

Extent of Ozone Injury to Trees in the Western United States

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The widespread nature of ozone air pollution in California and the suspected potential for ozone damage to forests near cities in other Western States led to field surveys and establishment of monitoring plots beginning in the mid-1960's. The surveys and plot results were divided into three categories depending on the evidence of injury that was documented, including (1) surveys that failed to reveal any evidence of injury even though ozone air pollution was suspected; (2) visible foliar injury that was detected although no structural or functional changes were evident in the forest ecosystem; and (3) the presence of both foliar injury and structural and functional changes. Recent monitoring has shown that ozone air pollution has not caused damage to pines in Colorado or western Washington. Slight damage was found in southern Arizona, slight to moderate damage was extensive in the Sierra Nevada, and moderate to severe damage was evident in the San Bernardino Mountains of southern California.

Injury Undetected

Front Range of Colorado

Ozone air quality for the Colorado Front Range country as summarized by Bohm (1992) showed daily peak concentrations sometimes exceeding 100 ppb. Highest concentrations generally occurred at valley and foothill locations of the central part of the Front Range. Rocky Mountain ponderosa pine (*Pinus ponderosa* var. *scopulorum*) dominated the lower foothills beginning at about 2,000 m. This species was the subject of extensive surveys for visible ozone symptoms and sampling of cores for tree ring analysis in two related studies (Graybill 1992). For the unmanaged old-growth stands distributed along the full north to south extent of the Front Range, no evidence of visible injury was found and tree-ring chronologies showed a consistent relationship with precipitation without any evidence of a departure that could be implicated with ozone exposure in recent decades. This result was also obtained by sampling second-growth stands in the same region (Peterson and Arbaugh 1992). Exposure of seedling *P. ponderosa* var. *scopulorum* to ozone in fumigation experiments did not indicate sensitivity to ozone at concentrations up to four times higher than the highest ambient concentrations observed at Front Range monitoring stations (Miller and others 1983).

Western Washington

Parts of the Douglas-fir (*Pseudotsuga menziesii*) region of western Washington, particularly Olympic National Park, have been characterized by the lowest ozone concentrations (< 60 ppb) in the West (Bohm 1992). However, Edmunds and Basabe (1989) observed transported peaks of ozone southwest of Seattle-Tacoma that reached 100 ppb. In the latter case no foliar symptoms of ozone injury were observed on Douglas-fir. The results of an extensive tree-ring study of old-growth Douglas-fir in western Washington revealed that the dominant pattern was one of growth increase (Brubaker and others 1992). Although examples of growth decrease were found, spatial patterns in these results did not suggest an impact by ozone or other air pollutants in the Puget Sound region.

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Visible Injury Without Structural or Functional Changes

Southern Arizona

A cruise survey was done of ponderosa pine stands (both *P. ponderosa* var. *scopulorum* and *P. ponderosa* var. *arizonica*) in the Rincon Mountains of Saguaro National Monument (Duriscoe 1990). A total of 660 trees were observed (20 trees per sampling point at 33 points). The two varieties of ponderosa pine were intermixed, and the survey results were not described separately for each variety. Foliage was inspected on a sample of branches cut from the lower crown of each tree. Fifteen percent of the trees (99 out of 660) were diagnosed as having ozone-induced chlorotic mottle on the foliage. Twenty-six of the 33 sample points contained at least one tree with ozone injury symptoms. A significant difference was found in number of whorls retained, with ozone sensitive genotypes retaining fewer whorls. The individual point showing the most injury was on Heartbreak Ridge, between Mica Mountain and Happy Valley Lookout. The average ozone injury for the whole sample was considered slight. Because Tucson is located 30 miles west-northwest, it is the most probable source of ozone-polluted air.

Graybill and Rose (1989) examined the tree ring chronologies of 11 ponderosa pines from Saguaro National Monument that had evidence of needle injury. Only three of these trees showed evidence of a post 1950 decline in ring growth; thus, many other variables must be considered as participating causes of changes in the observed chronologies. Further studies by Graybill (1992) of tree ring chronologies from the Santa Catalina and Rincon Mountains showed four of five chronologies from ponderosa pine sites that had extreme growth suppression after 1950. No evidence of a correlation between ozone injury to foliage and change in ring growth for these sites was found, and the possible factors contributing to post-1950 growth changes are being investigated further.

Joshua Tree National Monument

Temple (1989) conducted surveys of native vegetation for ozone injury in 1984 and 1985 at Joshua Tree National Monument—which is located about 100 km east of the Los Angeles basin in southern California with maximum daily concentrations of ozone recorded after 8 p.m. because of the extra time needed for transport from the basin through San Geronimo Pass. During 1984 and 1985 the peak value frequently exceeded 100 ppb. Permanent plots were established to include woody riparian species, namely *Acacia greggii*, *Chilopsis linearis*, *Rhus trilobata*, and *Salix gooddingii*. No symptoms were observed on any species under field conditions, however, *R. trilobata* was sensitive when fumigated with ozone (100 ppb, 4 hours/day, for 4 days). Subsequent field surveys revealed ozone injury symptoms on squaw bush by ambient levels of ozone when soil moisture was not a limiting factor (Stolte, personal communication).

Western Slope of the Sierra Nevada

Detection of ozone injury symptoms to ponderosa and Jeffrey pines in the Sierra Nevada, California (Miller and Millecan 1971) and subsequent surveys by Forest Service pest management specialists using 52 trend plots (Allison 1982, 1984a, 1984b, Pronos and Vogler 1981) provided the earliest data describing the extent of ozone injury and the early trends of the severity of injury. For example, Pronos and Vogler (1981) reported that between 1977 and 1980 the general trend was an increase in the amount of ozone symptoms present on pine foliage.

Peterson and others (1991) sampled crown condition and derived basal area growth trends from cores collected from ponderosa pines at sites in seven Federal administrative units (National Forests and National Parks) located from north to south in the Sierra Nevada including Tahoe National Forest,

Eldorado National Forest, Stanislaus National Forest, Yosemite National Park, Sierra National Forest, Sequoia–Kings Canyon National Park, and Sequoia National Forest. In July–August 1987, four symptomatic and four asymptomatic sites were visited in each unit and only sites with ponderosa pines greater than 50 years old were selected for sampling. The symptomatic plots generally indicated increasing levels of chronic ozone injury (reduced numbers of annual needle whorls retained and chlorotic mottle symptoms on younger age classes of needles) from north to south. In general, the results of this study documented the regional nature of the ozone pollution problem originating primarily from the San Joaquin Valley Air Basin (SJVAB), as well as the San Francisco Bay Air Basin further to the west. The study found no evidence of recent large-scale growth changes in ponderosa pine in the Sierra Nevada mountains; however the frequency of trees with recent declines of growth did increase in the southernmost units. Because these units had the highest levels of ozone (and more chlorotic mottle symptoms on needles of younger age classes) strongly suggests that ozone is one of the contributing factors to decline in basal area increase. Other factors limiting tree growth in this region include periodic drought, brush competition and high levels of tree stocking.

A region-wide survey (Peterson and others 1991) of ponderosa pine provided a useful backdrop for reporting a number of other studies or surveys in the Sierra Nevada that were more narrowly focused. Another tree ring analysis and crown injury study was focused on Jeffrey pines in Sequoia–Kings Canyon National Park (Peterson and others 1989). This study suggested that decreases of radial growth of large, dominant Jeffrey pines growing on xeric sites (thin soils, low moisture holding capacity) and exposed to direct upslope transport of ozone, resulted in as much as 11 percent less in recent years compared to adjacent trees without symptoms.

Both permanent plots and cruise surveys have been employed in Sequoia, Kings Canyon (SEKI) and Yosemite (YOSE) National Parks to determine the spatial distribution and temporal changes of injury to ponderosa and Jeffrey pine within the Parks (Duriscoe and Stolte 1989). Comparisons of the same trees at 28 plots between 1980–82 and 1984–85 in SEKI showed increases of ozone injury to many trees and increases of the total number of trees with ozone injury. Ozone injury was found to decrease with increasing elevation of plots. The highest levels of tree injury in the Marble Fork drainage of the Kaweah River at approximately 1,800 m elevation were associated with hourly averages of ozone frequently peaking at 80 to 100 ppb, but seldom exceeding 120 ppb.

A cruise survey in 1986 evaluated 3,120 ponderosa or Jeffrey pines in SEKI and YOSE for ozone injury (Duriscoe and Stolte 1989). More than one-third of these trees were found to have some level of chlorotic mottle. At SEKI symptomatic trees comprised 39 percent of the sample (574 out of 1,470) and at YOSE they comprised 29 percent (479 out of 1,650). Ponderosa pines were generally more severely injured than Jeffrey pines. The Forest Pest Management (FPM) score (low score equals high injury) was 3.09 for ponderosa and 3.62 for Jeffrey (Pronos and others 1978). These cruise surveys identified the spatial distribution of injury in SEKI and YOSE, and indicated trees in drainages nearest the San Joaquin Valley were most injured.

In SEKI field plot observations of seedling health and mortality in natural giant sequoia groves from 1983 to 1986 showed that emergent seedlings in moist microhabitats had ozone-induced foliar symptoms. Seedling numbers were reduced drastically from drought and other abiotic factors during this period. A variable such as ozone that could injure seedling foliage sufficiently to reduce root growth immediately after germination could increase vulnerability to late summer drought. After fumigation giant sequoia (*Sequoiadendron giganteum* Buch.) seedlings developed chlorotic mottle

following *in situ* exposure to both ambient ozone concentrations and 1.5× ambient ozone in open top chambers during the 8 to 10 weeks after germination (Miller and others 1994). Significant differences in light compensation point, net assimilation at light saturation, and dark respiration were found between seedlings in charcoal filtered air treatments and 1.5× ambient ozone treatments (Grulke and others 1989). These results could mean that ozone has the potential to be a new selection pressure during the regeneration phase of giant sequoia, possibly reducing genetic diversity.

The Lake Tahoe Basin is located at the northern end of the Sierra Nevada sampling transect (near the Eldorado National Forest) (Peterson and others 1991). Because the Basin is distinct, its air quality is the product of mostly local pollution sources in contrast to most other Sierra Nevada sites where pollution results from long-range transport. In 1987 a survey of 24 randomly selected plots in the basin included a total of 360 trees of which 105 (29.2 percent) had some level of foliar injury (Pedersen 1989). Seventeen of these plots had Forest Pest Management (FPM) injury scores (Pronos and others 1978) that fell in the slight injury category. Of 190 trees in 16 cruise plots that extended observations to the east outside the basin, 21.6 percent had injury—less than in the basin.

Visible Ozone Injury with Structural and Functional Changes

San Bernardino Mountains

The source area for pollutants transported to the conifer forests of the San Bernardino Mountains is the South Coast Air Basin of southern California. Confirmation that ozone was the cause of foliar symptoms on ponderosa pine was reported by Miller and others (1963). Between 1976 and 1991 the weather adjusted ozone data for the May through October “smog season” showed that the number of Basin days exceeding the Federal Standard (> 120 ppb, 1 hr average) declined at an average annual rate of 2.27 days per year (Davidson 1993). The number of days with Stage I episodes (> 200 ppb, 1 hr average) declined at an average annual rate of 4.70 days per year during the same time period. For the Federal Standard the total days per year with exceedances was as high as 159 in 1978 with the lowest at 105 days in 1990. Regarding Stage I episodes the high was 108 in 1979 and the low was 33 days in 1990. The 1974 to 1988 trends of the May through October hourly average and the average of monthly maximum ozone concentrations for Lake Gregory, a forested area in the western section of the San Bernardino Mountains, also showed a decline (Miller and McBride 1989). Similarly the injury index has shown an improvement in chronic injury to crowns of ponderosa and Jeffrey pines between 1974 and 1988, in 13 of 15 plots located on the gradient of decreasing ozone exposure in the San Bernardino Mountains (Miller and McBride 1989). The two exceptions were plots located at the highest exposure end of the gradient.

Miller and others (1991) reported that for the 1974 to 1988 period the basal area increase of ponderosa pines was generally less than competing species at 12 of the 13 plots evaluated. The total basal area for each species, as percent of the total basal area for all species (*fig. 1*), shows that ponderosa and Jeffrey pines lost basal area in relation to competing species that were more tolerant to ozone, namely, white fir, incense cedar, sugar pine and black oak at plots with slight to severe crown injury to ponderosa or Jeffrey pine. The accumulation of more stems of ozone tolerant species in the understory presents a fuel ladder situation that jeopardizes the remaining overstory trees in the event of a catastrophic fire. The ozone tolerant species are inherently more susceptible to fire damage because of thinner bark and branches close to the ground.

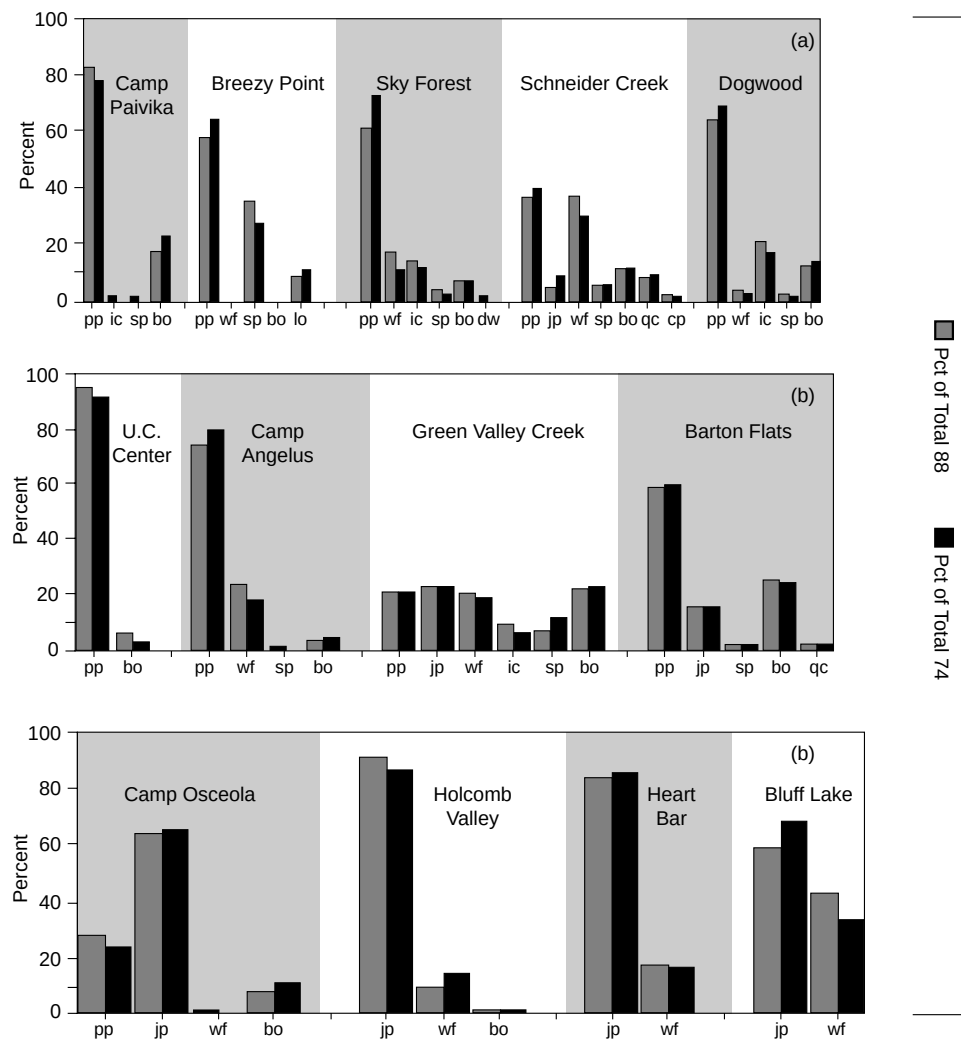


Figure 1—Total basal area for each species as percent of the total basal area for all species at 12 sites in the San Bernardino Mountains in Southern California (Miller and others 1991);

pp= ponderosa pine
 ic= incense cedar
 sp=sugar pine
 bo=black oak
 dw=dogwood
 qc=Chrysolepis oak
 cp=Coulter pine
 jp=Jeffrey pine
 lo=live oak.
 wf=white fir

On the basis of these investigations of ozone injury in California, Colorado, Arizona, and Washington, the mixed conifer forest type in the Sierra Nevada and southern California mountains has become the major focus of interest and concern now and in the immediate future because of extensive ozone injury to ponderosa and Jeffrey pines. If ozone levels should increase with the expansion of urban areas in other regions of the West, a monitoring protocol should be established with baseline plots observed at long-term intervals of 5 or 10 years to track forest health.

Conclusion

