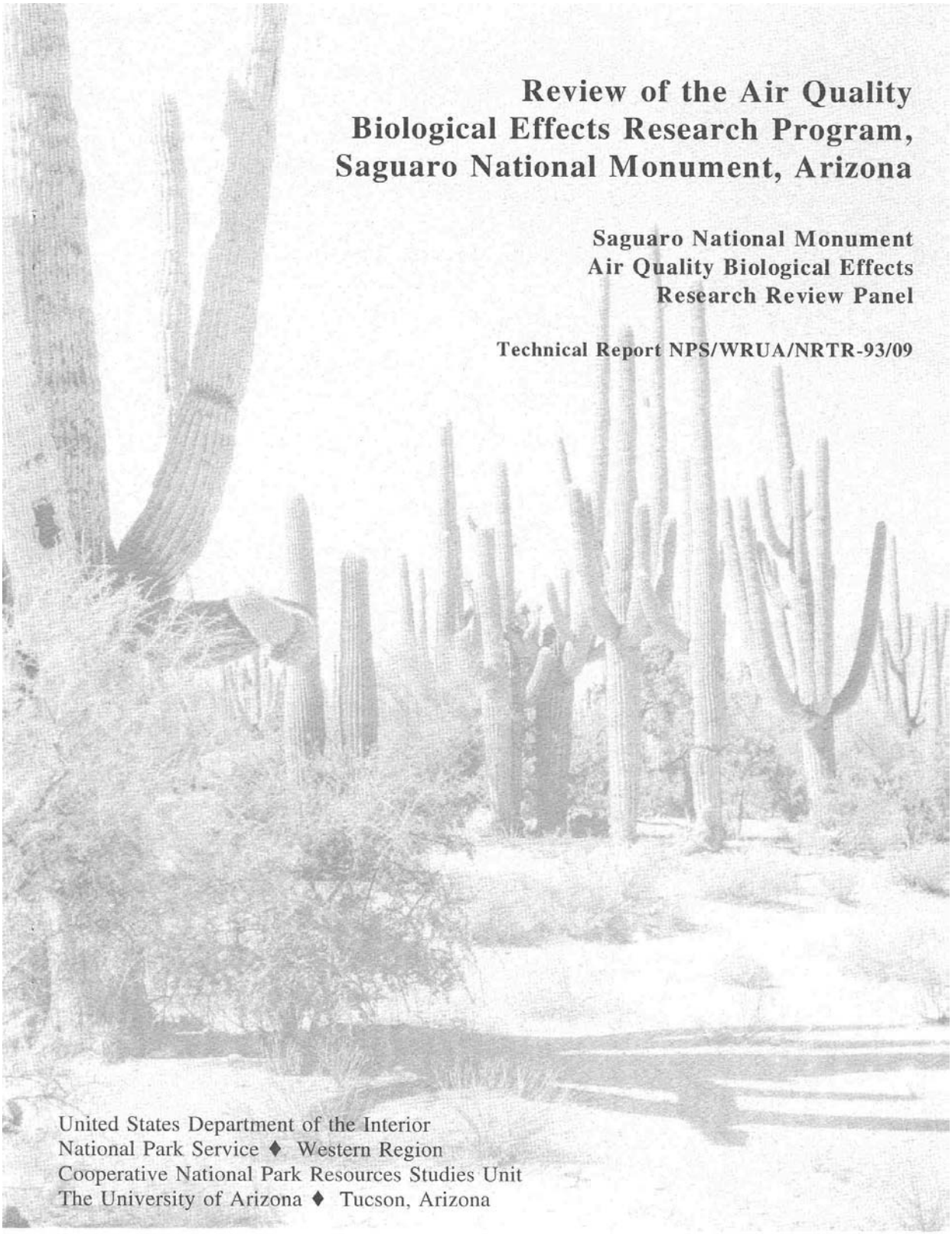

Review of the Air Quality Biological Effects Research Program, Saguaro National Monument, Arizona

Saguaro National Monument
Air Quality Biological Effects
Research Review Panel

Technical Report NPS/WRUA/NRTR-93/09

United States Department of the Interior
National Park Service ♦ Western Region
Cooperative National Park Resources Studies Unit
The University of Arizona ♦ Tucson, Arizona

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The University of Arizona, Tucson

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(CPSU/UA no. 49)

September 1993

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Contents

Abstract

This is a report of a review of the Biological Effects Program of the National Park Service's (NPS) Air Quality Division (AQD) at Saguaro National Monument (SAGU), Tucson, Arizona. The Air Quality Division of the NPS Washington Office invested significant time and money in biological effects research and monitoring at SAGU. This research included work on mountain trees, cacti, soil crust organisms, and lichens. The review evaluated the past research and made recommendations for future directions in biological effects research at the monument. The review was conducted by a panel of 8 reviewers, who were selected for their expertise in conifers, cactus and lichen ecology research, air pollutant research, and/or research program management. The committee members each reviewed a selected number of reports that were sent ahead of time and then came together in a workshop setting. The workshop included most of the researchers who were active in the program and was held in Tucson, Arizona, on 1-3 September 1992. The committee divided its discussion into the following categories: (1) Conifers, (2) Saguaros, (3) Crusts, (4) Lichens, (5) Nitrogen Enrichment, (6) Biomonitoring Gardens, and (7) General Program Issues. Evaluations of each of these were made separately and recommendations listed. Finally, AQD responded to this evaluation and recommendations, providing insight as to what changes were deemed reasonable and giving justifications for those that were not. As a result of this review and changes made within AQD, the program at SAGU has been curtailed.

Introduction

The Air Quality Division (AQD) of the National Park Service (NPS) Washington Office has invested significant time and money over the last few years in biological effects research and monitoring at Saguaro National monument (SAGU). This research has included work on mountain trees, cacti, soil crust organisms, and lichens. Because of changes in personnel, and a re-evaluation of direction, AQD wanted a review of the past research and recommendations for future directions in biological effects research at the monument. Therefore, AQD commissioned this project.

Objectives of the review were defined through discussions between AQD, SAGU staff, and the NPS Cooperative National Park Resources Studies Unit at The University of Arizona (CPSU/UA).

1. Conduct a review and summarize the general literature on the sensitivity of desert plants and conifers to air pollution injury as it relates to studies done in SAGU.
2. Review a selected number of study plans, interim reports, final reports, and journal manuscripts relevant to air pollution research in SAGU.
3. Determine if the methodology used in the individual reports was valid, and if the conclusions reached by the authors were supported by the data.
4. Determine the need for future air pollution-related biological effects studies at SAGU; if such studies are warranted, make recommendations on what direction the research should take.
5. In particular, the following questions would be answered to the best possible degree:
    A. Are saguaro cacti being adversely affected by air pollution? If so, what should we do next?
    B. Are desert annuals susceptible to air pollution injury?
    C. Should the saguaro/desert annual nitrogen fertilization study be supported?
    D. Are conifers in the Rincon Mountains being adversely affected by air pollution? If so, how often should the pine plots be re-read? Should more tree-ring studies be done?
    E. Are biomonitoring gardens in desert ecosystems useful? Is it worthwhile for the gardens in SAGU and Joshua Tree National Monument (JOTR) to be continued? Should emphasize be placed, instead, on field surveys? Could the existing gardens possibly be used for some other experiment?
    F. Is the wet deposition site providing useful information as operated? If not, should it be discontinued? Upgraded?
    G. Should more air pollution research on lichens be done in the monument?

H. Would it be worthwhile for SAGU to continue the UV-B experiment?

I. Would it be better to focus air pollution effects research on some other resources in the monument?

J. What are the policy/regulatory issues that would require these data, and how important are these issues at SAGU in light of the limited funds available in the AQD Biological Effects Program, which in national in scope?

Methods

The review was conducted by a panel of 8 reviewers, who were selected because of their expertise in conifer, cactus, and lichen ecology research; air pollutant research; and/or research program management. Prior to the meeting, committee members each reviewed a selected number of reports. The workshop was held in Tucson, Arizona, on 1-3 September 1992 as follows:

Day 1

The review panel spent the day at SAGU. During the morning, Meg Weesner, chief of the SAGU Science and Resource Management Division led a field tour of the monument, research sites, and the biomonitoring garden. In the afternoon, there were presentations by Meg Weesner and members of the AQD staff (John Christiano, Kathy Tonnessen, Miguel Flores, and Tonnie Maniero). During both of these sessions, there were periods of general discussion aimed at understanding the research that had been conducted at SAGU.

Day 2

Invited researchers made presentations on their research program at SAGU. There were also periods of discussion on this day aimed at understanding the researchers' points of view, questioning methods used, and results obtained (also see appendices 1 and 2).

Researchers who discussed their work on the second day of the workshop were:

Jayne Belnap (desert crust)
Dan Duriscoe (pines/cactus plots)
Lance Evans (UV light/saguaros)
Ernie Gladney (elemental analysis)
Kate Lajtha (cactus physiology)
Dave Meko (Donald Graybill's pine work)
Bob Moon, Mark Heuston, and Jerry Freilich (biomonitoring gardens)
Ken Stolte (general program and Wetmore's lichen work)

Day 3

The review panel spent the day discussing the research and drafting this report, which we hope succinctly reviews the past program and makes reasonable recommendations for the future.

Discussion and Recommendations

The committee divided its discussion into the following categories: (1) conifers, (2) saguaros, (3) crusts, (4) lichens, (5) nitrogen enrichment, (6) biomonitoring gardens, and (7) general program issues. Each of these will be dealt with separately.

Conifers

Biological effects work at SAGU started with conifers. A survey of 23 biomonitoring plots in the Rincon Mountains in 1985 indicated that there might be ozone-caused mottling of needles on more than half of the ponderosa pine *(Pinus ponderosa)* trees examined (Duriscoe and Selph 1985). The degree of injury as measured by percent leaf area affected was slight. Correlated with the mottling was a slight thinning of crown density as measured by the number of retained whorls. The percentage of injured trees was higher on the west side of the mountains adjacent to the city of Tucson.

Tree-ring analysis of 41 chronologies (5 species of conifers) from central and southern Arizona indicated 2 types of anomalous tree growth, predominantly in ponderosa pine (Graybill and Rose 1988; Graybill 1990). The most severe type of anomaly, observed at 7 of 41 sites, was a great reduction in growth rate, or cessation of growth in a period beginning in 1920 and continuing to the end of the record in 1987. As many as half the trees at these sites exhibited this phenomenon. The outer parts of the cores were undatable because of missing rings and greatly compressed growth. Six of the 7 chronologies showing this problem were from southern Arizona; and 4 were from mountain ranges near Tucson.

The less severe type of tree-ring anomaly was a statistically significant depression in growth (1950-87) below the growth rate projected from a climate-tree growth model calibrated on data before 1950. The problem again was most common at ponderosa pine sites in the southern part of the study area. Growth indices at these sites generally tracked annual precipitation from 1897 into a drought near mid-century, but failed to recover to previous levels with the increased annual precipitation of recent decades.

Value of Past Work

The studies mentioned above are valuable in pointing out a potential problem with growth and appearance of conifers at SAGU. Results, however, do not conclusively point to air pollution as the source of the problem. The appearance of ozone-related symptoms on needles, and the geographical clustering of affected trees in both the tree-ring and biomonitoring study indicate that air pollution might be affecting the conifers.

The significance of the findings of ozone mottling of ponderosa pine needles is clouded by several factors. First is an incomplete understanding of the ozone symptoms of the particular subspecies/varieties of pine studied. Second is the low degree of observed "damage" to needles, combined with a lack of comparative data from mountain ranges remote from sources of anthropogenically-induced ozone. Data from a control site would be helpful. Third is the lack of ambient ozone measurements at these elevations due to the unavailability of remote monitors.

Several factors argue against acceptance of the tree-ring results as evidence of air pollution effects. First, although sites with growth anomalies cluster in geographical areas with greater air pollution, some sites with the same types of growth anomalies are found in areas of relatively

low air pollution (e.g., north of Mogollon Rim). Second, currently unknown aspects of the population dynamics and climate-growth relationships of the sampled conifers in the Rincon Mountains could offer alternative explanations for the observed growth anomalies. Graybill and Rose (1988) postulate that differences in response to severe drought are caused by genetic differences of individual species or populations. Another possible explanation is biological competition changes associated with fire history (Baison 1992). Finally, not all trees showing severe ring-width suppression showed foliar evidence of pollution (e.g., ozoneinduced mottling).

Recommendations

1. Continue surveys of permanent pine biomonitoring plots, including periodic (5- to 10-year interval) resampling by increment boring for tree-ring analysis of growth trends. The design should allow for future statistical testing of alternative hypotheses for growth variations (e.g., climate change competition, slope, exposure). The periodic tree-ring sampling should include some specimens showing extreme growth suppression (undatable cores) after 1950.

2. Determine whether the types and degrees of hypothesized ozone damage observed in the Rincon Mountains are also occurring in the same varieties and species of ponderosa pine where there are greater and where there are lesser concentrations of ozone. This could be accomplished by establishing plots similar to those of Duriscoe and Selph (1985).

3. Conduct fumigation studies to (1) identify the symptoms of ozone damage specific to *Pinus ponderosa,* var. *arizonica*, and to individuals of var. *scopulorum* from southern Arizona; and (2) verify their usefulness as ozone effects indicators.

4. Encourage studies aimed at gaining a better understanding of the population dynamics and genetics of conifers in the high elevations of southern Arizona. The possible effects of fire-suppression policy on altering the naturally occurring biological competition of ponderosa pine is one possible area of focus. Another serious issue that could be addressed through the Global Change Program is the growth response of these pines to alternating periods of drought and normal precipitation.

5. Consider alternative models of climate-growth relationships in future studies of statistical significance of observed growth changes. The choice of climate variable, seasonal grouping of climate variable, and form of model (e.g., linear regression vs. multivariate time-series model) should be studied closely to ensure that conclusions are not unduly sensitive to data analysis methodology. Proposed work under the NPS Sonoran Desert Global Change Program will address some of these issues.

6. Discontinue elemental analyses of tree rings. Enough information exists to show that this is a non-problem area and should not be pursued at this time.

7. Since ambient ozone levels are not known at the elevated sites in SAGU, concentrations should be measured for at least 1 year using a remote ozone monitor as soon as a reliable one is available.

Saguaro

Demographic data collected from the 45 long-term monitoring plots by Duriscoe and Graban (1992) demonstrated that overall, saguaros are not undergoing a recent and general population decline in either management unit of SAGU. These data corroborate the findings from the plots

examined by Turner (1992) over the last 3 decades. While it is true that there have been dramatic declines in the older cohorts, populations of saguaros, in general, have experienced considerable new recruitment over the last 2 decades. This recent reproduction reverses the trend of the post-1930 population declines attributed to the effects of catastrophic freezes.

Studies focused on the phenomenon of epidermal browning have clearly described the directionality of the brown discoloration and indicate that solar radiation, but not necessarily UV-B wavelengths, is at least in part responsible for the browning condition. Elemental analyses indicate a lack of any relationship between elemental contamination of soils and either cactus tissues *or* epidermal browning. Attempts to link epidermal browning with recent increases in ultraviolet radiation have been plagued with problems in research design, methodology, and statistical analysis.

Value of past work

One of the most important accomplishments of the research directed at saguaros at SAGU is the establishment of 45 permanent plots by Duriscoe and Graban. The baseline information obtained from these plots will provide an invaluable foundation for studies of saguaro populations over the next century. To date, Turner's (Turner 1992) single plot has provided the only published data on the resurgence of recruitment in the Cactus Forest of the Rincon Mountain Unit. The additional plots provide a thorough coverage of the monument and allow for a more general and complete assessment of saguaro population trends.

The establishment of these plots, along with the single collection of data, has resulted in an important volume of information. The value of the permanent plots will be lost, however, unless the complete data set is stored and archived at several locations. Multiple copies of the data set should be stored at AQD offices, SAGU Headquarters, CPSU/UA, and perhaps other repositories in a manner that makes the data accessible to both NPS and non-NPS scientists.

Much of the saguaro-related research involving extensive surveys of soils and plant tissues has well documented a lack of plausible linkages between saguaro condition and contamination by toxic elements. The committee believes that there is little benefit in continuing with extensive elemental analyses in search of possible causes of epidermal browning or saguaro population decline.

The factors responsible for epidermal browning are not understood. Although browning originates on the southern exposure of saguaros and is clearly related to exposure to solar radiation, the role of non-UV-B wavelengths (e.g., infrared) has not been investigated, and the studies on UV-B wavelengths have been met with mixed reviews due to questions on methods used. Preliminary work has indicated epidermal browning is a ubiquitous phenomenon throughout the range of saguaros. It even occurs in other columnar cacti in both North and South America. However, careful comparisons of the degree of browning exhibited by saguaros in SAGU and other areas have not been made.

Recommendations

1. Multiple copies of the Duriscoe and Graban data set and photos for 45 plots must be immediately deposited in multiple locations, including SAGU headquarters. These records must be stored in a manner that will pose no difficulty for retrieval throughout the next century (e.g., acid-free paper working copies, microfilm copy, etc.). Storage exclusively in

computer-read format is not appropriate for such long-term storage because of rapid changes in computer technology.

2. Complete sets of information from other saguaro plot studies (e.g., Turner, Alcorn) should be requested and suitably archived by NPS.

3. The 45 permanent plots, including the 10-m^2 ecological plots, should be monitored regularly. A schedule for monitoring should be established for the purpose of future budget planning. As a model for such a schedule, Turner has monitored his 10 permanent plots located throughout Arizona and Sonora, Mexico, at intervals of approximately 10 years. Considering the slow growth and great longevity of saguaros, together with the large number of plots, the evaluation of plots at intervals much shorter than 10 years may not be necessary or possible.

4. Population patterns of saguaros at SAGU need to be considered in context of a broader examination of demographic and population patterns throughout the saguaro's entire range. The research of Turner on multiple permanent plots established in the Sonoran Desert more than 30 years ago can serve as a substantial part of this expanded outlook.

5. The known biology of the saguaro should be summarized in a workshop in which recognized experts in all facets of saguaro ecology and biology contribute. Such a workshop would provide a more complete foundation for saguaro-related research and clear up popular misconceptions about the condition of saguaro populations.

6. The pattern of epidermal browning needs to be examined and compared throughout the entire range of saguaros in the United States and Mexico.

7. Physiological studies involving gas exchange, water balance, and heat loading should be continued. This basic information holds promise for providing a better understanding of physiological processes and mechanisms leading to epidermal browning. These broader investigations of browning should also involve studies of root system structure and function.

8. Research on UV-B as a potential cause for epidermal browning should be ended unless problems of design, repeatability, and statistical analysis are resolved.

9. Extensive surveys of toxic element contamination of soils and saguaro tissues should not be continued. Irradiated samples collected from 60 saguaros by Gladney should be archived at suitable facilities at Los Alamos National Laboratory.

10. A closer look should be taken at the surveys of the saguaro mortality transects. If these transects contain only moribund cacti, perhaps these could be discontinued in light of the 45 saguaro plots noted above. Observing and recording only the death of these older individuals provide little useful information concerning overall saguaro population dynamics.

11. Monitoring of nitrogen input should be upgraded to include both wet and dry deposition to provide an analysis of trends in this important nutrient.

Crusts

Cyanobacterial-lichen soil crusts play an important role in the functioning of arid and semiarid ecosystems. These roles include stabilization of soils and the fixation of atmospheric nitrogen and carbon (Harper and Marble 1990).

Previous studies have demonstrated that the physiological functioning of cyanobacteria and soil lichens found in these crusts are affected by air pollution. Characteristics measured have included chlorophyll degradation rates, nitrogenase activity, and elemental analysis of cold-desert crusts, and chlorophyll degradation in hot-desert crusts. Cold-desert crusts showed decreased chlorophyll degradation and nitrogenase activity near a coal-fired power plant; increased chlorophyll degradation when exposed to urban pollutants; and decreased chlorophyll degradation with decreasing pH of simulated acidic precipitation (Belnap 1990). Work with hot-desert crusts also demonstrated a decrease in chlorophyll degradation with decreasing pH of simulated acidic precipitation (Belnap, unpublished data).

Nitrogen fixation by crusts has recently been demonstrated to be the major source of nitrogen for some cold-desert ecosystems (Evans and Ehlringer, in manuscript). No comparable work has been done in hot deserts. Addition of nitrates in the laboratory has been found to reduce nitrogenase activity in cyanobacteria that are commonly found in both northern and southern deserts (Stewart 1969). Addition of nitrogenous compounds by a coal-fired power plant to a cold-desert shrub and grassland ecosystem resulted in reduced nitrogenase activity of cold-desert crusts in both systems (Belnap 1990; Sheridan 1979). No field work has been done in southern deserts to examine the effects of anthropogenic additions of nitrogen on nitrogenase activity of these crusts.

At SAGU, cyanobacterial-lichen soil crusts were surveyed in the long-term plots established for monitoring epidermal browning of the saguaros. Percent cover, composition, chlorophyll degradation ratios (chlorophyll *a/* phaeophytin *a*), and nitrogenase activity were measured. No correlation was found between saguaro cactus browning and the amount of soil crusts present or the composition of the crusts. Significant correlations were found between saguaro cactus browning and an increase in chlorophyll degradation and an increase in nitrogenase activity. This pattern suggests that the crusts in plots with increased saguaro browning may have higher levels of nutrients available that are stimulating chlorophyll production, or reducing chlorophyll degradation, in the crusts. Since nitrogenase activity is stimulated in these crusts, these nutrients are probably not nitrogen-containing compounds.

Value of past work

Crust work at SAGU is of a survey nature and, therefore, incomplete. Work on crusts in general suggests 2 significant roles in a regional and national air quality program. First, crusts can be used to document the presence of pollutants in desert systems through elemental analysis and physiological measurements. More importantly, their role in the nitrogen budget of desert ecosystems needs to be considered in any studies concerning anthropogenic additions of nitrogen to these systems.

Recommendations

1. Crusts have been shown to be useful in documenting the effects and presence of pollutants in arid systems and should be considered in research and monitoring programs in these

ecosystems; however, the committee feels that the data available indicate the presence of too low a concentration of pollutants to be a problem in SAGU at this time.

2. In combination with nitrogen fertilization studies related to saguaros and annuals, research* on nitrogen fixation by crusts in hot deserts and the effect of fertilization on fixation should be investigated.

Lichens

The lichen survey conducted at SAGU was one of a series done in many park units throughout the country funded by the AQD Biological Effects Program. The purpose of the surveys was to establish a baseline for studies of trends in air quality within a park unit. The surveys included (1) a lichen collection of each area, (2) a listing of lichens known to be sensitive to elevated sulfur dioxide (SO_2), and (3) elemental analysis of selected individuals to indicate current air quality.

Value of past work

The lichens collected in this survey were identified by one of the top lichen taxonomists in the world and, therefore, are considered to be highly accurate. The resulting lichen species list and collection is a good start to a flora for SAGU. In addition, we now know that there are lichen species in SAGU sensitive to $S0_2$. However, use of the flora as a baseline to detect trends in air quality is questionable for the following reasons:

1. The methods are not given in enough detail to repeat.
2. The selection of collection points was subjective.
3. No quantitative information was collected.
4. The level of effort is only roughly estimated.
5. There is no way to estimate the percentage of completeness of the resulting species list.

Because of the above difficulties, there is no way to return to a particular area and measure any quantitative change, and it would be meaningless to record a "change" in the species list by conducting another "walk-about" survey.

At SAGU, the elemental analysis indicated that no lichens have taken up selected toxics above the level that is expected. Another factor that is important to note is that there are and have been low levels of SO_2 in and around Tucson.

Recommendations

1. Further survey work should be done to complete the lichen flora of SAGU.

2. Quantitative lichen monitoring plots should be established within selected communities, and as part of an integrated ecosystem monitoring program. This would serve as an early warning for change. If a reduction in lichen coverage begins to be recorded, that should then trigger research into the causes of the reduction.

Nitrogen Enrichment

The effects of anthropogenic additions of nitrogenous compounds to native systems are poorly understood. As sources of nitrogen inputs increase, understanding these effects becomes more important. This may be especially critical in nitrogen-poor systems such as semi-arid and arid landscapes, and dune systems. The first step in this process is an assessment of current nitrogen inputs into park ecosystems of concern. This information can be used to (1) provide a baseline

for nitrogen input to park lands, (2) identify geographic areas of concern, and (3) estimate realistic future loading levels for determining fertilization levels in laboratory and field experiments. Both field and laboratory fertilization experiments should be used to examine effects on ecosystem nitrogen budgets, individual species (perennials, annuals, microflora, and microfauna), and community structure.

Value of past work

This project only got to the point of having some hypotheses developed and having 1- x 1-m plots constructed at SAGU. The hypotheses to be tested were that (1) saguaros are more susceptible to freezing in early spring due to increased fertilization, and (2) the relationship between annuals and perennials will change with increased fertilization. This work was not carried out, and the plots have never been tended. In addition, it has not yet been established that nitrogenous compounds are on the increase at SAGU.

Recommendations

1. Continue the wet deposition monitoring, with samples analyzed for pH and nitrogenous compounds so that there will be a database to show trends or indicate changes.

2. Basic research into the issue of effects of increased nitrogenous compounds in arid landscapes should be conducted. There is some indication that increased nitrogen levels will be a more important issue in the future. Research should be conducted now so that we will know what changes to expect.

3. The proposed experiment involving nitrogen-enrichment effects on cold hardening in young saguaros should be implemented for its scientific value. Even though we do not know if nitrogen enrichment occurs at SAGU, it does at other and areas; therefore, this information will have general applicability.

Biomonitoring Gardens

Experimental biological gardens have been employed in a number of ways in agriculture and forestry and recently as a method to evaluate the occurrence of response to ambient, low-level atmospheric ozone (Kromroy et al. 1990) or ozone and $S0_2$ (Stolte and Bennett 1985). Under the direction of the AQD Biological Effects Program, native plant gardens were developed at JOTR (1986) and SAGU (1989) to observe native perennial plants for foliar injury due to ozone under ambient conditions. These were set up near ambient ozone monitors. Of 13 species evaluated at SAGU, only squaw bush *(Rhus trilobata)* has shown ozone effect symptoms (Danisiewicz and Weesner n.d.). Fifteen perennials and four annuals were tested at JOTR. Of these, squaw bush exhibited ozone effects on several occasions and chuparosa *(Beloperone californica)* presented symptoms on one occasion (Heuston 1991).

Value of past work

The results of the garden work lead to field surveys for *Rhus* at both JOTR and SAGU, but few if any symptomatic plants were found in either monument. No additional species have been placed in the biomonitoring gardens for screening, and none are scheduled for future screening. The gardens are currently in a maintenance status, using a combination of park-base funds and AQD funds. Both monuments expressed concern and confusion as to the purpose and value of the gardens.

Recommendations

1. In the absence of a clear need for additional work under good scientific guidelines, we believe that the gardens have served their initial purpose and that their operation for the purpose of screening for air pollution effects should be discontinued at SAGU and JOTR.

2. If additional screenings of desert species are needed in the future, the option of conducting controlled dose exposures in a laboratory setting should be examined. This would eliminate the problems associated with physiological changes in plants due to gardening them away from their normal limits of distribution.

3. Gardens and greenhouses should be viewed as tools to conduct various types of botanical research. If these particular facilities could be used to good benefit for research planned in the near future, they should be maintained at minimal levels until that time.

General Issues

There is a vast array of potential ways in which airborne contaminants may influence the biotic resources of national parks. These effects range from immediate and lethal impacts on sensitive organisms to far more subtle and complex effects that may result from interactions involving several types of contaminants as well as more than one species of organism. Since there will never be adequate funds or personnel to address all of the possible immediate and long-term effects of air pollution on plants and animals, a critical issue in administering this program concerns identifying what to study and assigning research priorities. The committee understands that AQD is concerned about past program difficulties and offers these comments in the spirit of support for restructuring some of the ways in which air quality biological effects research is conducted.

The issue of assigning priorities for research needs to be addressed at the national, regional, and park levels. The role of NPS in contributing to research involving the impacts of air contaminants on biotic resources and how the NPS research program relates to the research programs of other organizations are important issues. It seems to us that a basic point of departure for all NPS research in this area should be an explicit research goal statement that provides a basis for prioritizing research--e.g., "NPS air contaminants studies should focus on issues or problems that present a clear threat to the NPS ability to preserve our natural heritage and provide for public enjoyment of this heritage." Criteria should be developed for assigning priorities based on such things as the immediacy of perceived threats (short-term vs. long-term) and magnitude of potential impact (extinction vs. superficial damage).

Most air contaminant research has occurred in more mesic environments. The committee understands that national priorities need to be kept; however, we believe that there is a critical need for an arid ecosystem component in air quality studies. This component should not be modeled after wet climate programs, but designed specifically to address air quality problems that are unique to arid environments. For example, desert communities seem to have low nitrogen availability, and the input of nitrogen as a component in air contaminants could have a significant impact on specific types of plants and on the composition of plant communities. Dry deposition may play a much more important role in and environments than in more mesic systems.

At SAGU, the biggest shortcoming with existing air quality research is not the quality of specific investigations but rather the lack of systematic direction concerning what to study, and the lack of some basic biological information. Furthermore, lacking a system for broad peer review and justification, research thrusts tended to jump to an inappropriate level of specificity. For example, the detailed saguaro physiology research was driven by 2 basic assumptions: (1) that saguaros are declining in numbers, and (2) that epidermal browning is increasing and may be causing this mortality. However, neither of these assumptions appears to be supported by available data.

A shortcoming in past research emphases has been a lack of adequate attention to general description and understanding of the function of plant communities in SAGU. Before attempting to explain how air pollution is causing saguaro mortalities, it would be appropriate to determine if the perceived decline is real and if so, to make certain that the decline is not a natural process. That is it say, we need a better understanding of overall saguaro population dynamics. For browning, we need to have a better understanding of its relation to mortality as well as a broader research approach to understanding its causes.

Dissemination of information is another area where improvement is needed. For example, considerable effort has been expended in establishing saguaro monitoring plots, but only recently (February 1993) did SAGU staff receive the documentation that can be used to relocate the plots and the data from those plots. There is a need for better information exchange between AQD and SAGU and for both offices to be more concerned with their information and database management systems. This is particularly critical at times when personnel changes occur.

Recommendations

1. National Park Service needs to do a better job of archiving, and making available, research data. This problem exists throughout the service, but the committee hopes that in its efforts to revamp the Biological Effects Program, AQD will address this for its program. We recommend that, at a minimum, one copy of all published papers, field notes, photographs, etc. should be stored at the park unit(s) concerned, and a second complete copy, perhaps in microfiche form, should be stored and cataloged by the Denver office. Lists of research reports and data available should be produced at the park and national level and distributed to interested investigators.

2. National Park Service should place a greater emphasis on long-term monitoring, including coordination of the many diverse research programs; this needs to be done primarily at the park level. Monitoring should include selected plant and animal species as well as such physical parameters as air and water quality data. We understand that there is little that AQD can do in this regard; however, we again hope that this need is considered in general program development discussions.

3. It would be helpful for SAGU to have a regional database to relate to. We hope that NPS could work toward obtaining more air quality data for the Tucson area than is currently being utilized and toward better interagency cooperation and coverage of conditions. For instance, not enough is known about the meteorological patterns influencing SAGU; not enough is known about variability of pollutant levels within the monument. This cooperation/coordination is probably best done at the park level with some assistance on the part of AQD.

Research Questions

Of those research avenues taken by the AQD Biological Effects Program in SAGU, the most significant have been the conifers on mountain peaks and investigations of the saguaro aimed at determining the causes of the decline in mature individuals and the causes of the "browning" of the epidermis. Questions posed to the committee and accompanying short answers follow:

1. Are saguaro cacti being adversely affected by air pollution? If so, what should we do next?

There are insufficient data to answer this question fully. We can say that no toxics have yet to be implicated in any saguaro decline. "Browning" and, therefore, gas and water exchange reductions are positively correlated with solar radiation, but further research is needed to determine which wave length(s) are critical.

2. Are desert annuals susceptible to air pollution injury?

None have thus far been identified as being sensitive, but this is primarily a case of too little investigation. Common understanding is that, with their short life cycle, other members of any community will show effects before annuals do. There remains the issue of nitrogen fertilization and what effect that will have on community composition.

3. Should the saguaro/desert annual nitrogen fertilization study be supported?

Yes, because arid regions are likely to be the most sensitive to anthropogenic increases in nitrogen. We should try to gain an understanding of this relationship before it becomes a problem.

4. Are conifers in the Rincon Mountains being adversely affected by air pollution? If so, how often should the pine plots be re-read? Should more tree-ring studies be done?

Again, there are insufficient data to give a definitive answer to this question. We suggest that additional surveys of permanent pine biomonitoring plots, including periodic (5- to 10-year interval) resampling by increment boring for tree-ring analysis of growth trends, be done; also, that fumigation studies and studies aimed at gaining a better understanding of the population dynamics and genetics of conifers in the high elevations of southern Arizona be conducted.

5. Are biomonitoring gardens in desert ecosystems useful? Is it worthwhile for the gardens in SAGU and JOTR to be continued? Should emphasis be placed, instead, on field surveys? Could the existing gardens possibly be used for some other experiment?

Close the gardens until such time as research need arises. They are not useful for monitoring of pollutants.

6. Is the wet deposition site providing useful information as operated? If not, should it be discontinued? Upgraded?

There is still a good deal of confusion as to what happens to the data from this monitor. The committee feels that it should be upgraded so that nitrogen compounds, and perhaps others, are recorded along with pH. The data from this monitoring should be a concern to SAGU; the monument should also have records that are available to interested investigators.

7. Should more air pollution research on lichens be done in the monument?

Not air pollution research per se. Further surveys to complete the species list need to be done and systematic, long-term monitoring should be carried out at the park level as soon as financially feasible.

8. Would it be worthwhile for SAGU to continue the UV-B experiment?

Not in its present state. Experiments to determine the relationship between solar radiation and epidermal browning should be developed so that more wavelengths than UV-B are considered (e.g., infrared causing heat loading).

9. Would it be better to focus air pollution effects research on some other resources in the monument?

The focus of air pollution effects research should first be conifers for the time being. A second and very important issue is whether epidermal browning of saguaros, which is well recognized as a solar radiation (and, therefore, air quality in the broad sense) problem, is in fact an air pollution problem. This is a critical issue that needs to be resolved, but it's a big question as to what the appropriate funding source should be.

10. What are the policy/regulatory issues that would require these data, and how important are these issues at SAGU in light of the limited funds available in the AQD Biological Effects Program, which is national in scope?

The policy/regulatory issues relate to clean air in the entire Tucson region. It is very important that SAGU stay tied in to a regional database and coordinate its efforts in monitoring air quality with other agencies in the region. This is important so that SAGU will be better able to protect its resources and its viewshed.

Research Priorities

Research Needed

1. Multiple copies of the Duriscoe and Graban data set and photos for 45 plots must be immediately deposited in multiple locations, including SAGU headquarters. These records must be stored in a manner that will pose no difficulty for retrieval throughout the next century (e.g., acid-free paper working copies, microfilm copy, etc.). Storage exclusively in computer-read format is not appropriate for such long-term storage because of rapid changes in computer technology. The data must be available for future comparisons.

2. Continue surveys of permanent pine biomonitoring plots, including periodic (5- to 10year interval) resampling by increment boring for tree-ring analysis of growth trends. The design should allow for future statistical testing of alternative hypotheses for growth variations (e.g., climate change competition, slope, exposure). The periodic tree-ring sampling should include some specimens showing extreme growth suppression (undatable cores) after 1950.

3. Complete sets of information from other saguaro plot studies (e.g., Turner, Alcorn) should be requested and suitably archived by NPS.

4. The 45 permanent plots, including the 10-m^2 ecological plots, should be monitored regularly. A schedule for monitoring should be established for the purpose of future budget planning. As a model for such a schedule, Turner has monitored his 10 permanent plots located throughout Arizona and Sonora, Mexico, at intervals of approximately 10 years. Considering the slow growth and great longevity of saguaros, together with the large number of plots, the evaluation of plots at intervals much shorter than 10 years may not be necessary or possible.

5. The known biology of the saguaro should be summarized in a workshop in which recognized experts in all facets of saguaro ecology and biology contribute. Such a workshop would provide a more complete foundation for saguaro-related research and clear up popular misconceptions about the saguaro decline.

6. Determine whether the types and degrees of hypothesized ozone damage observed in the Rincon Mountains are also occurring in the same varieties and species of ponderosa pine where there are greater and where there are lesser concentrations of ozone. This could be accomplished by establishing plots similar to those of Duriscoe and Selph (1985).

7. Conduct fumigation studies to (1) identify the symptoms of ozone damage specific to *Pinus ponderosa,* var. *arizonica,* and to individuals of var. *scopulorum* from southern Arizona; and (2) verify their usefulness as ozone effects indicators.

8. Encourage studies aimed at gaining a better understanding of the population dynamics and genetics of conifers in the high elevations of southern Arizona. The possible effects of fire-suppression policy on altering the naturally occurring biological competition of ponderosa pine is one possible area of focus. Another serious issue that could be addressed through the Global Change Program is the growth response of these pines to alternating periods of drought and normal precipitation.

9. Physiological studies involving gas exchange, water balance, and heat loading of saguaros should be continued. This basic information holds promise for providing a better understanding of physiological processes and mechanisms leading to epidermal browning. These broader investigations of browning should also involve studies of root system structure and function.

10. The pattern of epidermal browning needs to be examined and compared throughout the entire range of the saguaros in the United States and Mexico.

11. Population patterns of saguaros at SAGU need to be considered in context of a broader examination of demographic and population patterns throughout the saguaro's entire range. The research of Turner on multiple permanent plots established in the Sonoran Desert more than 30 years ago can serve as a substantial part of this expanded outlook.

12. Basic research into the issue of effects of increased nitrogenous compounds in arid landscapes should be conducted. There is some indication that increased nitrogen levels will be a more important issue in the future. Research should be conducted now so that we will know what changes to expect. In this regard, the proposed experiments involving nitrogen-enrichment effects on cold hardening in young saguaros, and experiments on effect of fertilization on annual plant growth should be implemented. Also, research on nitrogen fixation by crusts in hot deserts and the effect of fertilization on fixation should be initiated.

13. Monitoring of pH and nitrogen input should be upgraded to include both wet and dry deposition to provide an analysis of trends in these important constituents.

14. Further survey work should be done to complete the lichen flora of SAGU.

15. Quantitative lichen monitoring plots should be established within selected communities, and as part of an integrated ecosystem monitoring program. This would serve as an early warning for change. If reductions in lichen coverage begin to be recorded, that should then trigger research into the causes of the reduction.

16. If additional screenings of desert species for ozone-related damage are needed in the future, the option of conducting controlled dose exposures in a laboratory setting should be examined. This would eliminate the problems associated with physiological changes in plants due to gardening them away from their normal limits of distribution.

17. Alternative models of climate-growth relationships should be considered in future studies of statistical significance of observed conifer growth changes. The choice of climate variable, seasonal grouping of climate variable, and form of model (e.g., linear regression vs. multivariate time-series model) should be studied closely to ensure that conclusions are not unduly sensitive to data analysis methodology. Proposed work under the NPS Sonoran Desert Global Change Program will address some of these issues.

18. Since ambient ozone levels are not known at the elevated sites in SAGU, concentrations should be measured for at least 1 year using a remote ozone monitor as soon as a reliable one is available.

Further Study Not Needed

1. Discontinue elemental analyses of tree rings. Enough information exists to show that this is a non-problem area and should not be pursued further at this time.

2. Research on UV-B as a potential cause for epidermal browning should be ended unless problems of design, repeatability, and statistical analysis are resolved.

3. Extensive surveys of toxic element contamination. of soils and saguaro tissues should not be continued, for the same reason as in number 1 above. Irradiated samples collected from 60 saguaros by Gladney should be archived in suitable facilities at Los Alamos National Laboratory.

4. The committee recommends a closer look at the surveys of the saguaro mortality transects. If these transects contain only moribund cacti, such surveys should be discontinued. Observing and recording only the death of these older individuals provide little useful information concerning overall saguaro population dynamics.

5. Crusts have been shown to be useful in documenting the effects and presence of pollutants in arid systems and should be considered in research and monitoring programs in arid ecosystems; however, the committee feels that there is little value in doing further crust work related specifically to pollutants at this time in SAGU.

6. In the absence of a clear need for additional work under good scientific guidelines, we believe that the biomonitoring gardens have served their initial purpose and that their operation for the purpose of screening for air pollution effects should be discontinued at SAGU and JOTR.

General Program Needs

1. National Park Service needs to do a better job of archiving-and making available research data. This problem exists throughout the service, but the committee hopes that in its efforts to revamp the Biological Effects Program, AQD will address this for its programs. We recommend that at a minimum 1 copy of all published papers, field notes, photographs, etc. should be stored at the park unit(s) concerned, and a second complete copy, perhaps in microfiche form, should be stored and cataloged by the Denver office. Lists of research reports and data available should be produced at the park and national level and distributed to interested investigators.

2. National Park Service should place a greater emphasis on long-term monitoring, including coordination of the many diverse research programs; this needs to be done primarily at the park level. Monitoring should include selected plant and animal species as well as such physical parameters as air and water quality data. We understand that there is little that AQD', can do in this regard but, again, hope that this need is considered in general program development discussions.

3. It would be helpful for SAGU to have a regional database to relate to. We hope that NPS can work toward obtaining more air quality data for the Tucson area than is currently being utilized and toward better interagency cooperation and coverage of conditions. For instance, not enough is known about the meteorological patterns influencing SAGU; not enough is known about variability of pollutant levels within the monument. This

cooperation/coordination is probably best done at the park level with some assistance on the part off AQD.

Response of Air Quality Division

In this section, AQD provides detailed responses to the SAGU Air Quality Biological Effects Research Review Panel's recommendations. The responses are numbered to correspond with the recommendations made in the Research Priorities section (pages 16-19).

Research Needed

1. Copies of the data resulting from the Duriscoe and Graban saguaro study were archived with the Denver Service Center Technical Information Center/Project Information File (TIC/PIF), and the original data sent to SAGU, in February 1993. The material sent to the monument included: the final report on hard copy and computer disk; original artwork for the report; individual cactus, cactus plot, and ecological plot data on hard copy and computer disk; instructions for drawing the plots with AUTOCAD; topographic and cactus mortality transect maps; and 3 loose-leaf binders containing the set of cactus slides. In addition, the TIC/PIF forwarded a microfiche copy of the Duriscoe and Graban maps, data, and report to SAGU. Any interested party can order copies of this information directly from the TIC/PIF at (303) 969-2130 (TIC/PIF #151/D-58). Unfortunately, the cost and time involved in duplicating and labeling 1,500 project slides was prohibitive. Therefore, SAGU has the only copy of Duriscoe and Graban's cactus slides. The monument is the logical storage location for the slides so that they will be readily available for comparison during future surveys. We recommend that SAGU seek funding to prepare a duplicate slide set for archival purposes. It may also be useful to have the slides digitized.

2. We agree that pines in SAGU should continue to be monitored for ozone-induced foliar injury and growth effects. The documentation of past foliar injury, though slight, indicates that periodic monitoring is warranted. However, we do not believe that it would be appropriate to re-survey the existing plots following the procedures used by Duriscoe and Selph in 1984 and 1985. A number of agencies, including NPS, Environmental Protection Agency (EPA), and U.S. Forest Service (USFS), have continued to do pine surveys, and knowledge about maximum plot size and injury criteria has changed since 1985. We are currently involved in an effort with USFS and California Air Resources Board (called Project FOREST) to develop standard survey techniques for documenting ozone injury on conifers. The techniques should prove useful to a number of NPS units, including SAGU, in future pine injury surveys. We are encouraging park units to wait until the Project FOREST survey techniques have been field-tested and validated before re-surveying old plots or establishing new ones. We are also encouraging park units to plan to incorporate such periodic survey work into their ongoing resource management programs.

3. While we agree that data from saguaro studies not funded by AQD would be of interest, we defer to SAGU and CPSU/UA staff on the usefulness of this information and their ability to locate and archive the data.

4. We agree that the Duriscoe and Graban saguaro plots should be monitored regularly and that a 10-year monitoring schedule is appropriate. However, because research has indicated that air pollution does not appear to be responsible for any change in saguaro cactus physiology or population dynamics, we consider regular monitoring of the plots to be a general ecological issue rather than an air quality issue, and, therefore, beyond the purview of AQD.

5. We agree that a workshop on saguaro ecology would be useful, and we encourage SAGU, the NPS Western Region, and CPSU/UA to pursue this with organizations such as the Desert Botanical Garden and U.S. Geological Survey. Air Quality Division would be happy to participate in such a workshop.

6. We agree that pine plots should be established outside the Rincon Mountains, in "cleaner" and "dirtier" sites, to compare ozone-induced injury along a gradient. In particular, we would like to see pine plots established in all appropriate southwestern park units. However, as we mentioned in response number 2 above, we recommend that no new plots be established until standardized survey methods are developed, field-tested, and verified. Obviously, local, state, and other federal agencies would need to participate in establishing similar plots in non-NPS areas.

7. We agree that ozone fumigation studies should be performed to verify symptomology on *Pinus ponderosa* var. *arizonica* and var. *scopulorum.* We understand that the USFS Center for Forest Environmental Studies is currently collecting wild seed of both varieties, in addition to that of var. *ponderosa,* for an ozone study at the USFS fumigation facility in Georgia. The study will compare physiological effects and visible symptoms of ozone to determine the relative sensitivity of the three *Pinus ponderosa* varieties. We have asked the USFS project manager to keep us informed of the study's progress, and we will pass any relevant information on to CPSU/UA and SAGU staff.

8. We agree that studies investigating the population dynamics and genetics of conifers in Arizona would be of interest; however, this is. not specifically an air quality issue and thus is beyond the purview of AQD. We suggest that such studies may be appropriate as a regional initiative under the National Biological Survey (NBS).

9. We agree that physiological studies should be continued to increase understanding of the basic biology of saguaro cacti. However, because this is not exclusively an air pollution issue, it is beyond the purview of AQD. Again, we suggest CPSU/UA and SAGU recommend these studies to NBS.

10. In the summer of 1992, Kate Lajtha examined saguaros at nine sites in Arizona and Mexico to compare epidermal browning and tissue metal accumulation. Preliminary reports from Lajtha indicate that epidermal browning is widespread throughout the saguaro range. After Lajtha's final report is received and approved (due to AQD in September 1993), we will provide it and the data to the monument, CPSU/UA, and region.

11. We agree that there needs to be further investigation of saguaro demographic and population patterns throughout its range to compare to the patterns observed in SAGU. However, as we mentioned in our response to the similar recommendation for conifers, this is not an air quality issue.

12. While we agree that not enough is known about the effects of increased anthropogenic nitrogen on native species-in any type of natural ecosystem- we disagree that the nitrogen fertilization and fixation experiments should be implemented at SAGU at this time. As we discussed at the review meeting last September, based on National Atmospheric Deposition Program (NADP) data, wet nitrogen deposition in southern Arizona is relatively low compared to other areas in the West. In addition, there is no indication that

the species discussed would be responsive to increased nitrogen input. Rather than embarking on a project so limited in scope, we recommend that (1) a literature review be performed to determine the types and extent of research that have already been done, (2) a well-designed, long-term, ecosystem-based study be developed, and (3) ambient monitoring be performed, in advance, to ensure that the levels of nitrogen enrichment selected for the study are realistic. We suggest that CPSU/UA would be the appropriate office to coordinate the literature review and design the study in a cooperative project between NPS and NBS.

Furthermore, while we agree that the effects of air pollutants on desert park units warrant further research, given our limited resources and the demonstrated adverse effects in park units in the Appalachians, Sierra Nevada, and Northeast, extensive research in desert park units is a lesser priority for the AQD program. However, this should not preclude NPS regions and park units from funding air pollution effects-related studies with discretionary money or through programs such as the Natural Resources Protection Program.

13. We understand that the wet deposition monitoring program initiated and conducted by SAGU staff includes only field pH and conductivity testing, and is not part of the quality-assured/quality-controlled NADP network. Because the site does not conform to the strict NADP sample collection and equipment maintenance requirements, the data are not reviewed, summarized, or disseminated by NADP. In addition to pH, NADP samples are analyzed in the laboratory for concentrations of sulfate, nitrate, and other ions. For obvious reasons, NADP site data are preferred over non-NADP site data for regulatory and research purposes. Saguaro National Monument can contact the NADP program manager in Fort Collins, Colorado, and request that the site be included in the NADP network. If the site is approved, SAGU may need to install additional wet deposition monitoring equipment, and will have to commit to site operation and sample analysis costs of $6,000 per year.

    As far as dry deposition is concerned**,** the only national dry deposition monitoring program in the United States is the EPA-funded National Dry Deposition Network (NDDN). We do not know of any plans by EPA to fund additional NDDN sites in the western United States. As a matter of fact, EPA recently proposed to shut down all western monitoring sites to increase coverage in the upper Midwest and Northeast. Some states, such as California and Wisconsin, have established their own dry deposition monitoring networks. We are not aware of a similar program in Arizona. Cost estimates for a dry deposition monitoring site, without ozone and meteorological monitoring, are approximately $7,000 for equipment and $6,000 per year for sample analysis. Air Quality Division is not currently in a position to fund either an NADP or a dry deposition monitoring site at SAGU, and we do not anticipate our monitoring commitments changing in the near future. Therefore, it would be necessary for either SAGU or the NPS Western Region to cover these expenses out of base funds or solicit funding from another source. Pima County has recently taken over operation of the existing monitoring station, and we suggest that SAGU approach the county about upgrading the site to include wet and dry nitrogen and sulfur deposition monitoring using NADP and NDDN protocols.

14. We agree that a complete lichen flora for SAGU would be desirable. Air Quality Division started funding lichen surveys and elemental analyses research in park units a number of

years ago because nobody else in NPS was doing that type of work. The NPS Inventory and Monitoring (I and M) Program is now responsible for resource inventories, and we suggest that SAGU prepare a proposal to the I and M Program for a comprehensive lichen survey.

15. We agree that lichen monitoring plots should be established as part of an ecosystem monitoring program. However, while these plots maybe of interest from an ecological perspective, there is no indication from past work that lichens in SAGU are being adversely affected by air pollution. In fact, sulfur dioxide concentrations at the monument are below published lichen damage thresholds. Therefore, this is not an air quality issue. Again, we suggest that SAGU approach the I and M Program and ask them to establish and monitor lichen plots in the monument.

16. We agree that controlled ozone fumigation, with follow-up field verification of symptoms, is the best way to characterize ozone injury on vegetation. Unfortunately, operating fumigation chambers is expensive and labor-intensive, and so it is not realistic to conduct such fumigations in a number of NPS units. However, the USFS Center for Forest Environmental Studies, mentioned in response 7 above, is planning another fumigation study that will likely benefit SAGU and a number of other western park units. Forest Service is soliciting wild seed from western sites for ozone fumigations to identify bioindicator species. While most of the seed is being collected on USFS lands, seed from other sites will be accepted. If SAGU staff are interested in contributing wild seed for the study, we would be happy to provide them with the name and phone number of the USFS project manager.

17. We agree that further research is needed to explore alternative causes of observed conifer growth changes, and we are pleased with the efforts of the Sonoran Desert Global Change Program to address this issue.

18. We agree that it is desirable to characterize ambient ozone concentrations at high elevation sites in SAGU, particularly in light of the observed foliar ozone injury on ponderosa pine in 1984 and 1985. The study conducted by AQD and a number of NPS park units in 1991 to test the reliability of passive ozone monitors was inconclusive. We are performing a follow-up study in 2 park units this summer, and we hope that the new data will indicate if currently available passive monitors will prove reliable in remote areas.

Further Study Not Needed

l. We agree that the elemental analysis of tree rings should not continue. The data collected to date on elemental analysis of biological samples are so variable that they are not . useful in assessing possible air pollution effects.

2. The pilot experiment investigating the potential effects of UV-B radiation on saguaro epidermal browning has been discontinued. We agree that unless the problems involved in the experiment can be resolved, the study should not resume. However, even if these issues are resolved and there is interest in re-initiating the study, UV-B research is not an AQD responsibility. This type of research would possibly be appropriate for the Global Change Program.

3. We agree that there does not appear to be a need to re-initiate elemental analysis of soils and saguaro tissues at this time as past surveys have not produced any data that reliably link element accumulation to either air pollution or toxic effects. We understand that the

irradiated saguaro tissues collected by Gladney and Ferenbaugh have been properly archived and stored at Los Alamos National Laboratory.

4. We agree that the saguaro mortality transect surveys provide little information on overall saguaro population dynamics and that re-survey of the transects should be a low priority.

5. We have not seen any peer-reviewed, published data that link changes in crusts directly to air pollution. We agree that further crust work is not warranted at this time.

6. We agree that the biomonitoring gardens at SAGU and JOTR should be discontinued as a means of screening plants for air pollution injury.

General Program Needs

1. We agree that NPS suffers from a lack of archived data, and we have taken steps to correct this problem in our own program. We are now archiving all information with TIC/PIF. Reports and related information are stored in hard copy and on microfiche at this location. Original information can be checked out from TIC/PEP on-site, and TIC/PIF will mail copies to anyone who requests them for a nominal xeroxing fee. Copies of all reports resulting from AQD-funded research at SAGU have been archived with TIC/P1F; and we plan to follow this procedure with all future reports until NPS develops a service wide protocol for archiving information. Saguaro National Monument has been sent copies of all reports and data contained in the AQD office. We understand that TIC/PIF regularly produces a list of the reports available through their office, and we agree that it would be useful for park units to produce a similar list to provide to interested researchers. The CPSU/UA could, no doubt, assist the park units with the appropriate distribution of such a list.

2. While we think it is essential for NPS, as a whole, to conduct long-term monitoring, AQD is not in a position to fund a long-term monitoring program at every one of the 48 NPS Class I air quality areas. Therefore, over the past 2 years, our Biological Effects Program has directed its efforts toward developing research and monitoring techniques that will benefit a number of park units. We will encourage NBS to continue to fund air quality-related projects in this manner. Because our program is national in scope and our staff is limited, we tend to be at a disadvantage in terms of staying abreast of local and regional research and monitoring initiatives. We agree that park, and also regional and CPSU, staff are in a better position to coordinate research efforts from a number of programs.

3., We agree that a regional air quality database would be useful, and AQD is taking a number of steps to develop such databases. For example, the Monitoring and Data Analysis Branch is preparing an "Air Atlas" that includes wet and dry deposition, gaseous pollutant, and emissions data collected in the vicinity of each of 250 NPS units, including SAGU. We hope to have the Air Atlas available in 1994. In the short-term, we suggest that SAGU work with the Pima County air quality office or Council of Governments to obtain this information.

The Biological Effects Program is funding a series of "regional review" documents. These documents will characterize air quality, describe past and ongoing biological effects research, identify sensitive air quality related values (AQRVs) and sensitivity thresholds, and make research recommendations. In addition to regional discussions, these documents will contain information specific to each of the NPS Class I areas. The contract for the first

document, for the 5 Pacific Northwest Region park units, was issued in May 1993, and the document should be finalized in June 1994. Because of the cost and time involved, we anticipate that it will take a number of years before all the documents are completed. In the meantime, AQD has developed an air quality survey to help identify park-specific AQRVs. We hope to complete these surveys, with regional and park assistance, in a shorter time frame.

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Appendix 1

Brief Review Statements of Reports, Research, and Monitoring Activities Provided to the SAGO Air Quality Biological Effects Research Review Panel by AQD

General

- Deborah Mangis, Jill Baron, and Kenneth Stolte, eds. 1991. Acid rain and air pollution in desert park units. Workshop Proceedings. (NPS, AQD).

Discusses effects research in desert park units.

- Charles Hutchinson, Gary Rydout, and Allan Matthias. 1984. An analysis of air pollution sources, transport, and concentrations in the vicinity of the Rincon Mountains District of the Saguaro National Monument, Arizona. Final report submitted to AQD.

Discusses ozone levels in SAGU as they relate to transport from Tucson area..

- Ernest Gladney, Roger Ferenbaugh, and Kenneth Stolte. 1991. An investigation of the impact of inorganic air pollutants at SAGU. Published in the SAGU 75th Anniversary Proceedings. (Gladney and Ferenbaugh, Los Alamos National Lab).

Summary of environmental data (soils and vegetation) related to the evaluation of inorganic air pollutant input to the monument. Elemental analysis of soils, cacti, lichens and tree ring cores. Lots of variability in soils. Several trace elements indicate anthropogenic input from dry deposition; but see no evidence of impacts on biological resources. Examined 4 cacti to date, increased manganese seems to correlate with browning. Have not yet analyzed tree rings or lichens.

- Kenneth Stolte. 1991. Air pollution threats to biological resources in Saguaro National Monument. Published in the SAGU 75th Anniversary Proceedings. (U.S. Forest Service, Research Triangle Park).

Discusses general air pollution impacts on plants and concerns in the monument.

Rincon Mountain District Trees

- Dan Duriscoe and Mona Selph. 1985. Geographic extent and severity of air pollution injury in SAGU (Rincon Unit). Final Report submitted to Air Quality Division. (Duriscoe, NPS, Sequoia and Kings Canyon national parks).

Established 23 plots of 15 trees each. Looked at ponderosa pine, Gambel oak, aspen, sycamore, and black walnut. Found slight ozone injury symptoms on oak and walnut. No injury on aspen or sycamore. Injury on pines greater at higher elevations. Techniques for studying injury on pines were changed during the course of the study.

- Dan Duriscoe and Mona Selph. 1985. Air pollution biomonitoring plots, Saguaro National Monument, Rincon Unit 1984 and 1985. A field guide. Submitted to AQD.

Describes techniques used to establish and evaluate pine plots.

- Dan Duriscoe. 1987. Evaluation of ozone injury to selected tree species in the Rincon Mountains of Arizona. Results of 1985 survey. Final report submitted to AQD.

Established 23 permanent plots. 117 out of 225 pine trees, or 52 percent, showed injury. Injury most severe in mountains near Tucson. No injury to hardwoods.

- Dan Duriscoe. 1990. Cruise survey of oxidant air pollution injury to Jeffrey and ponderosa pines in Saguaro National Monument, and Yosemite and Sequoia/Kings Canyon national parks. Results of 1986 field work. Final report submitted to AQD.

Evaluated 660 pines in 33 plots in SAGU. Fifteen percent of the trees showed some degree of visible ozone injury.

- Frank Telewski. In press. Ethylene production by different age class ponderosa and Jeffrey pine needles as related to ozone exposure and visible injury. Draft journal article. (Buffalo and Erie County Botanical Gardens, Buffalo, New York).

Data suggest that measurement of ethylene in conifer needles as a measure of stress needs to be calibrated for needle age class. Also suggests that ozone sensitivity may be regulated by ability of individual to produce ethylene.

- Donald Graybill and Martin Rose. 1988. Analysis of growth trends and variation in conifers from central Arizona. I. Network chronology development and analysis. Results of surveys in 1987 and 1988. Final report submitted to the Western Conifers Research Cooperative (study not funded by AQD). (Graybill, Laboratory of Tree-Ring Research, The University of Arizona).

Survey in 1987 showed 11 of 37 ponderosa pines had slight mottle that was attributed to ozone injury. Three showed substantial growth decline in recent decades. Survey in 1988 of 34 pines, 11 Douglas firs, 10 white firs, none showed air pollution injury. Ponderosa pine and Douglas fir, in general, showed decreased mean expected growth in recent decades while white pine and white fir showed expected growth.

- Donald Graybill. 1990. Analysis of growth trends and variation in conifers from Arizona and New Mexico: youthful trees, competition, and densitometric chronologies. inal report submitted to the Western Conifers Research Cooperative (study not funded by AQD).

Continuation and expansion of study directly above.

Cacti

- Patrick Temple. 1990. Effects of acidic precipitation on cryptogamic crusts, cacti seed germination and cacti seedling survival. Final report submitted to AQD. (University of California, Statewide Air Pollution Research Center).

Used treatments of pH 3.5, 4.5, 5.5, and 6.5 once a week for 6 to 8 weeks. No effects of pH on macroscopic appearance of crusts. No visible effect on seedlings or seedling germination. Theorized that desert soil buffers effects of short-term acidification.

- Dan Duriscoe and Sandra Graban. 1991. Epidermal browning and population dynamics of giant saguaros studied in permanent plots. Draft prepared for the SAGU 75th Anniversary Proceedings.

Established 45 permanent, 4-ha plots, 30 cacti per plot, throughout both units of park, to determine extent and severity of browning. Results showed browning widespread. Little geographic pattern found. Browning more severe on south side of cacti, and positively correlated with height. Negatively correlated with retention of spines.

- Dan Duriscoe and Sandra Graban. 1991. Epidermal browning and population structure of giant saguaro cactus *(Carnegiea gigantea)* in Saguaro National Monument, Arizona. Final report submitted to AQD.

See above.

- Lance Evans, Vincent Cantarella, and Kenneth Stolte. 1991. Phenological changes associated with epidermal browning of saguaro cacti at Saguaro National Monument, Arizona. Results of 1988-90 studies. Draft prepared for the SAGU 75th Anniversary Proceedings. (Evans, Manhattan College).

Examined 472 cacti, and took a 3- x 3- x 3-cm section from each one. Brown cacti had cuticular wax buildup and missing spines, axillary buds, and areoles. Brown cacti also had decreased stomatal density, decreased photosynthesis, and increased number of cells with few chloroplasts per cell. Study concluded that wax buildup hinders gas exchange followed by polyphenols being produced internally, resulting in browning.

- Lance Evans, Vincent Cantarella, Kenneth Stolte, and Keith Thompson. 1991. Epidermal browning of saguaro cacti *(Carnegiea gigantea).* Results of 1988-90 studies. Report submitted to AQD.

See directly above.

- Lance Evans, Kathleen Howard, and Keith Thompson. 1991. Epidermal browning of saguaro cacti *(Carnegiea gigantea):* is it new or related to direction? Results of 1990 studies. Report submitted to AQD.

Continuation of above.

- Kate Lajtha. 1991. Final Report. Ecophysiological, nutrient cycling and toxic element cycling studies to determine cause of decline of the saguaro cactus. Results of 1990 studies. Final report submitted to AQD. (Boston University).

Heavy metal concentrations in saguaro tissue were low. N concentrations were higher in healthy tissue than in brown tissue. South sides of cacti showed the highest physiological activity. Browning accompanied by decreased C uptake but not water loss. Author thinks that browning is not caused by UV-B. Browning appears to be more apparent on south sides because more physiologically active.

Crusts and Lichens

- Jayne Belnap. 1991. Characteristics of cyanobacterial-lichen soil crusts in long-term monitoring plots in Saguaro National Monument. Draft prepared for the SAGU 75th Anniversary Proceedings. (National Park Service, Canyonlands National Park).

No correlation between amount of soil crust present and saguaro browning. Did find a correlation between increased chlorophyll/phaeophytin ratios and nitrogenase activity and browning. Theorizes that browning due to non-nitrogenous acidic air pollution.

- Jayne Belnap. 1991. Effects of wet and dry pollutants on the physiology and elemental accumulation of cryptogamic crusts and selected rock lichens. Draft report.

Includes baseline data for SAGU.

- Clifford Wetmore. 1987. Lichens and air quality in Saguaro National Monument with chemical analysis of Chiricahua lichens. Final report submitted to AQD. (University of Minnesota).

Found some species known to be sensitive to sulfur dioxide (absent at annual average levels above 50 ug/m^3) present in monument. Most of these were found in the Rincon Mountain District. Elemental analysis showed no abnormal accumulation of any elements.

N Enrichment Study Plan

- Study of N enrichment on saguaros and desert annuals.

Hypotheses are that annuals are susceptible because of brief life cycle, and cacti more susceptible to freezing after fertilization.

This study was never carried out, but methods planned were as follows:

Saguaros: Establish 30 1- x 1-m plots with 20 saguaro seedlings per plot; located at the Baker Well site, 0.5 mile west of park headquarters. Use 5 N treatment levels, and repeat treatments annually for 5 years. Determine treatment levels based on ambient nitrogen dioxide levels. Fifteen plots will be under paloverde trees to determine effects of shading.

Annuals: Use seeds from three common annuals and common grasses. Set up 9 trays, each containing a mixture of annual and grass seed (using all possible combinations). Use 3 N treatments (0, low, and high). Measure biomass, height, and diversity.

Monitoring

- Air Quality Division. 1991. Saguaro National Monument 1989 gaseous pollutant and meteorological monitoring annual data summary. Air Quality Division Technical Report.

- Air Quality Division. 1991. Saguaro National Monument 1990 gaseous pollutant and meteorological monitoring annual data summary. Air Quality Division Technical Report.

- Air Quality Division. 1992. Detailed statistical analysis of Saguaro National Monument IMPROVE (fine particle monitoring) data.

- Saguaro National Monument. 1992. Wet deposition data from Saguaro National Monument.

- Saguaro National Monument. 1991 results from biomonitoring garden and *Rhus* field surveys.

- Mark Heuston. 1991. Ozone effects monitoring at Joshua Tree National Monument, an interim report.

Description of, and 1990 data from, biomonitoring garden at JOTR.

Current Research

- Kate Lajtha. 1991-1992 workplan. Awaiting final report from her 1991 research on saguaro physiology and elemental analysis.

- Lance Evans. 1991-1992 workplan. Awaiting final report from his 1991 research on saguaro epidermal browning and tissue injury, and also from his pilot project on the effects of UV-B on saguaro.

- Gaseous, meteorological, fine particle, and wet deposition monitoring will continue in 1992.

- The biomonitoring gardens at both SAGU and JOTR were maintained, and *Rhus* field surveys will continue, during the summer of 1992.

Appendix 2

Table 1. Summary of research projects at Saguaro National Monument (SAGU) provided to the SAGU Air Quality Biological Effects Research Review Panel by Ken Stolte.

Plant Group	Plants	Pollutants	Studies	PI
Conifers	Ponderosa pine Douglas fir Western white pine White fir Pinyon pine	O_3 Acid deposition	Plots Surveys Dendrochronology Chemistry	Duriscoe Duriscoe Graybill Gladney
Cacti	Saguaro Barrel	Toxic inorganics Acid deposition	Chemistry Histology Physiology Plots - Trend - Mortality - Ecological Fertilization (N)	Gladney Lajtha Evans Loik Lajtha Evans Duriscoe Resource Mgmt.
Shrubs	Rhus	O_3	Gardens	Resource Mgmt.
Annuals	Common species	NO_x O_3	Gardens	Resource Mgmt.
Lichens	All species	SO_2 Toxic inorganics	Flora Chemistry	Wetmore
Crusts	Main species	Toxic inorganics	Physiology	Belnap

Appendix 3

National Monument Air Quality Biological Effects Research Review Panel Members

Jayne Belnap Canyonlands National Park	Steve Veirs, Leader NPS Cooperative Park Studies Unit

The cover photograph was taken October 4, 1935, in Saguaro National Monument by the first National Park Service photographer, George Alexander Grant (1891-1964).

As the nation's principal conservation agency, the U.S. Department of the Interior has responsibility for most of our nationally owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting fish, wildlife and plants, preserving the environmental and cultural values of national parks and historic places, and providing for enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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