SMOG INJURY, ROOT DISEASES AND BARK BEETLE DAMAGE IN PONDEROSA PINE

R. W. STARK • F. W. COBB, JR.

Photochemical oxidants (smog) are causing serious injury to ponderosa pine in the San Bernardino Mountains of southern California. Apparently, smog injury also renders the trees more susceptible to attack by two species of destructive forest insects, the western pine beetle, *Dendroctonus brevicomis*, and the mountain pine beetle, *D. ponderosae*. Recent studies have shown that photochemical oxidant injury to ponderosa pine results in reduced oleoresin yield, rate of flow and exudation pressure, sapwood and phloem moisture content and phloem thickness, all of which are believed important in the defense of the tree against bark beetles. Smog injury also affects growth rate and probably wood quality. Soluble sugars and reserve polysaccharides were reduced in diseased trees. Current studies indicate that similar injuries to ponderosa pine, with resulting increase in bark beetle attack, occur as a result of infection by root disease fungi, notably *Fomes annosus* and *Verticicladiella wagenerii*.

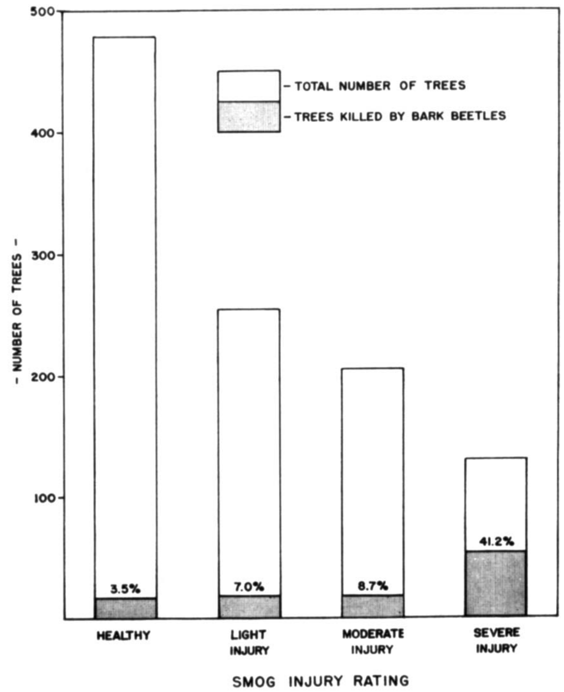
THE DISEASE OF PONDEROSA PINE caused by atmospheric pollution has been called X-disease, chlorotic decline, and ozone needle mottle. Gradual discoloration or mottling of needles exposed to smog is associated with premature chlorosis, which can lead to senescence and finally death and casting of needles (see photo). The disease is apparently associated with increased ozone in the atmosphere produced by photochemical reduction of air pollutants. There is a rapid loss of chlorophyll in foliage exposed to ozone which suggests that chlorotic decline results from a reduction in photosynthetic capacity below that necessary to support tree growth.

Older needles are affected first; discoloration generally begins at the needle tip and progresses toward the base. Where smog is persistent and severe, as in the Lake Arrowhead area of the San Bernardino Mountains, discoloration and defoliation continue until the tree is dead. All ages of trees are affected. Death can occur within two years but normally occurs at least five years after the onset of noticeable symptoms.

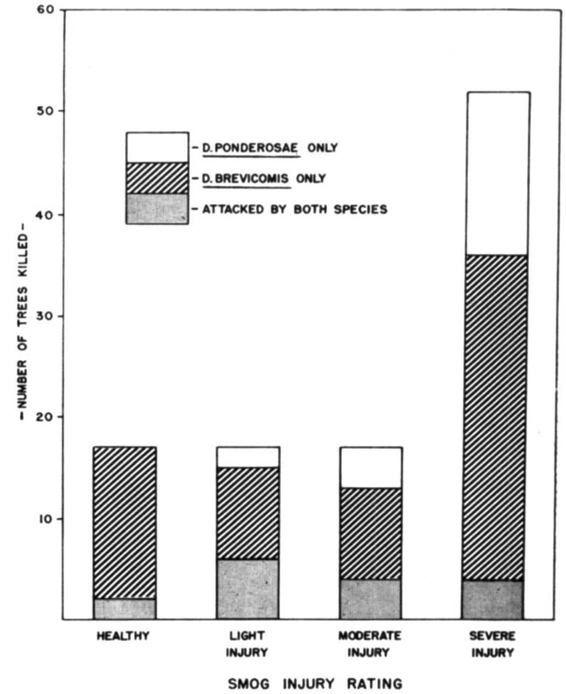
In 1965, U. C. plant pathologists noticed that smog-injured ponderosa pines in the San Bernardino Mountains frequently were attacked by the western pine beetle, *Dendroctonus brevicomis* LeConte, and the mountain pine beetle, *D. ponderosae* Hopkins. These beetles are the most destructive insect pests of pines in western U. S., causing an estimated loss of ponderosa pine alone in excess of $100,000,000 in the Pacific

Typical smog injury to ponderosa pine in San Bernardino Mountains.

GRAPH 1. RELATIONSHIP BETWEEN DEGREE OF SMOG INJURY AND BARK BEETLE ATTACK.



GRAPH 2. NUMBERS OF TREES KILLED BY THE WESTERN PINE BEETLE, THE MOUNTAIN PINE BEETLE OR THE TWO SPECIES TOGETHER.



coast states between 1921 and 1945. The western pine beetle attacks Coulter pine in southern California and ponderosa pine throughout its range. Although its attacks when its population is low are normally restricted to slow-growing, decadent or unhealthy trees, it can kill apparently vigorous fast-growing trees of all ages. The mountain pine beetle is more destructive in lodgepole, western white and sugar pines, but it often attacks ponderosa pine in substantial numbers as well.

Infestation means death

In southern California, the western pine beetle may have two to four generations per year, whereas the mountain pine beetle usually has one or two per year. Successful infestation of a tree by either of these species usually results in death of the tree. Occasionally, the mountain pine beetle may kill only a portion of some trees, but such trees usually succumb to the attacks of succeeding generations of beetles. These two insects are undoubtedly the major forest insect pests in southern California and are the object of major control efforts by state and federal agencies. The losses in high-use recreation areas such as Lake Arrowhead are often incalculable.

Beginning in 1966, scientists from the University of California at Berkeley and the U. S. Forest Service began studies to determine the relationships between air pollution injury and bark beetle attacks. An extensive survey of the area in the vicinity of Lake Arrowhead was made. A total of 1,072 ponderosa pines, 103 of which were attacked by bark beetles, were intensively examined for symptoms of smog injury. Fifty-five per cent of the trees had noticeable symptoms of injury, and many of the apparently healthy trees were being affected by smog to at least some degree. Graph 1, above, shows the observed relationship between degree of injury and incidence of bark beetle attack. Only 3.5 per cent of the apparently healthy trees were infested, compared with 41.2 per cent of the most severely affected trees.

Combined attack

Of the 103 beetle-infested trees, 65 were attacked by *D. brevicomis,* 22 by *D. ponderosae,* and 16 by a combined attack of both species (graph 2). None of the apparently healthy trees were successfully attacked by *D. ponderosae* alone, a result which agrees with the hypothesis that the mountain pine beetle is less "aggressive" than the western pine beetle. Neither smog injury nor attack by bark beetles was related to height, diameter or the position of the trees in the stand. A relationship was not unexpected with the western pine beetle (because it is an aggressive species which may attack almost all age classes), but the mountain pine beetle is usually found in suppressed, weakened or damaged trees. The attack of all tree sizes in the advanced-disease category by the mountain pine beetle indicates that these trees were reduced in vigor to a state where they were easy prey for the beetle. Thus, the results show that trees exhibiting chlorotic decline symptoms are more frequently attacked by bark beetles than are those exhibiting less severe or no decline symptoms.

Critical examinations of 100 living trees in each of three disease categories, healthy, intermediate and advanced, were made to determine incidence of attempted attack. In the advanced disease category, 36 trees showed evidence of attempted attack by bark beetles, in the intermediate-disease category 19 trees showed evidence of attempted attack and in the healthy category only five showed such evidence. These and the other observations suggest that trees subjected to smog injury not only are more frequently attacked by bark beetles but actually may be more attractive to the beetles.

After it was established that there is, indeed, a relationship between smog injury and bark beetle attack, studies were made to determine how air pollution injury affects the tree to make it more susceptible to bark beetle invasion. Characteristics of the tree studied included diameter and height growth, relative size of crown, oleoresin exudation pressure, oleoresin yield and rate of flow, crystallization rate, sapwood and phloem moisture content, phloem thickness, monoterpene and resin acid composition of oleoresin, phloem sugars, starch and nonstarch polysaccharides, and phloem pH.

More susceptible

These studies gave some evidence about the mechanisms by which the trees may have been rendered more susceptible to bark beetle attacks. Chlorotic decline reduced tree growth both in height and diameter. The most obvious external effect on the tree which seems to be related to incidence of bark beetle attack was the short crown, expressed as the live crown ratio (length of total live crown divided by total height). Smog injury killed an excessive number of the lower branches of the tree, thus reducing the live crown ratio.

The oleoresin system of pines is believed to be a major source of resistance to bark beetle attacks. The resin in trees is maintained under various pressures, and differences exist between pines as to resin quantity and rate at which oleoresin crystallizes. Pressure, yield, and rate of flow are physical barriers to entry by the bark beetle. Crystallization rate may have an effect once a wound is made in the tree; a rapid crystallization rate would probably improve the possibility of successful attack by bark beetles. Trees with a low oleoresin exudation pressure seem to succumb more readily to attacks by both the western pine beetle and mountain pine beetle—particularly the latter. Smog injury reduced oleoresin exudation pressure, resin yield and rate of flow significantly. Crystallization rate, on the other hand, was increased.

Sapwood and phloem moisture contents of the smog-injured ponderosa pines were also reduced. Since the moisture content of the tree is a reflection of the physiological condition of the host affecting oleoresin exudation pressure, it is possible that a reduction in moisture content and oleoresin would further encourage successful bark beetle invasion. The effects on brood development in the tree also might be advantageous to the beetles. On the other hand, inner bark (phloem) thickness and phloem carbohydrates were also reduced in severely injured trees. These reductions may not be favorable for brood development because the nutritional value of the phloem for the feeding larvae may become limiting. Phloem pH and quality of the sapwood oleoresin, based on the major monoterpene constituents, were not affected by smog injury.

Smog injury

Although there has been no apparent increase in bark beetle populations in the Lake Arrowhead area, smog-injured trees may serve as a focus for future outbreaks of bark beetles. Bark beetle populations in the southern part of the state have been relatively static for several years. The weakened stands in the San Bernardino Mountains may act as a reservoir and cause future damage by bark beetles to be concentrated in this valuable recreational area. Even if bark beetles remain low in number, mortality of ponderosa pine from photochemical atmospheric pollution injury is continuously increasing.

Current studies at the University of California Blodgett Research Forest and other areas of northern California indicate that a similar disease-insect relationship exists between root-infecting fungi and bark beetles. In the Blodgett area (El Dorado County), approximately 80 per cent of the bark beetle-infested ponderosa pines that were examined had been infected by root-disease fungi prior to beetle infestation. None of an equal number of living uninfested trees chosen at random from the general area were diseased. The major root-disease organism was *Verticicladiella wagenerii*, a fungus that moves from tree to tree via roots and causes a prominent dark stain in the infected tissue. The most common insects that occurred in these diseased trees were the western pine beetle and the mountain pine beetle. However, some of the trees also had been attacked by the red turpentine beetle, *Dendroctonus valens* LeConte and by flatheaded borers (Coleoptera; Cerambycidae).

Prior infestation

At the Boggs Mountain State Forest (Lake County), at least 60 per cent of the bark beetle-infested trees had been infected by *Fomes annosus* prior to beetle infestation. The insects were the same as those occurring in association with *V. wagenerii*. *Fomes annosus* is another potentially serious pathogen of conifer roots and is widespread in California. It occurs in natural stands undisturbed by man, but usually becomes a serious problem only after logging. The fungus commonly invades freshly cut stumps, moves down into the roots and then infects roots of adjacent trees by contact.

Surveys have shown that both *V. wagenerii* and *F. annosus* occur in association with bark beetle infestations in other areas of northern California as well. Other root disease fungi, *Armillaria mellea* and *Polyporus schweinitzii*, also have been found to infect ponderosa pine prior to beetle infestation, but these appear to be relatively unimportant in the overall root disease-bark beetle association in ponderosa pine at the present time. Preliminary studies of white fir, *Abies concolor*, indicate that root disease fungi, especially *Fomes annosus*, also may be important in weakening the resistance of that species and predisposing it to bark beetles such as *Scolytus ventralis*.

Studies are in progress to determine the effects of *Verticicladiella wagenerii* on the physiology of ponderosa pine. There is evidence that oleoresin exudation pressure, resin yield and rate of resin flow are reduced in diseased trees. Moisture content, especially of the foliage, also appears to be reduced. However, there appears to be no effect upon quality of the turpentine fraction of xylem oleoresin or upon phloem pH. Resin crystallization rate actually may be reduced in diseased trees, an effect which would be the reverse of that found in smog injured trees.

Predisposing trees

Our studies have shown that, in addition to such direct losses as reduced growth and mortality, air pollution injury and root disease organisms have a greater effect than had been generally recognized by predisposing trees to attack by bark beetles. These studies will also aid in analyses of the population fluctuations of bark beetles and thus in the control of these serious pests.

Current studies on the effect of air pollution injury and root diseases on the physiology of ponderosa pine hopefully will elucidate the mechanisms by which disease predisposes forest trees to bark beetle infestation and, conversely, the mechanisms of tree resistance to bark beetle attack.

R. W. Stark is Professor, Department of Entomology and Parasitology, and Entomologist; and F. W. Cobb, Jr., is Assistant Professor, Department of Plant Pathology, and Assistant Plant Pathologist, Agricultural Experiment Station, University of California, Berkeley.