

Predicting the Potential Sensitivity of High Elevation Wilderness Vegetation to Changes in Atmospheric Chemistry—A Strategy¹

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Our wilderness areas are a unique resource which ensures the maintenance of wild areas in our nation. While these areas are in remote locations they are not isolated from our industrial society and impacts associated with global change. Because of long-range atmospheric transport and the increase in regional air pollution sources, these areas may encounter anthropogenic pollutants.

The Clean Air Act of 1990, as amended, charges the Federal Land Manager (FLM) with the affirmative responsibility to protect air-quality-related-values (AQRVs, any wilderness components that can be modified by human-caused air pollution) in Class I areas from adverse air pollution impacts. Class I areas are wildernesses larger than 5000 acres (including later expansions) which existed as of 8/7/77. This protection is available through implementation of the Act's Prevention of Significant Deterioration (PSD) provisions.

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Abstract.—A new strategy to estimate the sensitivity of alpine plant species to atmospheric deposition is presented. This approach utilizes plant physiological and morphological characteristics to estimate pollutant uptake. The plant characteristics can be determined quickly and easily in the field within the constraints of allowable activities in Class I wilderness areas. Species in two alpine sites have been sampled and the first potential sensitivity rankings of alpine species have been constructed. While the accuracy of these rankings still needs to be verified, they provide a framework for prioritizing species for future research.

This discussion will address the constraints that the PSD process imposes on the scientific process to gather relevant data for the permit evaluation and why conventional air pollutant impact approaches are inadequate to address impacts to vegetation within these constraints. In addition, a new approach to address the protection of remote wilderness plant species will be presented, as well as a summary of the findings from the first field testing of the approach. The focus of this discussion will be on the high elevation, alpine ecosystems which are components of many of the Inter-Mountain and Rocky Mountain Class I wilderness areas. These areas have some unique problems associated with estimating the sensitivity of the vegetation to atmospheric deposition.

Constraints Imposed by the PSD Permit Process

The PSD program is a preconstruction review and permitting process for major new or expanding sources of pollution. Any major facility seeking a new source permit for location or expansion in a clean air area must

meet several requirements, as specified in the Clean Air Act. It is the responsibility of the FLM to determine whether a proposed source's emissions will have an adverse impact on Class I area AQRVs.

The major constraint of the PSD process is the short review period the FLM has to evaluate a permit application. The review period may be, at most, one field season. Therefore it would be prudent if some monitoring is done before a permit evaluation situation arises since the burden of proof as to the likelihood of impacts is on the FLM.

Many national forests have developed monitoring plans (Air Resource Management Plans) to gather baseline data for their lands and to attempt to detect any current impacts to AQRVs. While surface water chemistry and visibility are currently being monitored in some Class I areas of the Inter-Mountain and Rocky Mountain regions, no monitoring for sensitivity to or impacts on vegetation by pollutants is currently underway because of the lack of methodology and predictive tools. Therefore, permits are currently reviewed on the basis of potential impacts to surface water

chemistry and visibility and plant sensitivity is not considered. This may adequately protect wilderness ecosystems from effects caused by nitrogen and sulfur deposition, but will not adequately protect the ecosystem from impact by chemicals, such as ozone, where the primary impact is expressed by plants.

The PSD process establishes no prioritization for the importance of different components of the ecosystem. Each wilderness is a unique compilation of biotic and physical factors which interact to form the ecosystem. Therefore to develop a procedure to estimate the sensitive component of any wilderness ecosystem, the approach must be flexible. It must be applicable to each unique permit application scenario, taking into account the specific wilderness area that may be impacted with its specific diversity of species, genotypes, pollutant chemicals, and physical conditions. Therefore, the optimal approach would be one which incorporates data collected from the wilderness area in question with the model estimates of pollutant transport and exposure.

The data to be collected in each wilderness area must be simple and compatible within the constraints imposed by the Wilderness Act of 1964 (i.e. requiring no motorized transportation or excessive destructive sampling). This is complicated by the non-uniformity and complexity of the alpine landscape. The alpine environment is characterized by the severe physical environment of high radiation, winds, and snow fall. The interaction of these factors with the topography creates a mosaic of microenviron-

ments across the alpine landscape. The most obvious feature of this mosaic is the alternating pattern of windblown, snow-free sites with deep snow-accumulation areas. Distinct vegetative communities have evolved in response to these different snow regimes (Komarkova and Webber 1978).

The same mosaic of snow regimes that cause differences in plant community structure also creates a mosaic across the alpine landscape in the potential deposition rates of anthropogenic pollutants. It has been shown that distinct areas of the alpine tend to accumulate the deposition of fallout from nuclear testing (Hutchison-Benson et al. 1985). It is clear that for a given polluted air mass over an alpine environment, the pollutant loading to the ground will be non-uniform. In light of the potential for such heterogeneous pollutant loading rates, the pursuit of the most sensitive component of the ecosystem is inappropriate if it is only defined as the component with the lowest threshold of tolerance to a pollutant. More appropriately, the approach must be to identify the first component of the ecosystem which will exhibit a measurable change in response to deposition from a given air mass. This involves the identification of 1) the relative pollutant loading rates to the mosaic of alpine microenvironments and 2) the sensitivity of each community and its individuals to the pollutants delivered to its location. The combination of these two characteristics will provide a means of identifying which component of the system is most likely to show effects first in a given atmospheric chemistry.

Comparison of the Problem to Other Air Pollution Effects Programs

It is clear that the responsibility of determining the alpine species most likely to be affected once exposed to a polluted air mass is no small task - we are dealing with incredible diversity in a harsh environment. This alone makes this situation different than past air pollution-effects programs such as the National Acid Precipitation Assessment Program (NAPAP) and National Crop Loss Assessment Network (NCLAN). The NCLAN program was established to provide information on the economic impacts of ozone and sulfur dioxide on selected crop species. The NAPAP program was established to gain information to attempt to explain or unravel the components of the apparent 'forest decline' in the U.S. The species to be studied under each of these plans were specified because of the nature of the programs. Under the PSD program, there are no means of prioritizing the wilderness plant communities or species. The congressional mandate specifically implies that all the organisms in wilderness are of equal importance with respect to their protection. The PSD program is also different from the other programs because of the fact that it is designed to prevent damage from occurring - not to assess damage that is already occurring. Currently, there are no field observations of impacts in alpine wildernesses to help construct a preliminary list of sensitive alpine species.

Because of the differences between the PSD program and

past programs it is not surprising that the standard approach (dose-response studies) implemented in the past programs are not applicable here. The most obvious problem with the conventional approach is the fact that the sensitivity of an extraordinary number of species must be assessed. It is not feasible to construct an exposure-impact relationship for each and every species found in all alpine wilderness areas of the USA.

Additionally, there is a unique problem with conducting dose-response studies in controlled environments with alpine plants. The growth form of many alpine plants is a consequence of the harsh environment in which they live. It is not possible to transport alpine plants out of their environment without altering their morphology and quite likely their physiology and pollutant sensitivity. The expense and time required to attempt to simulate the alpine environment adequately is unacceptable within the criteria of this situation. There is always a question about the validity of the extrapolation of controlled environment data to the field, because of interactions of the pollutant effects with environmental factors. The severe environmental conditions present in high elevation areas may interact with the sensitivity of the species to pollutant impacts, further complicating the interpretation and extrapolation of data from experiments conducted under less severe conditions.

Conducting dose-response experiments in the alpine environment, outside of a wilderness area because of the obvious conflict between this activity and

the provisions of the Wilderness Act, is prohibitive because of the remoteness of alpine areas (i.e. the cost of installing line power and preventing damage to the fumigation system by the elements). Because of the slow growing nature of alpine plants, at least several seasons of exposure would be required before an effect would be measurable and could be attributed to the pollutant. This approach should be explored, yet, because of the technological advances that it requires, it is unlikely to provide information to the FLM in the near future. In addition, this approach is static such that the sensitivity determined by this technique would only apply to the conditions that existed during the study, and may not be applicable under different conditions that may be present under a changing climate.

The Strategy

What are our alternatives? Because of the magnitude of the problem, it is unlikely that the actual sensitivity of wilderness plant species will ever be known. We have to develop a way to estimate sensitivity from easily measured parameters. This requires information on the mechanisms of atmospheric pollutant effects which could be incorporated into a model. We know that there are 3 components of sensitivity to direct impacts of atmospheric chemistry to plants: exposure, plant uptake or dose, and biochemical sensitivity of the plant cell (table 1).

The first component, pollutant exposure, is one that is modeled

and estimated from air pollution transport models. The current models predict possible air chemistries above a given land area and do not predict deposition rates to different microenvironments. It is particularly difficult to make accurate predictions of potential atmospheric chemistries in mountainous terrain. Using these data alone to predict pollutant impacts on vegetation is unreliable. The relationship between exposure and impacts is quite variable from species to species (Reich 1987).

If the second component is added, plant uptake, another level of resolution is added to the prediction of potential impacts. Plant uptake can be divided into two categories, uptake of gaseous pollutants and uptake of water-deposited pollutants. Aerodynamic and stomatal conductance of plant leaves influence gaseous pollutant uptake; and leaf wettability and crown architecture influence interception and assimilation of pollutants delivered in precipitation. The relationships between pollutant uptake and these parameters have been established over several plant species (Mansfield and Freer-Smith 1981, Boyce et al. 1991). With measurements of stomatal and leaf characteristics of alpine plants and estimates of ambient pollutant concentrations and durations from the air transport models it is possible to estimate pollutant uptake by alpine plants.

Measurements of leaf conductance can easily and quickly be made with a steady-state porometer. This instrument is fully field-portable and can be carried and operated by a single person. Measurements on a leaf can

Table 1.—The components of plant sensitivity to atmospheric pollution. Examination of the mechanisms by which air pollutants affect plants has revealed that impact is more closely related to pollutant uptake than exposure.

Components of sensitivity:

- 1. Dose - how much gets into the plant
 - a. exposure (concentration in the air)
 - b. plant uptake ability - is a function of:
 - leaf conductance - uptake of gases (O₃, SO₂, NO₂)
 - leaf surface and crown structure - foliar absorption of wet deposition
 - nutritional status - uptake from the soil
 - 2. Internal Reactions - pollutant interaction in the cell
- Progress is being made in this area, but currently there are no consistent correlations between biochemical characteristics of cells and their sensitivity to damage among species.

Table 2.—Estimates of the most sensitive species (of the 24 species surveyed) to the uptake of gaseous pollutants, based on leaf conductance at two alpine sites (Monson 1989).

GLEES	Niwot Ridge
<i>Bistorta bistortoides</i>	<i>Acomastylis rossii</i>
<i>Penstemon whippleanus</i>	<i>Bistorta bistortoides</i>
<i>Psychrophila leptosepala</i>	<i>Carex scopulorum</i>
<i>Calamagrostis purpurascens</i>	<i>Psychrophila leptosepala</i>
<i>Erigeron peregrinus</i>	<i>Hymenoxys grandiflora</i>

Table 3.—Estimates of the most sensitive species (of the 27 species surveyed) to the uptake of pollutants from wet deposition, based on leaf, flower, and crown characteristics (Monson 1989).

Flower wettability	Leaf and crown water retention
<i>Psychrophila leptosepala</i>	<i>Clementsia rhodantha</i>
<i>Erythronium grandiflorum</i>	<i>Potentilla diversifolia</i>
<i>Phlox pulvinata</i>	<i>Erigeron melanocephalus</i>
<i>Achillea lanulosa</i>	<i>Hymenoxys grandiflora</i>
<i>Potentilla diversifolia</i>	<i>Potentilla nivea</i>

typically be accomplished in 15 to 30 seconds. In a survey of 24 alpine species in two alpine sites along the east side of the Rocky Mountains (Niwot Ridge, Nederland, CO and Glacier Lakes Ecosystem Experiments Site (GLEES), Snowy Range, WY), a wide range in stomatal conductance was detected suggesting a range of potential sensitivity to

the uptake of gaseous air pollutants (table 2). In a survey of 27 alpine species at GLEES, the crown retention of precipitation can be accurately predicted on the basis of some simple measurements such as crown height, diameter and width of the leaves at the base of the petiole (Monson et al. 1992).

Thus, by conducting a few selected measurements of these traits for alpine species, one can make some predictions about which species would be most susceptible to the uptake of gaseous and water-deposited pollutants (table 2, table 3). Making the measurements in each threatened wilderness area would further improve our predictive ability by avoiding extrapolations across genotypes and site characteristics, which have been shown to affect these measurements (table 2). By quantifying the proportion of a given community that is composed of a sensitive species, one can develop an index of overall community susceptibility to pollutant uptake. Finally, by quantifying the proportion of a given community (with their characteristic sensitivities) within a regional flora, an index can be developed to estimate the potential floristic susceptibility of a landscape to pollutant uptake.

At present, the empirically-based approach of estimating pollutant uptake rates, as described here, is most feasible for rapidly assessing the potential sensitivity of individual alpine wilderness areas to certain anthropogenic pollutants. Estimates of plant sensitivity to pollutants would have greater accuracy if more information on the internal sensitivity of plants to assimilated pollutants was known. There is relatively little information available on factors that control this aspect of sensitivity in plants. At this time, the relationships between biochemical characteristics and sensitivity are not well enough understood among species to incorporate this level of

detail into any wilderness vegetation monitoring program.

Before the current sensitivity rankings of alpine species (Monson 1989) can be used in the PSD review process, verification of the approach must be done with a subset of alpine species. This strategy assumes that the relationships between pollutant uptake and impacts that have been found for agronomic and tree species applies to wild alpine species; the relationships should be confirmed for alpine species. Comparisons of leaf conductance and impacts has begun in controlled fumigations in greenhouses using seedlings grown from seed collected from two alpine species (Berrang, personal communication). While these tests have all the problems discussed above regarding controlled-environment studies, they will provide a first approximation. Field verification of the approach is also being considered.

Summary

By relying on the exposure-impact relationship established with other plant species, predictions of potential impact at a very coarse level to alpine species can be made using exposure data generated by meteorological models. This is, however, not sufficient to ensure that the FLM is, in fact, protecting the area from impacts because of the poor correlation between exposure and impacts among plant species (Reich and Amundson 1985). The addition of information on the uptake of pollutants by plants can substantially improve our prediction because of the better relation-

ship between uptake and impact (Reich 1987). Estimates of pollutant uptake ability can be gathered in one field season by measuring stomatal conductance and leaf and crown characteristics.

This approach is progressive. This scheme is sufficiently flexible such that improvements can be made over time. The relationships can be adapted as more research information becomes available and can progressively be made more specific for alpine plants. Each step of this approach can be improved by improved understanding of air pollution delivery and impacts in general and our understanding of high elevation plants and their responses to pollutants. In this way the FLM's ability to evaluate PSD permits will evolve with the entire air pollution effects research effort, and not be limited to benefiting only from those studies that directly apply to alpine plant sensitivity.

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