After a century of logging and fire exclusion, the ponderosa pine forests that were historically a hallmark of the American West today face wildfires and insect epidemics of unprecedented severity. These hazards and the stagnating growth of young pines virtually eliminate development of large, long-lived ponderosas. Unique ecological, cultural, and archaeological values of historic ponderosa forests are being lost as they deteriorate or burn in wildfires. Forest managers and ecologists are attempting through intelligent management to restore sustainable conditions in ponderosa pine forests based on their historic structure and the disturbance processes that shaped them.

"GIANT PINES AND GRASSY GLADES"

THE HISTORIC PONDEROSA ECOSYSTEM, DISAPPEARING ICON OF THE AMERICAN WEST

In 1853, Rebecca Ketcham, a member of a wagon train ascending the Blue Mountains in the Oregon Territory, wrote, "Our road has been nearly the whole day through the woods, that is, if beautiful groves of pine trees can be called woods…. The country all through is burnt over, so often there is not the least underbrush, but the grass grows thick and beautiful."[1] Four years later, Lt. Edward Beale, traveling on horseback through the unexplored forests of northern Arizona, wrote, "It is the most beautiful region…. A vast forest of gigantic pines, intersected frequently with open glades, sprinkled all over with mountains, meadows, and wide savannahs, and covered with the richest grasses, was traversed by our party for many days."[2]

The pines those two early travelers so admired were *Pinus ponderosa*, and open forests of this species, with an average spacing of 25 feet or more between tree trunks, once covered upwards of 25 million acres in western North America, ranging from southern British Columbia to northern Mexico and from the western Great Plains nearly to the Pacific Ocean. In the semiarid West, where forest is often confined to the mountains, ponderosa pine forms the lowest-elevation forests. Evidence suggests that ponderosa-dominated stands once extended 1,000 feet higher in elevation than they do today.

The ponderosa pine was and remains highly valued for its wood, shelter, and beauty. During the frontier era, the open-grown ponderosas yielded such excellent lumber that often other tree species were not harvested for this purpose until the supply of ponderosa was depleted. Dominated by mature pines of many

BY STEPHEN F. ARNO, CARL E. FIEDLER, & MATTHEW K. ARNO

different ages along with occasional patches of young trees, these forests were intermittently thinned and pruned of low branches by surface fires that burned through grassy undergrowth and pine-needle litter. Because little fuel accumulated, frequent burning allowed the open-grown fire-resistant ponderosa pine to achieve large size and great age—400 to 800 years in many stands.

Today, ponderosa pine forests largely consist of crowded, stagnating stands of small trees vulnerable to wildfires and attack by insects and disease. The resulting dense, multistoried conditions now make ponderosa pine the primary forest type fueling massive stand-replacing wildfires in the wildland-urban interface. Nevertheless, perhaps because of our insufficient historical and ecological perspective, the ramifications of deteriorating ponderosa pine forests have received little attention. Threats to this forest are more perilous and of greater magnitude than the highly publicized loss of centuries-old Douglas-fir (*Pseudotsuga menziesii var. menziesii*), which eliminated most timber harvesting of that forest type.[3] The decline of ponderosa pine forests can be compared to the virtual disappearance of the vast and biologically rich longleaf pine (*Pinus palustris*) ecosystem in the southeastern United States.[4] Their vulnerability to fire has ecological, economic, amenity, and public safety impacts and threatens the loss of Native American cultural artifacts and historical information, but intelligent management may be able to effect the restoration of these once-majestic forests.

G. A. PEARSON, U.S. FOREST SERVICE

This view of a horse-drawn wagon traversing open ponderosa pine forest through the Tusayan National Forest, Arizona, in 1909, is representative of what settlers such as Rebecca Ketcham and Lt. Edward Beale saw a half-century earlier.

STRUCTURE AND ECOLOGY, THEN AND NOW

Journal accounts of presettlement ponderosa pine forests throughout much of the West describe magnificent stands dominated by large, high-crowned trees with smooth trunks sculpted by centuries of surface fires. Mature ponderosas grew in parklike stands, the impressive trees standing well apart or in small clumps, with a luxuriant undergrowth of grasses and herbs. Travelers commonly rode on horseback or even pulled wagons through these forests without need of clearing a trail.[5] Nineteenth-century

JOHN LEIBERG, U.S. GEOLOGICAL SURVEY

A fire-maintained open-grown ponderosa pine forest in 1897, near the mouth of Overwhich Creek, Bitterroot National Forest, Montana. Note the burned snag in left foreground. This is a moist site that today without frequent fires is readily taken over by young Douglas-fir and grand fir.

COURTESY OF CARL FIEDLER

Severe competition from dense thickets of younger pines left these old ponderosa pines vulnerable to bark beetle attack and wild fire. Photographed on the Dixie National Forest, Utah.

U.S. General Land Office surveys in ponderosa forests and forest inventories in the newly created federal forest reserves describe, quantify, and provide photographs of these conditions.[6]

In the Black Hills of South Dakota, early landscape photographs show some dense, young ponderosa forests, and these existed in other areas as well.[7] Still, dozens of retrospective investigations, from southern British Columbia to California and Arizona and eastward to the Continental Divide in the Rocky Mountains, suggest that most ponderosa forests in this broad region were open stands dominated by large old trees.[8] The open-grown pre-1900 forests generally averaged between 15 and 75 trees per acre, compared with 200 to 1,000 per acre in modern stands on the same sites.[9]

Investigations of presettlement ponderosa forests have found that most were maintained by frequent surface fires burning through the grass and needle litter at average intervals of 5 to 25 years.[10] The fires apparently killed a majority of saplings, especially the more fire-sensitive firs—inland Douglas-fir (*Pseudotsuga menziesii var. glauca*), grand fir (*Abies grandis*), and white fir (*A. concolor*)—which have finer and denser foliage, longer crowns, smaller buds, and thinner bark than young ponderosa pines. By "thinning" trees and returning nutrients to the soil, low-intensity fires favored grasses and other herbaceous plants, many of which resprout from rhizomes. Indeed, diverse undergrowth communities and animal habitats are defining features of presettlement forests shaped by frequent, low-intensity fires.[11] The unique structural components associated with these forests also provide habitat for wildlife at various scales. For example, the pygmy nuthatch relies on large individual trees, the Abert's squirrel requires patches of old trees to aid movement and provide adequate food, and the northern goshawk requires extensive old-growth across a landscape.[12]

The pattern of frequent, low-intensity fires has been traced back to the late 1400s by dating fire scars on living pine trees and stumps.[13] Similar fire chronologies were extended back more than 2,000 years by dating fire scars on old stumps of giant sequoia (*Sequoiadendron gigantium*) located immediately upslope from a ponderosa pine forest in California.[14] The pattern of frequent burning in ponderosa forests was disrupted around 1900 by organized fire suppression, heavy grazing that removed fine fuels, conversion of forestland to agriculture, and relocation of Native Americans (one source of ignitions) to reservations.

Frequent burning was the primary factor in maintaining ponderosa pine dominance over shade-tolerant firs, which are better adapted to growing in the understory and can outcompete pine for soil moisture. Frequent burning induced pitch to concentrate at the base of mature ponderosas, affording resistance to some decay-causing organisms and increasing tree longevity. The fires evidently affected pH and other soil properties in ways that helped control some root diseases.[15] Pitch and foliar chemicals called terpenes also helped the trees combat attacks by bark beetles and other destructive agents.

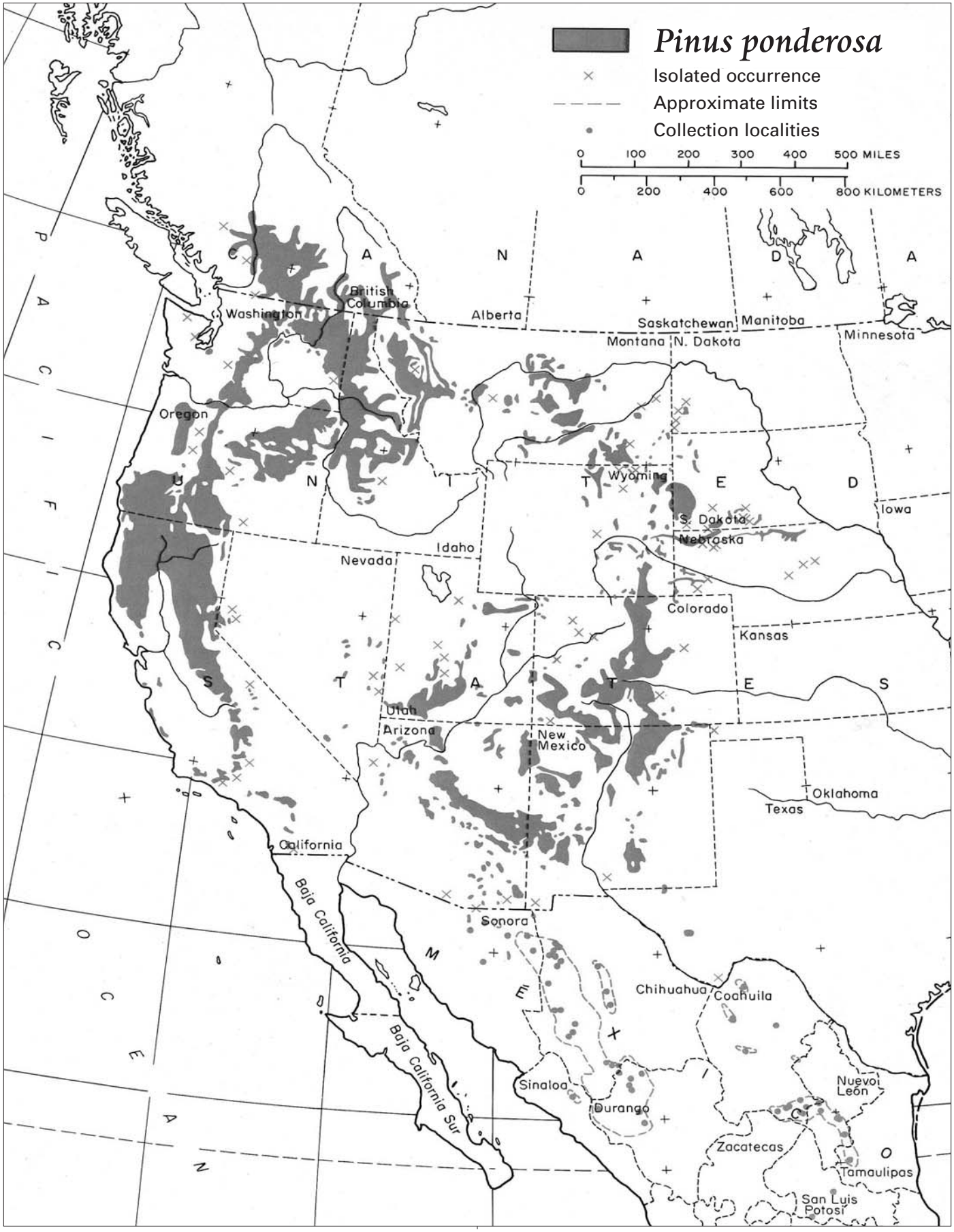
Studies of forest succession from southern British Columbia and Montana to California suggest that millions of acres of historical ponderosa pine forest have now been replaced by fir-dominated stands.[16] Moist sites that today are dominated by firs often retain stumps and other remnants of a former forest of large ponderosa pines, with scars from past fires. Even in forests too dry for firs, old ponderosa pines are weakened by asymmetrical competition if young pines are not removed by thinning or surface fires.[17] A prolonged drought—a common phenomenon in the semiarid West—or even a low-intensity fire easily kills the stressed, vulnerable trees.[18]

FORCES OF CHANGE

Since large ponderosa pines were historically abundant and accessible and yielded high-quality lumber, they became the focus of the timber industry in the Interior West. They supplied the needs of bustling frontier communities, intensive mining operations, and rapidly expanding railroads whose untreated pine ties had to be replaced every few years. In 1897, a forest reserve inspector, John Leiberg, observed that in western Montana the booming lumber industry relied on ponderosa pine, but it was evident that dwindling supplies would soon require switching to other species.[19]

Early logging practices typically removed most of the mature trees, opening the forest and creating conditions favorable for pine regeneration. Ponderosa pine is shade intolerant and requires ample light and space to develop into large, mature trees. But because the new stands developed without the thinning effect of frequent fires, few trees died, and after several decades the crowded stands began to stagnate. Most of the original ponderosa pine forest had been harvested by 1950. Thereafter, extensive road systems penetrated the more rugged and remote national forest and private lands to remove the remaining mature ponderosas.

Starting about 1880, unregulated livestock grazing damaged many ponderosa pine forests throughout the West. Heavy grazing by cattle, sheep, and horses destroyed native grasses and bared the soil, allowing massive numbers of tree seedlings to colonize.[20] Grazing and trampling of surface fuels also reduced historically frequent fires even before the U.S. Forest Service's fire suppression policy was enacted in the early 1900s.[21] Removal of Native Americans, an ignition source, further reduced burning.[22] Agricultural and other development also prevented fires from



Although the range of the ponderosa pine tree is fairly extensive, open grown ponderosa pine forests now cover probably less than 5 million acres, down from a peak of about 25 million acres before European settlement.

COURTESY OF HUMPHREY'S TYPE 1 USDA/USDI SOUTHWEST REGION INCIDENT MANAGEMENT TEAM

The remains of homes following the Rodeo-Chediski wildfire (2002) in Arizona are seen from the air. Housing developments built in the wildland-urban interface like this one complicate plans for active forest management.

spreading across the landscape as they had in the past. Organized fire suppression developed quickly in the early 1900s and extinguished most low-intensity fires in ponderosa pine forests, which were readily accessible to early fire crews. By the end of World War II, fire suppression had become so effective that wildfires burned only about half a million acres annually in the 11 contiguous western states, compared with an estimated 20 million to 25 million acres prior to 1900.[23] Forests were likely about one-third of the historical acreage burned, with the ponderosa type accounting for the lion's share.

In the early 1900s, prominent timberland owners in northern California campaigned to get the U.S. Forest Service to test fire as a tool in managing mixed conifer forests. One timberman published an article in *Sunset* magazine asserting that "We must count on fire to help in practical forestry…[using] fire as a servant…[otherwise] it will surely be master in a very short time."[24] The Forest Service refused, maintaining that fire damaged trees and killed saplings that could help create a denser forest, producing more timber.[25] Ironically, forestry research and the emerging science of ecology eventually concluded that a semiarid climate prevents ponderosa pine forests from sustaining a high density of trees.[26]

In 1943, a government forester named Harold Weaver risked his career by challenging national fire policy in the *Journal of Forestry*.[27] Weaver's controversial article highlighted the negative effects of fire exclusion, already apparent in ponderosa pine forests. That same year, the U.S. Forest Service reluctantly accepted controlled burning as a potentially useful treatment for forests in the southeastern United States but still refused to sanction the use of fire in western forests.[28]

By the 1960s, ecologists had elucidated the important natural role that fire plays in maintaining ponderosa forests. In the late 1970s, the Forest Service acknowledged that accumulating forest fuels were contributing to an alarming increase in massive, uncontrollable wildfires. In response, the agency replaced its fire exclusion policy with "fire management."[29] The instigator and leader of the 70-year crusade to eliminate fire from the forest now recognized a need to restore fire under suitable conditions and use prescribed burning.

Revising official policy, however, was far easier than implementing change on the ground. Many ponderosa forests had changed so fundamentally in density, species composition, tree vigor, and fuel accumulation that fire managers and ecologists discovered prescribed fire might now cause more harm than good. For fire to be beneficial, it would be necessary to restore appropriate structural conditions. Altering structure required "restoration forestry," which, unlike traditional logging, emphasizes leaving the best trees for the future forest and removing excess small trees, most of the firs, and dead fuels. Restoration cutting might be followed by prescribed burning, with the entire process likely costing more than any proceeds from harvesting.[30]

Implementing the new fire policy also depended on acceptance by a skeptical public that for generations had been led to view fire in the forest as an unmitigated evil. Furthermore, between 1980 and 1999, 8.4 million new homes had been built in the wildland-urban interface, with ponderosa forests at the western edge.[31] Housing development complicates plans for active forest man-

agement and especially for prescribed burning. Still another problem was the National Environmental Protection Act and other environmental laws that generally failed to recognize the essential role of fire in forests, and instead created barriers to fire use. For example, the Clean Air Act and related state and local smoke regulations severely restrict opportunities for restoring fire.[32]

IMPLICATIONS OF MODERN CONDITIONS

Present-day ponderosa pine forests are a testament to the failure and tragedy of the fire exclusion policy. By the late 1970s, most ponderosa forests had already missed several natural fire cycles and had been further damaged by logging and grazing. Forest conditions were spiraling downward, with overcrowded second-growth stands vulnerable to insect epidemics. Since 1980, bark beetles have killed the weakened ponderosas and inland Douglas-firs on millions of acres from southern British Columbia to Arizona and New Mexico. Some second-growth ponderosa stands have been logged or thinned, but small trees continue to proliferate in the understory because they have no value as merchantable products or even firewood and are too costly to remove. What had once been resilient, durable forests dominated by centuries-old ponderosas now consisted of crowded young stands in decline.[33]

When drought struck the inland northwestern forests in the mid 1980s, even the firs that had displaced ponderosas suffered. Several million acres east of the Cascade crest and in the Blue Mountains of Oregon and Washington turned gray as firs died or were top-killed by a defoliating insect, the western spruce budworm. The budworm irruption resulted from an unprecedented buildup of firs ill-adapted to the dry habitats formerly dominated by ponderosa pine.[34]

Wildfires also escalated during the 1980s. Annual area burned in the 11 contiguous western states was averaging 2 million acres, a level not experienced since the early 1930s.[35] Much of the burning was taking place in the historic ponderosa pine type, but with the thickening forest growth, the burns were becoming uncontrollable crown fires. Such fires kill most trees, creating dead fuel for another fire and allowing invasive weeds to proliferate.[36] Despite improved firefighting technology, western burns exceeded 5 million acres in 2000 and 6 million in 2006. Expenditures for fire suppression, which do not include the equally daunting burned-site rehabilitation costs[37] or the costs of lost homes, recreation areas, timber, and property values, spiked to $1.6 billion in 2006. In many charred areas, scorched soils became impermeable to water, with erosion and debris flows from subsequent rains clogging streams and damaging roads.[38]

Relict ponderosa pines and related cultural and ecological artifacts are also at risk to today's wildfires. Some ponderosa forests in western Montana, central Idaho, Arizona, and New Mexico still contain trees with large, oval bark-peeling scars made by Native Americans in centuries past,[39] when the sweet inner bark was harvested as a food supplement or treat. Fire scars on ancient trees and stumps can be aged to reveal the chronology of historic fires. Growth-rings of relict ponderosas also provide a continuous record of climatic fluctuations and other environmental events stretching back hundreds of years.[40] For example, without long-term tree-ring records, scientists would not have elucidated the relationship of El Niño-induced climatic patterns to survival of the Anasazi and other ancient farming civilizations in the Southwest.[41] These artifacts—unique evidence of past events—are easily destroyed in modern wildfires.

THE PROMISE OF RESTORATION FORESTRY

Today there are still sizable tracts containing scattered old ponderosa pines and even some stands that have never been logged—mainly in wilderness and other natural areas—but collectively, these probably represent less than 5 percent of the historical forest type. Furthermore, simply protecting relict pre-1900 ponderosa forests from logging fails to safeguard them from the impacts of overcrowding and destructive wildfires.

Despite highly variable and often degraded forest conditions, strategies are available to restore extensive landscapes of ponderosa pine forest to a more productive, sustainable status.[42] Different restoration treatments are designed for forests that harbor centuries-old trees than for forests consisting of younger trees only. Because of their scarcity, forests with old trees should receive priority for treatment. A second priority is to begin preparing areas of second-growth forest as future old-growth, particularly on public lands. Well-designed treatments can accelerate development of some presettlement features in these forests within decades.

Restoration treatments are informed by knowledge of the forest's historical structure and the ecological processes that shaped it. Costs are considerable but pale compared with the wildfire-related expenses they could reduce.[43] One nontechnical book, *Mimicking Nature's Fire*,[44] and many specialized publications present details of restoration techniques and their application. A brief overview of restoration methods follows.

Forests containing relict ponderosa pines and other old shade-intolerant trees, such as sugar pine (*P. lambertiana*) or western larch (*Larix occidentalis*), can benefit from the removal of young trees, especially those in the rooting zone around old trees. If prescribed burning is planned, litter and duff should be raked away from the base of relict trees, particularly those with open scars. Fire-retardant foam and fire-shelter material can also be used to protect trunks of the most vulnerable old trees.

In younger forests, like the second-growth ones that followed early logging, restoration focuses on establishing a generally open structure or many small openings. Open conditions allow existing trees to grow vigorously and provide treeless patches where the shade-intolerant pine can regenerate. Beyond simply germinating, pine saplings need room to grow rapidly lest they stagnate or succumb to disease. The initial cutting treatments, and later treatments at intervals of perhaps 15 to 30 years, are designed to create and maintain an appropriate number of pines in different size classes so that the stand can perpetuate itself indefinitely. Published guidelines help define appropriate numbers of trees by size classes.[45] Generally, there are fewer large trees and progressively more medium and small trees, since large trees need more growing space and some of the small trees will die before maturing.

Cutting treatments focus on retaining the most vigorous pines as the future forest. If firs are abundant, they should be largely removed, since partially shaded conditions favor their regeneration and seed-bearing firs can soon regenerate prolifically. Historically, summertime fires killed young firs more effectively than today's prescribed fires, which are often conducted in spring

or fall, and many stands are not burned at all.

Some naturally occurring (lightning) fires might be allowed to burn in very large natural areas (where spread to private land is highly unlikely), particularly after fuel accumulations have been reduced. Prescribed burning alone may be sufficient to restore and maintain the ponderosa pine forest in special places, such as national parks. However, burning alone is not a reasonable option over most of ponderosa pine's range, considering air quality regulations and limited availability of personnel and suitable weather. Well-designed removal of trees of various sizes allows for efficient use of fire when and where it is most needed. Additionally, forestlands managed to yield revenue can use restoration forestry concepts patterned after natural processes and still produce commercial timber products.[46]

Smaller investments to restore ponderosa pine forests before they burn could provide many ecological and social benefits while also preventing destructive fires. However, it is difficult to obtain funding for this kind of restoration forestry because unlike fighting fires, restoration is not considered an emergency by state or federal agencies. Also, some environmental activists view restoration as "tampering with nature" and appeal or delay projects by invoking National Environmental Policy Act and National Forest Management Act regulations that fail to consider the role of fire in forests.[47]

CONCLUSIONS

To have any hope of saving remnant old-growth and recreating the forests of "giant pines and grassy glades" extolled by nineteenth-century travelers, restoration must be undertaken. Having spent decades studying ponderosa pine forests and developing and practicing restoration forestry along the way, we are convinced that this form of management could be applied successfully over large areas. This includes ponderosa forests adjacent to homes and developments, stands where income from timber is a goal, and areas where maintaining natural conditions is foremost. Restoration forestry can put these forests on track toward a resilient, low-hazard future as safe, attractive environments and habitat for wildlife. Nearby developed areas also benefit from reduced risk of impacts from wildfire. With ponderosa pine forests providing a buffer, natural fires could be allowed to burn in more remote, higher-elevation forests, and fewer taxpayer dollars would be needed for wildfire suppression.[48]

The challenge is to apply restoration treatments that approximate presettlement conditions in ponderosa pine forests—not because they are historical but because they are sustainable. The goal is a forest featuring large old trees but with enough small and medium-sized trees to be self-perpetuating and resistant to wildfires and insect epidemics. Fortuitously, using these methods to restore strategically located stands could create relatively fire-safe zones that would pay for themselves in reducing costs of severe wildfires.[49] □

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