

MONITORING AND RESEARCH RELATED TO ATMOSPHERIC DEPOSITION
IN GREAT SMOKY MOUNTAINS NATIONAL PARK,
NORTH CAROLINA AND TENNESSEE

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INTRODUCTION

Uplands Field Research Laboratory, a research station of the National Park Service (US Department of Interior) in Great Smoky Mountains National Park (GRSM), has had an air quality related research and monitoring program since 1977. GRSM is a Class I airshed and thus has a legal mandate to monitor criteria pollutants and to assess atmospheric deposition effects. The park is the largest natural area in the southern Appalachian mountains (a region in which atmospheric deposition is significant), possesses the highest biological diversity in temperate North America for several plant and animal groups (e.g., vascular plants, bryophytes, salamanders), and contains remnant undisturbed hardwood and conifer forests. Research in GRSM has been carried out by park scientists, by NPS scientists not based in the park, and by researchers from a variety of academic and governmental institutions. Uplands Lab plays an important role in coordinating and participating in these diverse research programs.

RESEARCH AND MONITORING 1977-1981

Early projects (1977 to 1981) included monitoring of precipitation chemistry (the park has an National Atmospheric Deposition Program site), research on storm flow stream pH, physical and chemical characterization of park streams, aircraft analysis of ozone concentrations, surveys of ozone symptoms on white pine, evaluation of visibility within the park (visibility is a key National Park Service air quality related value), and surveys of lead concentrations in plant tissues and soil litter. In 1980, Uplands Lab, the NPS Air and Water Quality Division, and EPA assisted TVA in establishing the Look Rock Air Quality Monitoring Station, one of the most sophisticated stations of the type in the eastern US. Additional atmospheric monitoring within the park has been carried out by the Tennessee Division of Public Health (Air Quality Branch) which has maintained the criteria pollutant monitoring under the Clean Air Act. Between 1977 and 1981, plant ecologists at Uplands Field Research Lab established over 300 0.1 ha permanent plots. While these have not been used to specifically test hypotheses about air quality impacts, they

represent a valuable resource for detecting vegetation change.

CURRENT RESEARCH AND MONITORING

Since 1982 air quality research has intensified. This has resulted from demonstration of both significant atmospheric deposition and possible biological effects. In particular, data has shown dramatic and recent (since 1960-1970) growth declines in several dominant trees, including a high elevation (>1,400 m) dominant, red spruce (S. McLaughlin, FORAST Project, personal communication). This species occurs along the Appalachian mountain chain to the Northeast where a dramatic increase in mortality has occurred in the last decade (Siccama et al. 1982). In GRSM, red spruce shares dominance with Fraser fir, a southern Appalachian endemic which has become severely threatened by an exotic insect pest, the balsam woolly aphid. Spruce-fir is a restricted ecosystem type and is rich in regionally rare organisms. Because of these biological values, because of changes brought about by the balsam woolly aphid, and because high elevation ecosystems are thought to be particularly vulnerable to atmospheric deposition, we have chosen to focus research efforts on this ecosystem. This program seeks to address the following primary hypotheses concerning impacts to terrestrial ecosystems due to atmospheric deposition: 1) ozone damage, individually or in combination with other gases; 2) nutrient stress due to leaching from soil and foliage by acid precipitation; 3) acidification and aluminum toxicity; 4) heavy metal deposition and uptake by plants; and 5) foliar uptake of nitrogen resulting in altered plant metabolism. This current research is described below.

Monitoring. The Look Rock Air Quality Station is now run cooperatively by the National Park Service, the State of Tennessee, and the Tennessee Valley Authority. The station includes the continuous monitoring of sulfur dioxide, NO_x, ozone, total suspended particulates, visibility, and standard meteorological parameters. A stacked filter sampler separates airborne particulates into two size classes, which are then analyzed separately on a biweekly basis for elemental composition. An NADP wetfall sampler at a different location is used to obtain a record of chemical composition of precipitation.

Precipitation pH in GRSM averages less than 4.5 and is below 4.0 at times (NADP laboratory values). Rainfall amounts average over 200 cm annually at high elevations. High rates of cloud moisture deposition have also been recorded (D. Holland, personal communication). Summer ozone concentrations frequently reach 100 ppb and have been recorded in excess of 120 ppb (the national ambient air quality standard) (TVA, Look Rock data), concentrations that are known to effect some plants. Lead levels in vegetation tissue and soils are about 50 percent of the values reported for New England mountains, but are still high enough for concern (Turner and Bogle, in press).

The only major components not yet monitored in GRSM are absolute deposition rates of the gases and particulates, (now measured only as ambient concentrations) and cloud moisture deposition. In addition, nearly all of the monitoring is taking place at only one location. The need for convenient, year-round access, and reliable power have dictated that this station be at a relatively low elevation (Look Rock).

Preliminary work indicates that low elevation measurements may not be representative of the situation in the higher elevations. For example, measurements of precipitation pH indicate that it is somewhat less acidic in the high elevations, but that overall hydrogen ion deposition may be higher because of greater rainfall (R. Mathews and D. Silsbee, unpublished data). Deposition is increased further by cloud moisture, which may contribute a volume equal to rainfall in the highest elevations (D. Holland, unpublished data). Cloud moisture deposition may also be important because of its long contact time with leaf surfaces, probable lower pH, and higher pollutant concentrations.

Ozone and particulate concentrations also vary substantially and unpredictably with elevation. Ozone can concentrate in atmospheric inversion layers, resulting in high levels at the elevation of the inversion which are not detected at lower elevation stations (T. Stephens and D. McReady 1982). We are therefore increasing our monitoring efforts at high elevations. Two monitoring sites are being established at elevations of 4100 and 6600 feet. Initially these sites will have only ozone monitors and meteorological instruments, but once shelters and power are available, we hope to be able to add further instrumentation.

Monitoring at high elevations has gotten a recent boost from a major research effort funded by the Electric Power Research Institute. This project is directed by D. Johnson and S. Lindberg of Oak Ridge National Lab (ORNL) and will quantify all significant atmospheric inputs into the ecosystem, including precipitation, cloud moisture deposition, plus dry deposition of gases, aerosols, and particulates as well as study their interactions with vegetation and soils. Although basically process-oriented research rather than a monitoring program, the project will provide data on atmospheric inputs and high elevation air quality and will help in identifying what parameters are most important to consider in a monitoring program.

Terrestrial effects. Our research in the spruce-fir zone is multifaceted and includes researchers from a variety of institutions. Central to the effort is a series of permanent vegetation plots designed to document the extent and magnitude of change at the individual, population, community, and ecosystem level. Also incorporated into our approach are surveys of the extent and environmental relationships of pollutant loading and decline/dieback symptoms as well as controlled environment studies of plant sensitivity and injury symptoms of selected species.

Past research in the spruce-fir of GRSM has provide valuable background and data for our expanded terrestrial effects studies. These have included a study of balsam woolly aphid history, distribution, and ecological characteristics of infestation spread (Hay et al. 1978); a spruce-fir vegetation cover map prepared in 1981 (Eagar, unpublished); computerization and plot summaries of an extensive 1930's vegetation data set (MacKenzie, unpublished data); mapping of land-use and disturbance history (Pyle, in preperation); and a vascular flora checklist with ecological and biological information for most species (White 1982; White, unpublished data).

Permanent plot locations are stratified by elevation, topographic class and aspect. Data collection on each plot includes detailed sampling of all vegetation strata, an assessment of visible foliar damage, increment cores from five dominant red spruce, sampling of standing and downed dead woody biomass, and standard site characteristic data. At each plot soil samples from the litter, organic and upper mineral horizons are collected from three soil pits. These samples will be analyzed for all standard soil chemical properties plus elements associated with atmospheric deposition. Small mammal populations are also being sampled at a subset of these plots.

In order to expand our sampling of the extent of increment suppression and its relationship to elevational and aspect gradients as well as determine the level of red spruce mortality, we developed a cooperative project with ORNL (S.B. McLaughlin and S. Adams). Five elevation transects were sampled at 500 foot elevation intervals from 4500 to 6500 feet using Bitterlick prisms for evaluation of stand structure and the extent of spruce mortality. At each site, 15 dominant red spruce were cored. Dr. Adams is also assessing the extent of annual increment suppression in a Norway spruce plantation in GRSM and canopy donimant red spruce from three age classes.

Data from the permanent vegetation plots and elevation transects will be used to address the following specific null hypotheses: 1) Decreases in annual wood increment and the occurrence and severity of decline/dieback symptoms are evenly distributed with respect to stand composition and structure, elevation, slope aspect, slope steepness, landform class, balsam woolly aphid damage, and soil chemical characteristics. 2) Community characteristics and decline symptoms will not change over time. 3) Stand composition and structure and the extent of red spruce mortaility, stratified by the gradients listed in 1, are not significantly changed from the 1930's, 1950's, and 1976/1977 data sets.

A continuing project at ORNL, initially funded in 1983 by the NPS Air Quality Office and expanded in 1984, is examining changes in plant and soil chemistry as a function of elevation and aspect with reference to elements associated with anthropogenic sources (F. Baes and S. B. McLaughlin). Sampling

is being conducted on two mountains with sites at 500 foot elevation intervals beginning at 2000 feet and ending at 6000 feet. Total elemental analysis for 32 elements are being determined by inductively coupled plasma optical emission spectroscopy for tree growth rings and young and old foliage of hemlock at low elevations and spruce at high elevations, foliage for perennial and annual herbaceous plants (within a single genus), and litter, organic and mineral soil horizons. Additionally, this study will make a more detailed analysis of foliar chemistry of red spruce growing on Clingmans Dome. Old and new needles will be collected from three levels within the crown and analyzed as above.

As part of the integrated effort needed to assess adverse impacts to vegetation caused by air pollution, the NPS Air Quality Office in cooperation with Uplands Lab has funded controlled environment ozone fumigation studies of several plant species. This work is being conducted by the USDA Agriculture Research Service, North Carolina State University (R. Reinert, Principal Investigator). Initial effort is directed towards four species of rare plants, three of which are plants of the spruce-fir type. Uplands Lab has also funding a pilot study at NCSU to determine visible injury symptoms and the associated ozone concentrations for red spruce, Fraser fir and yellow birch.

As part of the expanded atmospheric monitoring program in GRSM, the USDA-ARS staff at NCSU are assisting Uplands Lab personnel in evaluation of ozone damage to plants growing in the vicinity of the four ozone monitors within the park. The coupling of known ambient ozone concentrations and foliar damage will allow us continue to expand our knowledge of the extent and magnitude of ozone related injury to the vegetation within the park.

Two studies are currently underway in GRSM which are not directly associated with the spruce-fir type. Both are funded by the NPS Air Quality Office and are part of a multi-park network. One study involves an assessment of the extent of ozone related foliar damage on white pine. Trees are permanently marked and mapped. An overall evaluation of foliage condition is made as well as assessment of individual needles stratified by age. The second is directed at using Hypogymnia physodes, a common folios lichen, as a biological monitor of atmospheric sulfur. A systematic sampling design involving over 200 sites throughout GRSM was used for sample collection. Lichen substrate was restricted to a single tree species -- yellow birch. Analysis of sulfur accumulation is being coordinated by J. Bennett, NPS Air Quality Office and performed by L. Gouge of the US Geological Survey.

Summary. As evident in this summary of atmospheric deposition related work in GRSM, current activities are focused on surveys of the extent of, adverse effects of, and monitoring of pollutant inputs. The permanent plots will allow for evaluation of change at several levels of biological

organization. A preliminary evaluation of data collected during 1984 indicates potentially serious biological and ecological problems in the spruce-fir ecosystem of GRSM. As information pertaining to specific cause-and-effect relationships between specific atmospheric pollutants and the various components of forest ecosystems become available, we will incorporate that information into our field studies. Additionally, we do not intend to focus only on the spruce-fir type. As time and resources permit, we will expand our efforts to other critical community types. The atmospheric deposition monitoring and effects program at Uplands is an evolving one. A major emphasis at Uplands Lab is placed on cooperative research with other governmental agencies and academic institutions, both in field oriented and laboratory studies.

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