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AIR POLLUTION IMPACTS ON FOREST TREES: DIAGNOSIS AND BIOINDICATORS

Abstract. Air pollution is an important stress factor on forest trees in much of the world. However, the effects of air pollution are often subtle and difficult to verify. This paper describes the most important considerations in diagnosing suspected air pollution injury, and reviews literature with regard to using lichens and plants such as tobacco, eastern white pine, and trembling aspen as bioindicators of air pollution.

Key words: forest trees, air pollution, pollution injury, bioindicators.

Introduction

The diagnosis of air pollution injury to trees is complicated because the injury can occur in many different forms, depending on the pollutant, the tree species, and the environmental conditions under which the trees are growing. However, there are types of visible symptoms that are associated with specific air pollutants. These symptoms, along with a number of other factors, allow for accurate diagnosis of many air pollution problems on trees. This paper will first discuss procedures for diagnosing air pollution injury to forest trees and then examine how bioindicators can be used to monitor air pollution and assist in the diagnosis of suspected air pollution problems.

Because so much information has been written on these two topics, this article cannot possibly cover all of the important literature. Rather, the article is intended to provide the reader with an introduction to these topics and with access to some of the most significant literature relevant to forest trees. For more detailed reviews of diagnosis of pollutant injury, the reader is referred to books by Applied Science Associates, Inc. (1978), Jacobson and Hill (1970), and Malhotra and Blauel (1980). An excellent review of biomonitoring air pollutants with plants is presented by Manning and Feder (1980).

Diagnosis

The United States Environmental Protection Agency's manual on diagnosing vegetation injury (Applied Science Associates, 1978) lists seven questions that are useful in diagnosing suspected air pollution injury. Below are the six that are the most important:

1. What plant species are injured?
2. What are the injury symptoms and what plant parts are affected?
3. Is there a pollution source nearby capable of causing injury?
4. What is the distribution of affected plants?
5. Are biological agents (insects, diseases, nematodes) present?
6. What is the recent history of the affected area?

In contrast to insects or diseases which often are quite selective in the species they affect, air pollution usually injures a wide range of plants, especially if the fumigation is severe. Knowing what plant species are injured also is useful because some plants are especially sensitive to certain pollutants and so make good bioindicators of the presence of that pollutant. Bioindicators will be discussed later in this paper. Some common bioindicators are shown in the Table.

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Typical symptoms of air pollution injury on hardwoods and conifers and some bioindicator plants

Pollutant	Hardwood Symptoms	Conifer Symptoms	Bioindicator Plants
Ozone	Upper leaf surface stipple or fleck, often purple or black in color. Premature leaf drop	Current-year needle tip necrosis (tip-burn), shortened needles (chlorotic dwarf), needle mottling. Premature needle drop	*Asclepius syriaca*, *Fraxinus pennsylvanica*, *Nicotiana tabacum* var. Bel-W3, *Pinus strobus*, *Populus tremuloides* (selected clones), and *Prunus serotina*
Sulfur dioxide	Bifacial, interveinal tan or brown necrosis	Current-year needle tip necrosis (extending to needle base when severe). Yellowing of older needles	*Betula papyrifera*, lichens, *Medicago sativa*, and *Pinus strobus*
Hydrogen fluoride	Leaf tip or margin chlorosis or necrosis	Current-year needle tip necrosis (extending toward needle base when fumigation is severe)	*Gladiolus gandavensis* var. Snow Prince or Flowersong, and *Larix decidua*
Deicing salts	Leaf margin chlorosis, premature fall coloring, dieback, witches'-brooming	Needle tip chlorosis or necrosis for one-half needle length or more (visible in late winter or spring). Premature needle drop	*Pinus strobus*, *Thuja occidentalis*, and *Tsuga canadensis*

Examining the types of symptoms present will also help in diagnosing air pollution injury. The color of the foliage injured, the pattern of injury on the leaves, the leaf surface affected, the state of maturity of the injured leaves, and the location of the plant where the injury occurred are all useful information to note. Some typical symptoms are described in the Table.

If the injury symptoms appear to be caused by air pollution, then a source of the pollution problem must be identified. With the exception of long-distance transport of ozone, most pollutant injury to trees occurs within close proximity to the pollution sources. Air monitoring data from various local, state, or federal agencies will sometimes verify the presence of a pollutant fumigation episode in an area with suspected air pollution injury.

The distribution of suspected pollutant injury on trees is another important diagnostic tool, especially when point sources of pollution are involved. Damage is usually most severe downwind from point sources. The distribution of injury can also be used to distinguish air pollution problems from those caused by insects or disease which often have distinct patterns of spread.

Any plants showing suspected pollutant injury should be examined carefully for biological agents that may have caused symptoms that mimic air pollution injury. Spider mites (family Tetranychidae) and leafhopper (*Empoasca*, *Edwardsiana*, *Erythroneura*, and *Typhlocyba* species) insects, for example, can cause upper leaf surface stipple on hardwood trees similar to ozone injury (Hibben, 1969).

It is also important to be aware of any abiotic stresses such as water stress, frost, or nutrient deficiency that may be present and could cause symptoms similar to those of air pollution.

Obtaining information on the recent history of the affected area can sometimes help make the diagnosis. This could reveal information on factors such as soil fertility, pesticide applications, drought stress, or changes in drainage patterns.

In addition to the above-mentioned diagnostic procedures, it is useful to document the suspected episode by taking photographs and herbarium specimens of injured leaves. These can be used for laboratory diagnosis long after the leaves have dropped in the field. For example, foliar analysis can be used to verify elevated levels of air pollutants such as sulfur dioxide and hydrogen fluoride (Linzon, Temple, Pearson, 1979; Molski, Bytnerowicz, Dmuchowski, 1981).

Bioindicators

Plants that respond predictably to air pollutants can be used independently or in conjunction with mechanical monitors to biomonitor the presence and amount of air pollution. Some examples are listed in the Table. The rapid response of plants to air pollution, the relatively inexpensive nature of biomonitoring versus monitoring with instruments, and the fact that biomonitors can be used in remote sites where a power supply needed for instruments does not exist, are advantages of using bioindicators to monitor air pollution.

There are also some disadvantages. First, the effects of air pollution on plants are under the influence of many factors such as climate, soil, water, pathogens, and the genetic variability of the plants (Posthumus, 1976). Also, the measurement of effects is often difficult to standardize. Frequently, bioindicators allow us to determine that a given pollutant was present but not the exact pollutant dose that occurred.

Tobacco. Tobacco (*Nicotiana tabacum*) is a very commonly used bioindicator plant. The cultivar Bel-W3 is extremely sensitive to low ozone concentrations, while Bel-B is quite tolerant (Menser, Hodges, 1968). Since its discovery in the early 1960s by Heggestad and Menser (1962), Bel-W3 has been used extensively to monitor ozone levels in the United States (Heck, Heagle, 1970; Jacobson, Feder, 1974; Kelleher, Feder, 1978), Europe (Posthumus, 1976), and elsewhere (Horsman, 1981; Naveh, Chaim, Steinberger, 1978). Techniques for culturing and collecting data from tobacco are thoroughly described by Manning and Feder (1980).

Eastern White Pine. Eastern white pine (*Pinus strobus*) trees show considerable genetic variation in their pollutant responses (Houston, Stairs, 1973). Berry (1973) isolated individual trees with differing sensitivities to ozone, sulfur dioxide, and hydrogen fluoride. One advantage of biomonitoring with a tree such as eastern white pine is that once the tree is outplanted, it needs little attention and it can be utilized for several growing seasons. This is a sharp contrast to short-lived tobacco which must be grown under stringent cultural conditions. One disadvantage of using eastern white pine is that many pollutants cause similar types of foliar injury, namely a necrosis of the needle tips. However, needle mottling is also common on eastern white pine, and this symptom shows promise of being accurately quantifiable (Dochinger, Arner, 1978).

Hardwood Trees. Karnosky (1976) determined threshold levels for a number of clones of trembling aspen (*Populus tremuloides*) for exposures to ozone and sulfur dioxide, alone and in combination. These clones have since been grown under field conditions in the greater New York City area. Two of these clones have shown a degree of ozone sensitivity in chamber and field that is similar to that of Bel-W3 tobacco. Two others have good ozone tolerance. These aspen have the advantages as biomonitors of being longlived and of continually flushing new growth during the growing season. Thus, the same plants can be observed throughout the growing season, in contrast to the multiple plants needed for tobacco. Another valuable biomonitoring attribute of these aspen is that they are readily propagated vegetatively.

Two other hardwood trees showing consistent chamber and field sensitivities to ozone and having excellent potential as bioindicators are the 'Imperial' honeylocust (*Gleditsia triacanthos inermis* 'Imperial') and the 'Fastigiate' English oak (*Quercus robur* 'Fastigiate'). These two trees both display classic upper leaf surface black stipple or flecking in response to ozone (Karnosky, 1981), in contrast to the more variable symptoms on aspen.

Green ash (*Fraxinus pennsylvanica*) and white ash (*F. americana*) are two species that have been described as being very sensitive to ozone and thus good bioindicators. However, there is a wide range of variation of pollutant responses within these two species (Karnosky, Steiner, 1981) and only selected tolerant and sensitive individuals should be utilized for biomonitoring.

Davis (1982) has found black cherry (*Prunus serotina*), which is widely distributed in the eastern hardwood forests, to be a valuable bioindicator of ozone. It deserves further attention to standardize its pollution response and determine the degree of intraspecific variation in response.

Lichens. Lichens, formed by an association of a fungus and an alga, are probably the most commonly used biomonitors. Reviews by Nash (1976) and Richardson and Nieboer (1981) detail why lichens are so popular for pollution monitoring.

Because they are widely distributed and very efficient at taking up sulfur from the air and storing it in excess of their needs, lichens have been frequently used to biomonitor sulfur dioxide (Gilbert, 1970; Hawksworth, Rose, 1970; Laaksovirta, Olkkonen, 1979; LeBlanc, De Sloover, 1970; Sundström, Hällgren, 1973). Lichens have also been used to biomonitor fluorides (Perkins, Millar, Neep, 1980; Roberts, Thompson, 1980) and lead from automobile exhausts (Lawrey, Hale, 1979).

Although there are no universal criteria of lichen evaluation, Manning and Feder (1980) described the following techniques which have been commonly used:

1. Determine the total number of lichen species;
2. Determine the degree of cover for each species;
3. Determine the frequency of each species; and
4. Determine the luxuriance of each species.

Lichen studies can either be done on naturally-occurring lichens or ones transplanted into study areas. Brodo (1961) developed a method of cutting circular discs of bark, with lichens on them, from healthy trees and moving these into areas where pollution problems were suspected. Subsequent development of transplanted lichens was determined by comparing periodic photographs. This technique was later used to study the sulfur dioxide problem around Sudbury, Ontario, Canada (LeBlanc, Rao, 1973).

Subtle Effects. With the exception of the observations on lichen growth, the previous discussion of plant biomonitoring has been oriented toward visible injury symptoms. There are also several more subtle effects on plants that can serve as good indicators of the presence of air pollution. Accumulation of airborne sulfur (Bieberdorf et al., 1958; Laaksovirta, Olkkonen, 1979; Linzon, Temple, Pearson, 1979) and fluoride (Molski, Bytnerowicz, Dmuchowski, 1981; Perkins, Miller, Neep, 1980) has been used in studying the boundaries of pollution problems around industrial areas. Keller (1974) has used peroxidase enzyme activity of several tree species to map pollution zones around cities and industries in Switzerland. Similar work with esterase enzyme in spruce (*Picea*) needles (Yee-Meiler, 1975) and dehydrogenase enzyme in several agricultural crops (Rabe, Kreeb, 1979) suggests that enzyme systems deserve more study as indicators of pollution levels which are not high enough to produce visible damage on plants.

Analysis of growth rings also can be used effectively to indicate air pollution effects. Linzon (1971) used growth-ring analysis along with measurements of height and diameter growth of eastern white pine to document zones of pollution effects in the Sudbury, Ontario, Canada area. Increment cores were also used to document decreased growth in eastern white pine and loblolly pine (*Pinus taeda*) near a periodic source of sulfur dioxide and nitrogen oxides (Phillips, Skelly, Burkhart, 1977a, 1977b).

Summary

Although the diagnosis of pollutant injury to forest trees is a complicated matter, the trained observer can make accurate diagnoses by following the guidelines discussed in this article. The examination of naturally-occurring or planted bioindicator plants can provide useful information about the occurrence of air pollution. However, pollutant concentration monitoring data based totally on bioindicator plants will probably never be as readily accepted as those from properly-calibrated mechanical monitors. Thus, bioindicators should generally be viewed as supplements to and not as substitutes for traditional mechanical monitoring systems.

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