provide the mosaic of foraging habitat and vegetation cover required by many species of resident and migrant birds.

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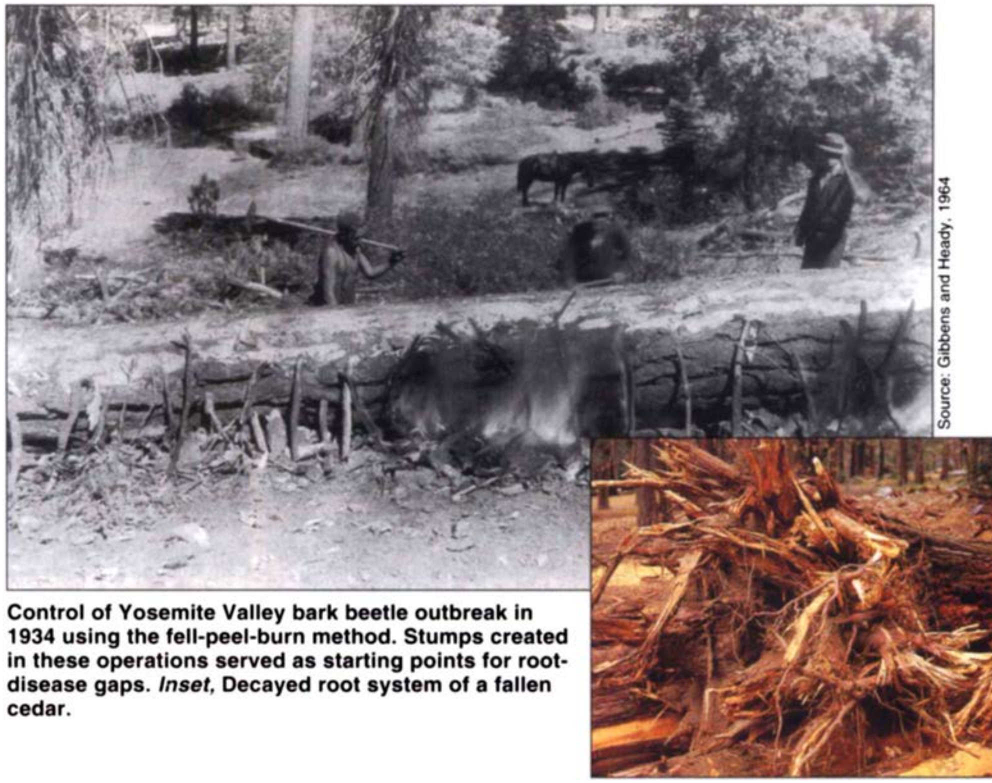


Source: Gibbens and Heady, 1964

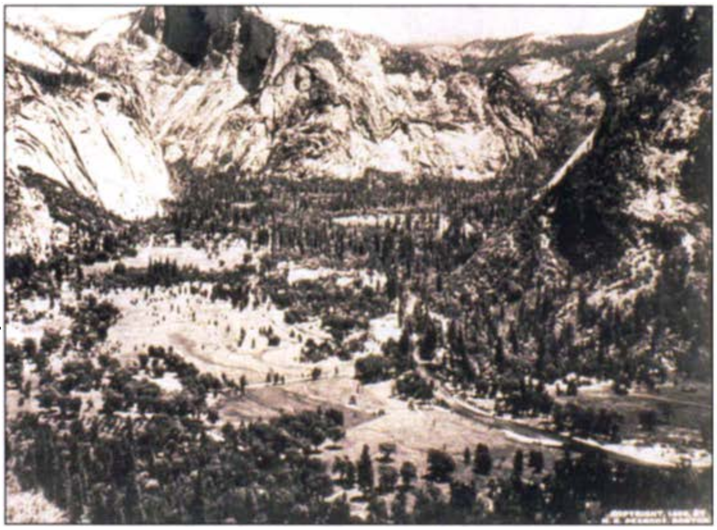
Control of Yosemite Valley bark beetle outbreak in 1934 using the fell-peel-burn method. Stumps created in these operations served as starting points for root-disease gaps. *Inset,* Decayed root system of a fallen cedar.

Past forest management promoted root disease in Yosemite Valley

Garey W. Slaughter ❑ David M. Rizzo

Root disease is one of the most important vegetation-management considerations in Yosemite Valley. Large trees with root decay have fallen in the valley causing human fatalities and property damage. Many of the problems associated with root disease in Yosemite Valley can be traced back to the area's history of vegetation management. Wildfire suppression and meadow draining were implemented after the arrival of Euroamericans in the mid-19th century. These practices created conditions that encouraged the development of a dense conifer forest within the valley. Tree removals for vista clearance, campground and lodging construction, and bark beetle control projects created thousands of stumps. Many of these stumps have been infected with spores of* Heterobasidion annosum, *a fungal pathogen that causes root decay in conifers. The fungus has since spread from initial infection sites into the surrounding forest, creating hundreds of enlarging tree mortality gaps. Park resource managers have established a program of hazardous-tree removal, but efforts to restore natural ecosystem processes must be continuously reconciled with public safety.

Yosemite National Park's resource managers are attempting to integrate ecosystem-based management techniques (such as prescribed burns) with the impact of 4 million visitors per year. We believe that the presence of



East end of Yosemite Valley from Columbia Point in 1899 *(left)*, showing open meadows, scattered oaks and large pines. *Right*, view in 1961 showing development of dense conifer forest.

root disease in conifers and hardwoods will play an important role in determining the direction of vegetation management in the park, particularly Yosemite Valley. Our preliminary surveys indicate that root disease is the most common disturbance associated with canopy gaps in Yosemite Valley (as compared to bark beetles or wind-throw). Since 1970, well over 200 canopy gaps associated with root disease have been recorded in Yosemite Valley, and approximately one-half of these have been mapped. In some developed areas of the valley such as campgrounds and lodging facilities, one-third to one-half of the forested area is associated with root disease infestations in conifers (authors, unpublished).

Root disease in forest trees has influenced management decisions within Yosemite Valley in at least three ways. First, wind-thrown trees with rotted roots have caused human fatalities as well as extensive property damage and liability settlements. Hazardous trees were first reported as a problem in the 1950s. Since 1973, tree failures have resulted in seven fatalities, 19 serious injuries and approximately $1 million in damages (National Park Service 1997). This includes damage to buildings, tent cabins, automobiles and power lines. The option of hazardous tree removal in developed areas of the park must be balanced among the often competing requirements for public safety, aesthetics and ecosystem function. Second, canopy gaps associated with root disease can have a potentially important effect on biodiversity. The composition of the dominant tree species may be altered, and regeneration of plant species in stand openings may be influenced. Third, mortality of trees associated with root disease will also increase fuel loads and influence fire behavior in the park. This is critical in light of efforts to restore historical influences on ecosystem processes in Yosemite Valley.

The problems currently associated with root disease in Yosemite Valley appear to be the result of a series of natural-resource management actions taken many years earlier. The current state of the forests of Yosemite Valley is another example of unintended consequences that may result from vegetation-management decisions.

Valley's natural history

Yosemite Valley is located within Yosemite National Park, in the central Sierra Nevada of California. The Merced River flows in a westward direction through the valley, creating a relatively flat, alluvial plain about 7 miles (11 kilometers) long and averaging 0.5 miles (0.8 kilometers) wide with an elevation of approximately 4,000 feet (1,220 meters). Sheer granite walls up to 3,300 feet (1,000 meters) high enclose the valley floor on three sides. The Mediterranean-type climate is characterized by hot, dry summers and cool, wet winters. The high cliffs of the valley cause some microclimatic differences on the valley floor. The south side tends to have shadier, cooler conditions during summer months and lower temperatures in winter, and the north side tends to have warmer, drier conditions throughout the year. Winter and spring floods are common, each time leaving another layer of fine silt and sand over as much as 50% of the valley floor (Heady and Zinke 1978).

Vegetation in the valley before the arrival of Euroamericans was predominantly scattered black oaks *(Quercus kelloggii)* and large ponderosa pines *(Pinus ponderosa)* intermixed with meadows of sedges, grasses and wildflowers (Gibbens and Heady 1964; Heady and Zinke 1978). This plant community existed in the presence of both natural wildfires and fires set intentionally by Native Americans. Evidence suggests that humans have inhabited Yosemite Valley at various times for at least 9,000 years. About 650 years ago, a more sedentary lifestyle associated with the acorn as a major food source seems to have been adopted by the Native Americans (National Park Service 1997). Fire and sometimes hand-eradication were used to clear small, invading trees from the meadows. This encouraged a flush of new growth in grasses and shrubs that provided highly nutritious food for wildlife, enhanced berry production, allowed for efficient acorn collection, and permitted easier foot travel.

Euroamericans came to Yosemite Valley in the 1850s. They planted crops and orchards, and created pastures by fencing and draining meadows. Fire was assumed to be destructive to agriculture and forestry, so meadow burning was phased out on the valley floor and wildfires were routinely extinguished. Beginning in 1864, the valley came under the supervision of a succession of state and federal entities. Park managers in the early part of this century had two often conflicting goals: to preserve natural conditions as much as possible and to encourage public use. Fire was thought to be essentially destructive and wildfires were suppressed. The glacial moraine was opened with explosives in 1879, reducing flooding and lowering the water table in portions of the valley. Agriculture continued throughout this period, but decreased with the advent of large numbers of tourists. Most of the meadows were grazed by cattle until 1924, when the last dairy herd was removed.

As a result of fire suppression policies and meadow draining, conditions improved dramatically for conifer germination and for seedling and sapling survival. Dense stands of conifers came to occupy much of the valley floor by replacing significant portions of meadows and oak woodlands. The predominant forest type in Yosemite Valley is now a typical west-side, mid-elevation, mixed-conifer Sierra forest containing dense aggregations of ponderosa pine and incense-cedar *(Calocedrus decurrens)*, with smaller numbers of black oak and other species. On the hotter, drier north side of the valley, scrub oak *(Quercus chrysolepis)* is present in the understory below mostly ponderosa pine. On the shady south side, white fir *(Abies concolor)* and Douglas-fir *(Pseudotsuga menziesii)* constitute a significant portion of the stand. Many of the pines have now reached sizes in excess of 40 inches (100 centimeters) in diameter and 150 feet (50 meters) in height. Many large oaks died or suffered extensive decay as a result of being overtopped and heavily shaded by taller conifers. Vistas from the valley floor of sheer granite cliffs, domes and waterfalls have often disappeared behind a wall of intervening forest (Gibbens and Heady 1964).

Courtesy of Yosemite National Park

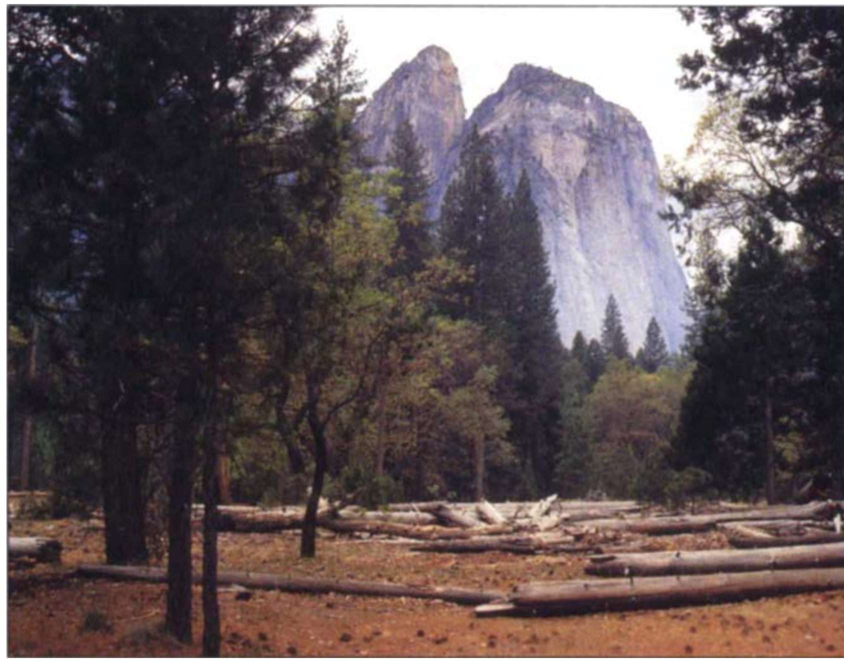
Courtesy of Yosemite National Park

Aerial photos of Yosemite Lodge area in 1975 *(upper)*, 1997 *(lower)*. Area in which root disease was detected is outlined. Note the significant reduction in trees due to root disease and hazardous-tree removal.

Root-disease pathogens

There are several fungal root diseases native to Yosemite Valley. From a resource-management perspective, *Heterobasidion annosum* is currently the most important disease-causing pathogen. The fungus causes root decay and mortality of coniferous trees throughout the Northern Hemisphere (commonly known as annosus root disease). The fungus initially becomes established in a forest stand via airborne spore infection of living trees. The presence of fresh, still-living stump tops associated with tree felling increases the likelihood that *H. annosum* will be established. The fungus colonizes the stump and then spreads into surrounding trees through root-to-root contacts; *H. annosum* cannot grow through soil. Once infected, diseased pines tend to die quickly because they are predisposed to attack by the western pine beetle *(Dendroctonus brevicomis)* and other scolytid beetles. Because bark beetles associated with incense-cedars are generally less aggressive, these trees — when infected — tend to die slowly and suffer extensive root decay, which causes them to fall. The mortality of trees leads to the formation of openings in the forest canopy which continue to enlarge as the fungus moves into adjacent trees. Following the death of a tree, *H. annosum* is capable of living as a saprobe. Receiving nourishment from the decaying tree, it slowly decomposes the underground root wood for a number of years. Because of this saprobic phase, the fungus has the capacity to infect regenerating conifers within a gap for 30 to 50 years. It is unlikely that *H. annosum* will infect trees already dead from other causes, as roots of these trees are rapidly colonized by competing fungi.

Armillaria mellea (commonly known as oak root fungus or shoestring root rot) also appears to be present throughout Yosemite Valley, particularly in association with oaks. *A. mellea* does not usually cause major losses in native stands, although it is an impor-



▲ **Large gap caused by root disease.**

◀ **Mortality gap (mostly pines) caused by *Heterobasidion annosum*.**

tant disease of orchard and landscape trees in California. Lack of overstory mortality in natural forests does not necessarily mean absence of the fungus. Our studies in other forest ecosystems in California indicate that 50% to 100% of trees in forest stands may support *A. mellea* on their root systems, usually confined to small lesions on the outer parts (Baumgartner and Rizzo, unpublished). As native trees are cut, the fungus colonizes the dying root systems, decays the wood and builds inoculum. Under the right conditions, with a susceptible host and favorable environment, *A. mellea* will then attack adjoining trees. Unlike *H. annosum*, *A. mellea* can kill both hardwoods and conifers. Small forest-canopy gaps caused by tree mortality associated with *A. mellea* are now common in the valley.

Impact of past practices

While fungal root diseases are clearly part of the natural ecosystem in Yosemite Valley, human activities have influenced the establishment and spread of these diseases over the past 100 years. As the number of people visiting Yosemite and staying overnight in the valley increased, projects were undertaken from the 1860s to the present to enhance the tourist experience. These have involved felling trees to open scenic vistas and accommodate building projects: campgrounds, tourist lodging, residences for park personnel and parking lots.

Droughts during the 1920s and 1930s led to extensive outbreaks of western pine beetle and subsequent ponderosa pine mortality in Yosemite Valley. While timber production was not a goal within the park, the excessive tree mortality concerned park resource managers. Control of beetle outbreaks was attempted by felling beetle-infested trees during the winter months. The beetle-infested bark was then peeled off the top half of the log, piled alongside, and burned (Miller and Keen 1960). The fell-peel-burn method was used extensively during the 1920s and 1930s by managers, with the goal of saving as many of the remaining large pines in Yosemite Valley as possible.

These management actions produced thousands of stumps during this period. As described previously, freshly cut stumps are an important starting point for infection by *H. annosum*. Unfortunately, the importance of stump tops in the fungal infection process was not demonstrated until the 1950s. The potential impact of tree felling was not known at the time it was used extensively. By 1970, 161 gaps associated with *H. annosum* had been identified in Yosemite Valley. These gaps were found primarily in campgrounds and other developed areas (e.g., Yosemite Lodge, Camp Curry, Ahwahnee Hotel, employee housing), but a number of root-disease gaps were located in the less-developed west end of the valley. In all cases, the gaps were initially associated with a stump remaining after tree felling.

J.R. Parmeter and colleagues at UC Berkeley and U.S. Department of Agriculture's Forest Service (Felix et al. 1974; Marosy and Parmeter 1989; Parmeter et al. 1978, 1979) documented and mapped 68 discrete gaps associated with *H. annosum* and created a database that has been used to follow progression of the disease over the past 30 years. Today these gaps range in size from just a few square yards to over 1 acre (4,000 square meters), with a mean gap size of 0.2 acre (712 square meters). By visiting these 68 gaps at 1 to 5 year intervals, we determined that the gaps enlarge radially from an initial stump at an average rate of 1.5 feet/year (0.47 meters/year). However, enlargement rates are variable, even within a gap, and may reach as high as 5 feet (1.5 meters) per year (table 1).

Recent research has revealed that the fungus does not spread indefinitely from the initial point of infection. Between 1965 and 1996, tree mortality ceased at 36 of 68 gaps. Such stabilization of gap enlargement is common throughout California east-side pine forests (Slaughter and Parmeter 1995). While still under study, reasons for this stabilization include a combination of factors acting along gap perimeters such as competing root-decay fungi, the presence of tree species not susceptible to infection by *H. annosum*, or trees that are already dead when the fungus first encounters their roots.

The effect of *H. annosum* as it moves through a stand is exemplified by the Sentinel Beach gap (table 1). As it enlarged to its current size of 0.63 acre (2,535 square meters), 106 trees were killed. This included a number of pines that were well over 40 inches (1 meter) in diameter. The pines tended to die much more quickly (within a few years of root infection), while cedars — with nonaggressive bark beetle associates — declined more slowly. Cedars generally die 10 to 30 years after adjacent pines die, giving more time for *H. annosum* to occupy a large portion of the still-living root system. The consequence of this is a rapid conversion of the stand to an overstory of incense-cedars, which also die over time, leaving openings in the forest canopy that are not occupied by trees. After 30 years, most of the gaps we surveyed had not returned to a closed forest canopy. In campgrounds, most gaps are now bare ground with no vegetation. Gaps in less developed areas are mostly occupied by herbaceous plants, shrubs and, less commonly, conifer regeneration. In no instance has regeneration in the gaps reached higher than 10% of the surrounding canopy height.

Once it became clear that root disease was associated with most conifer mortality observed in Yosemite Valley, park managers responded with a vigorous program of hazardous tree removal. Researchers developed a hazard rating system for incense-cedars (work on pines was never completed) to allow on-site workers to identify trees most likely to fail (Srago et al. 1978). As time passed, some canopy gaps ceased enlarging, while many others continued to sustain tree mortality and wind-throw at the gap edges. Discrete gaps often coalesced into large forest openings as tree mortality and removals continued. As part of a program to remove potential *H. annosum*-infected trees from the developed areas and prevent further spread of the disease, 247 trees were felled in the Yosemite Lodge complex between 1985 and 1987 (West 1989). There are now two large areas, each approximately 10 acres in size, within the lodge complex area that are virtually treeless. While the spread of the disease has apparently been slowed in this area, the presence of symptomatic cedars that were not removed during the original management action suggest that the fungus is still present and active on the site.

Sentinel Beach gap. Berries have replaced trees in the area where the stand has been opened due to root disease. Dead and dying trees can be seen at the gap margin.

TABLE 1. Dimensions and rates of enlargement of eight *Heterobasidion annosum* associated gaps in Yosemite Valley

Gap	Year started	1997 area	1997 mean radius	Mean radial enlargement rate	1997 maximum enlargement	Maximum enlargement rate
		m^2	m	m/year	m	m/year
Upper Pines	1974	43	3.7	0.16	11.2	0.5
Rocky Point	1967	305	9.9	0.33	21.1	0.7
Lodge/Creek	1969	431	11.7	0.42	30.9	1.1
Devil's Elbow	1965	639	14.3	0.45	29.4	0.9
Falls Trail	1968	1,145	19.1	0.66	30.5	1.1
Yellow Pine	1971	1,351	20.7	0.8	37.1	1.4
Cathedral Picnic	1970	1,863	24.4	0.9	35.7	1.3
Sentinel Beach	1965	2,535	28.4	0.89	45.3	1.4

Mean radius and radial enlargement rate were calculated based on the assumption of the gap as a circle with the point of origin in the center. Maximum enlargement and enlargement rate were determined by measuring the furthest progression of the disease in one direction from the point of origin. These 8 gaps were selected as examples because they were (a) discrete (not coalescing with other gaps), (b) represented the range of gap areas, and (c) had complete data from all ground visits.

Many small root-disease gaps have also become established since the 1970s. These occur often but not always in locations adjacent to older, stabilized gaps. Some of these new gaps are not associated with any stumps, suggesting that there may be other ways for the fungus to spread throughout the valley forest besides airborne spore germination on freshly cut stump surfaces.

Complexities facing managers

The current goal of vegetation management in Yosemite National Park is

Land managers struggle with tradeoffs:

Air quality concerns may hinder prescribed burn efforts

David J.I. Tait

Fire is an important tool for managing forest lands in Yosemite National Park; yet, difficulties with air quality have limited the park's ability to meet prescribed burning objectives. In an effort to balance air quality and resource management, Yosemite is attempting to minimize smoke emissions and impacts during prescribed burns. However, smoke management is still controversial.

In recent decades, we have begun to better understand fire as a historic and natural component of Sierran ecosystems. Burn scars in trees show that forest fires used to occur approximately every decade. Prior to settlement by European immigrants, lightning-ignited fires regularly thinned forests and consumed accumulated dead fuel. According to Yosemite archaeologists, the Yosemite Valley ecosystem evolved with regular burning by Native Americans for at least the last 600 years.

Fire is beneficial to both plants and wildlife. Resulting high-nutrient soil enables sensitive plant species to thrive. Fire-thinned brush fields provide more accessible wildlife habitat. Thinned forests allow more light into the understory, enabling the growth of deciduous trees, shrubs and herbaceous plants, which are more palatable to wildlife. Dense stands of conifers can shade out and kill ancient oaks. Fires can thin encroaching conifers, enabling the resilient oaks to grow well in abundant sunlight and produce acorns — a staple food source for deer and other wildlife. Also, fire scarification is essential for the seeds of some plants to germinate. The Ackerson wildfire of 1996, which "devastated" over 64,000 acres of forest (51,000 acres in Yosemite), demonstrated this point. The Hetch Hetchy monkeyflower *(Mimulus filicaulis)* was once on Yosemite's rare plant list with only three remaining populations, covering less than a single acre combined. After the Ackerson fire, it began to flourish as a single population, which now covers more than 5,000 acres. Many of these plants germinated from seed that had been dormant for over 50 years. A more familiar plant, the famous Giant Sequoia *(Sequoiadendron gigantea)* also requires fire for natural propagation.

Yosemite National Park is one of many federal land managers attempting to incorporate fire into forest management strategies to restore the natural processes that have shaped the ecosystems of the Sierra Nevada. During the last century, policies of aggressive fire suppression inhibited these natural processes. The resulting dense accumulations of forest fuels have contributed to diminished forest health and catastrophic wildfires. Realizing the importance of fire, Yosemite changed its fire policy in 1968, and in 1970 conducted the first prescribed burn in the El Capitan Meadow of Yosemite Valley. Under "prescribed" conditions, lightning-ignited fires are now allowed to burn in the back country, and management-ignited fires are used to reduce hazard fuels and mimic the natural process in areas of wildland-urban interface.

Although fire is extremely beneficial, it has a controversial drawback: the impact on air quality from smoke. Smoke consists of fine airborne particulate matter that contributes to regional haze and can affect human health. Children, the elderly, and persons with respiratory conditions are especially sensitive to these particles. Yosemite is under close scrutiny to maintain National Ambient Air Quality Standards established under the Clean Air Act. As a national park, Yosemite is a Class 1 airshed, subject to the highest visibility standards, and Yosemite Valley does not meet the federal standard for PM-10 (particulate matter less than 10 microns in diameter) largely due to campfires.

Because of its topography and high population, Yosemite Valley is the most controversial area of the park for prescribed burning. Under stable atmospheric conditions, the deep chasm of the valley acts as a sump for smoke. Campfires saturate the valley air with smoke, and natural fires upriver can pour smoke into the valley at night. During stable atmospheric conditions, poor quality air can be trapped under inversions until the weather changes. Complicating the problem further, Yosemite Valley air quality is already degraded by vehicle emissions, campfires, and air pollution transported from the Central Valley.

Especially in Yosemite Valley, Yosemite fire management is taking several measures to minimize public exposure to smoke while accomplishing resource management objectives. During unstable atmospheric conditions, smoke can loft out of the valley with minimal human impact. Prior to implementation of a controlled burn, fuel loading is measured to determine approximate smoke emissions. Then managers develop a prescription for the burn, identifying fuel moisture, relative humidity, wind direction and other factors to minimize smoke impacts. The public is notified of the planned burn location and acreage, as well as anticipated impacts, and suggest steps to minimize exposure. Burn prescriptions are also crafted for opti-

David Rizzo

mum firefighter safety and combustion of fuels. In some burn units, trees up to 6 inches in diameter are mechanically thinned, dried and pile-burned for more complete combustion.

In 1998, Yosemite instituted a smoke-monitoring program using hourly weather and smoke observations, time-lapse cameras, and real-time PM-10 monitors to keep track of smoke behavior and impacts. Test burns are conducted to see if atmospheric conditions are adequate to loft and disperse the smoke. By identifying smoke behavior, and adjusting prescriptions as needed, Yosemite hopes to minimize impacts on the public.

Mechanical thinning is often advocated as an equivalent alternative to fire, but there are at least two problems with this method. On one hand, mechanical removal of trees can cause detrimental disturbance to sensitive plant and animal species. Secondly, fresh-cut "live" tree stumps are more susceptible to infection by spores from the root-rot fungus and therefore may contribute to the spread of disease.

Controlling smoke emissions and impacts is a formidable task because smoke behavior varies with every change in the weather. Yet, the need for smoke management is becoming more evident. Fire is now, more than ever, being understood and managed to promote public safety and the health of natural ecosystems, but the impact of smoke on human health may hinder its use. The Environmental Protection Agency has endorsed a more stringent PM-2.5 standard, which though designed to protect public health from human-caused pollution, may inhibit the ability of land managers to fulfill their mandate to restore the role of fire in the natural environment. Already, because Yosemite Valley has exceeded the standard for PM-10, the use of fire in the valley is strictly limited. Yosemite has even been forced, at great cost, to shut down natural and beneficial lightning-ignited fires in wilderness, due to public "nuisance" from the smoke.

Fire is imminent. If forests are not burned under controlled conditions, they will inevitably burn later with catastrophic results. According to Tom Cahill, UC Davis professor of atmospheric science, the extreme heat intensity of wildfires vaporizes nitrogen in living pine needles, creating nitrate compounds that are major contributors to smog. Controlled fires do not appear to create these chemicals because they burn at lower temperatures and do not reach up into the trees. The immediate air quality impacts from prescribed burning can be a nuisance and should be minimized. However, unlike wildfires, prescribed burning can enhance biological diversity and prevent catastrophic fires with a less severe impact on air quality.

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to preserve, restore and perpetuate the natural processes that act upon the native plant life as part of natural ecosystem functioning (National Park Service 1997). Under this management protocol, vegetation in Yosemite Valley would be expected to gradually return to the open meadows and predominantly open oak woodlands present before the arrival of European immigrants. The extensive stands of high-density large pines and cedars that currently occupy the valley would be significantly reduced in area. Tree mortality is now considered as just one of numerous, ongoing ecological processes.

Gaps caused by root disease in the valley forest canopy are continually opening, allowing colonization by a variety of plant species (shrubs, grasses, herbs) not normally present in the shady understory of dense stands of large trees. These gaps also provide edge effects and increased food for wildlife. Gaps can re-establish vistas from the valley floor that had become obscured by trees. It could, therefore, be argued that naturally occurring root diseases do not necessarily have a negative effect on park vegetation. In fact, root disease may aid the park in its goal of reducing the density of conifers in the valley. Given this perspective, a fungus such as *H. annosum* may cause disease but also not be considered a "pest." It would simply be part of an ecological process that promotes biodiversity.

From a different perspective, the campground manager's goals would include providing a safe environment for the public. When confronted with a large pine having just fallen and crushed a tent, he or she (and the tent owner) would probably not consider root disease as a positive part of the environment. The hazardous tree removal program is designed to prevent such an occurrence, and is an example of the trade-offs required when management goals conflict. To avoid windthrow in developed areas of the valley and along major roads, trees must be removed when root disease causes substantial decay. Such decisions may initially be unpopular with the public because trees provide shade for campers, protection from wind and habitat for animals. Undeveloped portions of the park (most of the area outside Yosemite Valley) do not require such a program.

These examples demonstrate that like their 19th-century counterparts, resource managers in national parks today face conflicting goals: to preserve natural conditions as much as possible while encouraging public use. An additional example of the conflict between ecosystem function and public use is demonstrated by efforts to restore fire to Yosemite Valley (see sidebar page 22). Planned ignitions (prescribed burns) have been used since the 1970s to reintroduce fire into the ecosystem. We do not have adequate data on the influence of fire on disease development. For example, residual trees may be more susceptible to infection by *H. annosum* following a prescribed burn, as fire scar wounds may act as entry points for the fungus. In addition, increased fuel loads within enlarging gaps may make it difficult to control fire intensity during prescribed burns. The reintroduction of fire into park ecosystems is another area in which trade-offs may be required when conflicting goals and competing environmental values are integrated into management plans and activities.

Knowledge of root disease is currently being integrated into park service planning. Following severe flooding of the Merced River in January 1997, many camping and lodging facilities in the valley were damaged or destroyed. As planning progressed for the relocation and construction of new campgrounds, motel units, cabins and dormitories, it was determined that root diseases should be considered. The current management policy for *H. annosum* is to avoid initiating additional infection sites. Mitigation activities include the treatment of all conifer stumps with Sporax (a borate chemical which protects stump surfaces from *H. annosum* spore germination) and the sifting out of potentially *H. annosum*–infected root chunks from soils excavated during construction. Revegetation planning emphasizes oak regeneration, which will minimize problems associated with annosus root disease. However, such revegetation plans may now strongly influence the development of Armillaria root disease. As trees are cut to clear ground for new buildings, buildup of *A. mellea* inoculum may strongly impact residual trees or newly planted trees. During the restoration period, oaks should be left undisturbed or, if necessary, totally removed, including the entire stump and root system. Post-construction, long-term monitoring will be essential if we are to assess the efficacy of these and other guidelines.

Given the progress of existing gap enlargement, the initiation of new gaps, the hazardous nature of root-rotted trees, and changing management goals, one might ask if the dense stands of large conifers now existing in the valley are sustainable over the long term. If the disease is allowed to run its course, what will be the long-term consequences? Currently we do not have sufficient information on regeneration of vegetation in disease-caused gaps. If conifers colonize these gaps, we do not know the probabilities that they will be killed by residual *H. annosum* before reaching maturity. We have an incomplete understanding of the genetic variability of the *H. annosum* and *A. mellea* within gaps associated with root disease. Research in the valley is planned to determine the origins, spatial distribution, genetic variability and potential for enlargement of existing root-disease gaps and initiation of new gaps. In the future we need to evaluate the impact of canopy gaps caused by root-disease fungi on the valley ecosystem and determine the implications of root disease on current and proposed management practices.

G.W. Slaughter is Staff Research Associate and D.M. Rizzo is Assistant Professor, Department of Plant Pathology, UC Davis. *Both authors contributed equally to this paper. Over the years, many people have contributed to work on root disease in Yosemite Valley. These include Dick Parmeter, Det Vogler, Leonard Felix, Mark Schultz, John Pronos and Fields Cobb. The authors appreciate the cooperation of Yosemite National Park personnel including Sue Fritzke, Louise Johnson and Brian Mattos. Funding for the authors' work was provided by USDA Forest Service and the National Park Service.*

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