Research Note 97-5: Topic = Nitrogen-containing air pollutants, effect on trees, conifers, forests

No. 97-5

May 1997

RESEARCH NOTES

Brief Reports to the Scientific and Technical Community

California Environmental Protection Agency

Air Resources Board

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Effects of Nitrogen Deposition on a Mixed Conifer Forest

This three-year study characterized the aerometric conditions at a mountain site downwind from metropolitan Los Angeles, with special emphasis on atmospheric concentrations of ozone and deposition rates of nitrogen-containing air pollutants. The study also assessed pine tree health and soil quality at the site. Measured ambient ozone concentrations reached levels that have been shown to cause injury to pine needles, and estimated annual rates of nitrogen deposition were low to moderately high. The effect of nitrogen deposition on soil nutrient processes was examined with a simulation model calibrated for the site. At present, it does not appear that adverse, irreversible effects of nitrogen on vegetation and soil have occurred at the site, but the long-term outlook is uncertain given the elevated levels of ozone that occur there. This study was conducted by the U.S.D.A. Forest Service and Desert Research Institute.

Background: Throughout the year, mixed conifer forests in the San Bernardino mountains are exposed to elevated levels of ozone and nitrogen-containing pollutants generated in the urban centers of the Los Angeles metropolitan area. Studies conducted in the 1960s showed that ambient levels of ozone injured the needles of ponderosa and Jeffrey pine growing in the San Bernardino mountains, but the influence of co-deposited nitrogen-containing pollutants, namely nitric acid vapor and ammonia, has been largely unstudied. In recent years, investigations of forest ecosystem responses to air pollution indicate that the deposition of nitrogenous pollutants can have pronounced adverse effects on soil chemistry and plant nutrition. The resultant alterations in soil chemistry (e.g., depletion of calcium, magnesium, and potassium ions) could adversely affect tree health, soil microbial processes, and the quality of

groundwater.

To examine the combined effects of ozone and nitrogen-containing pollutants on mixed conifer forests in the San Bernardino Mountains, the U.S.D.A. Forest Service and Desert Research Institute conducted this interdisciplinary field study at Barton Flats to collect air quality, tree health, and soil chemistry data to characterize the condition of a representative forest stand subjected to these pollutants. The data were also used to calibrate and test a simulation model to project the effects of elevated nitrogen deposition on soil nutrient cycling at the site.

Methods:

An aerometric monitoring station and three pine tree survey plots were established at Barton Flats (elevation 2,000 meters) in the San Bernardino mountains. Barton Flats lies near the midpoint of a west-to-east gradient of decreasing ozone concentration. Monitoring sites to the west of Barton Flats (e.g., Camp Paivika and Crestline) receive higher exposures to ozone and nitrogen-containing pollutants, while sites to the east of Barton Flats (e.g., Heart Bar) receive lower pollutant exposures. The tree survey plots for this study were located within 1.6 km of the aerometric monitoring station.

To characterize the aerometric conditions at the site, measurements of ambient ozone concentration and a suite of meteorological parameters were made continuously from November 1991 through August 1994. In addition, acidic wet and dry deposited pollutant levels were measured weekly and once every six days, respectively, except for the 7-month period October 1993 through May 1994. Deposition of atmospheric nitrogen to trees was estimated by an inferential method (the Big Leaf Model) and two field-based procedures (foliage rinsing and analysis of throughfall). Soil condition was evaluated by excavating soil pits and characterizing the chemical composition of the organic and upper mineral layers of soil. Tree health was assessed in three tree survey plots by measuring selected growth, physiological, and structural parameters.

Results:

On summer days, gaseous and particulate pollutants from the urban-industrial are to the west are transported by upslope wind flows to Barton Flats. At night, a shift in wind direction causes downslope wind flows that bring air depleted in nitrogen oxides to the site. The lack of nitrogen oxides allows ambient ozone levels to remain near 50 ppb due to low rates of ozone scavenging. Thus, Barton Flats exhibits a diurnally flat ozone profile typical of rural forest locations in the western U.S. During the study period, hourly average ozone levels exceeded concentrations that have been shown to cause pine needle injury (60 ppb), as well as the National Ambient Air Quality Standard for ozone (120 ppb). Daily maxima were greater than 200 ppb on several occasions.

Wet deposition at Barton Flats was weakly acidic with average pH values near 5.0 in summer (June through August), and 6.5 in winter (December through February). Approximately 50 percent of precipitation events occurred in winter, and less than 20 percent occurred in summer. Nitrate and sulfate were the analytes in highest concentration, accounting for 50 percent and 25 percent of all ionic species, respectively.

Samples of PM2.5 (particles with an aerodynamic diameter less than or equal to 2.5 mm) were collected to characterize atmospheric inputs of dry-deposited gases and particles. Concentrations of PM2.5 were highest in summer and lowest in winter. Differences in daytime and nighttime levels were greatest for nitric acid vapor and gaseous ammonia. Daytime levels of nitric acid were two to seven times higher than nighttime levels, and ammonia levels were two-fold higher during the day than at night. These nitrogen-containing pollutant concentration data were used to estimate dry deposition fluxes of atmospheric nitrogen with the Big Leaf model.

Because of known difficulties in determining rates of atmospheric nitrogen deposition to forest landscapes, three methods were used to estimate rates at Barton Flats. Using the Big Leaf model, an inferential method widely applied in the eastern U.S., dry nitrogen deposition was estimated to be 14 kg/ha/yr. By two field-based measurement techniques, foliage rinsing and throughfall analysis, dry nitrogen deposition was calculated to range from 5 to 9 or 2 to 5 kg/ha/yr, respectively.

Chemical analyses of soil in the vicinity of the tree survey plots indicated that soils at Barton Flats contain high levels of base cations (e.g., calcium, magnesium, and potassium) that may render them relatively insensitive to adverse pH-related effects. The abundance of base cations could moderate the acceleration of soil acidification and mobilization of aluminum, which have been proposed as causal factors of air-pollution-caused forest decline in the eastern U.S. and Europe.

The pine tree foliage condition was monitored in three tree survey plots established near the aerometric monitoring station at Barton Flats. During the study period, the amount of ozone-caused needle injury increased substantially in trees growing in all three survey plots. The amount of ozone-caused needle injury coincided with the incidence of an upper needle surface injury symptom, which has been associated with freezing temperatures in winter.

The effects of simulated nitrogen deposition ranging from 2 to 96 kg/ha/yr were performed with the Nutrient Cycling Model to project forest responses at Barton Flats after 40 years. In these model runs, it was projected that nitrogen deposition rates less than 19 kg/ha/yr could lead to mineral deficiencies in the trees, and rates of 38 kg/ha/yr/ or higher could lead to soil nitrogen saturation and groundwater pollution by nitrate.

Significance and Application:

Exposure to ozone and nitrogen-containing air pollutants poses a moderate-to-high risk to forest health at Barton Flats in the San Bernardino mountains. While summertime ozone exposures are high enough to cause needle damage and reduce the growth of native pines (daytime average concentrations > 80 ppb), rates of total (wet plus dry) nitrogen deposition are moderate (estimates range from 2 to 14 kg/ha/yr). In this regard, critical loads ranging from 10 to 20 kg/ha/yr have been proposed to protect soil quality from the impacts of excess nitrogen deposition in selected European forests. At present, it does not appear that adverse, irreversible effects of nitrogen on vegetation or soil have occurred at Barton Flats, but the long-term outlook is uncertain given the elevated levels of ozone that occur at the site.

Related Projects:

Previous ARB-sponsored research projects on the effects of air pollutants on ponderosa pine include controlled studies conducted at the U.S.D.A. Forest Service Tree Improvement Center in Chico, California, Shirley Meadow in the southern Sierra Nevada, and the Agricultural Experiment Station at the University of California, Riverside. At Chico, branch exposure chambers were used to investigate the effects of acidic deposition and ozone on gas exchange responses in mature branches and seedlings of ponderosa pine (contract no. A132-101 (*Gas Exchange by* Pinus ponderosa *in relation to Atmospheric Pollutants*) and A132-174 (*Determination of Acidic Gas and Particle Concentrations in Open-Top Field Chambers*)). At Shirley Meadow, the growth and physiological responses of ponderosa pine seedlings exposed to one or two years of ozone were evaluated (contract nos. A733-137, A833-083, and A033-056 (*Growth, Physiological, and Biochemical Responses of Ponderosa Pine* (Pinus ponderosa) *to Ozone*)). At Riverside, a set of physiological and growth responses were monitored in ponderosa pine seedlings exposed to acidic fog alone, or in combination with ambient ozone in open-top field chambers (contract no. A6-114-32).

This research was conducted under contract with U.S.D.A. Forest Service and Desert Research Institute (ARB contract nos. A032-180 and 92-335). Comments or questions can be directed to the contract manager, Brent Takemoto, by mail, FAX (916) 322-4357, phone (916) 324-2981, or e-mail: btakemot@arb.ca.gov. For an index of Research Notes, call (916) 445-0753 or FAX (916) 322-4357.

Copies of the research report upon which this Note is based can be ordered from:

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Titles: *(1) Assessment of Acidic Deposition and Ozone Effects on Conifer Forests in the San Bernardino Mountains; (2) Ecosystem Level Alterations in Soil Nutrient Cycling: An Integrated Measure of Cumulative Effects of Acidic Deposition on a Mixed Conifer Forest in Southern California*

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Top of page
1997 Research Notes Abstracts
Research Notes Table of Contents