

Evaluating the Effects of Ozone on the Plants of Great Smoky Mountains National Park

By James R. Renfro

Great Smoky Mountains National Park (GRSM) is one of the largest natural wildland reserves in the eastern United States. The 520,004-acre park contains approximately 1,300 native species of vascular plants including 130 native tree species. This large diversity of plant species can be attributed to the temperate climate, geologic history and the ranges of elevation, precipitation, topography and aspect. The scenic vistas that provide millions of visitors with seemingly endless views of forested mountains are among the important reasons people come to GRSM, the most visited national park in the National Park System (Peine and Renfro 1988).

Background. With such a large resource base, park management must be vigilant to see that these resources are not adversely affected from sources outside the park. Air pollutants, especially ground-level ozone (O_3), are suspected of being major threats to man and his environment, particularly forested ecosystems. Park managers are mandated by the 1977 amendments to the Clean Air Act to protect the natural vegetation from air pollutants. Great Smoky Mountains NP has been designated a Class I area which sets as a goal, "the prevention of any future degradation of air quality caused by manmade air pollution." This is a very difficult mandate to fulfill and requires careful documentation of potentially adverse impacts.

Ozone is a pollutant of primary concern in the eastern U.S. It is the most widespread air pollutant in the nation and causes more plant damage than any other source (USDA 1987). It is referred to as a secondary pollutant (produced via primary components) and is formed in the air by the action of sunlight on nitrogen oxides (e.g. motor vehicle exhaust, the burning of coal and oil furnaces) and hydrocarbons (e.g. unburned gasoline vapors). Ozone is also a natural component of our air, existing in the upper atmosphere, where it protects us from ultraviolet radiation. It is the ground-level ozone that appears to be responsible for widespread injury of several plant species in the U.S., such as

tobacco, soybean, lettuce, grape, common milkweed, eastern white pine, black cherry, sassafras and many lichens (Stern et al. 1984, NPS-AQD 1988).

The National Ambient Air Quality Standard for ozone is 0.12 parts per million (ppm), which exceeds the level at which adverse effects to many plants occur. Preliminary studies of ozone injury and field observation by qualified plant pathologists suggest that damage may occur to many plants in GRSM.

Early research addressing the effects of ozone on park resources was subjective and observational. While these approaches were appropriate for the initial assessment of ozone related impacts, the current projects must include specific peer reviewed Quality Assurance/Quality Control (QA/QC) elements. GRSM has just that kind of project underway.

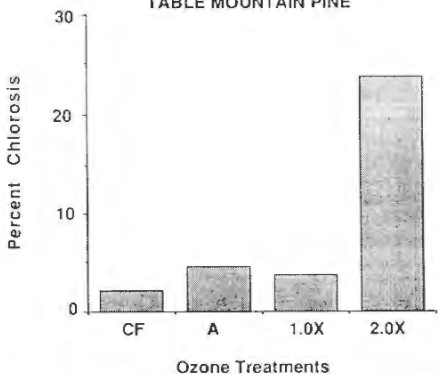
Objectives. In 1986, the NPS Air Quality Division in Denver funded a four-year program at GRSM designed to establish any effects of ambient ozone on native plant species in natural communities, and further, to tie any observed effects to established levels of known ozone exposures. The major study objectives are to:

1. Determine the ozone sensitivity and assess potential impacts on native plant species collected in GRSM, as indicated by foliar injury and altered growth, and
2. Determine the effects of ambient ozone concentrations on native species in natural communities within the park.

METHODS

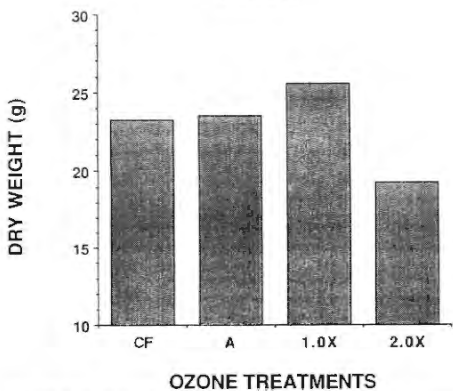
Study Site. The open-top chamber facility became fully operational in June of 1987 at a site located at the GRSM Uplands Field Research Laboratory in Gatlinburg, Tenn. There are 12 plant-growth points (9 of which are growth chambers). Five of the open-top chambers have been equipped to disperse ozone from a generation system on site. Each chamber is a cylinder 10 feet in diameter and 8 feet high, covered with teflon-cured polyvinyl chloride panels. The cham-

NEEDLE CHLOROSIS OF TABLE MOUNTAIN PINE



Needle chlorosis by treatment for *Pinus pungens*.
Note increased yellowing in high treatment.

BIOMASS ACCUMULATION IN RED MAPLE



Biomass accumulation by treatment for *Acer rubrum*. Note decreased weight for high treatment.

ber system is similar to that developed by Heagle et al. (1973), and described in Hogsett and Tingey (1985).

Treatments. There are five separate ozone treatments with 2-3 chambers allocated per treatment. These treatments consist of:

1. Ambient air without chambers (N=3);
2. Ambient air in chambers (N=2);
3. Charcoal filtered air in chambers – the control (N=2);
4. 1.5 X ambient air in chambers (N=2);
5. 2.0 X ambient air in chambers (N=3).

Ozone concentrations are regulated by controlling output of the generator with a data-logger and manual flowmeters. Chamber concentrations are measured using ultraviolet photometric ozone analyzers and are sampled sequentially using solenoid valves controlled by the data-logger. Each chamber is sampled three times an hour and averaged to give an hourly average value. These values are maintained as the permanent record of ozone to which the plants have been exposed.

Because other environmental factors interact to affect plant growth and vigor, several meteorological parameters are monitored at the fumigation site. These include:

1. Air temperature – in and outside of the chambers
2. Relative humidity – in and outside of the chambers
3. Solar radiation – in and outside of the chambers
4. Wind speed and wind direction – outside of the chambers

Plants Tested. Plant species targeted for the ozone exposure facility are selected by the Air Quality Division staff, principal investigator, and GRSM technical staff. Species are considered for their biological importance to GRSM, suspected sensitivity, rarity, and ease of collection and growth. Also, a variety of growth forms (trees, herbs, shrubs, grasses and vines), are targeted for each testing season.

Nearly all of the species selected to date are suspected of sensitivity to ozone. Seed material for each species is collected the year before the plants are to be tested. Seasonal field technicians gather, clean, store, precondition and germinate the seeds in the fall and winter of each year. Seed collection activities include locating the species of interest, determining the optimum time for collection, monitoring the fruits and seeds on a weekly basis, and actual collection and propagation. Stratified seeds are sent to a commercial greenhouse to germinate and grow to suitable size before being placed in the exposure chambers in late April. After a two-week acclimatization period, exposures begin, running from just after the last frost in late April, to around the time of the first frost in early October. To date, 12 species have been tested; in 1989, 12 additional species are scheduled for evaluation.

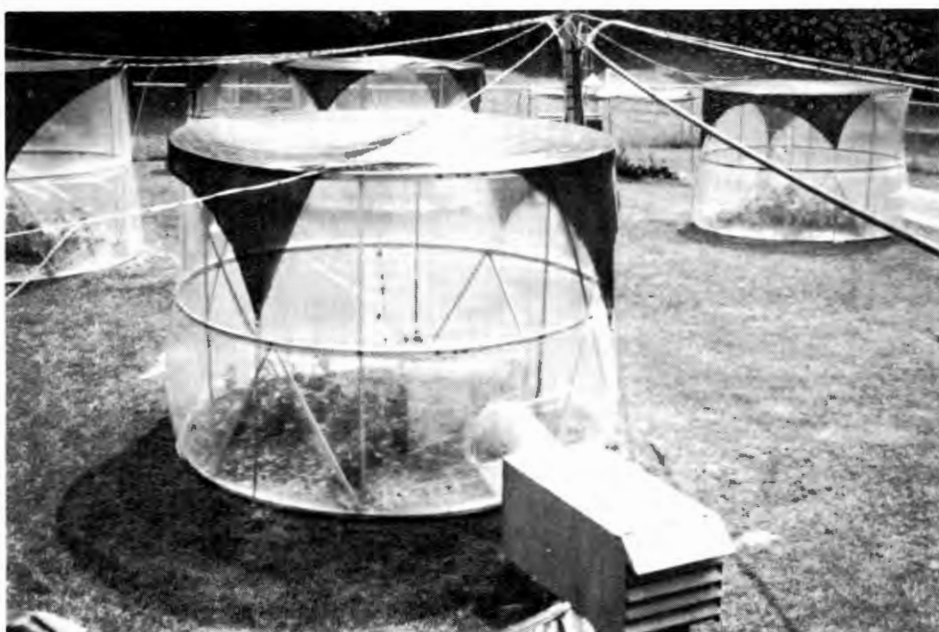
Plant Measurements. While in the chambers, plants have their responses carefully examined and documented. All measurements made on plants adhere to the standard operating procedures (SOP) given in the National Atmospheric Precipitation Assessment Program (NAPAP), and Forest Response Program's *Quality Assurance Methods Manual* (Evans and Dougherty 1986).

A regimen of objective and subjective measurements are taken on the plants in the chambers. These parameters include:

1. Stem diameter
2. Stem height
3. Leaf length and width
4. Leaf number
5. Percent leaf injury
6. Leaf area
7. Vigor estimate
8. Gas exchange (including photosynthesis and transpiration)
9. Productivity (dry weights of roots, stems and foliage)

Response measurements fall into two categories: injury and growth. Injury responses are defined as any change in leaf, stem or flower condition that is pathological in nature and visible to the naked eye. Assessing and describing foliar injury under controlled conditions can be useful in two ways: (1) it determines how much functional foliage has been damaged by exposure to ozone and, (2) it develops guidelines for identifying observed field injury and damage (Evans and Dougherty 1986).

The visible symptoms we look for are deviations from a normal, healthy appearance, including loss or change of color and cell and tissue collapse. When injury occurs on the outer or epidermal layers of the foliage, and a pattern of interveinal spots develops on the top surface of the leaf, it is likely that ozone damage has occurred. This spotty pattern, known as "stippling" or "flecking" is the most classic visible indicator of ozone injury (USDA 1987).



The ozone fumigation site at GRSM showing exposure chambers filled with native plants (Photo by Jim Renfro)

Exposures to ozone can also affect various other growth processes, such as causing premature senescence or leaf drop, stem or foliage elongation, foliar morphological aberrations and injury to the flowers and fruit. All of these alterations can have a significant negative impact on the health of the plant and result in a reduction of biomass accumulation or alter its normal reproductive processes (Stern et al. 1984).

During the 1987 and 1988 summer field seasons, park staff identified 50 potentially ozone sensitive plant species in GRSM. These species were identified based on field observation of symptoms that appeared to be the result of ozone injury. The list includes 21 trees, 15 herbs, 9 shrubs, 3 vines, 1 fern and 1 grass. Most of these species have been collected and samples of leaves showing putative ozone injury have been pressed and are on display in the GRSM herbarium at Sugarlands Visitor Center.

Data analysis is currently being done at Appalachian State University in Boone, NC by principal investigator Dr. Howard Neufeld, a plant ecologist working with the NPS. An interim report on the project has been completed.

Suspected Sensitive Plant Species List for GRSM

<i>Genus species</i>	<i>Common name</i>
TREES	
Aesculus octandra	yellow buckeye
Acer rubrum	red maple
Acer saccharum	sugar maple
Betula lutea	yellow birch
Cercis canadensis	eastern redbud
Cornus florida	flowering dogwood
Fraxinus americana	white ash
Halesia carolina	silverbell
Hamamelis virginiana	witch-hazel
Liquidambar styraciflua	sweetgum
Liriodendron tulipifera	yellow-poplar
Magnolia fraseri	Fraser magnolia
Nyssa sylvatica	blackgum
Picea rubens	red spruce
Pinus pungens	table-mountain pine

Pinus strobus	eastern white pine
Platanus occidentalis	American sycamore
Prunus serotina	black cherry
Rhus copallina	winged sumac
Robinia pseudoacacia	black locust
Sassafras albidum	sassafras

HERBS

Anemone quinquefolia	wood anemone
Anemone virginiana	thimbleweed
Aconitum uncinatum	wild monkshood
Apocynum cannabinum	dogbane, Indian-hemp
Asclepias exaltata	tall milkweed
Eupatorium rugosum	white snakeroot
Helianthus spp.	sunflower species
Menziesia pilosa	minnie-bush
Rudbeckia hirta	black-eyed susan
Rudbeckia laciniata	cutleaf coneflower
Sambucus pubens	elderberry
Solidago spp.	goldenrod species
Trautvetteria carolinensis	tassel-rue, false bugbane
Verbesina occidentalis	crown-beard

SHRUBS

Gaylussacia baccata	black huckleberry
Gaylussacia ursina	bear huckleberry
Lyonia ligustrina	maleberry
Rhododendron bakeri	flame azalea hybrid
Rhododendron calendulaceum	flame azalea
Rubus canadensis	thornless blackberry
Rubus idaeus	red raspberry
Stewartia ovata	mountain stewartia
Vaccinium spp.	blueberry species

VINES

Clematis virginiana	virgin's-bower
Rhus radicans	poison ivy
Vitis spp.	grape species

GRASS

Glyceria nubigena	mann grass
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FERNS

Pteridium aquilinum	bracken fern
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Ambient Ozone Monitoring, Permanent Plots and Field Surveys. Once a species has been determined to be sensitive to ozone from this chamber study, by showing visible foliar or growth effects, a series of permanent vegetation plots and field surveys will be added to the study. In GRSM, ozone monitors are located on an elevational gradient consisting of Twin Creeks Area (2000 ft.), Look Rock Air Quality Monitoring Station (2700 ft.), and Cove Mountain (4100 ft.).

During the summer of 1989, Uplands Field Research Laboratory staff is operating a mobile ozone sampling vehicle throughout the park to determine variability in ozone concentrations at different levels of the forest canopy (e.g. above tree canopy, within the top of the crown 60-100 feet, under the crown 30-60 feet, and in the understory 1-30 feet), in different vegetation types, elevations, aspects, slopes and topographic locations. This information will provide tremendous insight into the variability of ambient ozone concentrations in the forested ecosystems of GRSM.

The ozone monitors at GRSM provide the opportunity to assess the effects of ozone at both the species and community level. Species level effects will be evaluated several times a season, and community level effects on an annual basis for the duration of the study. Community level work will continue beyond this study as part of the GRSM long-term ecological monitoring program.

CONCLUSIONS

Very little is known about the effects of ground-level ozone on the natural communities of vegetation in GRSM. Understanding what biological processes are taking place in GRSM and being able to inventory and monitor these changes, will allow researchers to contribute to the knowledge about the effects of ozone on park resources and will better position the resources management team to make sound, land-management decisions.

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