

Great Smoky Mountain Plants Studied For Ozone Sensitivity

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Plants suffering from the ill effects of a variety of air pollutants are causing widespread concern within the National Park Service. Effects can vary greatly, some plants exhibiting no symptoms, some showing reduced vigor, and some suffering widespread tissue necrosis and death. Injury is not limited to individual plants, but may also be displayed on a community or ecosystem level.

Since 1986, putative ozone injury symptoms have been observed on over 70 native species of plants in Great Smoky Mountains NP (GRSM). GRSM contains more than 1500 native plant species and is one of the largest temperate forest reserves in North America. Ozone (O_3), with its widespread distribution, probably has the greatest negative impact on vegetation of all air pollutants (Reich 1987, Krupa and Manning 1988, de Steiguer et al. 1990). Ground level or tropospheric ozone is a secondary pollutant formed by the reaction of sunlight on the primary pollutants of nitrogen oxides and hydrocarbons. Ozone levels in GRSM rarely exceed the National Ambient Air Quality Standard (NAAQS), but moderate chronic levels do exist.

Ozone is an extremely phytotoxic air pollutant. Ozone enters the plant through the stomata, which are the small pores on the underside of the leaf. Once the ozone is inside the substomatal cavity of the leaf interior, the possibility for foliar injury is present. At low concentrations, typically the first sign of ozone damage is a water-soaked appearance of the leaves. This occurs because of loss of water into the intercellular spaces, due to the loss of membrane integrity. If the ozone stress is removed, the cell membranes may repair themselves and the symptoms disappear. If exposure continues or increases, flecking or stippling may appear followed by chlorosis and then necrosis (Tingley and Taylor 1982).

Ozone, being a very unstable substance, reacts in water and/or with organic compounds to form a number of highly toxic oxides, including O_2^- - superoxide; H_2O_2 - hydrogen peroxide. All these compounds can react with cellular membranes causing damage.

Damage arises primarily from reactions with lipids or fats that are constituents of membranes. For example, superoxide can cause the double bond in the fatty acid half of a lipid to convert to a single bond. The properties of the lipid then are changed, and if enough lipids are altered, the membrane properties are modified.

Ozone itself reacts strongly with saturated fatty acids and other organic compounds, hence disrupting membranes (Heath 1980). Severe ozone exposure may even result in the cleavage of the fatty acid half of a lipid, giving rise to toxic 3C compounds. Ultimately these damaging effects lead to reduced photosynthesis (Reich and Amundson 1985, Reich 1983), modified carbon allocation (McLaughlin and McConathy 1983), or even death of the individual.

Scientists' estimates of percentage annual growth changes due to air pollution for the high elevation spruce-fir forests in the Appalachians varied from -2 to -70 percent, with a median estimate of -10 percent (de Steiguer et al. 1990). These estimates reflect only growth reduction and not air pollution induced death.

A study initiated by the NPS Air Quality Division and GRSM in 1986 was undertaken to characterize the



Figure 1. The Ozone fumigation site at Uplands Research Lab.

adverse effects of ozone on plants native to GRSM. This study is documenting the physical as well as the dynamic responses individual species exhibit to exposure to ozone. In 1989, the EPA funded a three-year program to study the physiological responses of ozone on selected plant species native to GRSM. This project also is being conducted at the GRSM's Uplands Field Research Lab fumigation site. Together, the NPS and EPA will be able to address the chronic problems of ozone pollution on GRSM plants.

Methods

Plants native to GRSM are examined in the field to determine if they exhibit any typical or classic symptoms of ozone sensitivity. If a species appears to be ozone sensitive, a specimen is brought back to the lab for verification of ozone damage. Once putative ozone damage has been determined, that species is listed for future ozone fumigation at Uplands Field Research Lab. To date, 74 species of plants in GRSM have exhibited putative ozone injury.

With the conclusion of the 1990 field season, 31 species of plants native to GRSM have been subjected to a gradient of ozone concentrations. In the experiment, plants are cultivated from seed collected in the park. Seedlings are grown in individual pots and are placed in one of 15 open-topped growth chambers or three open plots. This allows for three replications of six treatments.

Treatments include 0.5 x ambient, 1.0 x ambient, 1.5 x ambient, 2.0 x ambient, carbon-filtered, and open-ambient plots. All treatments except the carbon-filtered are proportional to ambient ozone concentrations in order to give a better reflection of what vegetation in GRSM is exposed to. Ambient concentrations are continuously monitored and treatments are updated every two minutes. In addition to monitoring ambient ozone concentrations, all meteorological parameters and CO_2 and NO_2 concentrations are analyzed and recorded on a data logger and computer.

Technicians water the plants manually to ensure that

all individuals receive enough water for soil saturation and luxury consumption. This is done because drought has been demonstrated to be a mitigating factor to ozone injury (Reich 1987).

Plants are visually inspected for incidence, extent, and symptoms of ozone damage periodically throughout the growing season. All species are photo-documented for all types of injury in all treatments. Full descriptions of ozone damage are documented and recorded. Growth measurements such as height and diameter are routinely documented at the beginning, the end, and at regular intervals during the growing season. Several phenological measurements are taken on herbaceous species including flower count, flower incidence, and seed weight. Most of the species are harvested at summer's end, and leaf count, leaf area, and biomass allocation of roots and shoots are recorded.

Histological sampling also is performed throughout the course of the field season. Sampling of leaf tissue in the fumigation chambers is compared to leaf samples collected in the field to verify that ozone is causing injury at the cellular level.

Results and Discussion

Twenty-five of the 31 species fumigated in the ozone exposure study displayed some degree of visible sensitivity to ozone. Typical symptoms in hardwoods and herbaceous plants varied, but generally small chlorotic patches would appear with the onset of ozone injury. As damage progressed, necrotic tissue would replace the chlorotic patches, giving a red or brown hue to the leaf. The leaf appeared to look "rusty." Commonly, visible ozone injury occurs on the surface of the leaf, usually in the interveinal areas and on older foliage.

If the disease progresses further, the dead leaf tissue expands, green tissue disappears, and the leaf blackens and dies. Conifers exhibit symptoms that differ from angiosperms. Instead of well defined stipple manifested on the top side of the leaves, conifers display a chlorotic mottled appearance. This is due to the

Table 1. GRSM ozone fumigation program plant testing and sensitivity list, 1987-1990

1987 – Species Tested	Common Name	Visible Sensitivity
1. <i>Acer saccharum</i>	sugar maple	R
2. <i>Angelica triquinata</i>	angelica	R
3. <i>Betula lutea</i>	yellow birch	SS
4. <i>Cacalia rugelii</i>	Rugel's ragwort	MS
5. <i>Euatorium rugosum</i>	white snakeroot	SS
6. <i>Glyceria nubigena</i>	manna grass	MS
7. <i>Liriodendron tulipifera</i>	yellow-poplar	ES
8. <i>Quercus alba</i>	white oak	R
1988 – Species Tested	Common Name	Visible Sensitivity
9. <i>Acer rubrum</i>	red maple	ES
10. <i>Cercis canadensis</i>	eastern redbud	MS
11. <i>Cornus florida</i>	flowering dogwood	MS
12. <i>Pinus pungens</i>	table-mountain pine	ES
1989 – Species Tested	Common Name	Visible Sensitivity
13. <i>Asclepias exaltata</i>	tall milkweed	ES
14. <i>Liquidambar styraciflua</i>	sweetgum	MS
<i>Pinus pungens</i> (12)*	table-mountain pine	ES
15. <i>Platanus occidentalis</i>	American sycamore	ES
16. <i>Prunus serotina</i>	black cherry	ES
17. <i>Rhus copallina</i>	winged sumac	ES
18. <i>Robinia pseudoacacia</i>	black locust	SS
19. <i>Rudbeckia hirta</i>	black-eyed susan	ES
20. <i>Rudbeckia laciniata</i>	cutleaf coneflower	ES
21. <i>Tsuga canadensis</i>	eastern hemlock	R
22. <i>Verbesina occidentalis</i>	crown-beard	ES
1990 – Species Tested	Common Name	Visible Sensitivity
<i>Tsuga canadensis</i> (21)	eastern hemlock	R
<i>Pinus pungens</i> (12)	table-mountain pine	ES
<i>Asclepias exaltata</i> (13)	tall milkweed	ES
<i>Liquidambar styraciflua</i> (14)	sweetgum	ES
<i>Liriodendron tulipifera</i> (7)	yellow-poplar	ES
<i>Rudbeckia laciniata</i> (20)	cutleaf coneflower	ES
23. <i>Aster acuminatus</i>	whorled-wood aster	MS
24. <i>Aesculus octandra</i>	yellow buckeye	MS
25. <i>Pinus virginiana</i>	Virginia pine	SS
26. <i>Krigia montana</i>	mountain dandelion	SS
27. <i>Sassafras albidum</i>	sassafras	ES
28. <i>Rubus canadensis</i>	thornless blackberry	MS
29. <i>Rubus idaeus</i>	red raspberry	R
30. <i>Magnolia tripetala</i>	umbrella magnolia	SS
31. <i>Pinus rigida</i>	pitch pine	R

*Plant species in parentheses were fumigated in previous year(s).

Sensitivity Codes:

ES – Extremely Sensitive. Foliage exhibited injury (stippling or chlorotic mottle on all treatments equal to or greater than ambient). Ambient treatment injury on >50 percent of the plants. Incidence of injury in the 2.0 times ambient treatment was >90 percent. Symptomatology in chambers was similar to injury documented in the field.

MS – Moderately Sensitive. Exhibited injury to <50 percent of the plants in the ambient treatment and injury was documented on >50 percent of the plants in the 2.0 times ambient treatment. The symptomatology in chambers was similar to injury documented in the field.

SS – Slightly Sensitive. No injury was documented in the ambient treatment. Only visible injury documented in the 2.0 times ambient treatment, but <50 percent. Injury documented in the field only on several individuals (<5 percent sampled).

R – Resistant. Species did not show visible effects from ozone to the foliage of the plant in any of the treatments. Visible injury not observed in the field.

undifferentiated tissue conifers have in their needles: hence all the cells are equally sensitive to the effects of ozone.

Other symptoms of ozone damage on conifers are tip burn, which tends to be the first sign, overall chlorosis of the foliage, and necrotic lesions on the needles.

Sensitivity of plants to ozone exposure is ranked from very sensitive to resistant. In the GRSM study, it was discovered that many species indigenous to

GRSM were sensitive to ozone, with 16 species being very sensitive, 5 species displaying moderate sensitivity, 4 species showing slight sensitivity, and 6 being resistant. Sensitivity based on visible symptoms by species is shown in Table 1.

With heightened public awareness of the problem of declining air chemistry, the need for continued research into the effects of air pollution on forest decline has never been greater. Ongoing research at Uplands Field Research Lab is quantifying the adverse

effects of poor air quality and providing baseline data so that resource managers can make educated decisions.

Hacker and Renfro conduct air pollution research at the Uplands Field Research Lab, Great Smoky Mountains NP.

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