. A., C. Whitlock, P. J. Bartlein, and S. H. Millspaugh. 1998. A 9000-year fire history from the Oregon Coast Range based on a high-resolution charcoal study. *Canadian Journal of Forest Research* 28:774–787.

Loy, W. G., S. Allen, and C. P. Patton. 1976. *Atlas of Oregon.* Eugene: University of Oregon Press.

Maciliwain, C. 1994. Western inferno provokes a lot of finger-pointing, but little action. *Science* 370:585.

Martin, P. S. 1984. Prehistoric overkill: The global model. Pp. 345–404 in *Quaternary extinctions: A prehistoric revolution*, ed. P. S. Martin and R. G. Klein. Tucson: University of Arizona Press.

McLachlan, J. S., and L. B. Brubaker. 1995. Local and regional vegetation change on the northeastern Olympic Peninsula during the Holocene. *Canadian Journal of Botany* 73:1618–1627.

McLeod, A. R. 1961. Journal of a trapping expedition along the coast south of the Columbia in charge of A. R. McLeod C. T. Summer 1826. Pp. 141–217 in *Peter Skene Ogden's Snake Country Journal 1826–27*, ed. K. G. Davies. London: The Hudson's Bay Record Society.

Mehringer, P. J., Jr. 1985. Late Quaternary pollen records from the Pacific Northwest and Northern Great Basin of the United States. Pp. 167–189 in

Pollen records of late Quaternary North American sediments, ed. V. M. Bryant, Jr., and R. G. Holloway. Dallas: American Association of Stratigraphic Palynologists Foundation.

Mehringer, P. J., Jr., and P. E. Wigand. 1990. Comparison of late Holocene environments from woodrat middens and pollen: Diamond Craters, Oregon. Pp. 294–325 in *Packrat middens: The last 40,000 years of biotic change*, ed. J. L. Betancourt, T. R. Van Devender, and P. S. Martin. Tucson: University of Arizona Press.

Miller, R. F., and J. A. Rose. 1995. Historic expansion of *Juniperus occidentalis* (western juniper) in southeastern Oregon. *Great Basin Naturalist* 55:37–45.

Miller, R. F., and P. E. Wigand. 1994. Holocene changes in semiarid pinyon-juniper woodlands. *BioScience* 44:465–474.

Millspaugh, S. H., and C. Whitlock. 1995. A 750-year fire history based on lake sediment records in central Yellowstone National Park. *The Holocene* 3:283–292.

Minto, J. 1900. The number and condition of the native race in Oregon when first seen by white men. *Oregon Historical Quarterly* 1:298–315.

Mohr, J. A., C. Whitlock, and C. J. Skinner. 2000. Postglacial vegetation and fire history, eastern Klamath Mountains, California. *The Holocene* 10:587–601.

Morris, W. 1936. Forest fires in western Oregon and Washington. *Oregon Historical Quarterly* 35:313–339.

Morrison, P., and F. J. Swanson. 1990. *Fire history and pattern in a Cascade Range landscape*. USDA Forest Service General technical report PW-254.

Mutch, R. W., S. F. Arno, J. K. Brown, C. E. Carlson, R. D. Ottmar, and J. L. Peterson. 1993. Forest health in the Blue Mountains: A management strategy for fire-adapted ecosystems. In *Forest health in the Blue Mountains: Science perspectives*, ed. T. L. Quigley. USDA Forest Service General technical report PNW-295.

National Interagency Fire Center. 2000. On the Web at *http://www.nifc.gov.*

O'Hara, E. 1911. *Pioneer Catholic History of Oregon*. Portland, Ore.: Glass and Prudhomme.

Ohlson, M., and E. Tryterud. 2000. Interpretation of the charcoal record in forest soils: Forest fires and their production and deposition of macroscopic charcoal. *The Holocene* 10:519–525.

Oregon Department of Forestry. 1970. *Tillamook fires map* [scale: 1:126,720].

———. 1997. On the Web at http://www.odf.state.or.us/atlas/maps/light.gif.

Palmer, J. 1966. *Journal of travels over the Rocky Mountains*. Ann Arbor: University Microfilms.

Parker, S. 1840. *Journal of an exploring tour beyond the Rocky Mountains*. Ithaca, N.Y.: Parker.

Patterson, W. A., III, K. J. Edwards, and D. J. MacGuire. 1987. Microscopic charcoal as a fossil indicator of fire. *Quaternary Science Reviews* 6:3–23.

Pearl, C. A. 1999. Holocene environmental history of the Willamette Valley, Oregon: Insights from an 11,000-year record from Beaver Lake. Master's thesis, Interdisciplinary Studies Program, University of Oregon, Eugene.

Pyne, S. 1982. *Fire in America*. Princeton: Princeton University Press.

———. 2000. Where have all the fires gone? *Fire Management Today* 60:4–6.

Ramenofsky, A. F. 1987. *Vectors of death: The archaeology of European contact.* Albuquerque: University of New Mexico Press.

Riggs, T. 1900. The upper Calapooia. *Oregon Historical Quarterly* 4:74–77.

Romme, W. H., and M. G. Turner. 1991. Implications of global climate change for biogeographic patterns in the Greater Yellowstone Ecosystem. *Conservation Biology* 5:373–386.

Running, S. W., and R. R. Nemani. 1991. Regional hydrologic and carbon balance response of forests resulting from potential climate change. *Climatic Change* 19:349–368.

Sea, D. S., and C. Whitlock. 1995. Postglacial vegetation and climate of the Cascade Range, central Oregon. *Quaternary Research* 43:370–381.

Seton, A. 1993. *Astorian adventure: The journal of Alfred Seton 1811–1815,* ed. R. F. Jones. New York: Fordham University Press.

Shinn, D. A. 1980. Historical perspectives on range burning in the inland Pacific Northwest. *Journal of Range Management* 33:415–423.

Skinner, C. N., and C. Chang. 1996. Fire regimes, past and present. Pp. 1041–1069 in *Sierra Nevada Ecosystem Project: Final report to Congress,* vol. 2: *Assessments and scientific basis for management options.* Davis: University of California, Davis, Centers for Water and Wildland Resources.

Stuart, R. 1995. *The discovery of the Oregon Trail,* ed. P. Rollins. Lincoln: University of Nebraska Press.

Stuiver, M., and P. J. Reimer. 1993. Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program. *Radiocarbon* 35:215–230.

Stuiver, M., P. J. Reimer, E. Bard, J. W. Beck, G. S. Burr, K. A. Hughen, B. Kromer, G. McCormac, J. Van der Plicht, and M. Spurk. 1998. INTCAL89 radiocarbon age calibration, 24,000-0 cal BP. *Radiocarbon* 40:1041–1083.

Sugita, S., and M. Tsukada. 1982. The vegetation history in western North America I. Mineral and Hall Lakes. *Japanese Journal of Ecology* 32:499–515.

Suttles, W., and Ames, K. 1997. Pre-European History. Pp. 255–274 in *The rainforests of home: Profile of a North American bioregion,* ed. P. K. Schoonmaker, B. von Hagen, and E. C. Wolf. Washington, D.C.: Island Press.

Swetnam, T. W., and J. L. Betancourt. 1998. Mesoscale disturbance and ecological response to decadal climatic variability in the American Southwest. *Journal of Climate* 11:3128–3147.

Taylor, A. H. 1993. Fire history and structure of red fir (*Abies magnifica*) forests, Swain Mountain Experimental Forest, Cascade Range, northeastern California. *Canadian Journal of Forest Research* 23:1672–1678.

Teensma, P. D. A. 1987. Fire history and fire regimes of the central western Cascades of Oregon. Ph.D. diss., University of Oregon, Eugene.

Thompson, R. S., C. Whitlock, P. J. Bartlein, S. Harrison, and W. G. Spaulding. 1993. Climatic changes in the western United States since 18,000 yr B.P. Pp. 468–513 in *Global climates since the last glacial maximum,* ed. H. E. Wright, Jr., J. E. Kutzbach, T. Webb III, W. F. Ruddiman, F. A. Street-Perrott, and P. J. Bartlein. Minneapolis: University of Minnesota Press.

Towle, J. C. 1982. Changing geography of the Willamette Valley woodlands. *Oregon Historical Quarterly* 83:66–87.

Ubelaker, D. 1988. North American population size, A.D. 1500–1985. *American Journal of Physical Anthropology* 77:289–294.

Wagner, F. H., and Kay, C. E. 1993. "Natural" or "healthy" ecosystems: Are U.S. national parks providing them? Pp. 257–270 in *Humans as components of ecosystems*, ed. M. J. McDonnell and S. T. A. Pickett. New York: Springer-Verlag.

Weisberg, P. J. 1998. Fire history, fire regimes, and development of forest structure in the central western Oregon Cascades. Ph.D. diss., Department of Forest Science, Oregon State University, Corvallis.

Whitlock, C. 1992. Vegetational and climatic history of the Pacific Northwest during the last 20,000 years: Implications for understanding present-day biodiversity. *The Northwest Environmental Journal* 8:5–28.

Whitlock, C., and Bartlein, P. J. 1997. Vegetation and climate change in northwest America during the past 125 kyr. *Nature* 388:57–61.

Whitlock, C., and C. P. S. Larsen. 2000. Charcoal as a Fire Proxy. In *Tracking environmental change using lake sediments*, vol. 2: *Biological techniques and indicators*, ed. J. P. Smol, H. J. B. Birks, and W. M. Last. Dordrecht, Netherlands: Kluwer Academic.

Whitlock, C., and S. H. Millspaugh, 1996. Testing assumptions of fire history studies: An examination of modern charcoal accumulation in Yellowstone National Park. *The Holocene* 6:7–15.

Wigand, P. E. 1987. Diamond Pond, Harney County, Oregon. *Great Basin Naturalist* 47:427–458.

Wilkes, C. 1926. *Diary of Wilkes in the Northwest*, ed. E. S. Meany. Seattle: University of Washington Press.

Williams, G. W. 2000. Early fire use in Oregon. *Fire Management Today* 60:13–20.

Work, J. 1923. John Work's journey from Fort Vancouver to Umpqua River, and return, in 1834. *Oregon Historical Quarterly* 24:238–268.

Worona, M. A., and Whitlock, C. 1995. Late-Quaternary vegetation and climate history near Little Lake, Central Coast Range, Oregon. *Geological Society of America Bulletin* 107:867–876.

Zenk, H. B. 1990. Kalapuyans. Pp. 547–553 in *Handbook of North American Indians*, vol. 7: *Northwest coast*, ed. W. Suttles. Washington, D.C.: Smithsonian Institution.

Zucker, J. 1983. *Oregon Indians, culture, history and current affairs: An atlas and introduction*. Portland: Western Imprints, The Press of the Oregon Historical Society.

Zyback, R. 1995. Interview. *Forests Today and Forever* 9:6.