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EXPERT OPINION SURVEY ON THE IMPACTS OF AIR POLLUTANTS ON FORESTS OF THE USA

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ABSTRACT

A panel of experts was surveyed to obtain subjective estimates of the current impact of five air pollutants (SO_2, NO_x, O_3, H_2SO_4, and HNO_3) on growth, mortality, and leaf area of forests of the continental U.S. for later input to economic analysis. Results from the first two of three questionnaires are discussed. Estimates of impact were highly variable among panelists (CV's near 100%), but identify forest types at risk. Southern California conifers and high elevation spruce-fir were perceived most damaged with 10 and 12% median growth reductions. Southern pines, southern hardwoods, northern hardwoods and low elevation spruce-fir were equivalent with 5% reductions. Median impact for other western conifers was 0%. Ozone was perceived the most damaging pollutant in each of the seven forest types investigated, with damage by the two acidic pollutants likely limited to the high elevation spruce-fir. The amenity-related leaf area and mortality measures were less familiar and more volatile. Implications of pollutant interactions, temporal stability, and panel selection are also discussed.

INTRODUCTION

Fundamental understanding of the impact of air pollutants on forests can stem from direct experimental manipulations or from observation in uncontrolled field studies. The former provides strong evidence of causality at the sacrifice of realism, while uncontrolled field studies provide ultimate realism but limited inference of causality. Process models provide an explicit means for combining evidence from these contrasting methods, but development and especially validation of suitable models is a daunting task with definitive results likely years away. Scientific judgment provides an alternative method for producing estimates of forest damage suitable for planning and policy evaluation (de Steiguer, 1987).

Expert judgment has been used to estimate the combined impacts of long range transported pollutants on forests of Canada (Fraser *et al.* 1985) and to estimate ozone exposure response functions for several tree species of the U.S. It is also currently being used to estimate the impact of ozone on crops of British Columbia (Gordon Brown, personal communication, 1988).

Our study was designed to produce estimates of biological damage to American forests which would be suitable for economic evaluation. These estimates should reflect the diversity of scientific views on this complex issue, and should consider both market and nonmarket outputs of forests. Because the survey produces no new knowledge, it cannot replace fundamental research. However, surveys can improve the exchange of existing knowledge between natural scientists and economists and policy makers.

METHODS

Funding precluded face-to-face interview approaches, confining our survey to mailed questionnaires augmented by phone calls. To minimize misinterpretation of questions and encourage greater thought, the survey was structured as a series of three questionnaires delivered at three month intervals. The first questionnaire focussed on the response measures of greatest interest. The second questionnaire encouraged debate between respondents on specific conclusions from the first questionnaire and sought to broaden the range of forest conditions under consideration by panelists. The third questionnaire provided an opportunity for respondents to revise their initial response estimates in light of further consideration. Thus the first and third questionnaires were primarily quantitative, while the second elicited more qualitative answers.

Summaries of the results from the preceding questionnaire were provided to stimulate participation by panelists, to clarify questions, and to provoke greater consideration of the issues presented. To evaluate panel selection methods and clarify patterns of response, the first and third questionnaires also elicited information on panelist background and expertise.

The survey was designed to answer "what pollutants are causing what problems and in which forests." Forests of the continental United States were partitioned into 7 forest types or regions (Figure 1), representing pragmatic divisions based on pollution deposition patterns, forest biology, and economic values.

Five pollutants were identified for investigation: sulfur dioxide, nitrogen oxides, ozone, nitric acid, and sulfuric acid. Panelists were asked to estimate the impacts of individual pollutant assuming the other four pollutants had remained at pristine levels. Panelists were also asked to estimate the impact of all five pollutants acting together, termed "overall" in this paper.

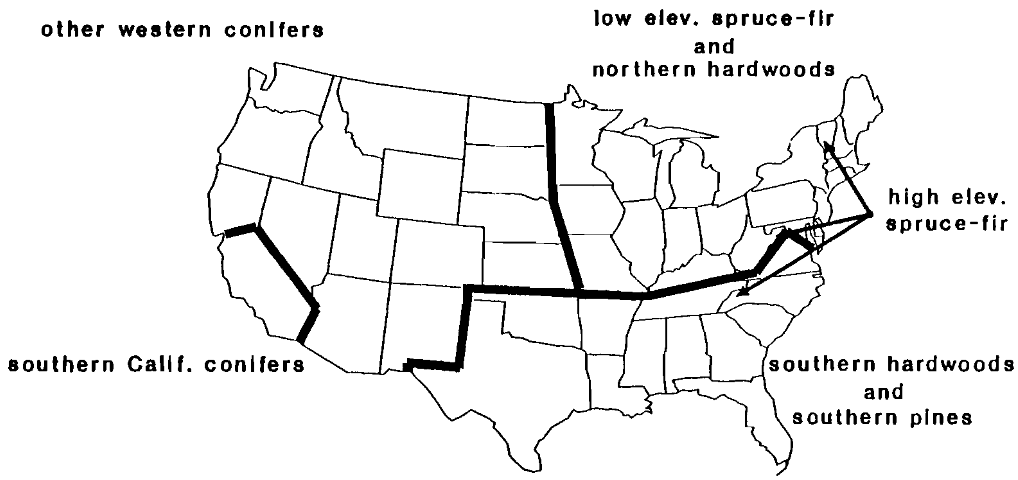

Figure 1 Definition of forest types used in the survey. High elevation refers to forests greater than 1000 m elevation.

Three response measures were selected as: a) plausibly affected by air pollutants, b) unambiguous to experts on the panel, and c) suitable for economic evaluation. These were growth, mortality, and leaf area. Growth and associated predictors has received the greatest attention in research, with clear relevance to timber markets. Mortality and leaf area were selected as potential indicators of impacts on recreation and other forest amenities.

Future impacts are arguably of greatest interest for planning purposes. However, we chose to focus initially on that period about which we know the most: the recent past. Panelists were asked to estimate impacts occurring over the past 5 years (termed "current"). Additional questions were posed to evaluate the dangers of applying these relationships into the future by asking panelists to estimate impacts under a hypothetical condition 20 years in the future. Impacts at that time were to be estimated assuming that air pollution levels remained at current levels throughout that 20 year period. We have termed this scenario "future," recognizing that pollution levels are projected to rise during much of this period (National Acid Precipitation Assessment Program, 1987).

For all response measures, panelists were asked to express their estimates relative to the conditions they anticipate would have occurred had pollutants always remained at pristine levels. This scale has been widely applied in other studies of air pollution impacts (Heck *et al.*, 1983; Pye, 1988) and is suitable for expressing both positive and negative impacts. Estimates appearing in this paper were transformed to express impacts as percent change from pristine. Thus negative numbers here refer to reductions and 0 indicates no change.

Panelists were selected based on two sets of criteria: scholarship and balance. Scholarship was judged by recent publication on air pollution impacts on trees or forests of the USA, with preference to those presenting original research. An initial list of candidates was drawn from our automated bibliography of 800 references on the subject. This list was augmented by review of presenters at relevant national symposia. Additional names were provided by 5 experts on air pollution impacts on forests. Author searches of BIOSIS, Agricola, and other electronic bibliographies were conducted as needed to crosscheck publication histories.

Because prioritization of pollutants and forest regions was a major objective of the survey, it was important that the panel include expertise in each of the forest types and pollutants involved. Because understanding of air pollution impacts requires input from a wide range of disciplines, the panel of 51 scientists eventually selected for participation included foresters, plant pathologists, mensurationists, soil scientists, and ecologists. Late respondents were telephoned to encourage participation and to answer questions on the survey itself. Most panelists were contacted by phone at least once. Second and third questionnaires were only mailed to those who returned the first questionnaire.

RESULTS

The survey is presently two thirds complete. The first and second questionnaires have been returned and partially analyzed. The third questionnaire was sent out in early July and questionnaires are still being returned and analyzed. The results reported here are limit-

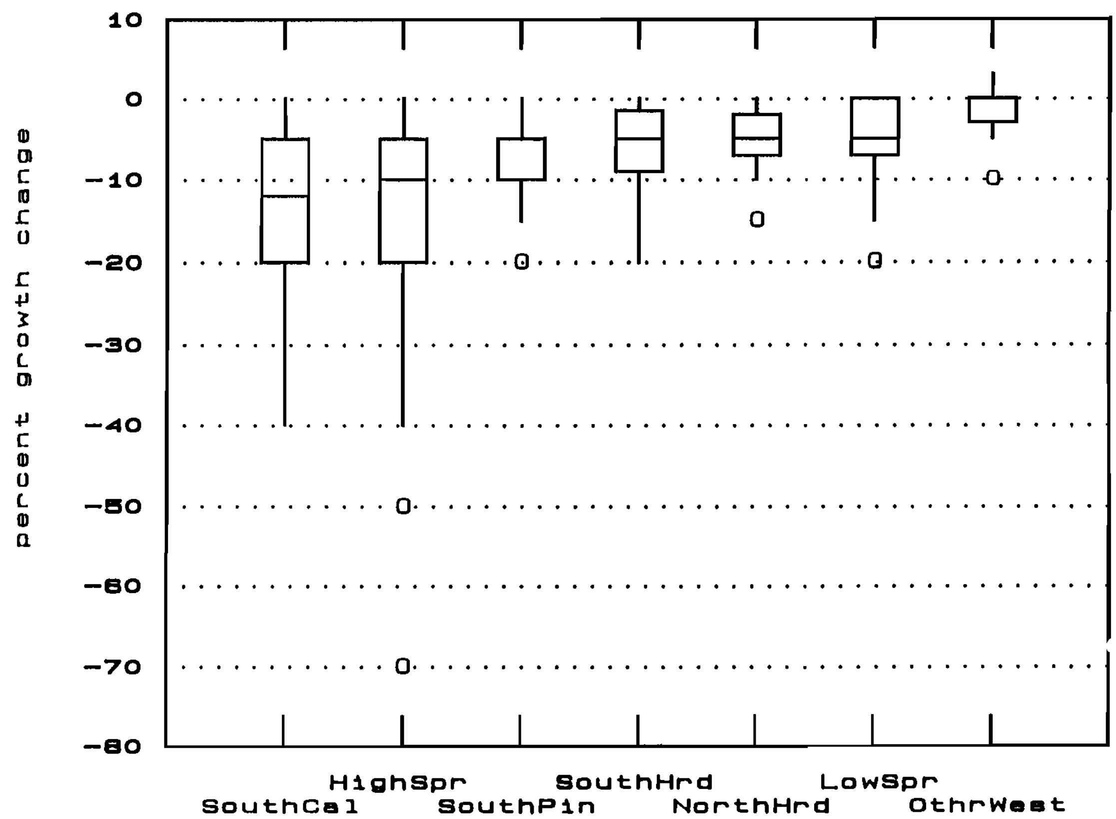

Figure 2 Medians, quartiles, and ranges of estimates of the overall impact of pollutants on the growth of forests of the U.S. Estimates are expressed as percent change from growth expected under pristine levels of pollutants.

ed to responses to the first two questionnaires.

The first questionnaire elicited 112 separate estimates of pollution impact. These explored overall pollution impacts for 7 forest types by three response measures by two "time" scenarios. For growth only, impacts of 5 pollutants acting individually were also explored for the two time scenarios. Forty one panelists completed and returned the first questionnaire. Because panelists were asked to only answer questions which they felt capable of answering, the response rate for specific questions ranged from 17 to 34.

The second questionnaire included 60 multiple choice questions, 7 short essays, and 5 fill in questions. The second questionnaire was only returned by 21 panelists of the initial 41, with specific questions answered by 13 to 21 panelists.

This paper cannot hope to present the complete results obtained thus far. Rather, it will focus initially on overall growth responses to pollutants, then discuss individual pollutant impacts on growth. Overall growth responses will then be compared with leaf area and mortality estimates, and results discussed in light of issues of panel composition.

The perceived growth impacts of all five air pollutants acting in combination are summarized in Figure 2. Because responses were often skewed, results are presented here as a box and whisker diagram. In this graph, the box indicates the range of the middle quartile of responses, while the lines and circles extending beyond the box indicate the full range of responses (circles are individual outliers). The horizontal bar in the middle of the box indicates the median response. For southern pine and other western conifer forests this median coincides with the upper (25th) percentile.

The most obvious characteristic in Figure 1 is the variability of estimates. Not surprisingly, panelists differed enormously in their perceptions of impact. For each forest type, coefficients of variation ranged from 66 to 160% (see de Steiguer and Pye, 1988). Note that our use of statistics must be primarily descriptive and should not be construed as relevant to hypothesis testing. The policy questions addressed offer no logical null hypothesis, nor does the panel represent in any fashion a "random" sample of experts. The variability in response does however demand considerable caution in presenting impacts as simple point estimates.

While estimates are quite varied, they do permit ranking of forest types at risk. Panelists were clearly most concerned about damage to the southern California and high elevation spruce-fir forest types, regions which suffer high levels of pollution and which have received the greatest study for pollution impact. Of least concern was the other western conifer forest type, where pollution levels are generally thought to be lower (National Acid Precipitation Assessment Program, 1987), and where less research has been conducted. The remaining four forest types were judged of intermediate damage, suffering roughly equivalent damage.

Panelists were also asked to estimate the impact of each individual pollutant, assuming that the other four pollutants had remained at pristine levels. Table 1 repeats the median overall impacts shown in Figure 2 and adds median estimates of the individual pollutant impacts. Space prohibits detailed presentation of variability. However, these estimates were also wide ranging, with coefficients of variation approximating the mean.

Table 1. Median estimates of growth changes in the past 5 years due to combined pollutants (overall) and pollutants acting individually. Estimates are expressed as the percent change from growth expected under pristine levels of pollutants.

forest	over-all	H_2SO_4	HNO_3	O_3	SO_2	NO_x
Southern Calif.	-12	0	0	-13.5	0	0
High elev. Spruce	-10	-5	-2.5	-5	0	0
Southern Pines	-5	0	0	-6.5	0	0
Southern Hardwoods	-5	0	0	-5	0	0
Northern Hardwoods	-5	0	0	-5	0	0
Low elev. Spruce	-5	0	0	-5	0	0
Other west. conifers	0	0	0	-1	0	0

As with forest types, while the panel was not able to reach a consensus on the magnitude of impact there was considerably more agreement on the relative ranking of pollutants. Ozone was perceived as the most damaging pollutant in each forest type. The second questionnaire confirmed this conclusion, where panelists were asked to agree or disagree with the statement "Ozone is presently the most damaging pollutant in all forest types of the continental U.S." Eighteen panelists agreed versus 3 who disagreed.

Panelists were uniformly less concerned about SO_2 or NO_x damage. Modest stimulation was indicated by many panelists, and median impacts were small. The statement "The gaseous pollutants SO_2 and NO_x are at present responsible for only minimal damage to most forests of the U.S." met with 19 agree's and 2 disagree's. Panelists indicated that injurious levels of these pollutants appeared confined to the vicinity of point sources.

The major components of acidic deposition, sulfuric and nitric acids, were of intermediate concern. As with SO_2 and NO_x, growth stimulation was perceived important by some panelists, although more so with nitric acid than sulfuric acid. Both were perceived most damaging to the high elevation spruce-fir forests. The second questionnaire suggests greater caution in this interpretation. The statement "Acidic deposition is at present only reducing growth in the high elevation spruce-fir forests" met with substantial disagreement among responding panelists (7 agree's versus 10 disagree's). Comments showed that disagreement stemmed from two sources. Some panelists objected to the implication that acidic deposition was responsible for any damage there, while others objected that damage may be more widespread.

Of course, co-occurring pollutants can exert an interactive effect, greatly complicating impact assessment. Although the survey could not directly investigate all pairwise interactions, the combination of individual and overall estimates does permit an implicit measure of pollutant interactions. We used a multiplicative model to indicate no interaction, calculated by multiplying the fractional growth indices for each of the pollutants in a forest type. For example, median estimates of growth impacts for high elevation spruce-fir were: sulfuric acid -5%, nitric acid -2.5, ozone -5, and SO_2 and NO_x 0. The null index was calculated as 100 less the product of .95, .975, .95, 1.00, and 1.00 (equals .88 or -12%).

The calculated null indices were quite close to the panel's overall estimates, with a small tendency toward antagonism. Calculated null indices for current growth were: southern California -13.5%, other western conifers -1, high elevation spruce-fir -12, low elevation spruce-fir -5, northern hardwoods -5, southern hardwoods -5, and southern pines -6.5. While the panel results suggest little overall interaction between pollutants, most panelists were unwilling to rule out their importance. Asked whether they agreed that "Pollutant interactions are not important on a regional basis under current levels of pollutants," only 9 out of 21 respondents agreed.

Estimates of leaf area effects showed similar patterns to those for growth (Table 2). Plots of individual estimates (not shown) revealed strong correlations between these two responses, but growth impacts exceeded leaf area impacts 72 to 19. When challenged in the second questionnaire with the statement "Leaf area changes due to air pollutants are likely to be of the same relative amount as changes in growth," panelists disagreed 12 to 4. Their comments revealed substantial disagreement on the direction of that disagreement however. Some panelists pointed out the minimal impact herbivory frequently has on growth. Others noted that pollutants often lower productivity per unit leaf area, implying greater impact on growth.

The mortality questions highlighted the importance of feedback and redundancy in questionnaires of this type. In the first questionnaire, panelists frequently provided answers indicating lowered mortality as a response to pollutants. In the 14 questions addressing mortality, lowered mortality was indicated 232 times versus only 27 indicating increased mortality.

These results were puzzling given the prominence of tree death in the decline literature. Conversations with panelists quickly showed widespread misunderstanding of the response measure and the scale employed. The summary document accompanying the second questionnaire discussed the implications of the different responses. In the second questionnaire, panelists agreed 13 to 1 with the statement "Air pollutants reduce the average lifespan of trees," and early returns of the third questionnaire indicate that changes in mortality questions far outnumber changes to other responses.

Table 2. Median estimates of overall percentage changes in growth, leaf area and mortality under current (curr) and future (futr) pollution scenarios.

	growth		leaf area		mortality	
	curr	futr	curr	futr	curr	futr
Southern Calif.	-12	-20	-10	-15	-5	-10
High elev. Spruce	-10	-15	-15	-20	-10	-15
Southern Pines	-5	-10	-6	-10	-2	-5
Southern Hardwoods	-5	-5	-5	-5	0	-2
Northern Hardwoods	-5	-10	-5	-5	0	-2.5
Low elev. Spruce	-5	-5	-5	-5	0	-2
Other west. conifers	0	-1.5	0	0	0	0

A single iteration survey would have left a mistaken impression of expert beliefs on this question. This type of misunderstanding occurred despite considerable attention to phrasing of questions by biologists familiar with the field and by a psychologist versed in survey design. All questions were additionally pretested by 5 representative experts not included in the main panel.

While the survey was primarily a retrospective evaluation, policy interests are more commonly prospective, i.e. concerned about future impacts. The "future" scenario investigated in the survey provides a measure of the likely stability of the relationships currently observed by scientists over the next 20 years. Because the scenario does not take into account changes in pollution levels likely to occur during that time, estimates should not be construed as realistic forecasts of damages yet to occur.

Panel responses indicated a pessimism among experts about future impacts of pollutants. Future impacts were generally perceived to be worse than impacts felt currently (Table 2) and was apparent for both acidic pollutants and for ozone. The second questionnaire asked panelists to respond to the statement "The ability of stands to tolerate current levels of air pollutants will likely diminish over the next 20 years." Eight panelists agreed versus 5 who disagreed (8 answered neither). Comments noted the importance of cumulative and delayed effects, particularly for soil mediated effects. Reduced future susceptibility through loss of susceptible genotypes was also noted as possible, particularly with gaseous pollutants.

The results shown here are based on the method of panel selection described in the methods section. The method emphasizes panel diversity and balance. Once selected, each panelist was permitted to answer any question asked, including those not in that individual's particular area of expertise. The survey includes two methods for revising final panel composition, approaches which improve the average level of expertise for individual questions but sacrifices balance and diversity. One approach makes use of each expert's subjective assessment of his or her areas of expertise to filter responses, while the second relies on assessment of expertise by ones peers. Although detailed analysis of the sensitivity of survey results to these selection processes is only beginning, a few results are available.

Panelists were asked at the beginning of the survey to rate their own expertise on each forest type and each pollutant, using a subjective scale of 0 to 10, with 10 indicating extreme familiarity. While this is not an unbiased estimator of expertise, it can be interpreted as an indicator of the panelist's confidence in each area. Panelists' ratings covered the entire range of the scale, but plots of overall growth impacts against familiarity with a given forest type revealed that those individuals expressing the greatest damage to growth mostly frequently indicated the highest familiarity with that forest type.

Whether panelists are "correct" about their knowledge is not known, but there are some indications that familiarity does not always coincide with perceived damage. Southern California was perceived in this survey to be one of the most damaged forest types. Nonetheless, this forest type was least familiar to panelists. Other western conifers was ranked next to least in familiarity, but was the system with the least perceived damage.

DISCUSSION

Questionnaires are still being received and much analysis remains to be done. However, some conclusions are possible. Did the survey produce the "right" answers? That one we cannot answer. Experts can accurately predict events in the real world if given adequate feedback on the accuracy of their predictions (Wallsten and Budescu, 1983), but such feedbacks are not available in this instance. Our appraisal must be more limited and consider the suitability and clarity of questions, the potential for bias in panel selection, the limitations of the survey design.

The questions asked represented a compromise between information available to biologists and other natural scientists, and information needed by economists for regional damage estimation. Although we believe the questions represented the minimum needed for conducting a national assessment, they obviously stretched scientific knowledge severely. Whether they will be useful to policy makers is not yet fully resolved, but early indications are encouraging.

Given the limitation of a mailed survey, the survey structure was reasonably successful. The cycle of elicitation, feedback, exploration and re-elicitation produced stable estimates, an indication of clarity. Although the estimates must be viewed with caution, they appear satisfactory for prioritization and for sensitivity analyses.

The low return rate on the second questionnaire was disappointing. While the questionnaire provided greater understanding of panelist responses, interchange of information between experts of diverse disciplines was limited. Focussed workshops and modeling efforts are more likely vehicles for such an interchange.

Three caveats should be noted. This survey reports the perceptions of air pollution researchers. We did not survey field foresters or general experts on forest growth, and would likely have received different answers had we done so. The closeness of panel members to air pollution may bias their results, whether for heuristic or strategic reasons. Second, the survey explored only three possible measures of forest response to stress. Impacts on foliar damage, tree species composition, or wildlife populations were not assessed despite their potential importance. Full evaluation of pollution control options must take into account the full range of effects air pollutants are likely to exert, whether they can be economically evaluated or not. For example, the two most damaged forest types in this survey are small suppliers of timber but are highly prized recreation sites. Economists will be challenged to evaluate such impacts, even with the estimates obtained in this survey. Third, the estimates of impact in this survey provide minimal information on uncertainty. Unlikely but catastrophic effects may be important but are slighted in this approach.

Continued funding of research will be required to improve our understanding of the stresses which air pollutants exert on our forests. Our survey shows that at present, informed scientists are of exceedingly diverse opinion on the amount of damage caused by these pollutants, particularly for those measures thought to be most useful for estimating effects on forest amenities. While quantitative estimates are varied, the survey does reveal substantial consensus regarding which American forest regions are at greatest risk to damage and the air pollutants most probably responsible for such damage.

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