3. TERRESTRIAL ECOSYSTEMS

By Anna Schoettle and William Moir

Perspective

The majority of Class I wilderness areas in Region 2 is high-elevation wilderness. Management of these areas is also regulated by the Wilderness Act of 1964, which states that these areas should be managed such that humans cause little if any impact. When considered in concert with the Clean Air Act, this implies that an adverse impact in a wilderness area is any unnatural change, regardless of whether it may be perceived by humans as positive or negative. With this in mind, the Terrestrial Ecosystems Group proceeded to identify sensitive receptors and LACs in support of our efforts to protect AQRVs.

The consensus of the Terrestrial Group was that everything—all wilderness components, from fungi and soil microorganisms to trees and mammals, regardless of their known or unknown ecosystem role—should be protected from adverse impacts from air pollution. There was considerable discussion of whether AQRVs should be limited to ecosystem functions rather than components; it was concluded that not enough is known about what controls ecosystem functions and therefore all components should be protected. The Terrestrial Group determined AQRVs to be any wilderness component that has the potential to be modified by human-caused air pollution; and sensitive receptors to be objects or processes, biological or otherwise, that can be identified as having low thresholds of tolerance to air pollutants. This is consistent with the perspective of the National Park Service, which considers *all* components of ecosystems as AQRVs needing protection. It was also acknowledged that humans are part of the "natural" processes in wilderness, and therefore some human effects upon wilderness ecosystems and biota are inevitable and not incompatible with the Wilderness Act. However, anthropogenic air pollutant impacts were not considered to be compatible with wilderness.

It is important to realize that the PSD process provides a means for the Forest Service manager to protect AQRVs in Class I areas only by recommending that the state deny a permit based on predictions of potential impacts prior to the start-up of a new source. As a result, it is critical that predictive techniques be applied during the permit review process and that they be scientifically sound and defensible. Increased control devices can be required after the source has begun operation, provided deleterious effects in Class I areas have been detected. Our goal, however, is to prevent impacts in Class I areas in the first place—not after a pollution source has started operating. It was also agreed that if the techniques were biased, the recommendations should be made toward over-protection of the Class I area, until better projections can be made. An attempt has been made to limit the list of sensitive receptors and LACs to those for which information is available that allows predicting impacts from a given change in air quality. This was not always possible since there are few predictive techniques available for components of terrestrial ecosystems.

The monitoring required to implement predictive techniques was discussed. The Terrestrial Group also discussed what information appears to be lacking from our scientific understanding of the sensitivity of Class I areas in Region 2, which potentially restricts Forest Service managers from effectively exercising the Clean Air Act mandate. The group has suggested research needs that could be pursued to provide for more effective review of PSD permits and protection of Class I areas from air pollution impacts.

Sensitive Receptors and Limits of Acceptable Change

There was a consensus that only the most sensitive components of the terrestrial ecosystem should be emphasized in the PSD review process to predict potential pollutant impacts. The Terrestrial Group considered the following attributes of ecosystem condition and function to be indicative of potential adverse impacts that should be addressed in defining LACs:

- loss of *any* species (over and beyond a natural extinction rate), even if general ecosystem function appears to be little affected;
- unnatural changes in species composition (floristics and faunistics) of communities or ecosystems;
- fertilizer effects that lead to accelerated or diminished productivity within ecosystems;
- landscape changes in the proportions of species or ecosystem mosaics as a result of air pollution;
- interruption or breaks in ecosystem function (e.g., air pollution-induced changes in the "hidden diversity" of ecosystem food webs such as mycorrhizal fungi or litter cryptozoans); and
- unnatural deterioration of archaeological or cultural objects.

Several review papers on effects of air pollutants upon ecosystems and specific plant or animal species were prepared for this workshop (Mangis et al. 1990, Bunin 1990). This information proved to be useful in the group discussions. However, there was a consensus that a more thorough literature review is necessary for the most suitable LACs to be identified. With this caveat in mind, the specific sensitive receptors and LACs which this group recommends for consideration are summarized in table 6. In the construction of table 6, the group focused on identifying sensitive receptors likely to be impacted by the most probable pollutants. The pollutants addressed were SO_2, ozone, acidic precipitation (SO_4^{2-}, NO_3^-, NO_x), and metals. Consideration was given to CO_2, but we did not specify LAC guidelines. Threatened and endangered species require special attention in relation to all pollutants. The tolerance limits, or LACs, for those species should be 0% change from population levels in an unpolluted environment. This recommended LAC might change when direct sensitivity testing data become available.

Predictive Techniques

In the PSD review process, the Forest Service manager must predict whether a change in air quality (supplied from the atmospheric transport models and the stack emissions of the proposed source) will cause a change in the sensitive receptor which will exceed the LAC. The group considered that the review of potential vegetation impacts would be accomplished with projected air quality information and any sensitive receptor monitoring information that was available (figure 1).

The relationship between atmospheric concentrations of pollutants and sensitive receptors is seldom known. Our techniques must be able to predict when an LAC will be exceeded in a given atmospheric chemistry and what critical pollution concentration will cause the LAC to be exceeded. This aspect of the application of terrestrial sensitivity to pollutants for use in the PSD permit process is the weakest. Pollutants have little effect on biological processes until deposition or uptake occurs. The calculation of pollutant uptake is difficult. Several studies on pollutant uptake have been completed, yet few studies have been conducted that assess the effects of long-term, low-exposure pollutant regimes. Two predictive techniques were discussed by the Terrestrial Group.

Direct impact projections

Direct impact projections may be obtained from controlled exposure/impact (dose-response) studies. This approach eliminates the need to know the uptake levels (figure 1), yet must be conducted for each species of concern. The relationships are established on a species-by-species basis and are usually conducted under controlled environmental conditions that rarely incorporate the natural stresses of the species. In addition, most of these studies are conducted over only 1-3 seasons with seedlings and at relatively high dosages. It is still uncertain if the sensitivity of a species is constant throughout its life. Regardless of these shortcomings, this type of data, coupled with field observations of impacts from elevated pollutant exposure, would be the most defensible for the PSD review process. However, these data are sparse and expensive to collect, especially in high-elevation ecosystems. In situ dose/response studies with wet deposition (e.g., McKenna 1991, Funk and Bonde 1989) are needed and are much more feasible than those with gaseous pollutants (see recommended research topics below).

Gaseous pollutant uptake

Another predictive technique is presently being developed (Schoettle 1995) that takes advantage of the fact that the relationship between pollutant uptake and impact are much more consistent among species than the relationships between pollutant exposure and impacts (Reich and Amundson 1985, Reich 1987). This technique will use

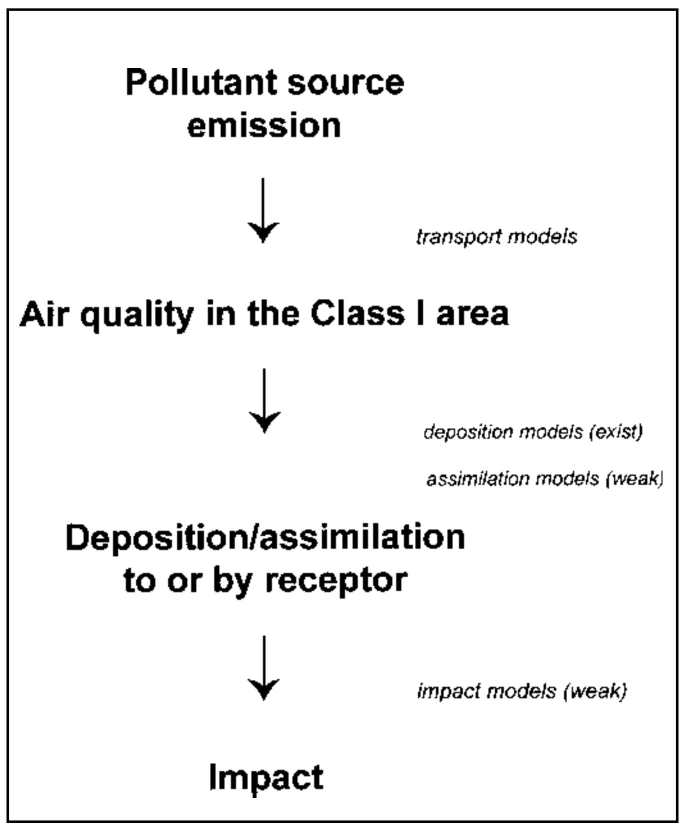

Figure 1. Scheme of information needed to predict terrestrial impacts caused by air pollution.

Table 6. Sensitive receptors and limits of acceptable change (LACs) relating to probable pollutants for terrestrial ecosystems in Class I wilderness areas of USDA Forest Service Region 2. LACs are suggested for impacts due to SO_2, O_3, SO_4^{2-}, NO_X, metals and VOCs, fluoride, and all pollutants.

Sensitive receptor Indicator (comments)	**Limits of acceptable change** (change from baseline)
RELATING TO SO_2	
Lichens (especially foliose-fruticose forms and epiphytes)	
Loss of species	0%
Species composition change	0%
Mosses, loss of species	0%
Vascular plants (fast growing species and riparian species may be the most sensitive due to high stomatal conductance)	
Species change	0%
Photosynthesis	<10% decrease
Conifers, foliar lesion	<5%
Conifers, leaf tissue S	<10% increase
Deciduous, foliar injury	<5%
Deciduous, leaf tissue S	<10% increase
Insects (especially pollinators)	
Species composition	0%
Fecundity	0%
Tissue content	0%
RELATING TO OZONE	
Vascular plants (fast growing species and riparian species may be the most sensitive due to high stomatal conductance)	
Species composition	0%
Phenology	0%
Tissue respiration	<10% increase
Photosynthesis	<10% change
Seedling mortality	0%
Conifers, foliar lesions	<5%
Conifers, leaf retention	<10% decrease
Conifers, foliated shoot length	<10% decrease
Deciduous, foliar injury	<5%
RELATING TO SO_4^{2-}, NO_X	
Vascular plants	
Growth (radial or shoot)	±5%
Species cover	±5%
Species composition	±5%
Tissue nutrient ratios (trees on poor soils, e.g., Dystric Cryochrepts, may be most sensitive)	
N/P (low N/P may be most sensitive)	LIT[1]
C/N (high C/N may be most sensitive)	LIT[1]
Bud break or set	±0 days

Continued

Table 6. (Continued)

Sensitive receptor Indicator (comments)	Limits of acceptable change (change from baseline)
RELATING TO SO_4^{2-}, NO_x (Continued)	
Vascular plants (Continued)	
Seedling mortality	0%
Leaf tissue S	<10% increase
Soils	
Base saturation (should be about 20 meq/l)	
Low elevation	<15% decrease
High elevation	0%
pH	±.5 unit
Deposition (NO_x)	<5kg/ha/yr
Soil flora and fauna	
Decomposition rate	LIT[1]
Earthworm abundance	0%
Cultural resources, petroglyphs (especially on basic rock)	0%
Lichens (same as above for SO_2)	
RELATING TO METALS AND VOCS	
Lichens, tissue concentration (lichens may contain high levels of metals without injury, values represent pristine conditions; consult vast literature for details)	
Pb 200 ppm	<10% increase
Zn 400 ppm	<10% increase
Hg 2 ppm	<10% increase
As 1 ppm	<10% increase
Cd 1 ppm	<10% increase
Se 1 ppm	<10% increase
Cu 100 ppm	<10% increase
Mosses	
Species composition	0%
Tissue composition	LIT[1]
Soils (sensitive soils will be those with low base saturation, i.e., Dystric Cryochrepts, Pergelic subgroups, and many Histosols)	
Concentration in inorganic soils	0%
Concentration in organic soils (peat)	<10% increase
Cu 100 ppm	<10% increase
Zn 400 ppm	<10% increase
Pb 200 ppm	<10% increase
Cd 1 ppm	<10% increase
Hg 2 ppm	<10% increase
Se 1 ppm	<10% increase
As 1 ppm	<10% increase
F 3 ppm	<10% increase

Continued

Table 6. (Continued)

Sensitive receptor Indicator (comments)	Limits of acceptable change (change from baseline)
RELATING TO METALS AND VOCS (Continued)	
Soil Fungi (same as above for SO_4^{2-} and NO_x)	
Vascular plants (cushion plants in exposed alpine areas may be most likely to accumulate due to year-round exposure)	
Tissue concentration (metals and values same as those given for lichens above)	<10% increase
Bees (domestic bees may be surrogate)	
Brood size	<10%
Tissue concentration	<0-10%
Loss of queen	0%
Bats	
Guano concentration	LIT[1]
Tissue concentration	LIT[1]
Birds	
Tissue concentration	LIT[1]
Nesting success	LIT[1]
RELATING TO ALL POLLUTANTS	
Threatened and endangered species	
Population levels	0% change from unpolluted environment

[1] *The Terrestrial Group recommended a thorough review of the literature for these LAC values. The group was confident that the information is available but did not have the expertise to identify the appropriate limits with any level of confidence.*

gaseous pollutant uptake and flux as a predictor of impact; it is based on the fact that stomatal conductance, a relatively easily measured value, is the primary determinant of gaseous uptake in plants. As a result, plants with higher stomatal conductance during pollutant exposure are more likely to be impacted than those with low stomatal conductance (Reich 1987). Knowledge of the average stomatal conductance to gases and the ambient pollutant concentration enables an estimate of pollutant assimilation from which impacts can be estimated.

This approach will reduce the need to study the pollutant response of each species, yet is limited to gaseous pollutants. There are biochemical factors that can increase the tolerance of some species to pollutant impacts, yet the current understanding of these factors and their roles in tolerance is not sufficient to incorporate them into predictions at this time. This is, of course, a source of error in the technique. This technique is founded on firm empirical data that supports its application (Reich 1987), but verification with native, field-grown plants is required before it can be implemented (and be defensible) in the PSD permit evaluation process. If this technique proves robust, it will enable predictions of impact to be made for many more species than could technically and economically be assessed using exposure/impact studies.

Recommendations

The Terrestrial Group recommended that more dose-response work be conducted for determining wet deposition sensitivity, and that the stomatal conductance modeling approach be further explored for predicting gaseous pollutant sensitivity.

Monitoring

As the Terrestrial Group developed sensitive receptors and LACs, it became apparent that baseline measurements are essential. The LACs identified represent unnatural changes from the baseline condition. Two important information needs are implicit in the context of considering change from a baseline condition: (1) baseline data for potentially threatened Class I wildernesses and (2) an understanding of the variation in that baseline that is a result of natural (nonhuman-caused) environmental changes (this might be called a natural baseline). This latter requirement is most difficult if pollutants are already present at the time baseline measurements are taken. Baseline levels are sometimes determined in the initial monitoring effort (this might be called a monitoring baseline), but need not be limited to this. Indeed, the current condition may be inappropriate if pollution levels are already high, yet this information will also be useful in the review process. Baselines can also be determined from archived collections, previous studies, or from similar, but more pristine (or at least less polluted) environments elsewhere. Baseline quantities should include means, seasonal and year-to-year variations, skewness, and other descriptive statistics against which comparisons of nonbaseline data can be made. Since effects of pollutants on populations of sensitive receptors are likely to be subtle (Gough 1991), good sample design is necessary. Of course, lack of baseline measurements precludes any implementation of the LACs (i.e., change from what?).

The purpose statement for developing and continuing a wilderness monitoring program can include additional benefits other than the factual basis for reviewing PSD permit applications. Most importantly, perhaps, managers and their public will have a data base with which an important aspect of wilderness "condition" can be assessed. While the purpose of the monitoring program will be to gather information on the current condition of the resource, the continuation and long-term data base will be valuable for evaluating and revising the predictive techniques, in the event that the new source is constructed. Such information will be valuable in future permit application reviews and should feed back into the review process to improve the management and protection of Class I areas.

A clear and concise monitoring manual of field locations and methods used is strongly recommended. The manual should be written, looking to the future, for people who will be responsible for updating and maintaining the records if the purpose continues to be persuasive. Managers in Region 2 are advised to consider the methods and design strategies of this monitoring program for use with National Forest System wilderness lands.

Another essential feature of monitoring is to build the decision-maker (the land manager who is responsible for making the recommendation to the state regulatory agency) into a monitoring feedback loop. Experience has shown that if this person is not part of the monitoring system, it will falter and eventually be abandoned.

What to monitor

The Terrestrial Group recommended that baseline measurements of the sensitive receptor attributes begin immediately in each Class I area. Priority sensitive receptors for monitoring should include those that are most at risk, in light of projected changes in air quality in the Region.

In addition to monitoring air quality related values, the Terrestrial Group recommends that the current air quality near Class I areas be monitored. Specifically, the Group recommends continuous monitoring of ozone (O_3) during the growing season or, if possible, year-round. Measurements of sulfur dioxide (SO_2) and nitrogen oxides (NO_X) would also be useful when reviewing a permit application.

Table 6 is not exhaustive, but suggests AQRV monitoring opportunities. Monitoring techniques are available for lichens, perhaps one of the easiest subjects to measure (but requiring a specialist at first) (see Stolte et al., 1993). Conifers, too, may be sensitive to several pollutants (O_3, SO_2, HF, NO_X, acid rain). Conifers at high elevations, such as species of *Abies*, *Picea*, and *Pinus*, may be quite sensitive. Alpine plant communities often grow in N-deficient environments and thus might be responsive to increased loadings of N-based pollutants. Some plants are exposed to pollutants during most of the year (including pollutant burdens discharged from melting snow) and tend to be accumulators (e.g., of heavy metals and S-based pollutants). Mosses, similarly, are accumulators, amenable to easy measurement and collection (again by a specialist), and are found in sensitive environments such as snowmelt areas where pollutants may build up. Top carnivores, both vertebrates and invertebrates, may accumulate toxins as part of the food web. Some, such as earthworms, have high exposure to soil contaminants or aluminum toxicity, and readily show toxic symptoms (Root 1990).

The Terrestrial Group often noted how little is known by scientists outside their immediate field of specialization. It is therefore recommended that literature searches be conducted on life histories or physiological tolerances to pollutants of the numerous organisms that might serve as biological monitors of wilderness pollution. Some literature searches have already been completed but may need updating (e.g., for animals see Newman and Schreiber 1984; for vascular plants, see Bunin 1990; for lichens, see Jackson et al. 1992, Stolte et al. 1993; for forests, see Olson et al. 1992, NAPAP 1991, Nuorteva 1990).

A recommended monitoring approach

At present, with some exceptions, air pollution in Region 2 is at low levels. Projected emission estimates, however, show both SO_2 and NO_x substantially increasing to levels potentially detrimental to nearby wilderness areas. Levels of nonlocal pollutants will also probably increase. Because the window of opportunity is both immediate and likely to be short-lived, the Terrestrial Group make the following recommendations:

1. Keep monitoring as simple as possible, but don't degrade monitoring to avoid more complicated or expensive techniques. Remember, monitoring is a service to future managers and publics.

2. Acquire current condition and air quality baseline information immediately. Baseline needs given in table 6 are not necessarily exhaustive, but include measurements of community composition (both plants and animals); tissue chemistry; distribution and abundance of threatened, endangered, or sensitive species; soil properties such as cation exchange capacity; elemental content of organic matter; condition of important cultural features; and other properties likely to be adversely affected by pollutants. (This recommendation parallels information needs given by Fox et al. 1989.)

3. Use established field and laboratory techniques, including updated QA/QC methods. Employ experts or specialists where needed (for example, lichenologists).

4. Design the monitoring system regionally; implement the system locally.

5. Incorporate into the design as many replicate samples as necessary to permit some degree of statistical interpretation in the future. Document field plots and samples thoroughly. Keep in mind that some plots will invariably be lost or otherwise rendered useless in the future, so there is a need to build redundancy into the system.

6. Make use of photographic reference points as often as possible, making sure the reference points are well documented and relocatable.

7. Leave room in the plans so that additions can be made as new information and technologies become available. Ensure that monitoring methods are not changed over time without complete documentation and cross-comparison to former methods.

Research Recommendations

The Terrestrial Group suggested a number of research topics. The group further recommends a high degree of integration and communication with other land managers responsible for Class I areas within Region 2 to make best use of research dollars and information. The following list of research recommendations is not prioritized at this time:

- Conduct comprehensive literature reviews periodically to evaluate new information and technologies for the revision and completion of table 6.

- Expand the data base of direct dose-response relationships for native species common to Class I areas in Region 2. Comparative studies with other more well-known species sensitivities would be useful. Sensitivity testing should ideally be conducted in the field, yet controlled environment studies would also be useful.

- Expand research to develop and test predictive techniques.

- Improve estimates of pollutant deposition to the terrestrial ecosystem.

- Expand the understanding of sensitive species' life cycles. Related to the above, research here would focus on critical aspects of life histories (for example, seed germination, pollination) affected by exposure to, or uptake of, specific pollutants.

- Expand the understanding of the food chain on which threatened and endangered species are dependent. Specifically concentrate on links that may accumulate pollutants and the determination of critical tissue concentrations for animals.

- Expand the understanding of pollutant/impact relationships of natural communities in already impacted regions with special attention to monitoring along pollution gradients. Research is needed on the efficacy of applying direct and indirect gradient analysis to determine pollutant effects upon plant communities or plant population attributes.

- Efficiency monitoring. Can monitoring systems be reduced to some minimum sampling level, in both space and time, and retain their power of detection? Closely associated is research into the manner in which sampling efficiency can be evaluated when determining baseline levels of tissues, population structure, and community composition.

Literature Cited

Bunin, J. 1990. Sensitivities of Colorado and Wyoming wilderness area vascular plants to sulfur dioxide, nitrogen dioxide, and ozone: an overview. Lakewood, CO: U.S. Department of Agriculture, Rocky Mountain Region, unpublished report. 14 p.

Fox, D.G.; Bartuska, A.M.; Byrne, J.G.; Cowling, E.; Fisher, R.; Likens, G.E.; Lindberg, S.E.; Linthurst, R.A; Messer, J.; Nichols, D.S. 1989. A screening procedure to evaluate air pollution effects on Class I wilderness areas. Gen. Tech. Rep. RM-168. Fort Collins, CO: U.S. Department of Agriculture, Rocky Mountain Forest and Range Experiment Station. 36 p.

Funk, D.; Bonde, R. 1989. Fertilizing effects of artificial sulfuric-acid mists on Bistorta vivipara plants in alpine tundra. Arctic and Alpine Research. 21: 169-174.

Gough, L. 1991. USGS/NPS air quality biomonitoring, Florida and California. Environmental Forum 1990: Geoscience investigations that emphasize chemical, physical, and biological ecosystem processes. Open-file Rep. 90-288. U.S. Geological Survey. 18 p.

Jackson, L.L.; Ford, J.; Schwartzman, D. 1992. Chemical analysis of lichens for biomonitoring. In: Huckaby, L.H. ed. Lichens as Bioindicators for Air Quality. Gen. Tech. Rep. RM-224. Fort Collins, CO: U.S. Department of Agriculture, Rocky Mountain Forest and Range Experiment Station. 96-115.

Mangis, D.; Stolte, K.W.; Maniero, T. 1990. Impacts of air pollutant to terrestrial ecosystems. Lakewood, CO: U.S. Department of Agriculture, Rocky Mountain Region, Air, Aviation, and Fire Management, unpublished report. 16 p. + 8 p. addendum.

McKenna, M. 1991. Effects of atmospheric processes on natural ecosystems. Final Report; FS contract 28-C8-490. 18 p. Available from: Rocky Mountain Forest and Range Experiment Station. Fort Collins, CO.

National Acid Precipitation Assessment Program. 1991. Final Assessment Reports 16, 17, 18. Washington, DC.

Newman, J.R.; Schreiber, R.K. 1984. Animals as indicators of ecosystem responses to air emissions. Environmental Management. 8: 309-324.

Nuorteva, P. 1990. Metal distribution patterns and forest decline. Seeking Achilles' heels for metals in Finnish Forest biocoenoses. No. 11. Helsinki. Publication of Environmental Conservation, University of Helsinki: 77 p.

Olson, R.K.; Binkley, D.; Bohm, M.; Arbaugh, M. eds. 1992. The response of western forests to air pollution. Ecological Studies. Vol 97. New York, NY: Springer Verlag: 532 p.

Reich, P.B. 1987. Quantifying plant response to ozone: a unifying theory. Tree Physiology. 3: 63-92.

Reich, P.B.; Amundson, R.M. 1985. Ambient levels of ozone reduce net photosynthesis in tree and crop species. Science. 230: 566-570.

Root, M. 1990. Biological monitors of pollution. BioScience. 40: 83-86.

Schoettle, A.W. 1995. Predicting the potential sensitivity of high elevation wilderness vegetation to changes in atmospheric chemistry - A strategy. In Tinus, R.W. (ed.) Interior West Global Change Workshop. Gen. Tech. Rep. RM-262. Fort Collins, CO: U.S. Department of Agriculture. Rocky Mountain Forest and Range Experiment Station. 63-67.

Stolte, K.; Mangis, D.; Doty, R.; Tonnessen, T. Technical Coordinators. 1993. Lichens as bioindicators of air quality. Gen. Tech. Rep. RM-224. Fort Collins, CO: U.S. Department of Agriculture, Rocky Mountain Forest and Range Experimental Forest. 131 p.

Terrestrial Ecosystems Workshop Participants

Will Moir (Chair), USDA Forest Service, Rocky Mountain Station
Clif Benoit, USDA Forest Service, Region 4
Dan Binkley, Colorado State University
Susan Caplan, USDA Forest Service
Lee Carr, USDA Forest Service, Region 2
Malcolm Edwards, Medicine Bow National Forest
Kathy Foster, San Juan National Forest
Larry Gough, USDA Geological Survey
Meg Lindsey, White River National Forest
Deborah Mangis, National Park Service
Jerry Mastel, Big Horn National Forest
John McCarthy, White River National Forest
Robert Missen, Pacific Power & Light
Robert Musselman, USDA Forest Service, Rocky Mountain Station
Anna Schoettle, USDA Forest Service, Rocky Mountain Station
Mike Sestak, National Biological Survey
Mike Sharon, USDA Forest Service, Region 2
Ken Stolte, National Park Service
William Weber, University of Colorado
Robert Willmot, Arapaho & Roosevelt National Forests