Occurrence of Air Pollution Symptoms (Needle Tip Necrosis and Chlorotic Mottling) on Eastern White Pine in the Southern Appalachian Mountains

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ABSTRACT

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The air pollution symptoms tip burn and chlorotic mottling were found on eastern white pine in about 23% of sampled stands in the southern range of this species in Virginia, North and South Carolina, Georgia, Tennessee, and Kentucky. Plantations had a higher percentage of trees affected than did natural stands. The percentage of stands with at least one symptomatic tree was highest in Kentucky (77%), followed by Tennessee (31%), and lowest in Georgia (10%). Elevation and percent slope were not correlated with incidence, but stands with symptomatic trees were most common on southwest aspects. Symptomatic trees had 49% less mean volume than healthy trees.

Common, ambient air pollutants adversely influence forest tree growth and productivity in some areas of the United States. In the San Bernardino Mountains in southern California, Miller and co-workers (19–21) reported severe growth losses in ponderosa (*Pinus ponderosa* Dougl. ex Laws.) and Jeffrey (*P. jeffreyi* Grev. & Balf.) pines resulting from elevated ozone (O_3) concentrations, which are generated from precursor substances emitted in the Los Angeles Basin. Others (2,7,13,15,18,23–26) have likewise documented growth reductions in several eastern forest tree species exposed to ambient concentrations of O_3 in the Blue Ridge Mountains of Virginia.

For many years, eastern white pine's (*P. strobus* L.) sensitivity to O_3 and sulfur dioxide has been recognized (1–5,8,9, 11,12). The most frequently observed needle symptoms associated with pollutant exposure are tip burn, chlorotic mottling, and chlorotic banding of needles (16). Air pollution injury on eastern white pine has been documented over a large geographic area, including Indiana and Wisconsin (27), Tennessee (5), New Hampshire (6), the Appalachian Mountains (13), Virginia (15), Virginia and North Carolina (24), and the southern Appalachians (3).

Eastern white pine shows significant genetic variation in response to pollutants such as O_3. In 1977, Gerhold (14) classified genotypes of eastern white pine as resistant (no symptoms), moderately resistant (some symptoms and growth loss), and sensitive (major symptoms and growth loss, with associated mortality). Berry and Hepting (5) reported that only 5.7% of the population they tested was resistant to O_3.

In 1979, Skelly et al (24) reported that 22, 67, and 11% of the eastern white pines in the southern Blue Ridge Mountains were resistant, moderately sensitive, and sensitive, respectively, to O_3. In many cases, the most sensitive genotypes were so severely affected that the authors concluded that these genotypes probably were being eliminated from the population. Benoit et al (2) estimated growth losses of 15% for moderately sensitive trees and 25% for sensitive trees exposed to ambient O_3 concentrations, compared with tolerant trees, in the Blue Ridge Mountains of Virginia.

There is concern that atmospheric deposition may be affecting forest productivity in the southern United States. Pine growth reductions have been reported in much of the Southeast (22), and although the causes of these growth losses have not been determined, air pollution is viewed as a possible cause. The need therefore exists to assess the potential impact of O_3, the predominant phytotoxic air contaminant in the eastern United States, on forest trees in the Southeast. As an initial phase in this assessment, we surveyed symptoms typical of air pollution injury on eastern white pine in the southern portion of its natural range in Georgia, Kentucky, North Carolina, South Carolina, Tennessee, and Virginia. The objectives of the survey were: 1) to determine the incidence and distribution of needle tip

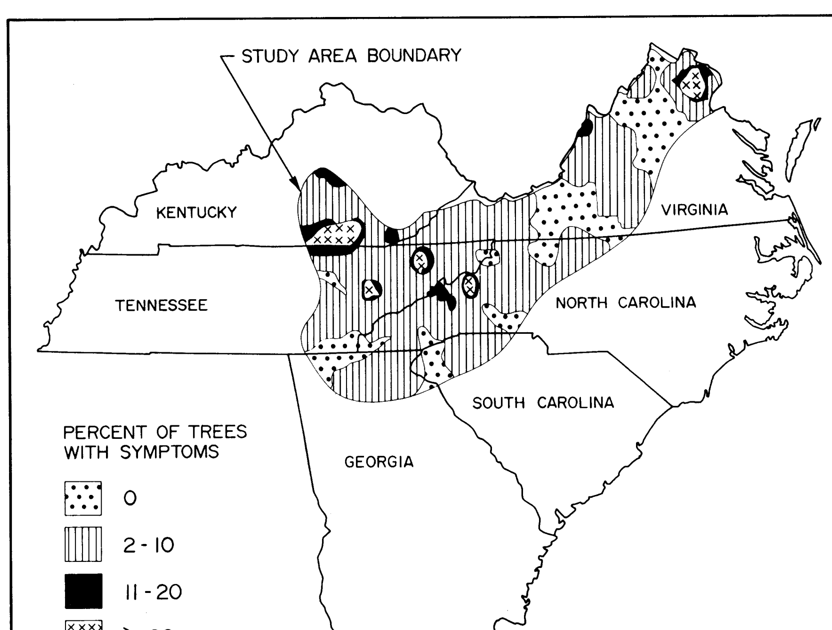

Fig. 1. Percentage of eastern white pines with tip necrosis and chlorotic mottling in a six-state survey area.

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burn and mottling in the study area, 2) to assess the potential growth loss on affected trees, and 3) to assess the possible correlation of site factors, such as slope, aspect, and elevation, with these symptoms.

The survey was designed to include only trees that had the typical air pollution symptoms of tip necrosis and chlorotic mottling. Where a cause other than air pollution could be identified, the tree in question was not tallied as having air pollution symptoms.

MATERIALS AND METHODS

During September through November 1985, 50 eastern white pines were examined on each of 201 sites systematically spaced across the natural range of this species in South Carolina, Tennessee, Virginia, North Carolina, Kentucky, and Georgia. Sample points were located on a map in a 24 × 24 km grid pattern. Every attempt was made to locate the white pine stand closest to the predetermined point on the map. All stands were located at least 40 m off a road and were not situated near major highways. The selected stands were at least 25% white pine and were of any age. The sampled trees had to have foliage that could be reached by hand (below 2.5 m) and that was fully exposed to the sun. The latter ensured that the foliage examined had been directly exposed to pollutants rather than to air filtered by other vegetation.

The current year's foliage that could be reached from the ground by hand on each sample tree was examined for needle tip necrosis and chlorotic mottling. A tree was considered affected if 20% or more of its branches had some necrotic needle tips and chlorotic mottling. A stand was considered affected if at least one tree of 50 examined showed air pollution symptoms. Foliar symptoms resulting from other stresses, such as insects, winter fleck, mites, herbicides, salt injury, drought, and plant pathogens, were noted, but these symptoms were not considered indicators of air pollution damage. Only field diagnosis was used to assess needle symptoms. Damage such as drought injury and needle cast can mimic air pollution-caused tip burn injury on conifers. However, chlorotic mottling is a symptom unique to ozone injury on eastern white pine needles.

The following factors were recorded for each stand: slope to the nearest 1%, aspect as north, south, east, west, northwest, northeast, southeast, or southwest; elevation to the nearest 15.2-m interval; stand type as planted or natural; longitude and latitude; location on a base map; and state. On trees with tip burn and chlorotic mottling, the crown position, age (counting whorls of buds or taking increment cores), diameter 1.4 m above ground (breast height), and height were recorded. For each symptomatic tree, the nearest symptom-free neighbor of the same age was examined for the same data to provide paired observations for growth comparisons. Many symptomatic trees did not have a paired symptom-free tree of the same age for growth difference comparisons, but a maximum of five paired trees were selected per stand.

Data were compiled by site location, and the effects of slope, aspect, elevation, and stand type (planted or natural) were examined. Sites were divided into categories, such as slope in 5% increments, and percentages of stands in each category were analyzed for differences in symptom occurrence. Tip necrosis and chlorotic mottling data were subjected to chi-square analysis to identify statistically significant differences ($P \leq 0.05$) among site and stand characteristics.

The diameter and height for each symptomatic and paired nonsymptomatic tree were used to determine and compare the volumes. These data were analyzed by a paired t test to identify any statistically significant differences in volume.

For each stand, the longitude, latitude, and percentage of trees affected were analyzed and graphically displayed. The computer program used located each data point, related it to adjacent points, and produced a symptom-severity distribution map for all sampled stands (10). Atmospheric concentrations of pollutants were not measured, and no effort was made to separate O_3-induced symptoms from other air pollution symptoms.

RESULTS AND DISCUSSION

Across the survey area, zones with few or no symptomatic trees and areas of high occurrence of air pollution symptoms were observed (Fig. 1). Around the high-occurrence areas, gradients of symptoms from high to low were present, as shown in Figure 1. Areas of high symptom occurrence were frequently associated with known sources of pollution. Table 1 shows that Kentucky had the highest number of stands affected by air pollutants (77%), followed by Tennessee with 31%. In the other states, 10–16% of the plots had at least one symptomatic tree.

Planted stands had a twofold higher percentage of trees affected, and the incidence per stand was 5% greater than in natural stands (Table 2). This observation was considered unusual, because seeds for plantations are generally selected from superior stock. This suggests that trees may be selected or seeds collected in areas of low hazard for forestation in higher hazard areas or that natural selection has been eliminating highly sensitive individuals in natural stands.

When stands were divided into 305-m elevation classes, no major differences in injury occurrence or severity (chi-square test) among classes were observed. In 1964 and 1986, differences were reported in diurnal O_3 profiles associated with elevation in the southern Appalachians (3) and Blue Ridge Mountains (17). Remote forested mountain sites (1,067–1,525 m) located outside the influence of local pollution sources had relatively flat daily O_3 profiles; the highest hourly concentrations occurred in the early morning before 5:00 A.M. In contrast, peak daily O_3 concentrations at valley sites occurred during midafternoon. Because symptom expression on eastern white pine was not affected by elevation, these differences in O_3 profiles may not be important in the development of foliar injury for this forest species.

Percent slope also was not significantly related to symptom severity (chi-square test). Aspect, however, did influence symptom occurrence. The southwest aspect had the highest percentage of stands affected (42%), followed by open (23%), then southeast and south (22%) (Table 3). The plot location procedure did not select sufficient stands on north slopes for statistical analysis. The higher

Table 1. Distribution of tip necrosis and chlorotic mottling symptoms on eastern white pines within the species' natural range in a six-state area (1985)

State	Plots in state	Plots with symptoms	Proportion of plots with symptoms (%)
Kentucky	13	7	77
Tennessee	32	10	31
Virginia	94	15	16
North Carolina	45	4	12
South Carolina	8	1	13
Georgia	10	1	10

Table 2. Distribution of tip necrosis and chlorotic mottling symptoms on eastern white pines in planted and natural stands

Stand origin	No. of stands	Stands with symptoms (%)	Symptomatic trees (for all stands) (%)	Symptomatic trees (for stands with at least one affected tree) (%)
Planted	125	28	4	15
Natural	70	14	2	10

Table 3. Distribution of tip necrosis and chlorotic mottle air pollution symptoms on eastern white pines by aspect

Aspect[a]	No. of stands[b]	Stands with symptoms[c] (%)	Affected trees on all plots (%)	Affected trees on affected plots (%)
South	31	22	2	7
East	13	0	0	0
West	12	16	1	4
Open	91	23	4	19
Southeast	18	22	2	9
Southwest	14	42	2	6

[a]Very few plots were on north aspects.
[b]Fifty trees were examined in each stand.
[c]Chi-square 100.08 (significant at $P = 0.01$) for symptomatic stands by aspect.

Table 4. Growth and associated volume loss from 48 paired tree observations in a six-state area

Type of tree	Average height (m)	Average dbh (cm)	Volume (m^3)
Symptomatic (tip necrosis and chlorotic mottle)	6.4	8.9	25.0
Nonsymptomatic	7.1	10.9	50.7
Difference	0.7	2.0	25.7

occurrence of symptoms on southwest slopes may be associated with prevailing wind direction. These sites could also be more drought prone, which could affect tip necrosis but not chlorotic mottling.

Even though many more paired trees were observed in the field, only 48 pairs of symptomatic or nonsymptomatic trees met the criteria of being on the same site, having the same age, and having foliage of the two trees touching. On the average, symptomatic trees were 0.7 m shorter and 2 cm smaller in diameter and contained 49% less cubic volume than unaffected trees (Table 4). Previous surveys have indicated that most eastern white pines are at least moderately sensitive to air pollution (2,27). In 1974, Skelly et al (24) reported that some eastern white pines had growth loss without visible symptoms. Because our nonsymptomatic trees may be growing slower than normal because of air pollution stress, our estimate of annual loss may be conservative. Also, sensitive trees that are showing symptoms may be of a genotype that naturally grows slower. The reported growth difference, therefore, may not have been caused by air pollution.

Most forest disease surveys involve a set of symptoms caused by a pathogen. These pathogens can be isolated to confirm the cause effect of the symptoms. In our survey, the cause of symptoms could not be delineated with certainty. Tip burn and chlorotic mottling were selected as the symptoms of air pollution. All attempts were made to eliminate trees when the cause of tip burn or mottling could be ascribed to another cause. Only when a tree clearly had tip necrosis and chlorotic mottle on the current year's needles, and when another cause could not be found, was the tree considered to have air pollution symptoms.

This survey showed that trees that fit the classification were present in the southern part of the eastern white pine range in 1985. Symptomatic trees did not occur uniformly across the survey area but were found in definite high- and low-occurrence areas. No attempt was made to assess the reason for the pattern of occurrence or to determine if there was a correlation between sources of pollution and the observed symptoms. This survey was designed to map the occurrence and determine the percentage of trees affected. The percentage of trees affected was low (2–4%), and the pattern of incidence was not uniform.

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