# XI. APPENDIX A -- TERRESTRIAL MONITORING METHODOLOGIES

Insufficient information exists on the ozone sensitivity of plant species native to national parks, making it difficult to estimate the current and long-term impact of regional ozone on terrestrial resources. Similarly, little is known of the impact of $NO_2$ and $SO_2$ on native vegetation. Studies can be conducted to identify sensitive receptors from each national park that may be at risk from exposure to ambient pollutant levels. Physiological and dose-response (controlled exposure) studies are expensive and time consuming but provide reasonable quantitative results. Candidate species for exposure studies should be those which are common and widespread. They should be species which are not prone to chronic fungal or other pathogen-caused foliar diseases that make field identification of pollutant injury difficult. From controlled exposure studies, detailed descriptions and photographs of foliar injury can be compiled into a guide for resource managers to use in the field.

In the absence of park-specific information on sensitive receptors, the current literature must be relied upon to provide candidate species. For each park, appropriate sensitive receptor species have been identified, based on the literature. Specific species and recommended locations for monitoring are presented in the individual park chapters in the "Research and Monitoring" sections. We propose that these species be monitored at each park according to the following methodologies. We propose three levels of monitoring, with increasing amounts of effort and expense. These monitoring activities are based on methods and protocols developed by the USDA Forest Service and NPS.

**Level 1**

Monitoring at this level consists of basic measurements and observations used to evaluate (1) ozone symptoms in trees, and (2) potential changes in lichen populations. Potential changes to herbaceous plants are also important, but there is far more information currently available for measuring pollutant impacts on conifers and lichens.

Level 1 monitoring of trees consists of repeated, standardized measurements of trees in permanent plots. It follows the methodology developed by Forest Service and National Park Service scientists for evaluating pollutant injury (Stolte and Miller 1991, Stolte et al. 1992). Monitoring of conifers involves identification of fifteen trees within a 20x100 m plot, at sufficient distance from roads, trails, or other potential impacts. Each tree should be at least 10 cm diameter at breast height (dbh) and be free of significant crown or stem defects. There should be a prunable live crown within 10 m of the ground.

Variables that are directly or indirectly affected by air pollutants are measured at the foliage, branch, and tree level. Foliage and branch level variables are measured from five pruned branches from the lower crown of trees as follows (Stolte et al. 1992) : (1) percent of foliar surface area with chlorotic mottle caused by pollutants, (2) percent surface area with necrosis, (3) percent surface area with other injury (biotic and abiotic), (4) number of internodes with live needles per branch (number of years of needles retained), (5) percent of needles remaining per stem internode with needles, (6) modal needle length per stem internode with needles. Tree level variables are (Stolte et al. 1992): (1) percent live crown, (2) crown density (upper and lower crown), (3) dbh.

Measurements should be conducted at the same time each year, preferably in late August when there is maximum opportunity for symptoms to have developed. Surveys should preferably be conducted every year. Observers should be trained by someone with expertise in air pollutant pathology in order to be able to identify and quantify pollutant effects (National Acid Precipitation Assessment Program, undated).

Variables that are measured can be evaluated individually or combined to calculate an index of the physiological status of a tree (Stolte and Miller 1991). We recommend assessing each variable individually and analyzing these data for individual trees. Plot means and other statistics can be calculated if desired. The following factors are most important with respect to primary effects of pollutants (primarily ozone) on conifers (Stolte et al. 1992): (1) chlorotic mottle -- the appearance of these symptoms reduces photosynthesis and production, (2) needle retention -- increased senescence of needles and reduced numbers of years of needles retained reduces the amount of carbon fixation, (3) percent live crown -- live crown ratio is reduced as lower branches die first in

affected trees, (4) needle length -- reduced length of emergent needles may indicate carbon reserves are becoming limiting. These factors should be emphasized with respect to physiological status of trees regardless of how measurements are analyzed.

Lichens are regarded by many as potential bioindicators of $SO_2$ and ozone injury (Nash and Wirth 1988), although it is difficult to diagnose and measure the relationship between pollutant exposure and lichen injury in the field. It is recommended that periodic lichen surveys (perhaps every five years) be conducted to determine the total lichen flora at any given park. Site locations should be recorded for particularly rare species. The flora can then be compared to older records of lichen species, including local herbaria records. If the modern flora has fewer species, this may suggest the loss of sensitive species due to air-pollution stress (especially ozone) (Sigal and Nash 1983). While not diagnostic of pollution stress, this approach may identify species which may be at risk. A large-scale monitoring effort for lichens is not justified at this point, although protocols and guidelines in Stolte et al. (1993) can be consulted for information on assessing injury.

Lichen monitoring consists of two separate efforts. First, ten 2 $m^2$ plots are established along a transect at each site. All lichen species present are recorded annually. In addition, 10 individuals of a lichen species sensitive to ozone should be marked at each site. The dimensions and morphological characteristics of each individual should be recorded annually. It is recommended that caespitose (shrublike) fruticose lichens and large, loosely attached and suberect foliose lichens be used for monitoring, because it is easier to measure growth changes in these species over time. It is strongly recommended that lichen monitoring be established after consulting protocols and guidelines in "Lichens as Bioindicators of Air Quality" (Stolte et al. 1993) in cooperation with someone trained in lichen taxonomy and ecology.

**Level 2**

Level 2 monitoring consists of the two permanent tree plots discussed in Level 1, as well as three additional plots. A lichen survey should be conducted as in Level 1.

**Level 3**

Level 3 monitoring consists of the plots established in Level 2, as well as additional plots along transects that evaluate other species. A lichen survey should be conducted as in Level 1.

Monitoring of herbaceous plants is recommended at this level. In the absence of information on the sensitivity of species to pollutants, we recommend that monitored species have the following characteristics: perennial, relatively common, distributed over a range of ecosystem types (wide elevation range), and relatively large leaves. Herbaceous monitoring plots should include at least 20 plants of a given species within a 10x50 m plot. Plant characteristics measured should include (1) percent of foliar surface area with chlorotic mottle or stippling caused by pollutants, (2) percent surface area with necrosis, (3) percent surface area with other injury (biotic and abiotic). Only leaves on the upper part of plants should be measured. These measurements should be made annually for at least five years, preferably in early August; measurement should always be conducted prior to the onset of seasonal leaf senescence that would obscure other foliar characteristics.