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Monitoring for Ozone Injury in West Coast (Oregon, Washington, California) Forests in 1998

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Cover

Photo by Tom Iraci, USDA Forest Service, Pacific Northwest Region.

Abstract

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In 1998, forest vegetation was monitored for ozone injury on permanent plots in two Sierra Nevada national forests in California, at three locations in Mount Rainier National Park in Washington, and at 68 forest health monitoring (FHM) locations throughout Washington, Oregon, and California. This was the first year that extensive monitoring of forest vegetation for ozone injury was carried out in Oregon and Washington. Injury was detected on ponderosa and Jeffrey pine in the Sierra Nevada permanent plots and on red elderberry at one FHM location in southwest Washington. No injury was detected at the Mount Rainier sites. We also report on results of a trial where red alder, huckleberry, blue elderberry, and chokecherry were exposed to ozone under controlled conditions.

Keywords**:** Ozone, plant injury, biomonitoring**,** forest health monitoring.

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Introduction

There is widespread concern about the potential impact of air contaminants on the long-term sustainability of our Nation's forests (Chappelka and Chevone 1992, Smith 1985, USDA Forest Service 1997, US EPA 1996b). Air pollutants, such as ground-level ozone, are known to interact with forest ecosystems and cause visible injury and other less obvious, but significant, effects (Hakkarienen 1987, Krupa and Manning1988, Smith 1990). Ozone is the only regional gaseous air pollutant that has been measured at known phytotoxic levels at numerous remote locations across the continental United States (Cleveland and Graedel 1979, Lefohn and Pinkerton 1988, Miller et al. 1997, US EPA 1996a).

The scientific evidence collected so far indicates that the response of western tree species to ozone pollution differs widely depending on species and genotype within species (Miller and Millecan 1971, Miller et al. 1983, Olson and Lefohn 1989, Smith 1990). Certain major forest species, such as ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), are sensitive to ozone at concentrations that normally occur over wide areas of the western landscape (Miller 1996, Peterson et al. 1991, US EPA 1996b). Because of the long life span of trees, there is ample opportunity for a long-term, cumulative effect on tree growth. Ozone has been implicated in the growth decline of pollution-sensitive eastern white pine genotypes in the Eastern United States (Benoit et al. 1982; Chappelka and Samuelson 1998; Karnosky 1981, 1989) and in pines in California (Miller et al. 1997). Ozone also may have a broad effect on forested landscapes, potentially altering species composition and influencing pest interactions, soil moisture, and fire regimes (McBride and Laven 1999, Miller et al. 1982, Smith 1974, Treshow and Stewart 1973, US EPA 1996b).

The greatest amount of ozone injury to western forests continues to be observed in the mountains east of Los Angeles (Miller 1996, Miller and Millecan 1971, Miller et al. 1989). In this area, foliar injury, premature defoliation, or growth loss have been documented on ponderosa and Jeffrey pines (*P. jeffreyi* Grev. & Balf.), white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.), and California black oak (*Quercus kelloggii* Newb.). Injury also has been observed on sensitive pines in the Sierra and Sequoia National Forests and, to a lesser extent, in the Stanislaus, Eldorado, and Tahoe National Forests (Arbaugh et al. 1998, Duriscoe 1990, Miller 1996, Peterson et al. 1995, Pronos et al. 1978). Elevated ozone concentrations occur downwind of Pacific Northwest urban areas such as Vancouver, BC; Seattle, Tacoma, and Vancouver, WA; and Portland, OR (Brace 1996, Brace and Peterson 1998, Cooper and Peterson 2000, Edmonds and Basabe 1989). Significant visible injury or effects on tree health have not been observed, however, in forests in these areas (Duriscoe and Temple 1996).

Ozone monitoring has consisted of either measuring the amount of ozone in the air (ambient ozone) with air quality monitors or visually evaluating the extent and severity of ozone-induced foliar injury to sensitive plants (bioindicators). The Environmental Protection Agency (EPA) and various state air quality agencies (US EPA 1996b) monitor ambient ozone primarily in urban areas. Ambient ozone also is measured on a more limited basis in some forested areas by land management agencies such as the Forest Service and National Park Service. Monitoring for plant injury (biomonitoring) has been carried out for over 20 years in California forests, primarily on pines (Dale 1996, Dursicoe 1990, Guthry et al. 1993, Miller 1996, Pronos and Vogler 1981, Pronos et al. 1978) and to a limited extent on other vegetation (Temple 1989, Temple 1999; Treshow and Stewart 1973). In 1998, the forest health monitoring (FHM)[1] program began monitoring for ozone injury on a number of indicator plants on all forested lands in Washington, Oregon, and California (USDA Forest Service 1999).

The FHM biomonitoring approach documents injury on hardwoods and understory perennials as well as conifers, thus providing an important opportunity to improve scientific understanding of ozone impacts on a variety of vegetation in the western forest types. Only a few of the bioindicator species used in the west coast FHM program are well tested in the field. Controlled exposure studies have been used to screen and identify species most sensitive to ozone (Brace 1996, Brace et al. 1999, Chappelka and Chevone 1992, Mavity et al. 1995, Smith 1990). Under controlled exposure, several species show characteristic foliar ozone injury (e.g., interveinal discoloration, chlorotic mottling of needles, premature leaf or needle drop). Observation of injury to these species in the field is the best way to validate controlled study results and identify the best bioindicator species for specific regions within the west coast region (Duriscoe and Temple 1996).

Results from several 1998 ozone monitoring efforts are reported in this paper: biomonitoring at FHM sites in Washington, Oregon, and California; at biosites in Mount Rainier National Park; and on permanent plots in the Sierra and Sequoia National Forests in California. We also report on a controlled ozone exposure study.

Methods

Forest Health Monitoring (FHM) Biomonitoring

Sixty-eight ozone biomonitoring sites, each associated with an FHM plot, were visited in Washington, Oregon, and California in 1998 (fig. 1). Sites were selected by using criteria defined by the FHM program (USDA Forest Service 1999) for location, size of opening, number of bioindicator species, and number of individual plants of each bioindicator species (table 1). Based on controlled exposure studies and field observations (Brace et al. 1996, Duriscoe and Temple 1996, Mavity et al. 1995), a list of bioindicator species was developed for each state (table 2). Ozone injury data were collected at the biomonitoring site at the time the FHM plot was visited. Ten to thirty plants of up to three bioindicator species at each site were rated for ozone injury and severity of symptoms. Samples of any plants with suspected ozone injury were collected and sent to FHM ozone injury experts for verification of injury. All FHM crews were trained to select ozone biosites, identify indicator species, and measure ozone injury. Each crew was audited at least twice during the 1998 field season—one training audit (“hot check”) and one remeasurement audit (“cold check”) where all FHM plot measurements, including ozone, were remeasured by a quality assurance crew.

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[1]The FHM program is a national program with five regions: northeast, north central, south, intermountain, and west coast. The west coast region includes Alaska, Washington, Oregon, California, and Hawaii. Ozone injury is just one of a number of forest and tree attributes measured by surveys and at ground plots by the program.

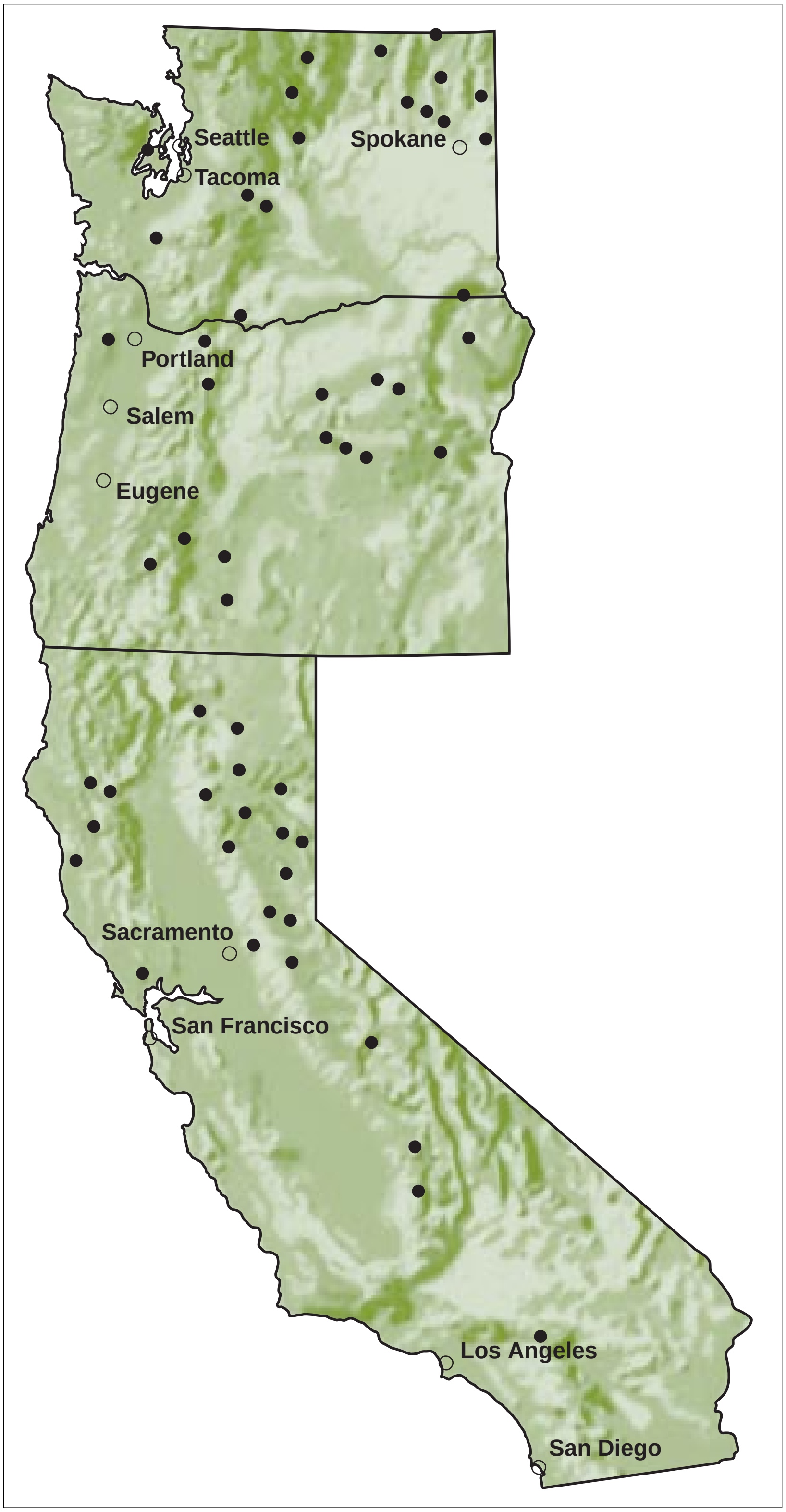

Figure 1—Ozone biosites for forest health monitoring in (from north to south) Washington, Oregon, and California, 1998. Closed circle represents ozone biosites (●), open circle represents cities (o).

Table 1—Criteria used by the forest health monitoring program to select ozone biomonitoring sites

Criteria	First choice	Second choice	Third choice
Access	Easy	—	—
Size of opening	> 0.2 hectare	< 0.2 hectare	Closed canopy
Site moisture	Wet or damp area such as a riparian zone, meadow, or bottomland	Moderately dry area such as a grassland or NE-facing slope	Very dry area such as an exposed rocky ledge
Plant numbers	> 10 plants of more than 1 ozone-sensitive species	> 10 plants of 1 ozone-sensitive species	10 plants of 1 ozone-sensitive species

Table 2—List of ozone-sensitive plants species used by the west coast forest health monitoring program as bioindicators

Species	Scientific name
Ponderosa pine	*Pinus ponderosa* Dougl. ex. Laws. var. *ponderosa*
Jeffrey pine	*Pinus jeffreyi* Grev. & Balf.
Quaking aspen	*Populus tremuloides* Michx.
Scouler's willow	*Salix scouleriana* Barratt ex. Hook.
California black oak	*Quercus kelloggii* Newberry
Chokecherry	*Prunus virginiana* L.
Red alder[a]	*Alnus rubra* Bong.
Ninebark	*Physocarpus malvaceus* (Greene) Kuntze
Pacific ninebark[a]	*Physocarpus capitatus* (Pursh) Kuntze
Thinleaf huckleberry	*Vaccinium membranaceum* Dougl.
Blue elderberry	*Sambucus mexicana* Presl.
Red elderberry	*Sambucus racemosa* L.
Evening primrose	*Oenothera elata* Kunth.
Western wormwood	*Artemesia ludoviciana* Nutt.
Thimbleberry	*Rubus parviflorus* Nutt.
Mountain snowberry	*Symphoricarpos albus* (l.) Blake

[a] Used in Oregon and Washington only.

Mount Rainier National Park Biomonitoring

Ozone injury monitoring was conducted at three biomonitoring sites in Mount Rainier National Park in 1998 (fig. 2, table 3). The park was selected for more intensive ozone monitoring because it is downwind (southeast) from the expanding Seattle and Tacoma metropolitan areas in western Washington. Ambient ozone monitoring at the park since 1987 has shown frequent occurrences of ozone at levels (> 60 parts per billion) that can cause injury to sensitive plants under prolonged exposure (Brace and Peterson 1998, Samora 1999[2]). Biomonitoring at the park used the FHM site selection criteria and data collection and sampling methods described above. Bioindicator plants at each site were examined six times during the summer for symptoms of ozone injury–weekly during July and biweekly in August and September—in contrast to the one visit made for the biomonitoring sites associated with the FHM plots (table 3).

Sequoia and Sierra National Forests Biomonitoring

In the Sierra Nevada of California, 27 ozone injury monitoring plots were evaluated in 1998 in the Sequoia National Forest and 26 in 1997 in the Sierra National Forest (fig. 3). These plots were first established in 1977 by forest pest management staff (USDA Forest Service, Pacific Southwest Region) and have been revisited every two years. All plots are between 1219 and 2438 meters elevation and initially each contained 10 ponderosa or Jeffrey pines. Foliage from each tree is examined at each visit for symptoms of ozone injury (chlorotic mottle) and placed into one of the following severity classes: none, slight, moderate, severe, or very severe. Plots are given a severity class rating equal to the average of the tree ratings on the plot.

Controlled Ozone Exposure Study

Four plant species native to western forests were exposed to known quantities of ozone at the Western Ecology Division of EPA in Corvallis, OR: chokecherry, red alder, thinleaf huckleberry, and blue elderberry. The primary objectives of the study were to validate results from previous controlled exposure studies and to obtain photographs of injury symptoms for use in training FHM and other field crews to recognize ozone injury on native species.

Elderberry, chokecherry, and huckleberry seedlings were grown for either one or two years at the Forest Service J. Herbert Stone Nursery in Central Point, OR. The alder seedlings were transplanted from Mount Rainier National Park early in summer. Seedlings were potted in 1-gallon containers, transported to the EPA facility, and acclimated in the EPA greenhouse and lathe house for 4 weeks prior to ozone exposure.

Seedlings were placed in open-top field chambers with charcoal-filtered air; they were then treated with one of three different regimes of ozone exposure. The pattern of ozone exposure consisted of varying the daily peak concentration each day over a 28-day exposure period (Clark et al. 1995). Ozone concentrations were low in the morning and evening, with daily peaks occurring in early to mid afternoon. The three regimes used were as follows:

1. High (total ozone about 39 parts per million [ppm] summed over 28 days): this regime had 13 days where the peak concentration (1-hour average) exceeded 120 parts per billion (ppb), including one peak that exceeded 200 ppb. The remaining days had lower peak concentration.

2. Moderate (total ozone 31 ppm summed over 28 days): this regime had 7 days where the peak concentration exceeded 120 ppb for 1 hour.

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[2] Personal communication. August 1999. B. Samora, biologist, Mount Rainier National Park, Tahoma Woods Star Route, Ashford, WA 98304.

Figure 2—Mount Rainier National Park, Washington, where three ozone biomonitoring sites were located in 1998.

Table 3—Description of ozone biomonitoring sites at Mount Rainier National Park, 1998

Location	Elevation	Ozone-sensitive species examined	Monitoring dates
	Meters		
Reflection Lakes, site 1	1487	*Vaccinium membranaceum*	7/16, 7/23, 8/6, 8/20, 9/4, 9/17
Wonderland Trail, site 2	1219	*Rubus parviflorus* and *Sambucus racemosa*	7/16, 7/23, 8/6, 8/20, 9/4, 9/17
Longmire Campground, site 3	793	*Salix scouleriana*	7/16, 7/23, 8/6, 8/20, 9/4, 9/17

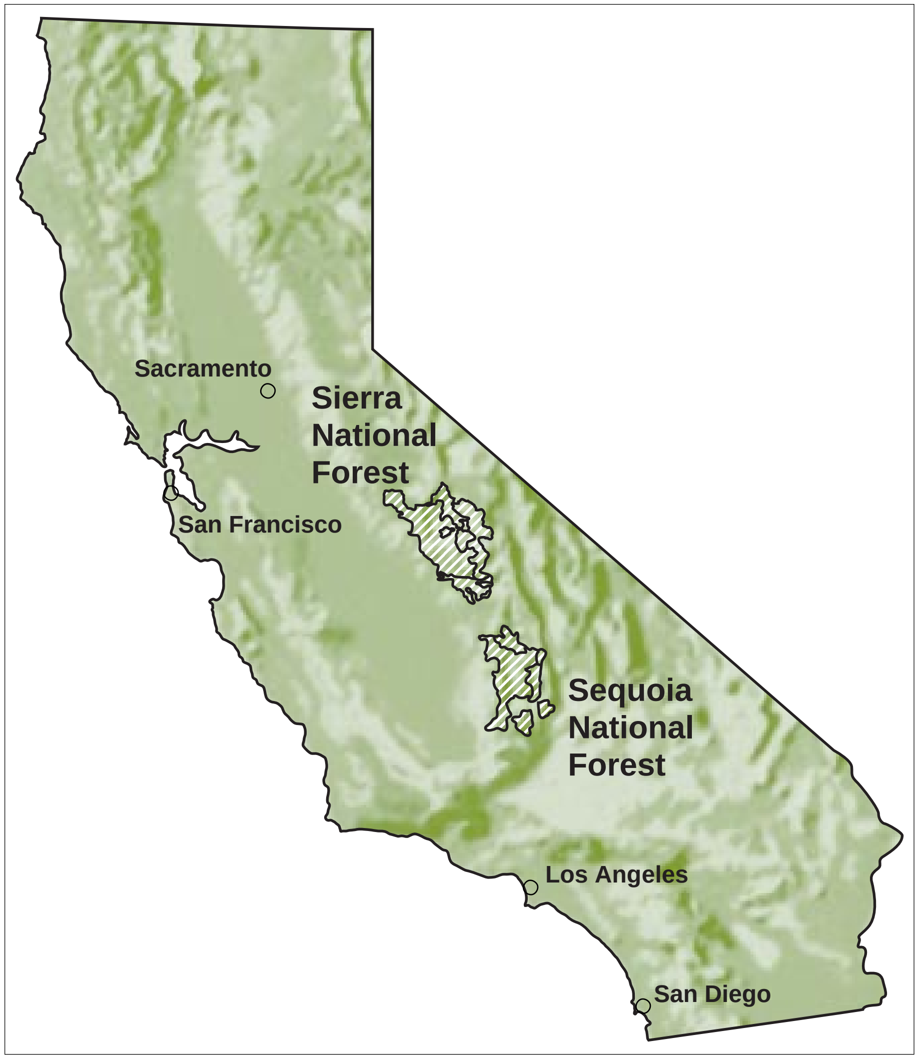

Figure 3—Sierra and Sequoia National Forests, California, where Forest Service (Pacific Southwest Region forest pest management) long-term ozone biomonitoring plots are located.

3. Control: no ozone was introduced into the charcoal-filtered air stream in this regime. Because the filter cannot remove all ozone, some ozone was present in the control chambers but was generally less than 4-5 ppm (summed over 28 days), with maximum daily concentrations below 15–20 ppb.

Each treatment was replicated twice; six seedlings of each species were assigned to each replication and placed in one of six field chambers.

Results

FHM and Mount Rainier Biomonitoring

Summary information on the number of plots with associated biomonitoring sites and the number of plants sampled by state is presented in table 4. Number of plants sampled, by species and by state, is given in table 5. Ponderosa pine and thimbleberry were the most common species; ninebark, quaking aspen, Scouler's willow, and snowberry also were relatively abundant. No sites were found with evening primrose, mugwort, or western wormwood.

West coast FHM and Mount Rainier field crews submitted 17 leaf samples of possible ozone injury–10 from FHM biosites and 7 from Mount Rainier biosites (table 6). Injury was confirmed on only one sample of red elderberry collected from Lewis County in Washington. It is worth noting that ozone injury, though not confirmed, could not be eliminated as the causal agent for two samples of thinleaf huckleberry from Mount Rainier National Park and one sample of ponderosa pine from the Plumas National Forest in California.

Sequoia and Sierra National Forests Biomonitoring

Figures 4 and 5 show the changes in number of trees with ozone symptoms over the past 20 years, beginning in 1977 when plots were first established in the two national forests. In the Sequoia National Forest, in the 2 years from 1996 to 1998, the percentage of trees with ozone injury symptoms changed very little: 45.2 in 1996 to 45.5 in 1998. For the Sierra National Forest, from 1995 to 1997, the percentage of trees with ozone symptoms decreased slightly, from 38.5 in 1995 to 35.4 in 1997. The greatest percentage of plots (45) fell into the slight injury class, but 42 percent of the plots were in the moderate, severe, and very severe classes (table 7). Statistical analysis and a more comprehensive examination of the data are currently underway and will be reported in a later publication. Data from earlier periods (1977–81) for these plots are previously reported (Pronos and Vogler 1981, Pronos et al. 1978).

Controlled Ozone Exposure Study

Symptoms typical of ozone injury occurred on three of the four species exposed to ozone in a controlled environment: red alder, huckleberry, blue elderberry (fig. 6). Symptoms on the red alder and huckleberry consisted of dark pigmented stippling on the interveinal tissue of the upper leaf surface, which is consistent with injury described by Brace et al. (1999). Exposed blue elderberry plants exhibited necrotic stippling and blotching between veins on both upper and lower leaf surfaces; these symptoms are similar to those previously described (Duriscoe and Temple 1996, Mavity et al. 1995, Temple 1999, Temple[3]). No injury was observed on chokecherry although a previous exposure trial by Mavity et al. (1995) resulted in purple stipple on the upper leaf. No symptoms of ozone injury were observed on any of the plants in the control chambers.

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[3] Observation by Temple.

Table 4—Number of west coast biomonitoring sites, plants sampled, and sites with validated ozone injury, 1998[a]

Location	Biosites visited	Plants evaluated	Biosites with ozone injury
Washington FHM	12	678	1
Oregon FHM	30	1283	0
California FHM	23	1731	0
Mount Rainier	3	60	0
Total	68	3752	1

[a] Does not include results for Sequoia and Sierra National Forests.

Table 5—Species and numbers of plants evaluated by west coast forest health monitoring and Mount Rainier National Park field crews, by species and location, 1998[a]

Species	Washington	Oregon	California	Mount Rainier NP	Total
Ponderosa pine	83	460	1,175	0	1,718
Thimbleberry	170	240	90	10	510
Quaking aspen	110	90	150	0	350
Scouler's willow	90	40	120	10	260
Ninebark	0	120	121	0	241
Mountain snowberry	90	120	0	0	210
Huckleberry	30	120	0	30	180
Pacific ninebark	90	30	0	0	120
California black oak	0	0	60	0	60
Blue elderberry	0	33	0	0	33
Chokecherry	0	30	0	0	30
Red elderberry	15	0	0	10	25
Mugwort	0	0	15	0	15
Evening primrose	0	0	0	0	0
Western wormwood	0	0	0	0	0

[a] Does not include results for Sequoia and Sierra National Forests.

Table 6—Summary of diagnoses for the 17 leaf samples sent in for validation of possible ozone injury by west coast forest health monitoring and Mount Rainier National Park field crews, 1998[a]

Species	Disease	Insect	Physiological	Ozone[b]	Unknown	Totals
Ponderosa pine	1			(1)		2
Quaking aspen	1					1
Thimbleberry	3		1		1	5
Ninebark					1	1
Scouler's willow			1			1
Huckleberry	2			(2)	2	6
Red elderberry				1		1
Total	7	0	2	1(3)	4	17

[a] Does not include results for Sequoia and Sierra National Forests.
[b] Numbers in parentheses are samples where ozone injury could not be ruled out.

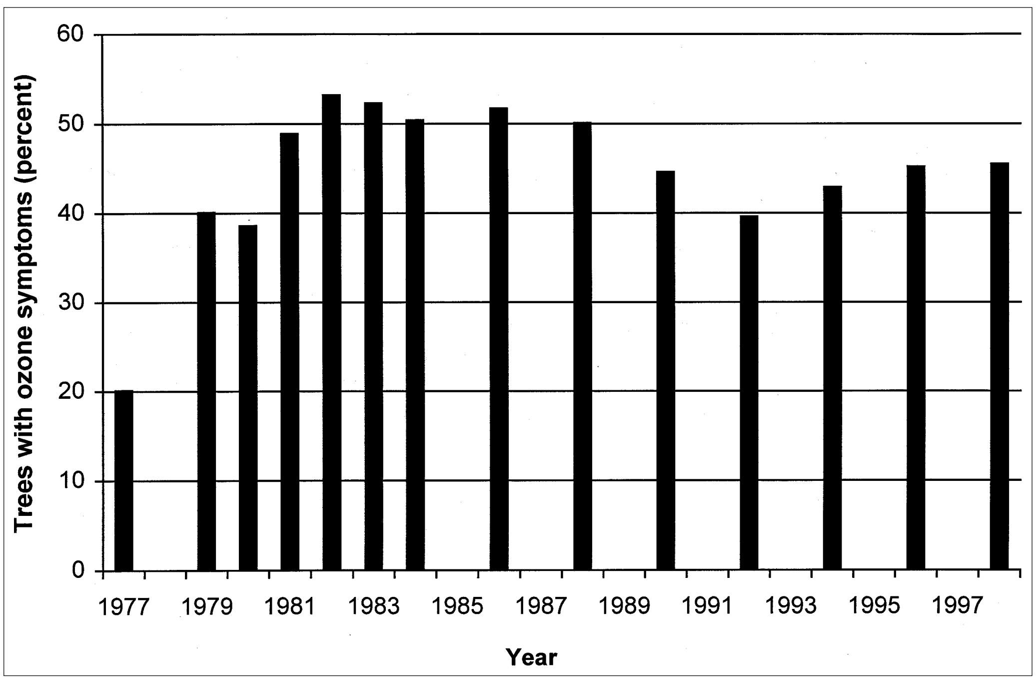

Figure 4—Percentage of trees with ozone symptoms in the Sequoia National Forest plots, 1977-98 evaluations.

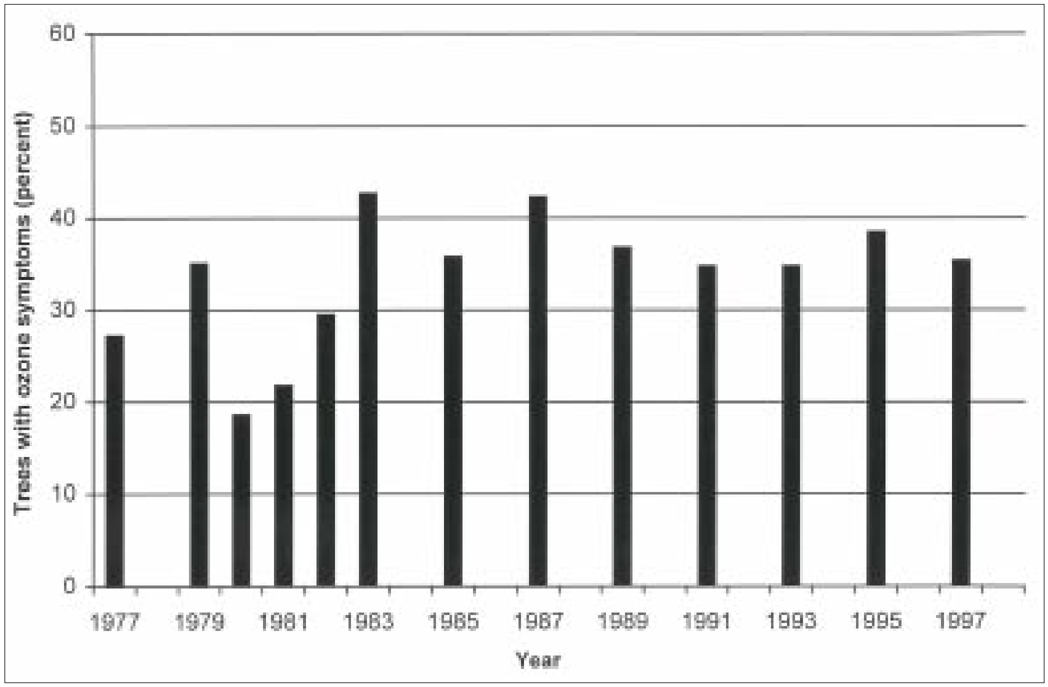

Figure 5—Percentage of trees with ozone symptoms in Sierra National Forest plots, 1977-97 evaluations.

Table 7—Ozone severity classes for ponderosa and Jeffrey pine plots, Sequoia National Forest, 1998

Severity class[a]	Number of plots	Percentage of total plots
No injury	4	15
Slight	11	43
Moderate	4	15
Severe	6	23
Very severe	1	4
Total	26	100

[a] Each plot was assigned a severity class based on the average ozone rating of all trees in the plot

Figure 6—Ozone injury symptoms on red alder (above), huckleberry (p.13, top), and blue elderberry (p. 13, bottom) following controlled exposure to 39 parts per million ozone over 28 days.

Discussion

Little or no ozone injury was detected in Oregon and Washington in 1998. The one FHM voucher plant sample positive for ozone was collected September 1, 1998, in Lewis County, WA, where industrial or automotive emissions from adjacent metropolitan areas (e.g., Centralia) may have contributed to the detected injury. Further monitoring is needed to confirm the presence of high ozone in this area.

Ozone injury was not detected on FHM biosites in California, although injury was recorded at the Sequoia and Sierra National Forests ozone plots and has been widely reported in past years in southern California forests (Miller 1996; Miller et al. 1997; Pronos and Vogler 1981; Temple 1989, 1999). Interestingly, fewer FHM biosites were located and established in southern California (where higher levels of ozone occur) than in northern California, perhaps owing to the difficulty in finding good biosites. Injury to pines in the Sequoia and Sierra National Forest plots is generally seen on 3-year-old or older needles, which indicates that symptoms are most visible only after injury has accumulated for several years (Peterson et al. 1991). All FHM indicator plants, except ponderosa and Jeffrey pines, are deciduous; leaves therefore are exposed over only one growing season.

There are other possible contributing factors to low ozone injury detection on FHM plots. The FHM program on the west coast in 1998 assessed ozone injury throughout the summer, instead of restricting ozone observations to a shorter period at the end of summer when ozone symptoms would be more likely after several months of cumulative ozone exposure. In addition, FHM plots and associated ozone biosites are not deliberately located in high ozone corridors and are widely spaced.

Work needs to continue regarding appropriate bioindicator plants for the west coast. Other species, in addition to the ones already used, may be useful as bioindicators. At relatively low levels of ozone, perhaps only species that retain their needles or leaves for several years are useful bioindicator plants.

Ozone concentrations over 60 ppb are capable of causing injury to some plant species (Krupa and Manning 1988, Miller et al. 1982, US EPA 1996b). In 1998, the 60 ppb (maximum 8-hour daily average) threshold was exceeded on at least one occasion during the summer at each of three forested sites in Washington (North Bend, Packwood, and Wishram) where ambient ozone is monitored (Bachman 1999[4]). Although little or no plant injury was detected in Washington on biomonitoring sites, nonvisible sublethal effects are possible (Chappelka and Samuelson 1998, Hakkarienen 1987, Krupa and Manning 1988, Smith 1974, US EPA 1996b).

In California, the maximum 8-hour daily averages for ozone in 1998 were reviewed for four forested sites monitored by the California Air Resources Board (it has over 200 air monitoring stations but only a handful of locations are in forested sites). The percentage of days between June 1 and September 30 when the maximum 8-hour daily average equaled or exceeded 60 ppb were (from north to south) 68.8 at White Cloud in the Tahoe National Forest, 76.2 at the 5 Mile Learning Center in the Stanislaus National Forest, 71.9 at Lower Kaweah in Sequoia National Park, and 83.6 at Lake Gregory in the San Bernadino National Forest. Visible foliar injury on pines due to ozone generally increases from north to south in California, consistent with ambient monitoring levels.

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[4] Personal communication. 1999. R. Bachman, biologist, USDA Forest Service, Pacific Northwest Region, P.O. Box 3623, Portland, OR 97208.

California has monitored ozone for many years, but Oregon and Washington lack historical data on ozone air quality (Treshow and Stewart 1973, US EPA 1996a). Until recently, the forests in Oregon and Washington were assumed to be relatively clean with only occasional intrusions of above-background concentrations of ambient ozone. Recent investigations show regional distribution of ozone in western Washington, with higher forest concentrations downwind (to the east) of metropolitan areas (Cooper and Peterson 2000). Similar patterns of ozone distribution are seen in California, although ozone concentrations there historically have been and continue to be much higher than in Oregon and Washington.

One of the goals of the FHM program is to collect baseline information on various forest health indicators, including ozone injury. Monitoring for ozone injury across the west coast forested landscape will provide a valuable biological record of ozone air quality for the entire region. Documenting the absence of a problem is just as important as detecting one. Many land managers have expressed concerns that ozone air quality problems are growing every year (Takemoto and Procter 1996). The FHM network of biosites is designed to detect the first visible sign of ozone stress and establish regional trends from a real baseline condition. Additional monitoring outside the FHM plot network, especially in Oregon and Washington forests where there is a high potential for ozone exposure, will be extremely important to supplement the FHM biosite network. In California, long-term ozone monitoring programs administered by the USDA Forest Service, National Park Service, and the California Air Resources Board have monitored ozone injury to pines for many years (Guthry et al. 1993).

The FHM ozone data has tremendous value as one of few large-scale biological networks of ozone air quality. The data undoubtedly will be used in the next scientific review of the secondary ozone standard. In a recent EPA report on the standard setting process, the need to examine foliar injury as an assessment endpoint is clearly stated, along with the need to understand the relation among foliar injury, growth, and other physiological parameters (Heck et al. 1998). Plant response data from natural (i.e., highly variable) ecosystems across a range of ozone concentrations are needed to provide the necessary biological argument to support or refute the need for a tougher ozone secondary standard to protect plant health and reduce the risk of ozone stress to our forested ecosystems.

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