From Science...

Major Themes

Worldwide Concern: Air pollution threatens wildlands such as forests by weakening and killing trees and other vegetation and by promoting nitrogen-loving invasive plants.

Direct Toxic Effects: Pollutants such as ozone, sulfur dioxide, and nitric acid vapor affect vegetation directly by injuring foliage.

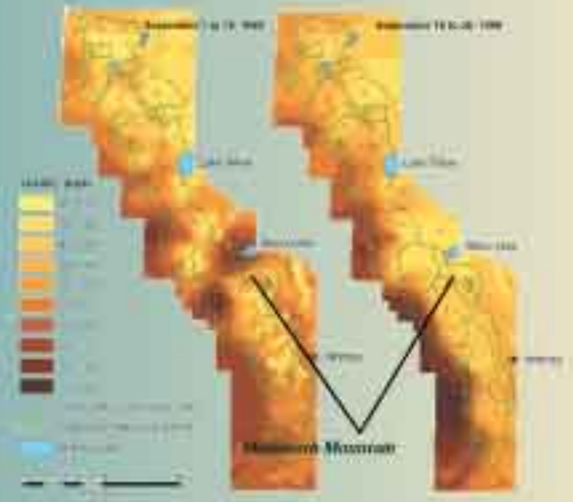
Nitrogen Deposition: Nitrogen-containing pollutants deposit onto soils and act as fertilizer. This promotes growth of some species over others, affecting biodiversity and forest structure. Nitrogen deposition also affects water quality.

Research Results

New Powerful Approach: Scientists model air quality over vast areas of forests and other wildlands by using passive air samplers in conjunction with geostatistical mapping.

Sierra Nevada: Elevated pollution levels occur along the western slopes of the Sierra adjacent to the Central Valley and the eastern Sierra near Mammoth. The highest levels are in the southwestern Sierra.

San Bernardino Mountains: High levels of ozone and nitrogenous deposition contribute to tree death and forest fire danger.



Left: Transported by southwest winds across the Sierra via the San Joaquin Valley, ozone reaches surprisingly high levels at remote Mammoth Mountain during the summer.
Right: Under different wind conditions, ozone levels peak in the southwestern Sierra.

Passive Samplers and Geostatistics

The first major development in mapping air quality was adapting air pollution passive samplers for use in forests. Simply designed, reliable, and inexpensive, the samplers require little maintenance and no electricity or special environmental conditions. Passive samplers can be deployed over wide areas to gather data for large-scale models, while dense installation permits detailed pictures of special-interest areas.

"The USDA Forest Service Riverside Fire Laboratory is in the forefront of testing and developing passive sampling techniques for forestry research," notes Bytnerowicz.

Passive samplers hold filters coated with chemicals that react with specific air pollutants. After a prescribed exposure, (usually two weeks), scientists determine, in the laboratory, the amount of pollutants on the filters. From this measurement they calculate pollutant concentrations in the air.

A second important development was successfully using ArcGIS Geostatistical Analyst for air quality modeling over mountainous landscapes. Geostatistical Analyst is a software package from Environmental Systems Research Institute (ESRI) of

Passive samplers for nitric acid vapor

Long-range transport brings ozone to Carpathian forests

Redlands, CA, that uses geostatistical techniques to model the way air pollutants are distributed over landscapes.

Initial Tests

Bytnerowicz' team first demonstrated the power of combining passive filter deployment and geostatistical-based mapping in the Carpathian Mountains of Central Europe. Beginning in 1997, together with European colleagues, Bytnerowicz measured ozone, nitrogen dioxide, and sulfur dioxide concentrations in 32 locations running through five countries.

With ozone data in hand, Bytnerowicz and Witold Fraczek, ESRI, used topographic information in conjunction with the geostatistical mapping program to analyze their data. Their results—estimates of ozone levels throughout the Carpathians—were displayed in an easily grasped format, a

Samplers installed at a remote location on Mammoth Mountain

A portable weather station, San Bernardino Mountains

map with ozone levels represented by different colors. The maps depicted how air quality varied over a large area (spatial variability). Additionally, comparing maps of the same area for different time periods showed how pollution levels varied over time (temporal variability).

Ozone concentrations were elevated throughout the Carpathian range, suggesting potential toxic effects on vegetation. The researchers concluded that the passive sampler network needed to be four times as dense for reliable estimates because ozone concentrations varied substantially.

California Mountains

With the basic methodology now worked out, Bytnerowicz, along with Michael Arbaugh, Trent Procter, and other USDA Forest Service colleagues, further developed, tested, and applied passive samplers for a variety of pollutants. The scientists also continued to work with ESRI to refine the statistical mapping program.

Efforts focused on measuring and mapping ozone and nitrogenous (nitrogen-containing) air pollution in the San Bernardino Mountains and the Sierra Nevada. A further goal was to figure out how much nitrogen was entering ecosystems from the air. This was essential information needed by ecologists seeking to explain biodiversity changes they were observing in wildlands. Bytnerowicz and colleagues adapted commercially available passive samplers for nitrogen oxides and ammonia and, in addition, developed a passive sampler specific for nitric acid vapor.

Most of the pollution affecting the San Bernardinos comes from automobiles, agricultural operations, and industry in the greater Los Angeles area. Two major pollutants, ozone and nitric acid vapor, inflict direct injury on conifers, causing needle lesions and discoloration.

In recent studies, Bytnerowicz found that, because of increased sprawl, a larger portion of the San Bernardino Mountains is exposed to elevated ozone concentrations than 30 to 40 years ago. And even though peak concentrations are lower than in the 1970s, average ozone concentrations stay high because nighttime values are elevated. These concentrations can damage susceptible vegetation.

"Forty years of exposure to air pollution was an important factor in weakening and killing trees that eventually burned in the 2003 conflagration," explains Bytnerowicz. "The weakened trees succumbed to bark beetle infestations and drought."

Additionally, elevated ozone levels caused trees to drop needles from prior years rather than retaining four or five annual sets; dead needles and branches that accumulated on the ground contributed fuel to the fire.

Indirect effects of nitrogen pollution also occur in the San Bernardinos, mainly from nitric acid vapor and particulate nitrate. Because Southern California is arid, most of the nitrogen enters forests and other ecosystems in a dry form, but in some years fog deposition is important.

Bytnerowicz' research demonstrates a steep gradient in nitric acid vapor and ammonia concentrations, with very high nitrogen deposition in the western San Bernardinos and lower deposition in the eastern sections. Nitric acid vapor concentrations are high enough in the west to potentially injure vegetation directly.

In contrast to the San Bernardino Mountains, most of the pollution affecting the Sierra Nevada blows in from the San Francisco Bay Area and agricultural areas in the Central Valley. The main form of nitrogen deposition is ammonium ion.

Bytnerowicz and his research group mapped pollutant levels over the Sierra Nevada to determine where problem areas were located. Pollutant levels are elevated throughout the western slopes of the Sierra; in southwestern Sierra forests, pollutants violate air quality standards. Though many miles from pollution sources, concentrations of ozone, ammonia, and nitric acid vapor in these forests are high enough to affect the health of vegetation, reduce biodiversity, and pose health hazards.

Surprisingly, the results also showed high ozone concentrations in the lightly populated eastern Sierra Nevada, especially in the vicinity of Mammoth between May and September. By deploying additional passive samplers along the San Joaquin Valley, Bytnerowicz showed that photochemical smog was traversing the Sierra via this valley during the summer months when the prevailing winds come from the southwest.

Serpentine Grasslands

In spring, serpentine grasslands display a treasure from California's past—its native wildflowers. When non-native grasses and other plants were introduced into California in large quantities during the last two centuries, the low nitrogen levels in serpentine soils kept exotics out.

But the latest news isn't good: during the last few decades exotic annual grasses have made substantial progress invading serpentine soils, threatening species like the Bay checkerspot butterfly that depend on native flora. Researcher Stuart Weiss, who has studied serpentine grasslands for many years, put together a complex puzzle when he figured out that nitrogen was being deposited to serpentine areas located downwind of urban areas or adjacent to heavily traveled roads.

"Passive sampler networks developed with assistance from Bytnerowicz nailed down patterns of nitrogen deposition on regional scales as well as fine-scale patterns near freeways," says Weiss. Ammonia, which increased in concentration after the introduction of catalytic converters, deposits quickly from the air directly onto plants and soil. It turned out to be a major factor in exotic invasions at Edgewood Park in San Mateo County, as well as other locations. Weiss found that in the absence of grazing, which tends to control exotic grasses, many serpentine grasslands are now at risk.

Bay checkerspot butterfly

Nitrogen deposition to serpentine ecosystems: Grazing keeps exotic grasses from outcompeting serpentine natives (right of fence) — otherwise invasives take over (left of fence)

...To Management

A Conversation with Andrzej Bytnerowicz

Q ***How does your work assist government agencies to manage air quality while keeping the health of forest ecosystems in mind?***

My work provides a way to obtain data about air pollutants in forests, and to model, from that data, air quality and nitrogen deposition on a landscape scale. In parallel, other researchers are developing procedures to collect biological data, for example, species distribution and the sensitivity of individual species to certain pollutants. With this primary biological data, scientists can model biological response to specific types and levels of air pollution.

Ultimately, by combining air quality and biological response models, scientists will be able to characterize and map the risk to specific forest lands from air pollutants. This will provide the information needed by government agencies to manage air quality with consideration for ecosystem health.

Q ***Could a forest manager work with the Pacific Southwest Research Station to monitor specific areas more closely?***

Managers have played essential roles in our research to date. These included discussing forest management issues and helping us to identify important avenues for research. Forest management staff also assisted in the actual installation and maintenance of passive samplers, and collected the filters for laboratory analysis. Finally, managers coauthored reports and articles stemming from our joint research.

Forest managers may be interested in obtaining detailed data when lands are at risk for high air pollutant levels or when forests show symptoms of pollutant damage. Reforestation of areas prone to ozone pollution, for example, could be best accomplished by avoiding plants that are ozone sensitive. Public health is also an issue—when appropriate, managers could warn unsuspecting recreational users about high pollutant levels, which often aggravate respiratory illnesses. We welcome involvement of forest managers in our research program. Our research group will design a network of passive air samplers and train managers to set up and maintain them.

Q ***Does your research have a bearing on reforestation?***

It makes sense to plant trees that are less ozone sensitive in areas prone to pollution. In current research on the Swiss stone pine (*Pinus cembra*), found in the Carpathians, we are collecting seeds from populations of trees that differ with respect to ozone sensitivity, and testing germinated seedlings against controlled ozone levels.

Q ***What about monitoring air pollution caused by forest fires?***

Evaluating pollution caused by smoke is one of our major research efforts. Our permanent network of passive samplers in the Sierra Nevada provides long-term monitoring. We are in the process of testing passive samplers for additional pollutants from both wild and prescribed fires. A further accomplishment is installation of monitoring equipment in a portable trailer in collaboration with Dr. Robert Musselman of the USDA Forest Service Rocky Mountain Research Station. The set-up has been field tested and is available for future monitoring and research.

Yellow color and needle loss typical of ozone exposure

Healthy Swiss stone pine branch

Multiple Scales: Air pollutant concentrations over wildlands can be mapped over broad areas or in fine detail.

Risk Models: By combining air quality data with knowledge of how ecosystems are affected, scientists will be able to characterize and map risk to wildlands from air pollutant sources, providing a tool for sound air quality management.

Forest Fires: Passive samplers and instrumentation on portable trailers are now available to assess air pollution from forest fires.

Reforestation: For reforestation, managers can choose ozone-tolerant trees where pollution is problematic.

Important Roles: Forest Service managers and field personnel play essential roles in air pollution research related to wildlands. For lands at high risk, managers can obtain detailed information through passive sampler networks.

Mature Swiss stone pine, Retezat National Park, Romania