

Chapter 12

Towards an air pollution effects monitoring system for the Sierra Nevada

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Abstract

Over the next ten to twenty years, California's population is projected to increase, particularly in air basins upwind of the Sierra Nevada mountain range (i.e., San Francisco Bay Area, Sacramento and San Joaquin Valleys). Related trends in ozone (O₃) concentrations are a matter of special concern, due to a long history of O₃ injury to sensitive pines in national forests of the Sierra Nevada. While the USDA Forest Service has limited authority over polluted air masses crossing into forest boundaries, monitoring results can be used in a collaborative effort with state and federal environmental protection agencies to protect resources at risk. One such effort was initiated under the Sierra Nevada Framework for Conservation and Collaboration. An ambient O₃ concentrations and O₃

effects monitoring system is under development that will integrate previous and current monitoring efforts across agencies, and will track pollutant concentrations and effects over the entire bioregion.

1. Introduction

As population increase in California and particularly in the foothills of the Sierra Nevada mountain range, ozone (O_3) concentrations are expected to rise, and increase the potential for alterations to the structure and function of focal ecosystems (Miller et al., 1989; Minnich and Padgett, Chapter 1, this volume). Although the USDA Forest Service (USDA-FS) has little control over the air masses that enter national forests, management can influence activities within national forest boundaries, and in some cases, in areas adjacent to the boundaries (Procter et al., Chapter 15, this volume). Mitigation measures can be employed to reduce the effects of air pollution, increase the efficiency of limited resources to projects with the most potential for success, and incorporate O_3 damage to risk assessments for other environmental factors (e.g., drought, pathogen mortality and fires). However, adequate air monitoring data required to make these decisions is lacking. The deployment of economical, passive O_3 monitoring systems will enable simultaneous monitoring of ambient O_3 conditions for the entire bioregion. This information, if linked to on-going vegetation assessments, will allow for bioregional evaluations of the status and trends in air quality in the Sierra Nevada.

The goal of this chapter is to outline an air pollution distribution and effects monitoring system for the Sierra Nevada that incorporates previous and ongoing efforts across agencies, and tracks air pollution concentrations and effects across the entire mountain range. This chapter discusses the background of the planning processes which have been instrumental in the development of the new O_3 monitoring system, briefly details the process by which O_3 was selected for monitoring in the Sierra Nevada bioregion, and summarizes the overall monitoring program design. In addition, future inclusion of other important pollutants (such as nitrogenous compounds and particulates) will be addressed.

2. Past and present monitoring efforts in the Sierra Nevada

2.1. Air quality monitoring

Several programs or studies have been initiated to evaluate O_3 concentrations and O_3 injury to vegetation over the last 30 years. The identification of injurious levels of O_3 in the Sierra Nevada in the 1970s prompted the California Air

Resources Board (CARB) and the USDI National Park Service (USDI-NPS) to establish continuous O₃ monitoring stations in the Sierra Nevada as part of the State and Local Ambient Monitoring Network (SLAM). In 1990–1991 a regional program, the Sierra Cooperative Ozone Impact Assessment Study (SCOIAS), was initiated to continue to monitor ambient O₃ concentrations and add determinations of associated meteorological variables. Originally, there were six Sierra Nevada sites—Yosemite, Sequoia–Kings Canyon, and Lassen Volcanic National Parks later joined SCOIAS by contributing ambient O₃ data at three locations within each Park. In addition, USDA-FS, Pacific Southwest (PSW) Research Station, provided four years (1992–1995) of ambient O₃ data from a site in the San Bernardino Mountains (Van Ooy and Carroll, 1995).

There are also a number of other O₃ monitoring stations outside of the Sierra Nevada, in the Mountain Counties of the San Joaquin Valley, that are operated by several different state and federal entities. Ozone data are available from CARB as printed summaries, on compact disk, and from their web site [<http://www.arb.ca.gov/aqd.htm>]. The USDI-NPS maintains both active and passive O₃ monitors at Sequoia, Kings Canyon, and Yosemite National Parks. Printed reports are available and the latest information can be obtained from the USDI-NPS web site [<http://www.aqd.nps.gov/ard1/gas>].

These active monitoring stations yield very accurate air quality information for the areas within two-to-four km of the active stations. However, the coverage is insufficient for the entire bioregional land base, and extrapolation of these data beyond one-to-two miles is difficult due to the complex, mountainous terrain. Greatly increasing the number of active, continuous monitoring sites would be prohibitively expensive and time consuming. A practical alternative is to supplement the active monitoring stations with passive monitoring systems, which do not require electric power. Passive monitors can be deployed in remote areas, are relatively inexpensive to use, and operators require only a few hours of training to deploy samplers in the field.

2.2. Ozone injury monitoring

The first effort at long-term monitoring for O₃ injury to pines began in 1990. A cooperative agreement between the CARB, USDA-FS, and USDI-NPS created the Forest Ozone Response Study (Project FOREST). This agreement led to the establishment of forest vegetation plots near active O₃ monitoring stations to perform annual assessments of O₃ injury to native ponderosa and Jeffrey pine populations. Other participants, including Yosemite, Sequoia–Kings Canyon and Lassen Volcanic National Parks, joined Project FOREST by establishing and assessing tree conditions at three plots in each Park. In addition, the USDA-FS, PSW Research Station, provided four years (1992–1995) of tree injury data from three sites at Barton Flats in the San Bernardino Mountains.

Tree response has been analyzed in Project FOREST in relation to several O₃ exposure indices from the nearest monitoring site (Arbaugh et al., 1998a). Significant associations were found between a measure of O₃ injury (Ozone Injury Index (OII); cf. Miller et al., 1998) and 4-year, 24-hour values of summer O₃ indices. These statistical associations were not adjusted for the influence of variable seasonal O₃ flux to foliage, which differs from year-to-year depending on soil moisture availability (Temple and Miller, 1998).

The USDA-FS, National Forest Health Monitoring (FHM) program is a nationwide O₃ biomonitoring program in partnership with the US Environmental Protection Agency (USEPA), USDI Bureau of Land Management, and the National Association of State Foresters. The goal of the program is to detect and monitor changes in O₃ stress in the forest environment. Detection is based on the documentation of visible foliar injury to known O₃ sensitive plant species under conditions of ambient exposure (USDA, 2000). Injury assessments to both overstory and perennial understory species are being conducted in the Sierra Nevada. Assessments of injury to species other than ponderosa and Jeffrey pine have only recently been conducted in the western US (Temple, 1999). Several species such as trembling aspen (*Populus tremuloides*), ninebark (*Physocarpus capitatus*), skunk brush (*Rhus trilobata*) and blue elderberry (*Sambucus mexicanus*) have expressed O₃ injury symptoms under experimental conditions (Temple, 1999). Several annual species are also known to show predictable symptoms, but the convergence of the annual drought cycle with the higher ambient O₃ concentrations makes these species less reliable as bioindicators.

2.3. Bioregional monitoring in the Sierra Nevada

The Sierra Nevada-wide monitoring system is the result of a decade long effort aimed at protecting the California Spotted Owl (*Strix occidentalis*) (CalOwl) (USDA, 2001a). In 1991, a technical report on the status of the spotted owl indicated that populations were declining throughout the Sierra Nevada. The USDA-FS, PSW Region responded by developing interim spotted owl protection guidelines. The guidelines were formally adopted in January 1993.

In 1995, the CalOwl Draft Environmental Impact Statement (DEIS) established long term, comprehensive management direction for the spotted owl. The final EIS was scheduled for release in 1996. However, in May 1997, the Secretary of Agriculture empowered the CalOwl Federal Advisory Committee (FAC) to evaluate the CalOwl EIS and the Sierra Nevada Ecosystem Project (SNEP) report, and make recommendations on how management should proceed. The CalOwl FAC found the revised DEIS to be inadequate as an owl protection document, and offered recommendations for improvement.

In response to the CalOwl FAC report, the USDA-FS and the PSW Research Station began a collaborative planning and management effort, known as the Sierra Nevada Framework for Conservation and Collaboration (SNFCC). The SNFCC's goal is to integrate the latest scientific information into national forest management practices through public and interagency participation in resource planning (USDA, 2001b). The SNFCC includes ten Sierra Nevada administrative units: the Sequoia, Sierra, Stanislaus, Eldorado, Inyo, Tahoe, Plumas, Lassen, Modoc National Forests, and the Lake Tahoe Basin Management Unit. Coordination efforts are also underway with the Humboldt–Toiyabe National Forest in Region 4.

The EIS for the Sierra Nevada Forest Plan Amendment (SNFPA) was one of several elements of the SNFCC (USDA, 2001b). The SNFPA effort, which includes all the national forests in the Sierra Nevada, focused on five problem areas:

- old forest ecosystems;
- riparian, aquatic, and meadow ecosystems;
- fire and fuels;
- noxious weeds; and
- lower west-side hardwood forests.

Air quality was not identified as one of the problem areas; however, the focus on air pollution-sensitive systems directed attention to O₃ and O₃ related effects.

Under SNFCC sponsorship, the Sierran Provinces Assessment and Monitoring (SPAM) Team was organized to develop a multi-scale, multi-resource monitoring strategy for the national forests of the Sierra Nevada. The initial step in monitoring strategy design was the development of the Ecosystem Process Conceptual (EPC) model (Manley et al., 2000). The model served as the foundation of the overall monitoring strategy, offering a common view of ecosystems and ecosystem dynamics, while providing an objective framework from which to select attributes for monitoring (cf. Manley et al., 2000 for details).

The next step involved the definition of eight monitoring “topic areas” relevant to issues and problem areas in the EIS. The topic areas included old-forest ecosystems, lower westside hardwoods, riparian/aquatic/meadow, fire and fuels, soil productivity, sociocultural, and air quality. Management goals were defined for each topic area, and the EPC model was used to identify suitable monitoring attributes. Monitoring attributes were further expanded into monitoring questions, and ultimately, topic area monitoring plans. One such product was an ambient O₃ and O₃ effects monitoring plan, whose components are discussed in this chapter.

3. A design to monitor ozone injury to vegetation

The foundation of the regional monitoring efforts will make use of the Project FOREST sites under the purview of the regional air pollution monitoring group and the FHM program sites under the purview of the national FHM program. Project FOREST currently maintains 10 sites on the westside of the Sierra Nevada, and eight-to-ten new sites will be added on the southern and eastern sides of the range. Four of the new sites will be established near existing SLAM or SCOIAS stations with active O₃ monitors (Fig. 1). Two sites will be associated with Interagency Monitoring of Protected Visual Environment (IMPROVE) sites, which only have visibility monitors. The remaining two-to-four sites will not be located near any active monitoring stations. The new sites will be comparable to existing installations (i.e., 50-tree plots), and all located away from major roads and urban population centers. Injury assessment of ponderosa and Jeffrey pine will be conducted using the OII, Forest Pest Management (FPM) system, or a compatible system (see Arbaugh and

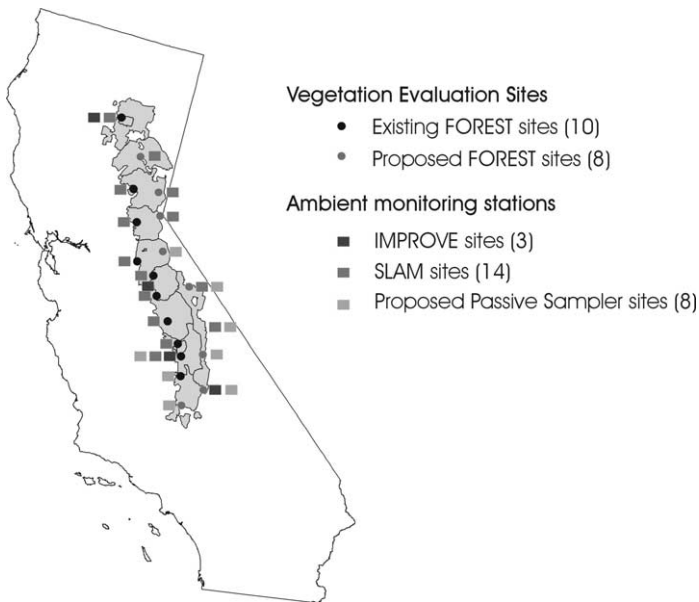


Figure 1. Vegetation and ambient monitoring sites existing and proposed for the Sierra Nevada. Circles indicate various types of vegetation evaluation sites, and squares indicate ambient monitoring sites. Notice that most of the existing ambient and vegetation evaluation sites have been collocated as part of previous studies. Forest Health Monitoring sites are not included, because they have not yet established locations for their sites.

Bytnerowicz, Chapter 6, this volume, for details). Understory species will be evaluated using FHM protocols.

We expect that the ambient O₃ data from the passive monitoring survey will be critical for the interpretation of O₃ effects sampling. This is supported by results from a previous study (Arbaugh et al., 1998b) that showed that cumulative ambient O₃ was generally linearly related with O₃ injury to pines. Using the ambient O₃ injury estimates (Frączek et al., 2002), we expect a total network of about 40-to-50 vegetation assessment sites will provide adequate coverage of the lower and upper montane forests. This network will consist of 18–20 Project FOREST sites and 20–25 independent FHM sites.

4. Ozone injury index protocol

The 18–20 Project FOREST sites will be surveyed for crown injury from O₃ using the OII method. The OII method (Miller et al., 1996) employs a five-branch sample pruned from the lower crown of each ponderosa or Jeffrey pine in the plot. Several variables are counted, estimated visually or measured on each branch:

- number of annual needle whorls;
- amount of chlorotic mottle on the needles of each annual whorl;
- the length of needles in each annual whorl; and
- percent live crown.

These variables are entered into an algorithm for weighting symptom responses and computing a final OII score for each tree (the range of the index is from 0 to 100 where higher values indicate more injury). The above listed components are weighted, and used to compute the OII as follows: needle whorl retention (40 percent), chlorotic mottle percent of each whorl (40 percent), needle length (10 percent) and percent live crown (10 percent). Because tree observations are best made between August 15 and September 15, when injury development is the most apparent, we will use at least two field crews to gather field data in the smallest possible window of time. Assessments of OII would be done once every four-to-five years, using trained crews and local USDA-FS employees to perform the field surveys.

Currently the OII scoring system is under review. The OII system is expensive to implement (app. \$1500–\$2000 per 150 tree site for an evaluation) and is subject to viewer bias that limits the number of people that can reliably be used to conduct the surveys. There is also recent physiological evidence that alternative tree measures may be better indicators of O₃ uptake (Grulke, Chapter 3, this volume). Therefore, in the future it is expected that the OII will periodically be reviewed and modified to reduce costs, and better estimate stand and

regional O₃ uptake and injury as new information becomes available. It will be a priority, however, to insure that past and future index data can be combined to examine important regional trends through time.

5. FHM pine and understory protocol

Basic procedures for biomonitoring have been standardized at the national-level with allowance for regional differences in O₃ exposure, growing season, topography, and forest type. The most recent version of the field manual for western cooperators may be viewed online at <http://www.fhmozone.net>. The manual details the sampling grid, training and quality assurance requirements for field crews, criteria for selection of biomonitoring sites and plant species, and injury evaluation procedures (USDA, 2000). The FHM crews are trained to select O₃ biomonitoring sites close to or at some distance from the FHM forested ground plots depending on the availability of open areas with O₃ bioindicator plants. Based on the findings of controlled studies and field observations, a list of potential bioindicator species was developed by FHM researchers (Mavity et al., 1995; Duriscoe and Temple, 1996; Brace et al., 1999).

Field crews are equipped with a portable data recorder, a 10× hand lens for close examination of plant leaves for O₃ injury, a forester-grade plant press for the voucher leaf samples, and standardized data sheets for plot maps and vouchers. At the start of each field season, all crews receive training in bioindicator species identification and site selection procedures. A second training in July, just prior to the start of the foliar evaluation window, certifies the crews in the O₃ injury evaluations and voucher handling procedures. The training and certification requirements reduce the amount of error during field measurement and sample collection. Additional quality assurance activities include: on-site field audits, re-measurements, sample validation, and final data assessment.

At each biomonitoring plot, 10-to-30 individual plants from no more than three bioindicator species, are evaluated for O₃ injury. Each plant is rated for the percent of the plant that is injured and the average severity of injury using a modified Horsfall–Barratt scale with breakpoints at 6, 25, 50, 75, and 100 percent injury (Horsfall and Barratt, 1945; Horsfall and Cowling, 1978). All foliar evaluations are conducted during a four-week period between mid-July and mid-August. Crews also collect voucher leaf samples for each injured species found at the site, which are mailed to a regional O₃ expert to verify the incidence of O₃ injury. Field data are zeroed out for any species with a voucher that is either missing or not validated.

6. FHM bioindicator species

The list of O₃ bioindicator species selected for use in western FHM regions was gleaned from a variety of sources including the peer-reviewed scientific literature, interagency reports, and communications with federal and university researchers experienced in O₃ biomonitoring work (Smith, 1995; Krupa et al., 1998). For a species to be selected, it must be relatively common across a variety of forest types, relatively easy to identify and distinguish from similar species, and O₃ sensitive, based on a combination of field evidence and causative fumigation experiments. The final selection of western bioindicators includes many species that respond to ambient levels of O₃ with distinct and easily diagnosed foliar symptoms. The FHM program funded the fumigation trials that have confirmed O₃ specific foliar injury symptoms on Scouler's willow (*Salix scouleriana*), trembling aspen, red alder (*Alnus rubra*), Pacific ninebark, skunk bush, snowberry (*Symphoricarpos albus*), and blue elderberry (Temple, 2000). Ozone specific injury symptoms were not confirmed on thimbleberry (*Rubus parviflorus*) and chokecherry (*Prunus virginiana*), two species thought to be potentially useful bioindicators from earlier reports (Mavity et al., 1995; Brace, 1996). Only a few western species are well tested under natural conditions of O₃ exposure. The FHM program's biomonitoring activities provide a significant contribution to this research effort as both field crews and regional experts cooperating with FHM program can gain critical experience with western bioindicator species.

Ponderosa pine (*Pinus ponderosa*) is by far the most common tree species on biomonitoring sites in California followed by quaking aspen (*Populus tremuloides*), Jeffrey pine (*P. jeffreyi*), California black oak (*Quercus kelloggii*), and Scouler's willow. The most common understory species include snowberry, blue elderberry, mugwort (*Artemisia douglasiana*), and ninebark. A few of the candidate bioindicator species, like red alder, are limited in their range in California and not sampled very often, while others like skunk bush and evening primrose (*Oenothera elata*) may not be useful as bioindicators either because they are scarce or difficult to identify under field conditions.

Across the sampling area, O₃ injury symptoms have been verified on ponderosa pine, Jeffrey pine, blue elderberry, and mugwort. In 1998 and 1999, only one site in California showed probable O₃ injury while in 2000, injury was detected and confirmed at six biomonitoring locations. As the sampling grid is complete in California, FHM program analysts will examine trends in the number and distribution of plots with O₃ injury, and increases or decreases in the biosite index values. The FHM program intends to use consecutive five-year periods with variable O₃ levels, weather, wind flow, and precipitation patterns to examine regional trends in O₃ air quality over the long-term.

7. An ambient air pollution monitoring design

The basic approach to both the ambient air pollution and air pollution effects monitoring is to unify ambient air data and vegetation evaluations. Presently, active O₃ monitoring systems are maintained as part of the SLAM, SCOIAS, and USEPA's Aerometric Information Retrieval System networks. In addition to mountain stations, O₃ data from stations in the San Joaquin Valley and adjacent eastern desert areas (Lee, Chapter 7, this volume) provide useful data for spatial extrapolation. Mountain and adjacent active monitoring stations will be supplemented with passive O₃ samplers to enhance spatial coverage in the Sierra Nevada. Analysis results indicate that as many as 124 passive monitors might be needed to develop an accurate spatial estimate of O₃ in the Sierra Nevada (Frączek et al., Chapter 9, this volume). This number is neither financially nor logistically feasible, so a less dense network will be utilized, and some spatial accuracy will need to be sacrificed.

Passive samplers will be installed at each vegetation evaluation site that lacks a nearby active monitor. Passive samplers will also be collocated at active monitoring stations in mountain locations to develop passive sampler-continuous monitor relationships (Arbaugh and Bytnerowicz, Chapter 10, this volume) for at least one summer season. To verify the accuracy of single-season ambient estimates made from passive samplers, portable electronic O₃ monitors (2B Technologies, Boulder, Co.) will be collocated at each vegetation evaluation site that lacks a permanent active monitor, for one summer season.

A single passive O₃ sampler, containing a pair of cellulose filters will be installed at each site (Ogawa & Co.). The samplers will be located 1.5–2.5 m above ground level in forest clearings 20 m or more away from the dense forest, and at least 200 m from frequently used roads, in open areas with good vertical air mixing. Small meteorological units that measure temperature and humidity will also be installed with each passive sampler unit. In the field, the filters for O₃ determinations will be changed every two weeks during the summer growing season. After the exposures, the filters will be placed in plastic vials, and refrigerated until analyzed. Local USDA-FS employees will perform the biweekly collections of the passive samplers. The samplers will be sent to the PSW Research Station's Chemistry Lab in Riverside for extraction and analysis.

8. Future additions to the monitoring design

Any monitoring plan should be flexible. As new technologies and knowledge arise, the plan has to allow for adaptation. The outline above does not measure other pollutants that affect forest growth and composition, or visibility. The

most important pollutants not considered in this plan are nitrogenous (N) pollutants. Nitric acid (HNO_3) and ammonia (NH_3) transported from urban areas are deposited in the Sierra Nevada, and may impact ecosystem function (Bytnerowicz et al., 1999; Fenn et al., Chapter 5, this volume). Deposition velocities for NH_3 and HNO_3 vapor to vegetation and other landscape surfaces differ (by an order of magnitude or more) from O_3 , so they need to be measured separately. In the future passive samplers being developed by the USDA-FS will be added at some O_3 sampler locations to measure these two compounds. Concentrations of HNO_3 and NH_3 will be calculated from regression curves developed at the USDA-FS, PSW Research Station in Riverside (Bytnerowicz et al., 2002).

Visibility and aerosol conditions in the Sierra Nevada are presently monitored in the IMPROVE program, a cooperative effort between the USEPA, federal land management agencies, and state air quality agencies, to measure visibility and aerosol conditions near Class I Areas. Ten IMPROVE stations are currently working in the Sierra Nevada. IMPROVE samplers operate on a one-in-three day sampling schedule, and their analyses include the N species, nitrate (NO_3^-) and nitrite (NO_2^-). It is unknown at this time whether data from IMPROVE can be extrapolated to all Class I areas in the Sierra Nevada. In the future these sites will be augmented with low-cost or portable particulate measurement systems (presently being developed at USDA-FS, PSW Research Station in Riverside) to more directly measure visibility degradation due to urban generated and fire emissions.

9. Evaluation checkpoints

The USDA-FS has little control over air pollution generated outside national forest boundaries; therefore, the establishment of rigid checkpoints for O_3 monitoring is probably not appropriate. Under some circumstances, the USDA-FS can recommend denial of a permit application adjacent to national forest lands because of the threat of decreased air quality, but for the most part, those decisions are predicated on air quality effects to Class I wilderness. Rules and regulations regarding Class I wilderness have already been incorporated into USDA-FS procedures.

However, USDA-FS management can adopt methods for managing pollution-impacted ecosystems. Air pollution is rarely the sole affecter in ecological responses, as studies have shown that drought, land disturbances, insects and changes in utilization patterns can combine with air pollution to reduce productivity or alter ecological function and species composition. Therefore, a true evaluation of air pollution effects must encompass a number of other

measures and parameters, and be coordinated with other ecological evaluations, whenever possible. We recommend that the air quality and distribution patterns that will be produced in the next several years be incorporated into the planning process.

10. Expected products

Annual concentrations and trends in air pollution and related damage to forest ecosystems will be provided in the form of graphs, maps, and written reports. Information relevant to specific locations, as well as general patterns in the status and changes in air quality in the Sierra Nevada bioregion will be available to managers on an annual basis. Because the information will be compiled annually, a minimal effort would be needed to develop assessments for the five and 10-year checkpoints.

A major effort will be required in assisting managers in the application of the information. For example, this information should be incorporated into risk assessments, particularly in projections of mortality due to drought and insects. It should also be used to inform USDA-FS management where fire hazards may occur in the future, and thus, where resources should be focused.

Maintaining good air quality in Class I wilderness areas will continue to be a primary concern and a major consideration in various permitting processes. The data generated from this monitoring effort will provide the USDA-FS with the necessary information to characterize the existing conditions in the short run, and the tools to project future conditions given changing scenarios over ensuing five- to ten-year increments.

The vegetation assessments, in combination with other ecological assessments will begin to address the influence of human activities on natural ecosystems. Very few of the other environmental assessment protocols include such specific attributes, such as the O₃ injury evaluation in pines that are tightly tied to known environmental conditions. It is expected that the nascent understory evaluations will mature over time, to provide a powerful tool to understanding the nature of air pollution effects on the structure and function of Sierran ecosystems.

A comprehensive bioregional monitoring system for air pollution is long overdue in the Sierra Nevada. Elevated ambient O₃ concentrations and O₃ injury has been documented in the mountain range since the 1970s. Individual detection and assessment projects, and multi-agency projects have been established, but none has been able to examine bioregional patterns of O₃ and O₃ effects on vegetation through time. With the development of low cost passive monitors, it is now possible to develop regional networks of sufficient density to estimate bioregional patterns. If this information can be used to supplement

vegetation survey information, then it may be possible to estimate changes in the spatial patterns of injury or injury risk from O₃. Continuation of this monitoring program into the future is critical for both the Forest Service and Park Service to effectively manage the Sierran ecosystems.

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