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The Potential Impact of the Long Range Transport of Air Pollutants on Canadian Forests

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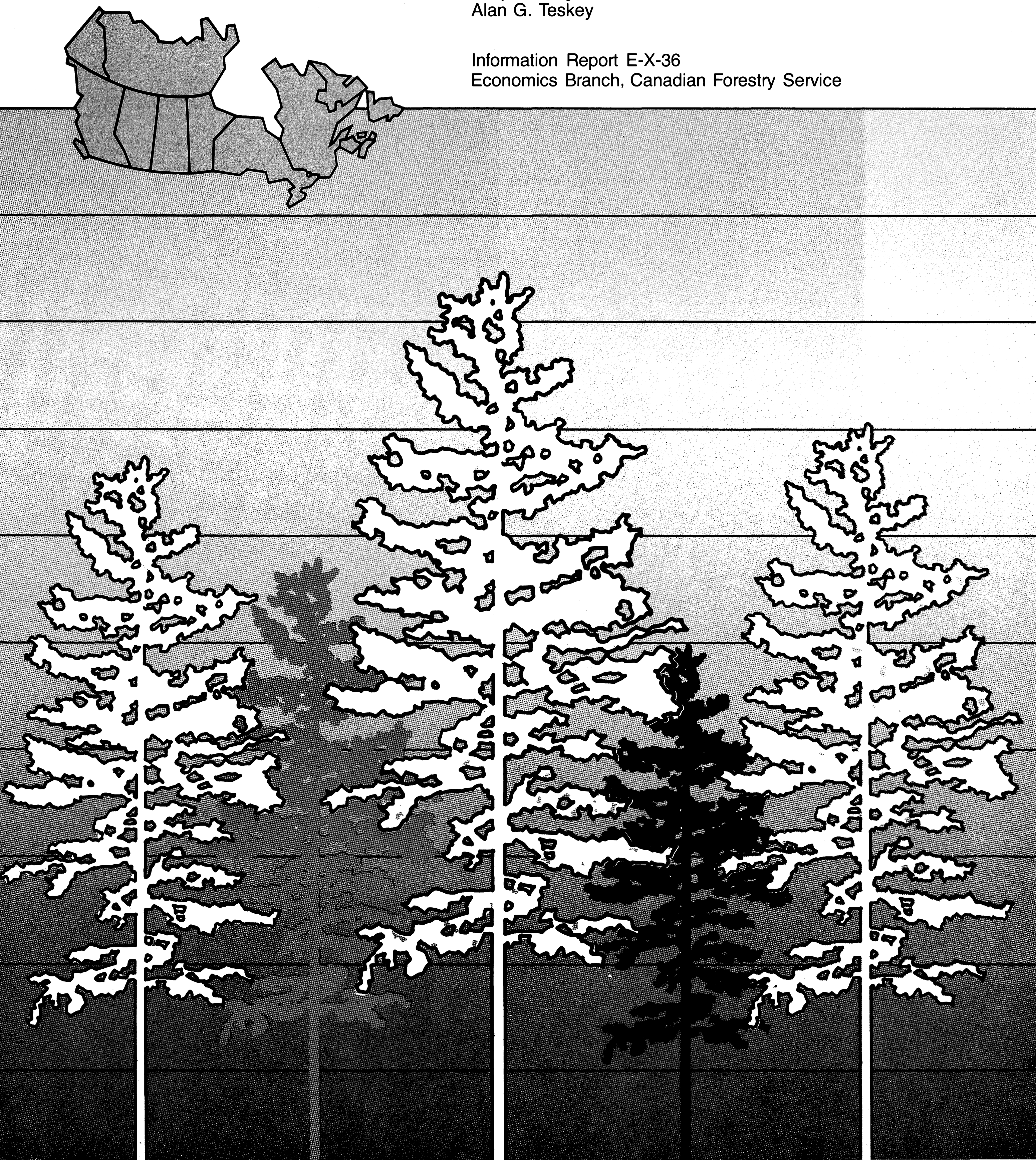
Information Report E-X-36
Economics Branch, Canadian Forestry Service



THE CANADIAN FORESTRY SERVICE
GOVERNMENT OF CANADA

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The Potential Impact of the Long Range Transport of Air Pollutants on Canadian Forests

Report of a Scientific Opinion Survey
Information Report E-X-36
Economics Branch
Canadian Forestry Service
by

G. Alex Fraser
William E. Phillips
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Canadian Forestry Service

University of Alberta

1985

Abstract

The effect of the long range transport of air pollutants (LRTAP) on forests is uncertain. A definitive scientific answer will require extensive scientific research over a period of years. In the interim, this study sheds considerable light on the potential effects. Using an iterative series of four questionnaires, expert opinion was solicited on the nature and extent of forest productivity change and the likelihood of alternative forest productivity effects under several different pollution scenarios. The results provide a realistic picture of the risk to Canadian forests from present and potential future levels of pollution.

Résumé

L'incidence sur les forêts canadiennes du transport à distance des polluants atmosphériques (TADPA) est incertaine. Pour obtenir une réponse scientifique définitive, il faudra faire des recherches intensives qui s'étendront sur plusieurs années. Dans l'intérim, cette étude jette une lumière appréciable sur ses répercussions potentielles. À l'aide d'une série de quatre questionnaires successifs, on a obtenu l'opinion des experts sur la nature et l'importance d'une altération éventuelle de la productivité forestière ou d'autres effets possibles du TADPA sur cette productivité, selon diverses hypothèses de pollution. Les résultats constituent une image réaliste du risque pour les forêts canadiennes que présentent les niveaux actuels ou futurs de pollution.

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Table of Contents

List of Tables in Text

List of Tables in Appendixes

Preface

This survey project was initiated by the Policy, Planning and Economics Directorate of the Canadian Forestry Service (CFS). The basic concept originated with Doug Ketcheson, the Director of Economics, who provided invaluable support throughout the survey process. An *implementation team* was responsible for setting overall policy on survey content, interpreting the results received, and preparing a final report. This team included Dr. Wayne Lamble and Dr. William Phillips of the University of Alberta (specialists in Delphi survey techniques and quantitative analysis) who were hired on contract to aid in the design, testing, implementation, and reporting of the survey. Also, Dr. Gary Hogan of the Canadian Forestry Service (Great Lakes Forest Research Centre) provided technical expertise in the area of air pollution/forest interactions. The last two members of the implementation team were G. Alex Fraser and Alan G. Teskey of Canadian Forestry Service (Economics Branch) who were responsible for the administration of the survey.

A *working group* of CFS Economics Branch employees provided day-to-day operations services. Russell Robinson provided computer programming and data input services. Diane Gratton provided translation services. Linda Maass and Karen Cheslock typed and formatted the questionnaires. Word processing and duplication of the final report was undertaken at the University of Alberta. Services in this regard were provided by Judy Warren and Jim Copeland of the Department of Rural Economy. Administrative services were provided by Reg Norby of the same department.

While all these individuals have made important contributions, the most significant contribution has been made by the respondents to the survey. In spite of extremely busy schedules and pressures of other commitments, all the respondents devoted considerable time and effort to the survey process. We hope the information gained is a suitable reward.

The nature and extent of forest productivity changes due to the Long Range Transport of Air Pollutants (LRTAP) are uncertain. Although circumstantial evidence from West Germany points to LRTAP as a primary causal factor of forest decline in that country, adequate information does not exist to prove this negative relationship. In North America, the evidence is even more tentative. The levels of pollutants are generally lower and the mixture of pollutants differs considerably from that in central Europe. Present and future levels of LRTAP in North America may or may not affect forest productivity. A definitive answer will require extensive scientific research over a period of years.

Unfortunately, there is a danger involved in awaiting the completion of scientific studies before making policy decisions regarding pollution control. If LRTAP causes serious irreversible damage to forests, then the evidence may come too late. Substantial social and environmental losses could be incurred by a failure to take action now. In the absence of conclusive evidence, the most appropriate alternative is informed judgment and opinion regarding the potential range of damages involved and the level of risk associated with inaction. The purpose of this study was to systematically solicit and aggregate informed opinions on these subjects. Specifically, a panel of 39 research scientists, selected through a peer nominating procedure, were surveyed using a set of carefully designed sequential questionnaires interspersed with summarized information and feedback of opinions. Each member of the panel was a recognized expert in one or more of atmospheric sciences, air pollutant/soil interactions, and air pollutant/vegetation interactions.

This survey panel provided opinions about the likelihood and magnitude of past and future changes in forest productivity in Canada due to LRTAP, and the processes by which these changes take place. Historical forest productivity change estimates were provided for the past decade and the past three decades. Future predictions of forest productivity change were provided for the next decade and the next three decades under three different pollution scenarios. These scenarios were increasing future pollution levels, constant future pollution levels, and decreasing future pollution levels. The results were broken down by four regions — Atlantic, Quebec/Ontario, Prairies/N.W.T. and British Columbia/Yukon.

A. Estimated Impact of LRTAP on Present Forest Productivity

The survey respondents were asked to rate the likelihood of an "increase", a "decrease", and "no change" in *present* forest productivity due to recent levels of LRTAP. Survey results indicate that "decrease" and "no change" outcomes are about equally likely in both the Quebec/Ontario and Atlantic regions, while an increase in forest productivity, due to pollution fertilization effects, is considered unlikely. In western Canada, "no change" in forest productivity is considered the most likely outcome. The respondents were asked to supplement their likelihood responses with judgments about the estimated magnitude of changes in forest productivity. Mean responses indicate estimated declines due to LRTAP in the Atlantic and Quebec/Ontario regions in the order of 3 and 5% respectively during the past decade, and 5 and 7% respectively during the past three decades. Estimates for western Canada indicated that no significant change in forest productivity has taken place during either period.

B. Estimated Impact of LRTAP on Future Forest Productivity with Increasing Pollution Levels

The respondents were asked to project future pollution levels in the absence of regulatory change. These responses provided the basis for the increased pollution scenario that was evaluated. Given increased future pollution, the survey results indicate a high likelihood of forest productivity "decline" in both the Atlantic and Quebec/Ontario regions over the next decade and beyond. Both "no change" and "increased" forest productivity outcomes were rated as unlikely. Mean responses on the estimated magnitude of change indicate forest productivity declines of between 8 and 11% in eastern Canada over the next three decades. In western Canada, even under this extreme scenario, "no change" in forest productivity was considered the most likely outcome. However, mean responses on the estimated magnitude of change indicate a statistically significant decline of about 2% throughout western Canada over the next three decades.

C. Estimated Impact of LRTAP on Future Forest Productivity with Constant or Declining Pollution Levels

Both alternative pollution scenarios assume some form of regulatory action on the part of government which limits future pollution level increases. In the case of the constant pollution scenario, survey results still indicate a high likelihod of forest productivity "decrease" in both the Atlantic and Quebec/Ontario regions over the next decade and beyond. As before, "no change" is considered the most likely outcome in western Canada. Mean responses on the estimated magnitude of change indicate substantial, although somewhat lower, percentage declines in forest productivity for the east while the projected declines for western Canada are very small but still statistically significant.

The final scenario that was evaluated assumes a 50% reduction in pollution levels over the next decade and that pollution will remain constant thereafter. In this case, survey results indicated that "no change" in forest productivity is the most likely outcome in all regions of the country. In the east, an "increase" in forest productivity is the next most likely outcome. Mean responses on the estimated magnitude of change indicate that no significant percentage change in forest productivity is expected in any region of the country.

* * * * *

Caution should be exercised in interpreting the results of the survey. It must be remembered that these results represent opinion and not proven fact regarding the present and future effects of LRTAP on Canadian forests. However, the participants in this survey were a select group of American and Canadian scientists who are considered to be among the most knowledgeable in this particular area of research. Consequently, their opinions accurately reflect the best informed judgment of the scientific community on the extent and likelihood of LRTAP impacts on forest productivity, given the limited information now available. As such, it is a realistic picture of the "risk" to Canadian forests from present and future levels of pollution. To place this risk in perspective, several key conclusions are emphasized:

a) Significant forest productivity declines may be already under way in both the Atlantic and Quebec/Ontario regions of the country.
b) In the absence of public policy measures to reduce future pollution level increases, forest productivity declines are expected to intensify in eastern Canada and to spread to western Canada.
c) If public policies on pollution control maintain pollution at present levels into the future, substantial productivity declines may still occur.
d) If public policies on pollution control reduce pollution levels by 50% over the next decade, no decline in future productivity is expected in any region of Canada.

A relationship between air pollution and forest damage has been recognized for many years. Since the 1940's, studies near point source polluters, such as smelters or thermal electric power plants, have indicated numerous adverse effects directly on vegetation, with resulting increased tree mortality and reduced growth rates for surviving stands.[1] Such studies, however, relate to high levels of pollutants impacting on relatively restricted areas close to a pollutant source. Much less is known about the effect of lower levels of pollutants spread over a much wider geographic area. Recent extensive, unexplained damage to many European forests (most notably in West Germany) has caused much concern.[2] Considerable effort has been devoted to clarifying the cause of this forest decline and, although the results are as yet inconclusive, circumstantial evidence points to air pollution as a primary causal factor.[3]

In the Canadian context, these European results may be of limited applicability. In North America, the levels of pollutants are generally lower and the mixture of pollutants differs considerably from that found in central Europe.[4] On the other hand, results from some Swedish and American studies are particular causes for concern. These studies of forests and environmental conditions, which more closely parallel the Canadian situation, indicate that loss of forest growth and the decline of some tree species may be pollution-related.[5]

Emphasis, however, must be given to the fact that the present state of knowledge is uncertain. Laboratory investigations have indicated that acidic deposition may have either beneficial, adverse, or undetectable effects on forests depending upon the particular species studied, the soil type, experimental conditions, and a variety of other considerations.[6] Similarly, field investigations that attempt to relate changes in tree growth to pollution levels have been inconclusive.[7] Adequate information simply does not exist to prove a relationship between the *long range transport of air pollutants* (LRTAP) and reductions in forest growth.[8] Considerable scientific research is necessary in order to determine the mechanisms through which pollutants act on forests and their impacts on forest productivity. To this end, extensive research programs are under way in a number of countries including the United States and Canada. Unfortunately, the complexity of the issues are such that satisfactory answers may require a period of many years.

It may be inappropriate to await conclusive evidence before taking public policy action to control future pollution. If LRTAP results in serious irreversible damage to forests, then the evidence may come too late. Substantial social and environmental losses would be incurred by a failure to take action now. While scientific research is not advanced enough to give definitive answers at the present time, considerable information does exist in the form of expert judgments and opinions. Although these opinions may vary because of different perspectives, the collective wisdom of research scientists can offer much to decision makers. Their knowledge can help to delineate the potential range of damages and the level of risk associated with inaction.

This study reports the results of a scientific opinion survey on the impacts of LRTAP on forests in Canada. The participants included both Canadian and American scientists, virtually all of whom are active researchers in the field of LRTAP and LRTAP/forest/soil interactions. The purpose of the survey was to systematically solicit and aggregate their informed opinions regarding potential effects on forests and potential processes at work within the forest ecosystem. The authors believe that the results accurately reflect the best informed judgments of the scientific community on the extent and likelihood of LRTAP impacts on forests given the information presently available. As such, it should prove useful to political decision makers in both the United States and Canada by giving them a realistic picture of the risk to forests from present and future levels of pollution. Also, it should prove useful to the scientific community itself by identifying areas where opinions vary widely and areas where a general consensus exists. This identification can aid in setting priorities for future research and in the design of specific research activities.

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[1] M. Katz (1939), *Effect of Sulphur Dioxide on Vegetation*, National Research Council No. 815, 477 pp.; S.N. Linzon (1958), *The Influence of Smelter Fumes on the Growth of White Pine in the Sudbury Region*, Joint publication, Ontario Department of Lands and Forests and Ontario Department of Mines, Toronto; E. Gorham and A.G. Gordon (1960), "Some Effects of Smelter Pollution Northeast of Falconbridge, Ontario," *Canadian Journal of Botany*, 38: 307-312.

[2] Anonymous (1983), *Summary Report on Forest Damage and Air Pollution*, Council of Environmental Advisors, Bonn, West Germany.

[3] K.E. Rehfuess, C. Bosch, and E. Pfannkuch (1982), "Nutrient Imbalances in Coniferous Stands in Southern Germany," *Proceedings of the International Workshop on Growth Disturbances in Forest Trees*, Jyuaskyla, Finland.

[4] R.L. Burgess (1984), *Effects of Acidic Deposition on Forest Ecosystems in the Northeastern United States: An Evaluation of Current Evidence*, ESF-84-016, State University of New York, Syracuse, N.Y.

[5] S.B. McLaughlin, T.J. Blasing, L.K. Mann, and D.N. Duvick (1983), "Effects of Acid Rain and Gaseous Pollutants on Forest Productivity: A Regional Scale Approach," *J.A.P.C.A.*, 33: 1042-1049.

[6] J.J. Lee and D.E. Weber (1979), "The Effect of Simulated Acid Rain on Seedling Emergence and Growth of Eleven Woody Species," *Forest Science*, 25: 393-398; L.S. Evans, G.R. Hendry, G.J. Stensland, D.W. Johnson, and A.J. Francis (1981), "Acidic Precipitation: Considerations for an Air Quality Standard," *Air, Water and Soil Pollution*, 16: 460-509.

[7] B. Jonsson and L.G. Svensson (1982), *A Study of the Effects of Air Pollution on Forest Yield*, A follow-up of the report of Jonsson and Sandberg, 1972, and a new study based on forest types, Audelningen for Skogsuppskattning och Skogsindelning Sveriges Lantbruksuniversitet, No. 9, 61 pp.; L.J. Puckett (1982), "Acid Rain Air Pollution and Tree Growth in Southeastern New York," *Journal of Environmental Quality*, 11: 376-381.

[8] I.K. Morrison (1984), "Acid Rain: A Review of Literature on Acid Deposition Effects in Forest Ecosystems," *Forestry Abstracts* 45: 483-506.

A. Survey Technique

In the survey the participants were to exercise their expert judgment to evaluate the present and potential future impacts of LRTAP on forests. Such judgments are contrasted to programmed or routine decisions based on a relatively complete state of knowledge and agreement concerning the nature and extent of a problem. Where these preconditions do not exist, better results can be obtained from pooling knowledge and increased individual awareness of, and reflection upon, the diversity of opinion. One structured procedure which has been developed to facilitate such judgmental decision making is the Delphi Technique.[9]

The Delphi Technique was developed by Dalkey and his associates at the Rand Corporation in the late 1950s. It is a set of carefully designed sequential questionnaires, interspersed with summarized information and feedback of opinions from earlier responses. The first questionnaire usually asks individuals to respond to a broad, general question designed to identify issues and relationships of interest. Subsequent questionnaires usually ask for review, clarification, and expression of opinion on previously collected and summarized information. The process stops when consensus has been approached, or sufficient information interchange has been attained to render further significant shifts in opinion unlikely. A minimum of three iterations is usually required. The specific design and implementation can be modified depending upon the nature of the problem being investigated. The only real constraint is the amount of human and physical resources available.

The Delphi Technique has gained considerable recognition and has been successfully applied to a number of problems. The original applications were in the area of forecasting where there were considerable uncertainty and differences of opinion regarding future trends. Since then it has had numerous business applications where there was uncertainty regarding the advisability of alternative corporate strategies. Also, it has been widely applied in social planning settings to establish priorities; to explore or expose underlying assumptions or information leading to different judgments; and to correlate informed judgments on topics spanning a wide range of disciplines.

Several inherent advantages of the technique made it particularly appropriate for the survey on LRTAP impacts on forest productivity in Canada. First, it was unnecessary to bring the respondents together in a face-to-face meeting. This was obviously convenient because the potential participants were spread over a wide geographic area. Second, the resulting anonymity was useful given the limited information available and the need for speculation. Selfconsciousness in a public setting could interfere with more creative thought processes. Third, the technique facilitated balanced participation by the full respondent group, and balanced attention to each idea generated. Again, in a more public setting individual personality styles, reputations, and seniority of position could be distracting; majority opinion could put considerable social pressure on individual judgments. Finally, the technique facilitated the use of mathematical quantification and rating procedures, which increases accuracy in aggregating individual judgments.

The technique does have some requirements which fortunately were not limiting factors in this particular case. For example, it did require a considerable amount of time to conduct. The full survey extended over a six-month period between September 1984 and February 1985 and required a considerable commitment of staff resources to develop and test questionnaires and to analyze results. The technique also required participant skill in written communication. Since the referent group consisted of research scientists, this requirement was not problematic. Finally, the participants required a high degree of motivation to commit the time and effort necessary to the process.

B. Survey Organization and Participant Selection Procedures

A team of experts was responsible for setting overall policy on survey content and interpretating the results received. This *implementation team* included two specialists in Delphi survey design and quantitative analysis, a scientist specializing in air pollution/forest research and two senior economists responsible for survey administration. The day-to-day operation of the survey was carried out by a *working group* of Canadian Forestry Service employees. This group was responsible for production and formatting of questionnaires in both official languages, delivery of questionnaires to the participants, contact by telephone with participants where necessary, computer programming, and general processing of numerical data received.

The first task involved participant selection. Given the purpose of the study, it was necessary to identify recognized scientific experts in the field of LRTAP and LRTAP/forest interactions in Canada. Inclusion of three general areas of scientific expertise were considered appropriate in the survey, namely:

1. atmospheric sciences (meteorology);
2. air pollutants and forest interactions; and
3. soils and forest interactions.

Several other general criteria were set for desirable participants in the survey:

1. individuals were to be personally active either in their own research in the area, or in managing other researchers directly involved in the area;
2. individuals were to have a broad knowledge of the scientific literature in the area; and
3. individuals were to have a detailed knowledge of the air pollution/forest situation in at least one Canadian region or another region closely related to Canadian conditions (e.g., northeastern U.S.).

Using these criteria as general guidelines, a peer nominating technique was used to identify individual participants. The process began with the scientific advisor to the implementation team nominating a group of well known and respected individuals who, in his opinion, met the stipulated criteria. Each of these individuals was then contacted, by telephone, by a member of the working group who explained the nature of the survey project, including the criteria for selecting respondents. The person contacted was then asked for nominations of individuals who they felt would be desirable participants in the survey. This ongoing referral process was continued through a series of approximately 60 telephone contacts. At the end of this process, lists of nominees were collated and multiple nominations were noted. More than 90 individuals were identified as having the relevant expertise, and 40 of these individuals received three or more nominations through the referral process. These 40 individuals were considered the core group for participation in the survey.

Each member of the core group was contacted by telephone and their participation in the survey was requested. During this contact, the obligations of the participants, the length of time the process would take, and the information that would be shared among participants was outlined. A heavy emphasis was placed on establishing, within the potential participants, the necessary motivation and interest in the study results by convincing them of the importance of the study and of their participation in it. A high degree of cooperation was received, with 34 of the core group of 40 agreeing to participate. The few refusals generally reflected lack of time or existence of other prior commitments. Analysis of the geographic spread and range of expertise among the group of confirmed participants was undertaken. As a result, five additional individuals were selected from the more than 50 remaining nominees and added to the group of confirmed participants. This final group of 39 individuals were the survey respondents (Appendix A).

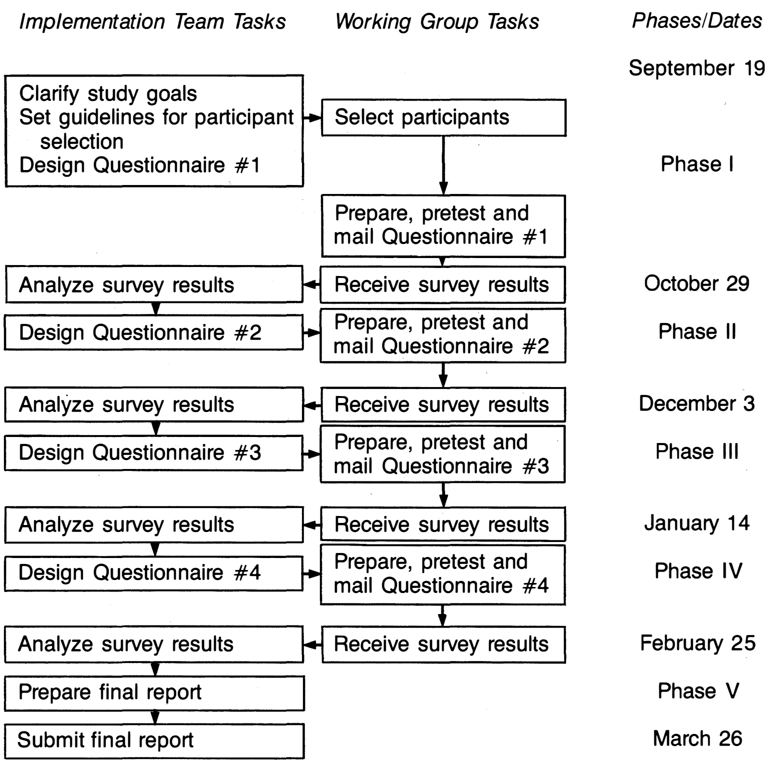
C. Survey Process

Figure 1 offers a schematic of the overall flow of the survey process. The survey was initiated by a meeting of the implementation team (see previous section) which clarified the study goals, set the overall guidelines for participant selection, and designed the first questionnaire. Following this meeting, the working group (see previous section) identified the respondent group and prepared and pretested the survey form. Questionnaire No. 1 was then sent to the respondents under a covering letter. A decision was made to use return courier services throughout the survey to avoid mail delays and ensure rapid turnaround time.

Question I was a preliminary question designed to identify the respondents' areas of geographic and technical expertise and their employers. The main body of Questionnaire No. 1 was divided into three sections. Question II focused on the present effect on forest productivity of the current levels of air pollution. Opinions were requested on the key pollutants that could be affecting present forest productivity, the nature of any forest productivity change, and the specific geographic regions where these productivity effects might be most significant. Questions

Figure 1

Project Flow Chart



III and IV were interrelated and both focused on the future. Question III requested opinion on future changes in the level of air pollution in Canada, the key air pollutants which were most likely to change, and the geographic regions where these changes were likely to be most significant. Question IV requested opinion on the likely impact of these future air pollution levels on forest productivity. Again, subcomponents of this question probed the identity of key pollutants, the nature of any productivity change, and the specific regions where such productivity change might be most significant.

In keeping with the Delphi survey technique, each question was framed in general terms and asked in a relatively open-ended manner. The respondents were encouraged to give written answers and to document reasons for their opinions. The primary objective in this round of the survey was to identify the full range of ideas and opinions in relation to LRTAP/forestry impacts.

After the responses to Questionnaire No. 1. were analyzed by the implementation team, the information was summarized and used to structure a series of focused statements covering the whole range of hypotheses generated regarding overall productivity impacts, and individual mechanisms which could affect forest productivity. Note was taken of the key pollutants identified and the geographic regions of interest. On this basis, Questionnaire No. 2 was designed, prepared, pretested, and distributed.

In contrast to the first round, the second-round questionnaire was more numerically oriented. Given identification of the full range of potential relationships between LRTAP and forest productivity, the intention now was to explore the strength of group opinion with regard to these relationships and to obtain a preliminary indication of possible quantitative impacts. All the respondents were asked to rate the likelihood of each potential effect, both now and in the future, on a five-point scale from "most likely" to "most unlikely". Other questions asked for opinions on the most likely percentage changes in both forest productivity and the level of key pollutants. Finally, one question asked the respondents to note the sensitivity of individual tree species on a five-point scale from "very sensitive" to "very insensitive".

The responses to Questionnaire No. 2 effectively represented a preliminary opinion of the respondent group regarding the likelihood and significance of the relationships identified. A key feature of the Delphi survey technique is reevaluation of individual opinion in light of new information generated. Consequently, in the third round of questioning (Questionnaire No. 3) the respondents were presented with summary statistics derived from responses to Questionnaire No. 2. In light of these preliminary results, the respondents were asked in Questionnaire No. 3 to rerate and requantify all appropriate items. In instances where their individual judgment differed markedly from the preliminary group results, they were asked to outline the reasons that underlay their opinions.

Also in Questionnaire No. 3, a series of new questions requested opinions on forest productivity effects under alternative pollution level scenarios. Prior to this stage in the survey, questions had focused on forest productivity impacts in the absence of regulatory change.

The responses to Questionnaire No. 3 represented closure of a substantial number of items. Opinions regarding the impact of current pollution levels on present forest productivity, species sensitivity to LRTAP, and potential future pollution levels in the absence of regulatory change were all accepted as final. The fourth-round questionnaire focused entirely on the future. Previous questions regarding the potential impact of alternative pollution scenarios were reiterated with summary statistics derived from previous results. The respondents were again asked to rerate and requantify all appropriate items in Questionnaire No. 4.

The responses to Questionnaire No. 4 represented closure on the remaining items in the study.

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[9]A.L. Delbecq, A.H. Van de Ven, and D.H. Gustafson (1975), *Group Techniques for Program Planning*. Glenview, Illinois: Scott, Foresman, and Company, pp. 83-107.

III. Survey Results

A. Respondent Characteristics and Response Rates

The 39 selected nominees (Appendix A) responded to Questionnaire No. 1. The majority of respondents are employed in government service (Table 1), which reflects heavy government involvement in air pollution research and monitoring programs. The next major employment group consisted of university researchers. Only 3 out of the 39 respondents were employed in the private sector (Table 1).

Table 1

Respondent Group by Employer Category[1]

Category	*Number of Respondents*
Government	24
University	14
Private sector	3

[1]Two respondents indicated both government and university as an employer. Consequently the total exceeds the total number of respondents.

The majority of the respondents were expert in the area of "soil" and/ or "air pollutant" interactions with forests. A substantial number of respondents indicated expertise in both areas. A smaller group indicated atmospheric sciences as their area of expertise (Table 2).

Table 2

Respondent Group by Professional Expertise[1]

Category	*Number of Respondents*
Soil and forest interactions	21
Air pollutant and forest interactions	25
Atmospheric sciences	8
Other	6

[1]Many respondents have expertise in more than one area. Consequently, the total exceeds the total number of respondents.

Geographic expertise existed among respondents for all regions of Canada. The majority of respondents indicated knowledge about a number of different regions. The largest number of respondents were knowledgeable about Ontario, with the next largest groups knowledgeable about Quebec and the Atlantic provinces (Table 3).

Table 3

Respondent Group by Geographic Expertise[1]

Geographic Area	*Number of Respondents*
Newfoundland	7
Maritimes	10
Quebec	14
Ontario	24
Prairies/Northwest Territories	9
British Columbia/Yukon	6
Other	12

[1]Many respondents indicated knowledge of more than one geographic region. Consequently, the total exceeds the total number of respondents.

As the survey proceeded through subsequent questionnaire rounds, the response rate dropped somewhat (Table 4). The reasons given were about equally distributed between two causes. First, a number of participants were simply unable to maintain the time commitment required to complete the questionnaires. Second, several respondents became uncomfortable with the degree of speculation required, particularly in the later rounds. In spite of these reactions, the overall participation rate stayed above 80% throughout the survey. This high response level was more than satisfactory given the intensive nature of the survey, and the extended period of time involved.

Table 4

Number of Respondents in Each Survey Round

Round	*Number of Respondents*
1	39
2	36
3	33
4	32

As anticipated, the response rates to individual questions in each of the four questionnaires varied somewhat and were lower than overall response rates for each round. As the survey progressed, questions became much more specific regarding potential effects, causes (or mechanisms), and geographic regions. Respondents were encouraged to leave unanswered those questions for which they had no informed judgment or opinion and to proceed to subsequent items. This approach was taken to discourage respondents from speculating in areas where they were unable to provide informed opinion. Response rates to individual questions ranged from a low of 14 to a high of 28. These rates are indicated in subsequent tables in the text and Appendix B of this report.

B. Delineation of the Issues and Factors

The first questionnaire was largely a collection of unfocused questions designed to facilitate open-ended responses. These responses were then used in the formation of the second questionnaire. In other words, the purpose of the first questionnaire was to generate opinion from the respondents on broad areas that could then be used to generate more specific questions in subsequent rounds. In this way, general responses about types and levels of pollutants and the nature of their effect on forest systems led to the development of a series of scenarios with regard to pollutant type, level, and region.

As expected, there was a general consensus that point-source pollutants can have considerable impact on forest systems, and numerous effects were cited in heavily impinged areas close to major polluters. There was a general consensus on the key pollutants which could have a significant impact on present and future forest productivity. However, considerable divergence of opinion was expressed with respect to future trends in air pollution levels and their impacts on both present and future forest productivity.

Sulphur dioxide (SO_2) was the most frequently identified air pollutant. Its phytotoxic nature in the gaseous state and its contribution to acid deposition were widely acknowledged. The toxicity of SO_2 to vegetation around major point sources was quoted by respondents, but they suggested that its role in acid-induced injury to forests was less well known. End products of SO_2 emission, SO_4 particulates, and wet and dry deposition, were acknowledged to be present on a wide scale throughout eastern Canada.

Oxides of nitrogen (NO*x*) were acknowledged as significant polluting agents in Canada but very litte mention was made of injury to vegetation caused by these compounds in the gaseous state. Respondents mentioned the role of nitrogen oxides as precursors of ozone and as components of acid deposition. Their distribution was indicated as being "potentially serious but uneven," i.e., close to major population centers. This places limitations on the probability of gaseous NO*x* interacting with vegetation except in the urban context. NO*x* appears to exert its major influence through ozone and acid deposition, but in nitrogen-limited forests it was acknowledged that this effect may not necessarily be harmful. Supplementary additions of nitrogen to these forests may actually produce an increase in productivity, at least in the short term.

Ozone was mentioned as a pollutant especially in areas downwind of urban plumes from major U.S. and Canadian cities. Frequent ozone damage to agricultural vegetation was cited as evidence from southern Ontario. The lack of a critical data base for ozone was mentioned, particularly as it relates to ozone in forest situations. Oxidants were considered to be an important factor, based on extrapolation from United States and German experiences or data.

The interrelationship of heavy metals with the other pollutants was consistently mentioned throughout the survey. Although little evidence of regional scale deposition was quoted, speculation on the involvement of metals in LRTAP was based on information obtained around point sources and in the northeastern United States.

With respect to potential future trends in air pollution levels and their regional distribution, many respondents emphasized the dependence on trends in industrial growth and technological change. In addition, public attitudes toward pollution control, government control legislation, and the future results of international negotiation were emphasized. Opinions varied widely on the end result of these various factors. Some participants emphasized the Canadian government's commitment to reduce SO_2 emissions and the heavy public pressure in both the United States and Canada for sulphur emissions control. Less optimism was expressed regarding future NO*x* emissions and ozone levels. Other participants emphasized the cost of controls and expressed uncertainty regarding public willingness to pay for placement of controls on the level of any pollutants.

With respect to potential productivity effects, responses fell into four categories:

1. increase in productivity;
2. decrease in productivity;
3. no net change in productivity; and
4. complete uncertainty regarding productivity impacts.

Predictions of an increase were based largely on the short-term observation that NO*x* levels would result in a nitrogen fertilization pulse to systems that are nitrogen-limited. However, this was linked to a realization that, in the longer term, these gains may be negated by losses due to accelerated leaching of cations.

Decreasing forest productivity was a potential scenario related to a number of physiological/chemical events which took place on an ecosystem level. This decline in forest growth was associated with declines observed in Europe and northeastern United States. Comments implied that it followed a similar general pattern and was due to a number of causes, including reduced germination and growth, accelerated leaching from soils and foliage, mobilization of toxic metals, increased susceptibility of trees to pathogens, and eventually significant reductions in leaf biomass resulting in loss of wood production. The similarities between some of the views expressed and those related to forest decline in Germany are certainly not coincidental. It is significant, however, that no specific comments were made relating site-specific forest decline in Canada to LRTAP deposition.

Another group of respondents were undecided about the impact of air pollutants (i.e., LRTAP) on forest productivity because the system was too variable, and forest type, site, and pollutant deposition cannot be generalized. It was emphasized that, in mixedwood forest situations, reduced productivity in species A might bring about increased productivity in species B and no net change in productivity of the whole system. This latter position was somewhat similar to the opinion that species replacement may occur. More tolerant species could perhaps occupy a new niche in response to the imposed pollutant stress and replace sensitive species in the regional forest. Other respondents simply felt that there had been no effect of LRTAP on forest productivity.

These responses to the first-round questionnaire provided the necessary focus for subsequent rounds of the survey. The type of questions that should be asked, and the areas that should be explored in more detail, became abundantly clear. Specifically, questions were required on (a) species sensitivity in relation to LRTAP, (b) future levels of the key pollutants identified, and (c) potential productivity changes and possible causes.

The following sections report the final aggregate responses to these more specific questions, and it is appropriate to caution the reader against misinterpretation. It should be emphasized that the aggregate or "mean" responses do not represent consensus views, but an average of the respondents' opinions. In the tables, appearing both in the text and in Appendix B, the diversity of opinion is reflected in the ranges of responses and the statistical standard deviations that are reported. (A higher standard deviation indicates that more diverse views were expressed.) At the same time, the reader should not dismiss the aggregate response as meaningless due to the range of opinions expressed. Where appropriate in the text, 95% confidence intervals around the means are reported and used to test for statistical significance.

C. Estimated Impact of LRTAP on Present Forest Productivity

1. Likelihood of Forest Productivity Changes from Recent Levels of LRTAP

Estimating the likelihood of recent forest productivity changes from LRTAP in various regions of Canada represents the first step in determining future impacts. To this end, respondents were asked to rate the likelihood of a decrease, no change, and an increase in forest productivity using a five-point likelihood scale. The mean likelihood scores are presented in Table 5 with further details given in Appendix B, Table B1.

The means scores for the Quebec/Ontario region indicate a higher likelihood of a "decrease" in forest productivity than "no change" (3.14 versus 2.50). The reverse holds for the Atlantic region in which the "no change" score is higher (2.69 versus 2.88). However, the mean scores in each region are not significantly different from one another at the 95% confidence level.[10] In effect, the likelihood of "no change" and a "decrease" in forest productivity are rated about equally. An increase in productivity for the two regions is rated as highly unlikely (1.42 for the Atlantic region and 1.61 for the Quebec/Ontario region). Both scores are significantly below the other scores for each region. In western Canada the mean scores indicate a very high likelihood of "no change" in forest productivity from recent levels of LRTAP. A "decrease" or an "increase" is very unlikely and significantly lower than "no change" scores for both the Prairies/N.W.T. region and the British Columbia/Yukon region.

2. Likelihood of Various Processes Causing Productivity Changes

The respondents had identified a number of possible mechanisms or processes by which recent LRTAP levels cause forest productivity changes. These processes were grouped by "decrease", "no change", or "increase" in forest productivity.

Table 5*

Mean Likelihood of Recent Levels of LRTAP Causing a Change in Present Forest Productivity

	Likelihood Scale: Most Likely 5 4 3 2 1 Most Unlikely		
Region	*Decrease*	*No Change*	*Increase*
Atlantic provinces	2.69	2.88	1.42
Quebec/Ontario	3.14	2.50	1.61
Prairies/N.W.T.	1.21	4.32	1.42
British Columbia/Yukon	1.25	4.29	1.42

Source: Appendix B, Table B1.

* Because of aggregation problems, readers should avoid assigning too much significance to the absolute scores. In certain instances, relative scores may be the more appropriate focus. For example, if scores for the three possible outcomes were 2.0, 2.0, and 2.0, it may be tempting to define all outcomes as unlikely. In such an event, it may be more approriate to view all outcomes as equally likely.

Table 6

Mean Likelihood of Various Processes Causing Present Forest Productivity Changes

Likelihood Scale: Most Likely 5 4 3 2 1 Most Unlikely

Process	*Atlantic*	- Region - *Que./Ont.*	*Prairies/N.W.T.*	*B.C./Yukon*
1. **Decrease** in forest productivity brought about by:				
a. Reduced germination and seedling growth;	2.21	2.31	1.00	1.04
b. Increased tree susceptibility to pathogens;	2.50	2.81	1.04	1.08
c. Accelerated nutrient leaching from soils and foliage;	3.08	3.33	1.29	1.38
d. Mobilization of toxic metals;	2.72	3.04	1.13	1.13
e. Reductions in leaf biomass and eventually wood production;	2.16	2.37	1.04	1.00
f. Loss of sensitive species (e.g., hemlock, white spruce, sugar maple);	1.91	2.20	1.00	1.04
g. Reduced timber quality (e.g., through pest invasion);	2.00	2.27	1.00	1.00
h. Increased susceptibility to drought and other climatic stress.	2.72	3.15	1.21	1.33
2. **No change** in forest productivity brought about by:				
a. Levels of pollutant too low to have an effect;	3.28	2.93	4.88	4.83
b. LTRAP in mixedwood situation leading to species productivity compensation[1];	2.13	1.92	1.74	1.70
c. Substitution of sensitive species by more tolerant species;	1.88	1.69	1.39	1.48
3. **Increase** in forest productivity brought about by:				
a. Sulphur fertilization;	1.42	1.46	1.68	1.82
b. Nitrogen fertilization;	2.08	2.44	1.82	1.91
c. Sulphur and nitrogen fertilization (interactive).	1.74	1.88	1.73	1.82

[1]Long range transport of air pollutants in a mixedwood situation causes decreased productivity in species A, which is compensated for by an increase in productivity of species B, leading to no net change.

Source: Appendix B, Table B1.

The respondents were then asked to indicate the likelihood of each process actually causing a change in current productivity. The mean scores of responses are contained in Table 6 with further details presented in Appendix B, Table B1.

In the Atlantic and Quebec/Ontario regions, where there is some likelihood of a productivity "decrease" currently under way, three causes emerge as moderately likely. They are, in descending order of mean scores, accelerated nutrient leaching from soils and foliage (3.08 and 3.33 respectively), increased susceptibility to drought and other climatic stress (2.72 and 3.15 respectively), and mobilization of toxic metals (2.72 and 3.04 respectively). Among the most unlikely causes, in ascending order of mean scores, are loss of sensitive species (1.91 and 2.20 respectively), reduced timber quality (2.00 and 2.27 respectively), reductions in leaf biomass and eventually wood production (2.16 and 2.37 respectively), and reduced germination and seedling growth (2.21 and 2.31 respectively). The Atlantic region scores are consistently lower than those for the Quebec/Ontario region. Since a productivity decrease is highly unlikely for western Canada, the causes are also highly unlikely as indicated by low scores of between 1.00 and 1.38 in Table 6.

In all regions of Canada under the hypothesis of "no change" in productivity, one likely reason emerges, namely that levels of pollutants are too low to have an effect. The likelihood is moderate for eastern Canada (3.28 for the Atlantic region and 2.93 for the Ontario/Quebec region) and is very high for western Canada (4.88 for the Prairies/N.W.T. region and 4.83 for British Columbia/Yukon region). The mean scores for the other two possible causes of no change in productivity in Table 6 are all significantly lower than those highlighted here. These other two causes are somewhat unlikely in contributing to no change in productivity in all regions.

An "increase" in forest productivity from recent levels of LRTAP is unlikely in all regions. Consequently, the possible causes are also unlikely. Sulphur, nitrogen, and sulphur/nitrogen fertilization likelihood scores range from 1.42 to 2.44 (Table 6).

3. Estimated Percent Changes in Forest Productivity in Recent Past

The respondents were asked to go a step further and supplement their likelihood responses with judgments about estimated magnitude of changes in forest productivity from LRTAP during the past decade (1974–1984) and past three decades (1954–1984). The responses have been aggregated and are presented in Table 7. These results, as expected, are quite consistent with the likelihood results on productivity change (Table 5). The response rates by region and time frame ranged between 17 and 20 respondents. The mean percent productivity changes are accompanied by standard deviations and ranges.

The respondents estimated a decline in forest productivity during the past decade (1974–1984) in both the Atlantic and Quebec/Ontario regions. Collective expert opinion indicates an average productivity decline of 3.45% for the Atlantic region and a 5.02% decline for the Quebec/Ontario region (Table 7). Confidence intervals at the 95% probability level are –5.04% to –1.86% for the Atlantic region and –7.42% to –2.62% for the Quebec/Ontario region.[11] Hence, there has been an estimated significant forest productivity decline due to LRTAP in both regions during 1974–1984. However, results for western Canada show no significant change in productivity over the same period. The mean percentages of +0.51 for the Prairies/N.W.T. region and –0.05 for the British Columbia/Yukon region are not significantly different from zero at the 95% level of confidence.

The results for the 1954–1984 period are similar to those just presented except that the estimated percent productivity declines for eastern Canada are more pronounced. The estimated percent decline in forest productivity in the Atlantic region is 4.51% for the three-decade period (95% confidence interval of –6.69% to –2.34%). The estimated decline for the Quebec/Ontario region is 6.73% (95% confidence interval of –10.34% to –3.12%) for the same period. A comparison of percentage for the two periods suggests that most of the 30-year decline in eastern Canada has taken place during the past 10 years. The results for western Canada show no significant change in forest productivity due to LRTAP during the past three decades. The mean percentages for the two western regions (0.59% and –0.05%) are not significantly different from zero.

The results in Table 7 provided an important base from which respondents estimated future productivity changes. More significantly, however, they strongly suggest that forest productivity declines in eastern Canada from LRTAP are already underway.

Table 7

Estimated Percent Change in Past Forest Productivity from LRTAP, 1974–1984 and 1954–1984

- During 1974–1984 -

Region	*Mean* (%)	*Std. Dev.* (%)	*Number of Respondents*	*Range* (%)
Atlantic provinces	–3.45	3.29	19	–10 to 0
Quebec/Ontario	–5.02	4.97	19	–20 to 0
Prairies/N.W.T.	+0.51	2.24	20	0 to +10
British Columbia/Yukon	–0.05	0.22	20	–1 to 0

- During 1954–1984 -

Region	*Mean* (%)	*Std. Dev.* (%)	*Number of Respondents*	*Range* (%)
Atlantic provinces	–4.51	4.23	17	–15 to 0
Quebec/Ontario	–6.73	7.26	18	–25 to 0
Prairies/N.W.T.	+0.59	2.29	19	0 to +10
British Columbia/Yukon	–0.05	0.52	19	–2 to +1

4. Estimated Sensitivity of Tree Species to LRTAP

Any forest productivity declines from LRTAP are likely to vary among forests of differing species, mixtures, and proportions. In order to get some insight into this variation, respondents were asked to rate the more important commercial tree species in terms of their sensitivity to LRTAP. The process also included an opportunity for respondents to add species to a preliminary species list provided by the implementation team. This endeavor is important for two reasons. First, it provides background to the respondents that may have put them in a better position to subsequently evaluate productivity changes brought about by mortality and/or growth reduction. Second, the species sensitivity information will facilitate an economic impact analysis that is scheduled to follow this project.

Respondents were asked to rate species according to their sensitivity to LRTAP using a 5-point scale, with 5 being very sensitive and 1 being very insensitive. The list of species was divided into hardwood and softwood groups (Table 8 and 9). Sensitivity scores (mean values), consensus scores (standard deviations), response rates (number of respondents), and ranges are indicated for both groups.

Among the softwood species, white pine and red spruce were rated as quite sensitive to LRTAP with scores of 4.00 and 3.85 respectively (Table 8). Both scores are significantly greater than the scale midpoint of 3.0 at the 95% confidence level. At the other extreme are the species which were rated as being insensitive: larch (1.85), blue spruce (2.08), western red cedar (2.08), yellow cedar (2.25), red pine (2.29), and to a lesser extent Douglas-fir (2.67). Each of these species have scores that are significantly less than 3.0 at the 95% level. The remaining species represent a middle group with scores that cluster around 3.0.

Among the hardwood species, silver maple (3.92), cottonwood (3.85), beech (3.79), and ash (3.69) were considered sensitive to LRTAP. The scores for these species were significantly greater than 3.0. In contrast, red oak (2.08) was rated insensitive to LRTAP. The remaining species represent a middle group with scores that clustered around the scale midpoint value.

D. Estimated Changes in the Future Levels of Key Pollutants by Region

In Questionnaire No. 1, respondents identified a variety of factors that may influence future trends in air pollutants. These factors included varied assumptions regarding future economic growth (and hence pollution levels), possible legislation and regulatory changes affecting emissions, and possible outcomes of international negotiations affecting LRTAP levels. To provide a common basis for subsequent questionnaire rounds, all respondents were asked to assume that there will be:

1. no substantive change in pollution control legislation in North America;
2. no successful international agreement limiting transboundary pollution; and
3. moderate population and economic growth in the future.

Respondents were then asked to provide an indication of the direction (plus or minus) and extent (percent) of changes in the levels of SO_2, SOx,

Table 8

Likely Sensitivity of Softwood Species to LRTAP

Sensitivity Scale: Very Sensitive 5 4 3 2 1 Very Insensitive

Species	*Mean*	*Standard Deviation*	*Number of Respondents*	*Range*
White pine	4.00	0.65	20	5 to 3
Red spruce	3.85	0.88	20	5 to 2
Balsam fir	3.24	0.56	17	4 to 2
Black spruce	3.17	0.86	18	5 to 2
White spruce	3.17	0.86	18	5 to 2
Eastern hemlock	2.80	0.41	15	3 to 2
Eastern white cedar	2.77	0.44	13	3 to 2
Jack pine	2.76	0.75	17	4 to 1
Lodgepole pine	2.67	0.62	15	3 to 1
Douglas fir	2.67	0.49	12	3 to 2
Red pine	2.29	0.69	17	4 to 1
Yellow cedar	2.25	0.62	12	4 to 2
Western red cedar	2.08	0.29	12	3 to 2
Blue spruce	2.08	0.86	13	4 to 1
Larch	1.85	1.21	13	5 to 1

Table 9

Likely Sensitivity of Hardwood Species to LRTAP

Sensitivity Scale: Very Sensitive 5 4 3 2 1 Very Insensitive

Species	*Mean*	*Standard Deviation*	*Number of Respondents*	*Range*
Silver maple	3.92	1.08	12	5 to 2
Cottonwood	3.85	1.34	13	5 to 1
Beech	3.79	0.70	14	5 to 2
Ash	3.69	0.75	13	5 to 3
Sugar maple	3.38	1.09	16	5 to 1
Balsam poplar	3.08	0.86	13	5 to 2
Aspen	2.94	0.68	16	4 to 1
White birch	2.93	0.59	15	4 to 2
Yellow birch	2.93	0.73	14	4 to 1
White oak	2.83	0.39	12	3 to 2
Red maple	2.69	0.63	13	3 to 1
Red oak	2.08	0.64	13	3 to 1

NOx, ozone, and heavy metals which were the key pollutants identified as potentially affecting forest productivity. Pollution level changes were requested for periods 1984–1994 and 1984–2014. This information, once aggregated, provided an important basis for respondents to provide subsequent estimated future forest productivity changes.

A summary of estimated changes in future pollutant levels is contained in Table 10 with further details contained in Appendix B, Table B2, B3, B4, and B5. All pollutants in all regions are expected to increase in the future. Furthermore, these estimated mean percent increases are significantly different from zero except for SO_2 in the Atlantic and Quebec/Ontario regions (1.80% and 2.88% increases respectively) during 1984–1994 only, and SO*x* in the Atlantic region (3.63% increase) during 1984–1994 only. Otherwise all pollution level mean predictions are significantly different from zero at the 95% confidence level in both the 1984–1994 and 1984–2014 periods.

During the next decade expected NO*x* and ozone level increases in eastern Canada are notable with values in the order of 10 to 11%. Estimated increases in western Canada for these two pollutants are lower and in the order of 5% for the Prairies/N.W.T. region and 7% for the British Columbia/Yukon region. Heavy metals are estimated to increase 3 to 4% by 1994 in all regions except the Quebec/Ontario region where a 6% increase is estimated. While SO_2 levels are not expected to increase significantly in eastern Canada during the next 10 years, increases of about 4% are estimated for western Canada. Levels of SO*x* are also expected to increase by about 4% in western Canada and over 5% in Quebec and Ontario.

During the next three decades pollutant level increases are expected to be quite pronounced. Levels of SO_2 are expected to increase by 11 to 12% and levels of SO*x* are expected to increase by 11 to 15% in all regions by 2014. Levels of NO*x* and ozone are expected to increase even more. These increases are in the order of 19% for the Atlantic region, 24 to 25% in the Quebec/Ontario region, 11 to 12% in the Prairies/N.W.T. region and 15% in the British Columbia/Yukon region. Heavy metals are expected to increase by 10 to 12% in all regions during the 30-year period.

There are two important points that should be kept in mind regarding these predictions. First, the predictions are based on the assumptions stated above. Second, there is considerable variation (lack of consensus) among respondents as to the direction and magnitude of change. While all respondents indicated nonnegative changes (i.e., zero or positive) in pollutant levels for all pollutants in all regions during the next three decades and for NO*x* and ozone in all regions during the next decade, some respondents did indicate expected decreases in SO_2, SO*x*, and heavy metals for eastern Canada during the next decade (Appendix B, Tables B2, B3, B4, and B5). Variation in magnitude of pollutant level changes is quite large in all cases. In fact, standard deviations tend to be the same order of magnitude as their respective means (Table 10). Some caution in interpreting these results is advised.

Table 10

Estimated Percent Change in Future Pollutant Levels, 1984–1994 and 1984–2014

	Atlantic		***Quebec/Ontario***		***Prairies/N.W.T.***		***British Columbia/ Yukon***	
Pollutant	*Mean*	*Std. Dev.*	*Mean*	*Std. Dev.*	*Mean*	*Std. Dev.*	*Mean*	*Std. Dev.*
- Percent Change by 1994 -								
SO_2	+ 1.80	7.71	+ 2.88	8.26	+3.89	3.07	+3.69	4.81
SO*x*	+ 3.63	6.47	+ 5.36	6.02	+4.10	3.23	+3.69	4.95
NO*x*	+ 9.79	8.92	+10.66	9.00	+5.23	4.59	+7.28	9.41
Ozone	+10.02	8.80	+11.32	8.78	+5.08	4.59	+7.43	9.32
Heavy metals	+ 3.99	5.69	+ 6.01	4.40	+4.06	3.13	+4.01	4.73
- Percent Change by 2014 -								
	Atlantic		***Quebec/Ontario***		***Prairies/N.W.T.***		***British Colombia/ Yukon***	
Pollutant	*Mean*	*Std. Dev.*	*Mean*	*Std. Dev.*	*Mean*	*Std. Dev.*	*Mean*	*Std. Dev.*
SO_2	+10.96	18.94	+12.16	18.34	+10.52	13.28	+11.28	18.81
SO*x*	+13.50	19.65	+14.97	18.93	+11.36	13.77	+11.83	19.44
NO*x*	+19.10	21.89	+24.59	34.78	+12.18	13.46	+15.46	23.32
Ozone	+19.12	21.86	+24.19	34.62	+11.22	13.27	+15.41	23.33
Heavy metals	+ 9.33	8.28	+12.42	9.41	+10.25	13.11	+10.16	14.08

Source: Appendix B, Tables B2, B3, B4, and B5.

E. Estimated Impact of Increased LRTAP on Future Forest Productivity

1. *Likelihood of Forest Productivity Changes*

Given the projected pollutant level changes outlined in Section D, the respondents were asked to indicate the likelihood of a decrease, no change, and an increase in future forest productivity using the five-point likelihood scale. Their responses were to be based on projected pollutant level changes, the assumption of moderate population and economic growth rates, and the assumption of an absence of future regulatory changes. Likelihood responses were provided by region for 1994 and 2014. The mean likelihood scores for future forest productivity changes are presented in Table 11 with further details in Appendix B, Table B6, B7, B8, and B9.

Mean likelihood scores indicate that a "decrease" in forest productivity is likely to occur in eastern Canada during the next decade (3.12 for the Atlantic region and 3.54 for the Quebec/Ontario region) and is still more likely during the next three decades (3.64 and 3.92 respectively). Decreases in western Canada are quite unlikely (scores between 1.38 and 1.80). The opposite result holds for "no change" in forest productivity. A "no change" result is unlikely for eastern Canada (scores between 1.70 and 1.88) but somewhat likely for western Canada (scores between 3.31 and 3.52). An "increase" in productivity is most unlikely anywhere in Canada (scores between 1.12 and 1.31).

2. *Likelihood of Various Processes Causing Productivity Changes*

The respondents had identified a number of possible mechanisms or processes by which LRTAP causes forest productivity changes (Table 6). These processes were grouped by "decrease", "no change", or "increase" in forest productivity. The respondents were asked to indicate the likelihood of each process actually causing a change in future forest productivity with increased pollutant levels by 1994 and by 2014. The mean scores of responses are contained in Table 12 and 13 with further details presented in Appendix B, Tables B6, B7, B8, and B9.

In the Atlantic region, where some likelihood of a "decrease" in forest productivity is indicated during the next decade, the one process likely to cause this decrease is accelerated nutrient leaching from soils and foliage (mean score of 3.35). All other possible processes

Table 11

Mean Likelihood of Increased Levels of LRTAP Causing a Change in Future Forest Productivity

Likelihood Scale: Most Likely 5 4 3 2 1 Most Unlikely

- By 1994[1] -

Region	*Decrease*	*No Change*	*Increase*
Atlantic	3.12	1.88	1.16
Quebec/Ontario	3.54	1.70	1.15
Prairies/N.W.T.	1.38	3.52	1.31
British Columbia/Yukon	1.48	3.42	1.28

- By 2014[1] -

Region	*Decrease*	*No Change*	*Increase*
Atlantic	3.64	1.85	1.12
Quebec/Ontario	3.92	1.63	1.12
Prairies/N.W.T.	1.65	3.44	1.27
British Columbia/Yukon	1.80	3.31	1.28

[1]Respondents were asked to assume the following: (1) no substantive change in pollution control legislation, (2) no successful international agreement limiting transboundary pollution, and (3) moderate economic and population growth in the future.

Source: Appendix B, Tables B6, B7, B8, and B9.

Table 12

Mean Likelihood of Various Processes Causing Future Forest Productivity Changes as a Result of Increased Levels of LRTAP by 1994

	Likelihood Scale: Most Likely 5 4 3 2 1 Most Unlikely			
	- Region -			
Process	*Atlantic*	*Que./Ont.*	*Prairies/N.W.T.*	*B.C./Yukon*
1. **Decrease** in forest productivity brought about by:				
a. Reduced germination and seedling growth;	2.35	2.50	1.22	1.33
b. Increased tree susceptibility to pathogens;	2.75	3.05	1.37	1.44
c. Accelerated nutrient leaching from soils and foliage;	3.35	3.64	1.63	1.56
d. Mobilization of toxic metals;	2.95	3.18	1.47	1.44
e. Reductions in leaf biomass and eventually wood production;	2.55	2.95	1.22	1.39
f. Loss of sensitive species (e.g., hemlock, white spruce, sugar maple);	2.15	2.45	1.18	1.22
g. Reduced timber quality (e.g., through pest invasion);	2.58	2.62	1.17	1.33
h. Increased susceptibility to drought and other climatic stress.	2.85	3.18	1.50	1.37
2. **No change** in forest productivity brought about by:				
a. Levels of pollutant too low to have an effect;	2.11	1.86	3.40	3.42
b. LTRAP in mixedwood situation leading to species productivity compensation[1];	1.89	1.86	1.63	1.61
c. Substitution of sensitive species by more tolerant species;	1.63	1.62	1.58	1.44
3. **Increase** in forest productivity brought about by:				
a. Sulphur fertilization;	1.37	1.38	1.63	1.28
b. Nitrogen fertilization;	1.58	1.62	1.63	1.50
c. Sulphur and nitrogen fertilization (interactive).	1.42	1.48	1.53	1.44

[1]Long range transport of air pollutants in a mixedwood situation causes decreased productivity in species A, which is compensated for by an increase in productivity of species B leading to no net change.

Source: Appendix B, Tables B6, B7, B8, and B9.

with mean scores below 3.0 are less likely to occur (Table 12). However, the number of processes that are likely to occur increase to four when the time period is expanded to three decades. The most likely causes of forest productivity decline are accelerated nutrient leaching from soils and foliage (3.74), mobilization of toxic metals (3.26), increased tree susceptibility to pathogens (3.16), and increased susceptibility to drought and other climatic stress (3.15) (Table 13). Processes contributing to "no change" or an "increase" in forest productivity are rated as quite unlikely because forest productivity is considered unlikely to remain constant or increase (Tables 11, 12, and 13).

In the Quebec/Ontario region where a future forest productivity "decrease" is considered quite likely, there are several probable causes: accelerated nutrient leaching from soils and foliage (3.64), increased susceptibility to drought and other

Table 13

Mean Likelihood of Various Processes Causing Future Forest Productivity Changes as a Result of Increased Levels of LRTAP by 2014

Likelihood Scale: Most Likely 5 4 3 2 1 Most Unlikely

	- Region -			
Process	*Atlantic*	*Que./Ont.*	*Prairies/N.W.T.*	*B.C./Yukon*
1. **Decrease** in forest productivity brought about by:				
a. Reduced germination and seedling growth;	2.58	2.62	1.39	1.50
b. Increased tree susceptibility to pathogens;	3.16	3.48	1.58	1.67
c. Accelerated nutrient leaching from soils and foliage;	3.74	4.05	1.84	1.78
d. Mobilization of toxic metals;	3.26	3.62	1.68	1.56
e. Reductions in leaf biomass and eventually wood production;	2.89	3.43	1.50	1.61
f. Loss of sensitive species (e.g., hemlock, white spruce, sugar maple);	2.58	2.81	1.41	1.39
g. Reduced timber quality (e.g., through pest invasion);	2.84	3.00	1.39	1.53
h. Increased susceptibility to drought and other climatic stress.	3.15	3.77	1.95	1.68
2. **No change** in forest productivity brought about by:				
a. Levels of pollutant too low to have an effect;	1.84	1.57	3.35	3.37
b. LTRAP in mixedwood situation leading to species productivity compensation[1];	1.89	1.86	1.68	1.67
c. Substitution of sensitive species by more tolerant species;	1.68	1.76	1.58	1.44
3. **Increase** in forest productivity brought about by:				
a. Sulphur fertilization;	1.42	1.38	1.68	1.28
b. Nitrogen fertilization;	1.68	1.76	1.68	1.56
c. Sulphur and nitrogen fertilization (interactive).	1.42	1.48	1.58	1.44

[1]Long range transport of air pollutants in a mixedwood situation causes decreased productivity in species A, which is compensated for by an increase in productivity of species B leading to no net change.

Source: Appendix B, Tables B6, B7, B8, and B9.

climatic stress (3.18), mobilization of toxic metals (3.18), and increased susceptibility to pathogens (3.05). During the next 30 years a forest productivity decrease is likely to be brought about by these same processes (mean scores of 4.05, 3.77, 3.62, and 3.48 respectively, Table 13), but with the addition of possible reductions in leaf biomass, and eventually wood production (3.43). "No change" or an "increase" in forest productivity is considered unlikely. Consequently, the possible associated processes are also unlikely (Tables 11, 12, and 13).

In western Canada some likelihood of "no change" in future forest productivity from LRTAP is indicated (Table 11). This result will probably be brought about by the fact that levels of pollutants are too low to have an effect. Likelihood scores for the Prairies/N.W.T. region and the British Columbia/Yukon region are 3.40 and 3.42 respectively by 1994 (Table 12) and 3.35 and 3.37 respectively by 2014 (Table 13). Other contributing processes are unlikely. Furthermore, processes associated with either a "decrease" or an "increase" in forest productivity are also unlikely in western Canada.

3. Estimated Percent Changes in Future Forest Productivity

The respondents were asked to supplement their likelihood responses with judgments about the magnitude of changes in future forest productivity from predicted LRTAP levels during the next decade (1984–1994) and the next three decades (1984–2014). The responses have been aggregated and are represented in Table 14. These results, as expected, are quite consistent with the likelihood results on future productivity changes with increased LRTAP levels (Tables 12 and 13). Estimated productivity changes in eastern Canada show notable declines whereas estimated productivity changes in western Canada, although showing declines, are much closer to zero (i.e., close to no change in productivity). Once again the respondents were asked to assume moderate population and economic growth and no regulatory changes regarding emissions.

In the Atlantic region LRTAP is expected to result in a 4.50% decline in forest productivity during the next decade (Table 14). The confidence interval of this mean value at 95% probability is between –5.53% and –3.47%. The decline during the next 30-year period (1984–2014) is expected to be 8.35% with a confidence interval between –10.34% and –6.36%.

Estimated productivity declines for the Quebec/Ontario region are more pronounced. The decline by 1994 is 7.41% with a confidence interval between –8.76% and –6.06%. By 2014 the decline is expected to reach 11.53% with a confidence interval between –14.02% and –9.04% (Table 14).

Forest productivity declines in the Prairies/N.W.T. region are expected. Although the decline by 1994 is quite low at 0.78%, it is, nevertheless, significantly different from zero. The confidence interval is between –1.31% and –0.25%. The decline by 2014 is expected to reach 1.63% with a confidence interval of between –2.62% and –0.64% (Table 14).

The British Columbia/Yukon forest productivity declines are similar to those of the Prairies/N.W.T. region. The expected decline by 1994 of 0.83% is significantly different from zero. The confidence interval is between –1.53% and –0.13%. By 2014 the forest productivity decline is expected to be 2.30% with a confidence interval of between –3.67% and –0.93%.

The results in Table 14 strongly suggest that unless efforts are made to reduce predicted increases in LRTAP levels, forest productivity declines can be expected in all regions of Canada. These declines will be particularly apparent in eastern Canada. These declines will also largely take the form of growth reduction (72% to 88%) with the balance taking the form of mortality

Table 14

Estimated Percent Change in Future Forest Productivity as a Result of Increased Levels of LRTAP, 1984–1994 and 1984–2014[1]

- By 1994 -

Region	*Mean* (%)	*Std. Dev.* (%)	*Number of Respondents*	*Range* (%)
Atlantic provinces	–4.50	2.32	22	–10.0 to 0.0
Quebec/Ontario	–7.41	3.26	25	–15.0 to 0.0
Prairies/N.W.T.	–0.78	1.25	24	–5.0 to 0.0
British Columbia/Yukon	–0.86	1.66	24	–7.5 to 1.0

- By 2014 -

Region	*Mean* (%)	*Std. Dev.* (%)	*Number of Respondents*	*Range* (%)
Atlantic provinces	–8.35	4.49	22	–20.0 to 0.0
Quebec/Ontario	–11.53	6.04	25	–30.0 to 0.0
Prairies/N.W.T.	–1.63	2.40	25	–10.0 to 0.0
British Columbia/Yukon	–2.30	3.32	25	–15.0 to 0.0

[1]Respondents were asked to assume the following: (1) no substantive change in pollution control legislation, (2) no successful international agreement limiting transboundary pollution, and (3) moderate economic and population growth in the future.

Table 15

Estimated Distribution of Future Decreases in Forest Productivity between Forest Mortality and Growth Reduction by 1994 and 2014

Region	*Year*	*Form of Decrease*	*Mean (%)*	*Std. Dev. (%)*	*No. Of Respondents*	*Range (%)*
Atlantic provinces	By 1994	Mortality	20.37	9.04	16	5 to 40
		Growth reduction	79.63	9.04	16	60 to 95
	By 2014	Mortality	26.06	9.77	16	5 to 40
		Growth reduction	73.94	9.77	16	60 to 95
Quebec/Ontario	By 1994	Mortality	23.56	8.15	18	10 to 40
		Growth reduction	76.44	8.15	18	60 to 90
	By 2014	Mortality	27.50	9.36	18	10 to 50
		Growth reduction	72.50	9.36	18	50 to 90
Prairies/N.W.T.	By 1994	Mortality	12.00	14.45	10	0 to 50
		Growth reduction	88.00	14.45	10	50 to 100
	By 2014	Mortality	14.80	13.14	10	5 to 50
		Growth reduction	85.20	13.14	10	50 to 95
British Columbia/ Yukon	By 1994	Mortality	14.40	13.10	10	5 to 50
		Growth reduction	85.60	13.10	10	50 to 95
	By 2014	Mortality	17.91	12.61	11	5 to 50
		Growth reduction	82.09	12.61	11	50 to 95

(28% to 12%). Respondents' collective judgments about the proportion of each form vary slightly among regions and between the next decade and the next three decades (Table 15).

F. Estimated Impact of Constant or Decreasing LRTAP on Future Forest Productivity

The preceding judgments on the likelihood and extent of future forest productivity changes (Table 11 and 14) represent collective expert opinions based on estimated increased future pollution levels (Table 10) in the absence of regulatory change. Although these results represent a useful and important "base" scenario, they may not accurately reflect the future. Canada is presently commited to a 50% domestic reduction in sulphur emissions. Furthermore, a memorandum of intent between Canada and the United States has been signed regarding control of transboundary pollution. Beyond these events, potential technological advances could increase pollution control. Given these possibilities, the survey sought expert opinion on future forest productivity changes under alternative future pollution scenarios.

Two alternatives were introduced into round three of the survey process. Respondents were asked to give opinions about (a) future forest productivity changes based on the assumption that present levels of pollution remain constant into the future, and (b) future forest productivity changes based on the assumption that present levels of pollution decline 50% by 1994 and remain constant thereafter. These alternatives can provide insight into the possible effectiveness of regulatory action.

1. Likelihood of Forest Productivity Changes with Constant LRTAP Levels

Respondents were asked to indicate the likelihood of a decrease, no change, and an increase in forest productivity based on constant future LRTAP levels using the five-point likelihood scale. Likelihood responses were provided for the years 1994 and 2014, and by region. The mean likelihood scores for future forest productivity changes are presented in Table 16 with further details given in Appendix B, Tables B10, B11, and B12.

Mean likelihood scores indicate that a "decrease" in forest productivity is likely to occur in eastern Canada during the next decade (3.08 for the Atlantic region and 3.29 for the Quebec/Ontario region) and is still more likely during the next three decades (3.54 and 3.61 respectively). These likely decreases emerge despite assumed constant pollution levels. Decreases in western Canada are quite unlikely (scores between 1.41 and 1.70). The opposite result holds for "no change" in forest productivity. A "no change" result is unlikely for eastern Canada (scores between 1.81 and 2.15) and somewhat likely for western Canada (scores between 3.46 and 3.69). An "increase" in productivity with constant pollution levels is most unlikely anywhere in Canada (scores between 1.11 and 1.31).

The results presented here are essentially the same as those under the increasing pollution scenario (Table 11). A comparison of corresponding means in Table 11 and 16 reveals no significant differences at the 5% significance level between corresponding pairs of means. This result suggests that further regulatory or other measures which prevent further pollution increases and maintain pollution at present levels will not prevent a decline in forest productivity in eastern Canada. Furthermore, a reduction in such declines may not be significant.

2. Estimated Percent Changes in Future Forest Productivity with Constant LRTAP Levels.

Respondents were asked once again to supplement their likelihood responses with judgments about the magnitude of future forest productivity changes. In this case they were asked to provide estimates of percent changes in future forest productivity based on constant future LRTAP levels during the next decade (1984–1994) and the next three decades (1984–2014). The responses have been aggregated and are presented in Table 17. These results, as expected, are consistent with the likelihood results on future productivity changes with constant LRTAP levels (Table 16). As in the case of increasing LRTAP levels (Table 14), estimated productivity changes with constant LRTAP levels in eastern Canada show declines whereas estimated productivity changes in western Canada, although showing declines, are quite close to zero (i.e., close to no change in productivity).

In the Atlantic region LRTAP is expected to result in a 3.19% decline in forest productivity during the next decade with constant pollution levels (Table 17). The confidence interval of this mean value at 95% probability is between –4.13% and –2.25%. The decline during the next 30-year period (1984–2014) is expected to be 6.09% with a confidence interval between –7.70% and –4.48%.

Estimated productivity declines with constant pollution levels for the Quebec/Ontario region are more pronounced. The decline by 1994 is 5.26% with a confidence interval between –6.56% and –3.96%. By 2014 the decline is expected to reach 8.73% with a confidence interval between –10.76% and –6.70% (Table 17).

Forest productivity declines with constant pollution levels in western Canada by 1994 are quite low. However, both mean percent decline figures, –0.47% for the Prairies/N.W.T. and –0.66% for the British Columbia/Yukon region, are significantly different from zero (confidence

Table 16

Mean Likelihood of Constant Levels of LRTAP Causing a Change in Future Forest Productivity

Likelihood Scale: Most Likely 5 4 3 2 1 Most Unlikely

- By 1994 -

Region	*Decrease*	*No Change*	*Increase*
Atlantic provinces	3.08	2.15	1.15
Quebec/Ontario	3.29	1.96	1.14
Prairies/N.W.T.	1.41	3.69	1.27
British Columbia/Yukon	1.48	3.62	1.31

- By 2014 -

Region	*Decrease*	*No Change*	*Increase*
Atlantic provinces	3.54	2.00	1.12
Quebec/Ontario	3.61	1.81	1.11
Prairies/N.W.T.	1.59	3.54	1.27
British Columbia/Yukon	1.70	3.46	1.27

Source: Appendix B, Tables B10, B11, and B12.

Table 17

Estimated Percent Change in Future Forest Productivity as a Result of Constant Levels of LRTAP, 1984–1994 and 1984–2014

- By 1994 -

Region	*Mean (%)*	*Std. Dev. (%)*	*Number of Respondents*	*Range (%)*
Atlantic provinces	–3.19	2.12	22	–7.5 to 0.0
Quebec/Ontario	–5.26	3.16	25	–10.0 to 0.0
Prairies/N.W.T.	–0.47	0.83	23	–2.5 to 0.0
British Columbia/Yukon	–0.66	1.26	23	–5.0 to 1.0

- By 2014 -

Region	*Mean (%)*	*Std. Dev. (%)*	*Number of Respondents*	*Range (%)*
Atlantic provinces	–6.09	3.65	22	–15.0 to 0.0
Quebec/Ontario	–8.73	4.91	25	–20.0 to 0.0
Prairies/N.W.T.	–0.93	1.37	23	–5.0 to 0.0
British Columbia/Yukon	–1.64	2.31	23	–10.0 to 0.0

intervals between –0.83% and –0.11% and between –1.20% and –0.12% respectively). Forest productivity changes in the two regions by 2014 are higher (–0.93% and –1.64% respectively). The confidence intervals are between –1.52% and –0.34% for the Prairies/N.W.T. region and between –2.64% and –0.64% for the British Columbia/Yukon region.

The results in Table 17 suggest that, if LRTAP levels do not increase but are held constant, forest productivity declines can still be expected in all regions of Canada. The declines will be particularly apparent in eastern Canada. Declines in western Canada with constant LRTAP levels will be near zero, but nevertheless significant, over both the 10-year and 30-year periods.

3. *Likelihood of Forest Productivity Changes with Decreasing LRTAP Levels*

Respondents were asked to reconsider the likelihood of a future forest productivity change based on the assumption that present levels of pollution will decline 50% by 1994 and remain constant thereafter. In particular, they were asked to indicate the likelihood of a decrease, no change, and increase in forest productivity using the five-point likelihood scale. Likelihood responses were provided for the years 1994 and 2014, and by region. The mean likelihood scores for future forest productivity changes are presented in Table 18 with further details given in Appendix B, Tables B13, B14, and B15.

If a decrease in LRTAP levels were to take place, the likelihood of a "decrease" in productivity anywhere in Canada would essentially disappear. The likelihood scores are between 1.23 and 1.93 among the regions and between the two periods of one and three decades, thus indicating that productivity decreases are most unlikely.

In western Canada, "no change" in productivity is quite likely by 1994 and 2014. The likelihood scores are between 3.60 and 3.64 (Table 18). At the same time an "increase" in future forest productivity in western Canada with a LRTAP level decrease is most unlikely over the same two periods. The likelihood scores are between 1.17 and 1.26.

In eastern Canada, opinions of respondents are divided between "no change" and an "increase" in forest productivity. The scores range between 2.04 and 2.50. These results are in marked contrast to likelihood results associated with increased or constant future levels of LRTAP, in which productivity "decreases" are quite likely (Tables 11 and 16).

Table 18

Mean Likelihood of Decreased Levels of LRTAP Causing a Change in Future Forest Productivity

Likelihood Scale: Most Likely 5 4 3 2 1 Most Unlikely

- By 1994[1] -

Region	*Decrease*	*No Change*	*Increase*
Atlantic provinces	1.77	2.42	2.04
Quebec/Ontario	1.93	2.43	2.14
Prairies/N.W.T.	1.23	3.60	1.26
British Columbia/Yukon	1.23	3.60	1.17

- By 2014[1] -

Region	*Decrease*	*No Change*	*Increase*
Atlantic provinces	1.62	2.50	2.27
Quebec/Ontario	1.75	2.39	2.43
Prairies/N.W.T.	1.27	3.64	1.26
British Columbia/Yukon	1.27	3.60	1.21

[1]Productivity changes are based on the assumption that pollution levels will be reduced by 50% from present levels by 1994 and that this reduced level will be maintained indefinitely thereafter.

Source: Appendix B, Tables B13, B14, and B15.

4. *Estimated Percent Changes in Future Forest Productivity with Decreasing LRTAP Levels.*

Respondents were asked to give their opinions about the magnitude of forest productivity changes based on the assumption that LRTAP levels will decrease 50% by 1994 and remain constant thereafter. They provided judgments about percent productivity changes for the next decade (1984–1994) and for the next three decades (1984–2014). The responses have been aggregated and are presented in Table 19. These results are consistent with the likelihood results in Table 18.

If LRTAP levels decrease 50% by 1994 and remain constant thereafter, little or no change in forest productivity is expected. The mean percentage changes range between –0.16% and +1.68% (Table 19). None of these values are significantly different from zero at the 5% level of significance. Consequently, current forest productivity levels in Canada are expected to remain unchanged if pollution levels are reduced in the manner described above.

Table 19

Estimated Percent Change in Future Forest Productivity as a Result of Decreased Levels of LRTAP, 1984–1994 and 1984–2014

- By 1994 -

Region	*Mean* (%)	*Std. Dev.* (%)	*Number of Respondents*	*Range* (%)
Atlantic provinces	+0.53	2.09	21	–2.5 to + 5.0
Quebec/Ontario	+0.48	3.89	22	–5.0 to + 7.0
Prairies/N.W.T.	–0.14	0.47	22	–2.0 to 0.0
British Columbia/Yukon	–0.11	0.62	22	–2.5 to 1.0

- By 2014[1] -

Region	*Mean* (%)	*Std. Dev.* (%)	*Number of Respondents*	*Range* (%)
Atlantic provinces	+1.20	3.57	21	–5.0 to +10.0
Quebec/Ontario	+1.68	4.97	22	–10.0 to +15.0
Prairies/N.W.T.	–0.16	0.68	22	–3.0 to + 0.5
British Columbia/Yukon	–0.07	1.24	22	–5.0 to + 2.0

[1]Productivity changes are based on the assumption that pollution levels will be reduced by 50% from present levels by 1994 and that this reduced level will be maintained indefinitely thereafter.

[10]A "t" test statistic is used in all cases. See Paul G. Hoel (1971), *Introduction to Mathematical Statistics*. John Wiley and Sons, New York, pp. 257-265.

[11]Calculated using the mean plus/minus the standard error (standard deviation divided by the square root of number of respondents) times the appropriate "t" test statistic at 95% probability.

IV. Summary and Conclusions

At the present time there is considerable uncertainty about the effects of the long range transport of air pollutants (LRTAP) on forest productivity in Canada. However, there is considerable current information available in the form of expert judgment and opinion. This collective wisdom can provide important insights into the risk to forests from present and future levels of pollution and the dangers of delaying public policy decisions on pollution control until conclusive evidence is forthcoming.

The purpose of the study reported herein was to systematically solicit and aggregate the informed opinions of scientific experts on LRTAP and forests using the Delphi technique. The process involved the conduct of an opinion survey using a set of carefully designed sequential questionnaires, interspersed with summarized information and feedback of opinions from earlier responses. Recipients of the four sequential questionnaires were identified using a peer nomination technique. A selection was made of 39 scientists with expertise in one or more of atmospheric sciences, air pollutants and forest interactions, and soils and forest interactions.

The survey respondents provided opinions about the likelihood of recent changes in forest productivity due to LRTAP as well as processes by which these changes took place. They provided opinions about the sensitivity of various commercial softwood and hardwood tree species. The respondents were then asked to predict future changes in air pollutants based on the assumptions of moderate population and economic growth and an absence of air pollution regulatory change. This information served as a basis for respondent judgments about future forest productivity changes given increased LRTAP levels and the likely processes and forms by which these changes would take place. Finally, respondents provided revised judgments based on the assumptions that future LRTAP levels would remain constant at present levels, and that present LRTAP levels would decline by 50% during the next decade and remain constant thereafter. Parallel with this, the respondents were asked to estimate the most likely percent change in forest productivity. Historical forest productivity change estimates were provided for the past decade and past three decades. Future forest productivity change predictions were provided for the next decade and next three decades. All the responses described here were provided for each of four regions: Atlantic, Quebec/Ontario, Prairies/N.W.T., and British Columbia/Yukon.

Highlights of aggregated survey results are presented in Table 20 by region and for various periods and scenarios. Mean percentage changes in productivity represent the relative magnitude of the estimated changes, and the signs of the values indicate the direction of change. Historically, estimated forest productivity declines due to LRTAP in the Atlantic and Quebec/Ontario regions have been in the order of 5% and 7% respectively during the past three decades and 3% and 5% respectively during the past decade. Estimates for western Canada indicate no significant change in forest productivity due to LRTAP during either period.

Under the three scenarios of increasing, constant, and decreasing future LRTAP levels, estimated forest productivity changes vary for each region. If LRTAP levels continue to increase into the future, productivity declines are estimated for all regions of the country. Declines in the Atlantic and Quebec/Ontario regions are expected to be in the order of 5% and 7% respectively during the next decade and 8% and 12% respectively during the next three decades. In the Prairies/N.W.T. and British Columbia/Yukon, estimated declines of less than 1% during the next decade are low but significant and estimated declines of 1% to 2% during the next three decades are also significant, albeit low (Table 20).

If steps are taken to ensure that present LRTAP levels remain constant in the future, instead of increasing, only very small declines in forest productivity are expected in western Canada. However, substantial productivity declines are still expected in eastern Canada although the magnitudes would be about two-thirds of the first scenario magnitudes. Declines in the Atlantic and Quebec/Ontario regions are projected to be in the order of 3% and 5% respectively during the next decade, and 6% and 9% respectively during the next three decades. Thus, simply maintaining future LRTAP at current levels would not eliminate forest productivity declines in Canada. However, if LRTAP levels are reduced by 50% over the next decade and remain constant thereafter, forest productivity declines in eastern Canada are not expected (Table 20). No significant change in productivity is expected in any region of Canada under this scenario.

Table 20

Estimated Percent Changes in Past and Future Forest Productivity as a Result of LRTAP Under Different Pollution Scenarios

- Mean Percent Forest Productivity Change -

Scenario	*Time Period*	*Atlantic*	*Quebec/Ontario*	*Prairies/N.W.T.*	*British Columbia/Yukon*
Historical estimate	1954-1984	–4.51*	–6.73*	+0.59	–0.05
Historical estimate	1974-1984	–3.45*	–5.02*	+0.51	–0.05
Increasing pollution levels	1984-1994	–4.50*	–7.41*	–0.78*	–0.86*
Increasing pollution levels	1984-2014	–8.35*	–11.53*	–1.63*	–2.30*
Constant pollution levels	1984-1994	–3.19*	–5.26*	–0.47*	–0.66*
Constant pollution levels	1984-2014	–6.09*	–8.73*	–0.93*	–1.64*
Decreasing pollution levels	1984-1994	+0.53	+0.48	–0.14	–0.11
Decreasing pollution levels	1984-2014	+1.20	+1.68	–0.16	–0.07

Sources: Tables 7, 14, 17, and 19.

*Significantly different from zero at 95% confidence.

It is the aggregate opinion of the survey panel of expert scientists that forest productivity has already declined because of LRTAP in eastern Canada. Furthermore, in the absence of measures to counteract continued pollution level increases, such declines are predicted to continue in eastern Canada and eventually spread to western Canada. About three-quarters of the decline would be in the form of reduced growth with the remainder attributable to tree mortality. Although the implications for forest industry employment and income remain subject to further investigation, the effects are potentially serious. Also, public policy measures that only eliminate future pollution level increases are insufficient to protect the forest resource. Under this scenario, significant forest productivity declines are still expected in all regions of the country. Only measures that result in a substantial 50% reduction in current pollution levels are expected to maintain forest productivity in all regions of Canada.

Appendix A

Participants

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Appendix B

Tables

Table B1

Likelihood of Recent Levels of LRTAP Causing a Change in Present Forest Productivity

Likelihood Scale: Most Likely 5 4 3 2 1 Most Unlikely

- Atlantic Provinces -

Item	*Mean*	*Std. Dev.*	*No. of Respondents*	*Range*
1. **Decrease*** in forest productivity brought about by:	2.69	0.97	26	5 to 1
a. Reduced germination and seedling growth;	2.21	1.06	24	5 to 1
b. Increased tree susceptibility to pathogens;	2.50	0.98	24	5 to 1
c. Accelerated nutrient leaching from soils and foliage;	3.08	1.00	25	5 to 1
d. Mobilization of toxic metals;	2.72	1.06	25	5 to 1
e. Reductions in leaf biomass and eventually wood production;	2.16	0.99	25	5 to 1
f. Loss of sensitive species (e.g., hemlock, white spruce, sugar maple);	1.91	1.08	23	5 to 1
g. Reduced timber quality (e.g., through pest invasion);	2.00	1.00	23	5 to 1
h. Increased susceptibility to drought and other climatic stress;	2.72	1.21	25	5 to 1
2. **No change** in forest productivity brought about by:	2.88	1.24	26	5 to 1
a. Levels of pollutant too low to have an effect;	3.28	1.24	25	5 to 1
b. LTRAP in mixedwood situation leading to species productivity compensation[1];	2.13	0.87	23	4 to 1
c. Substitution of sensitive species by more tolerant species.	1.88	0.80	24	3 to 1
3. **Increase** in forest productivity brought about by:	1.42	0.58	26	3 to 1
a. Sulphur fertilization;	1.42	0.58	24	3 to 1
b. Nitrogen fertilization;	2.08	0.83	24	3 to 1
c. Sulphur and nitrogen fertilization (interactive).	1.74	0.81	23	4 to 1

- Ontario/Quebec -

Item	*Mean*	*Std. Dev.*	*No. of Respondents*	*Range*
1. **Decrease*** in forest productivity brought about by:	3.14	0.89	28	5 to 1
a. Reduced germination and seedling growth;	2.31	1.12	26	5 to 1
b. Increased tree susceptibility to pathogens;	2.81	0.94	26	5 to 1
c. Accelerated nutrient leaching from soils and foliage;	3.33	1.04	27	5 to 1
d. Mobilization of toxic metals;	3.04	1.06	27	5 to 1
e. Reductions in leaf biomass and eventually wood production;	2.37	1.04	27	5 to 1
f. Loss of sensitive species (e.g., hemlock, white spruce, sugar maple);	2.20	1.26	25	5 to 1
g. Reduced timber quality (e.g., through pest invasion);	2.27	1.08	26	5 to 1
h. Increased susceptibility to drought and other climatic stress;	3.15	1.03	27	5 to 1
2. **No change** in forest productivity brought about by:	2.50	1.00	28	5 to 1
a. Levels of pollutant too low to have an effect;	3.93	1.17	27	5 to 1
b. LTRAP in mixedwood situation leading to species productivity compensation[1];	1.92	0.81	25	4 to 1
c. Substitution of sensitive species by more tolerant species.	1.69	0.74	26	3 to 1
3. **Increase** in forest productivity brought about by:	1.61	0.69	28	3 to 1
a. Sulphur fertilization;	1.46	0.58	26	3 to 1
b. Nitrogen fertilization;	2.44	0.97	27	4 to 1
c. Sulphur and nitrogen fertilization (interactive).	1.88	0.93	25	4 to 1

Table B1 Continued...

Table B1 Continued...

Likelihood Scale: Most Likely 5 4 3 2 1 Most Unlikely

- Prairies/N.W.T. -

Item	*Mean*	*Std. Dev.*	*No. of Respondents*	*Range*
1. **Decrease*** in forest productivity brought about by:	1.21	0.51	24	3 to 1
a. Reduced germination and seedling growth;	1.00	0.00	24	1 to 1
b. Increased tree susceptibility to pathogens;	1.04	0.20	24	2 to 1
c. Accelerated nutrient leaching from soils and foliage;	1.29	0.55	24	3 to 1
d. Mobilization of toxic metals;	1.13	0.34	24	2 to 1
e. Reductions in leaf biomass and eventually wood production;	1.04	0.20	24	2 to 1
f. Loss of sensitive species (e.g., hemlock, white spruce, sugar maple);	1.00	0.00	23	1 to 1
g. Reduced timber quality (e.g., through pest invasion);	1.00	0.00	24	1 to 1
h. Increased susceptibility to drought and other climatic stress;	1.21	0.59	24	3 to 1
2. **No change** in forest productivity brought about by:	4.32	1.35	25	5 to 1
a. Levels of pollutant too low to have an effect;	4.88	0.45	24	5 to 3
b. LTRAP in mixedwood situation leading to species productivity compensation[1];	1.74	1.14	23	5 to 1
c. Substitution of sensitive species by more tolerant species.	1.39	0.66	23	3 to 1
3. **Increase** in forest productivity brought about by:	1.42	0.83	24	4 to 1
a. Sulphur fertilization;	1.68	0.89	22	4 to 1
b. Nitrogen fertilization;	1.82	0.91	22	3 to 1
c. Sulphur and nitrogen fertilization (interactive).	1.73	0.88	22	4 to 1

- British Columbia/Yukon -

Item	*Mean*	*Std. Dev.*	*No. of Respondents*	*Range*
1. **Decrease*** in forest productivity brought about by:	1.25	0.53	24	3 to 1
a. Reduced germination and seedling growth;	1.04	0.20	24	2 to 1
b. Increased tree susceptibility to pathogens;	1.08	0.28	24	2 to 1
c. Accelerated nutrient leaching from soils and foliage;	1.38	0.58	24	3 to 1
d. Mobilization of toxic metals;	1.13	0.45	24	3 to 1
e. Reductions in leaf biomass and eventually wood production;	1.00	0.00	24	1 to 1
f. Loss of sensitive species (e.g., hemlock, white spruce, sugar maple);	1.04	0.21	23	2 to 1
g. Reduced timber quality (e.g., through pest invasion);	1.00	0.00	24	1 to 1
h. Increased susceptibility to drought and other climatic stress;	1.33	0.64	24	3 to 1
2. **No change** in forest productivity brought about by:	4.29	1.33	24	5 to 1
a. Levels of pollutant too low to have an effect;	4.83	0.49	23	5 to 3
b. LTRAP in mixedwood situation leading to species productivity compensation[1];	1.70	1.02	23	5 to 1
c. Substitution of sensitive species by more tolerant species.	1.48	0.67	23	3 to 1
3. **Increase** in forest productivity brought about by:	1.42	0.83	24	4 to 1
a. Sulphur fertilization;	1.82	1.05	22	5 to 1
b. Nitrogen fertilization;	1.91	0.87	22	3 to 1
c. Sulphur and nitrogen fertilization (interactive).	1.82	0.96	22	4 to 1

[1]Long range transport of air pollutants in a mixedwood situation causes decreased productivity in species A, which is compensated for by an increase in productivity of species B, leading to no net change.

*The initial row under each alternative outcome refers to the likelihood of a "decrease", "no change" or "increase" (see Table 11). Subsequent rows refer to specific causes.

Table B2

Estimated Percent Changes in Future Pollutant Levels for the Atlantic Region by 1994 and 2014

- By 1994 -

Pollutant	*Mean (%)*	*Std. Dev. (%)*	*Number of Respondents*	*Range (%)*
SO_2	+ 1.80	7.71	16	−15 to + 20
SO*x*	+ 3.63	6.47	14	−5 to + 20
NO*x*	+ 9.79	8.92	16	0 to + 40
O_3	+10.02	8.80	16	0 to + 40
Heavy metals	+ 3.99	5.69	15	−10 to + 15

- By 2014 -

Pollutant	*Mean (%)*	*Std. Dev. (%)*	*Number of Respondents*	*Range (%)*
SO_2	+10.96	18.94	17	0 to + 80
SO*x*	+13.50	19.65	15	0 to + 80
NO*x*	+19.10	21.89	17	0 to +100
O_3	+19.12	21.86	17	0 to +100
Heavy metals	+ 9.93	8.28	16	0 to + 25

Table B3

Estimated Percent Changes in Future Pollutant Levels for the Quebec/Ontario Region by 1994 and 2014

- By 1994 -

Pollutant	*Mean (%)*	*Std. Dev. (%)*	*Number of Respondents*	*Range (%)*
SO_2	+ 2.88	8.26	17	−20 to + 20
SO*x*	+ 5.36	6.02	15	−5 to + 20
NO*x*	+10.66	9.00	17	0 to + 40
O_3	+11.32	8.78	17	0 to + 40
Heavy metals	+ 6.01	4.40	15	0 to + 15

- By 2014 -

Pollutant	*Mean (%)*	*Std. Dev. (%)*	*Number of Respondents*	*Range (%)*
SO_2	+12.16	18.34	18	0 to + 80
SO*x*	+14.97	18.93	16	0 to + 80
NO*x*	+24.59	34.78	18	0 to +160
O_3	+24.19	34.62	18	0 to +160
Heavy metals	+12.42	9.41	17	0 to + 40

Table B4

Estimated Percent Changes in Future Pollutant Levels for the Prairies/N.W.T. Region by 1994 and 2014

- By 1994 -

Pollutant	*Mean (%)*	*Std. Dev. (%)*	*Number of Respondents*	*Range (%)*
SO_2	+ 3.89	3.07	17	0 to + 10
SO*x*	+ 4.10	3.23	16	0 to + 10
NO*x*	+ 5.23	4.59	17	0 to + 20
O_3	+ 5.08	4.59	17	0 to + 20
Heavy metals	+ 4.06	3.13	17	0 to + 10

- By 2014 -

Pollutant	*Mean (%)*	*Std. Dev. (%)*	*Number of Respondents*	*Range (%)*
SO_2	+10.52	13.28	18	0 to + 60
SO*x*	+11.36	13.77	17	0 to + 60
NO*x*	+12.18	13.46	18	0 to + 60
O_3	+11.22	13.27	18	0 to + 60
Heavy metals	+10.25	13.11	18	0 to + 60

Table B5

Estimated Percent Changes in Future Pollutant Levels for the British Columbia/Yukon Region by 1994 and 2014

- By 1994 -

Pollutant	*Mean (%)*	*Std. Dev. (%)*	*Number of Respondents*	*Range (%)*
SO_2	+ 3.69	4.81	16	0 to + 20
SO*x*	+ 3.69	4.95	15	0 to + 20
NO*x*	+ 7.28	9.41	16	0 to + 40
O_3	+ 7.43	9.32	16	0 to + 40
Heavy metals	+ 4.01	4.73	16	10 to + 20

- By 2014 -

Pollutant	*Mean (%)*	*Std. Dev. (%)*	*Number of Respondents*	*Range (%)*
SO_2	+11.28	18.81	16	0 to + 80
SO*x*	+11.83	19.44	15	0 to + 80
NO*x*	+15.46	23.32	16	0 to +100
O_3	+15.41	23.33	16	0 to +100
Heavy metals	+10.16	14.08	16	0 to + 60

Table B6

Likelihood of Increased Future Levels of LRTAP in the Absence of Regulatory Change Causing a Change in Forest Productivity in the Atlantic Region by 1994 and 2014[1]

Likelihood Scale: Most Likely 5 4 3 2 1 Most Unlikely

	- By 1994 -				- By 2014 -			
Item	*Mean*	*Std. Dev.*	*No. of Respondents*	*Range*	*Mean*	*Std. Dev.*	*No. of Respondents*	*Range*
1. **Decrease*** in forest productivity brought about by:	3.12	0.88	25	5 to 2	3.64	0.86	25	5 to 2
a. Reduced germination and seedling growth;	2.35	1.09	20	5 to 1	2.58	1.12	19	5 to 1
b. Increased tree susceptibility to pathogens;	2.75	0.91	20	5 to 1	3.16	1.07	19	5 to 1
c. Accelerated nutrient leaching from soils and foliage;	3.35	0.88	20	5 to 2	3.74	0.93	19	5 to 2
d. Mobilization of toxic metals;	2.95	1.00	20	5 to 1	3.26	1.10	19	5 to 1
e. Reductions in leaf biomass and eventually wood production;	2.55	1.15	20	5 to 1	2.89	1.24	19	5 to 1
f. Loss of sensitive species (e.g., hemlock, white spruce, sugar maple);	2.15	1.14	20	5 to 1	2.58	1.22	19	5 to 1
g. Reduced timber quality (e.g., through pest invasion);	2.58	1.02	19	5 to 1	2.84	1.07	19	5 to 1
h. Increased susceptibility to drought and other climatic stress;	2.85	0.99	20	5 to 1	3.15	1.04	20	5 to 1
2. **No change** in forest productivity brought about by:	1.88	0.91	26	5 to 1	1.85	0.88	26	5 to 1
a. Levels of pollutant too low to have an effect;	2.11	1.20	19	4 to 1	1.84	1.01	19	4 to 1
b. LTRAP in mixedwood situation leading to species productivity compensation[1];	1.89	0.88	19	4 to 1	1.89	0.88	19	4 to 1
c. Substitution of sensitive species by more tolerant species.	1.63	0.60	19	3 to 1	1.68	0.67	19	3 to 1
3. **Increase** in forest productivity brought about by:	1.16	0.47	25	3 to 1	1.12	0.44	25	3 to 1
a. Sulphur fertilization;	1.37	0.96	19	5 to 1	1.42	1.02	19	5 to 1
b. Nitrogen fertilization;	1.58	0.77	19	3 to 1	1.68	0.95	19	4 to 1
c. Sulphur and nitrogen fertilization (interactive).	1.42	0.61	19	3 to 1	1.42	0.61	19	3 to 1

[1]Respondents were asked to assume the following: (1) no substantive change in pollution control legislation, (2) no successful international agreement limiting transboundary pollution, and (3) moderate economic and population growth in the future.

[2]Long range transport of air pollutants in a mixedwood situation will cause decreased productivity in species A, which will be compensated for by an increase in productivity of species B leading to no net change.

*The initial row under each alternative outcome refers to the likelihood of a "decrease", "no change" or "increase" (see Table 11). Subsequent rows refer to specific causes.

Table B7

Likelihood of Increased Future Levels of LRTAP in the Absence of Regulatory Change Causing a Change in Forest Productivity in the Quebec/Ontario Region by 1994 and 2014[1]

Likelihood Scale: Most Likely 5 4 3 2 1 Most Unlikely

	- By 1994 -				- By 2014 -			
Item	*Mean*	*Std. Dev.*	*No. of Respondents*	*Range*	*Mean*	*Std. Dev.*	*No. of Respondents*	*Range*
1. **Decrease*** in forest productivity brought about by:	3.54	0.81	26	5 to 2	3.92	0.84	26	5 to 2
a. Reduced germination and seedling growth;	2.50	1.06	22	5 to 1	2.62	1.12	21	5 to 1
b. Increased tree susceptibility to pathogens;	3.05	1.00	22	5 to 1	3.48	1.12	21	5 to 1
c. Accelerated nutrient leaching from soils and foliage;	3.64	0.85	22	5 to 2	4.05	0.97	21	5 to 2
d. Mobilization of toxic metals;	3.18	0.96	22	5 to 1	3.62	1.12	21	5 to 1
e. Reductions in leaf biomass and eventually wood production;	2.95	1.13	22	5 to 1	3.43	1.29	21	5 to 1
f. Loss of sensitive species (e.g., hemlock, white spruce, sugar maple);	2.45	1.30	22	5 to 1	2.81	1.29	21	5 to 1
g. Reduced timber quality (e.g., through pest invasion);	2.62	1.02	21	5 to 1	3.00	1.18	21	5 to 1
h. Increased susceptibility to drought and other climatic stress;	3.18	1.05	22	5 to 1	3.77	1.02	22	5 to 1
2. **No change** in forest productivity brought about by:	1.70	0.91	27	5 to 1	1.63	0.93	27	5 to 1
a. Levels of pollutant too low to have an effect;	1.86	1.06	21	4 to 1	1.57	0.93	21	4 to 1
b. LTRAP in mixedwood situation leading to species productivity compensation[1];	1.86	0.85	21	4 to 1	1.86	0.85	21	4 to 1
c. Substitution of sensitive species by more tolerant species.	1.62	0.59	21	3 to 1	1.76	0.77	21	3 to 1
3. **Increase** in forest productivity brought about by:	1.15	0.46	26	3 to 1	1.12	0.43	26	3 to 1
a. Sulphur fertilization;	1.38	0.92	21	5 to 1	1.38	0.92	21	5 to 1
b. Nitrogen fertilization;	1.62	0.80	21	4 to 1	1.76	1.04	21	5 to 1
c. Sulphur and nitrogen fertilization (interactive).	1.48	0.68	21	3 to 1	1.48	0.68	21	3 to 1

[1]Respondents were asked to assume the following: (1) no substantive change in pollution control legislation, (2) no successful international agreement limiting transboundary pollution, and (3) moderate economic and population growth in the future.

[2]Long range transport of air pollutants in a mixedwood situation will cause decreased productivity in species A, which will be compensated for by an increase in productivity of species B leading to no net change.

*The initial row under each alternative outcome refers to the likelihood of a "decrease", "no change" or "increase" (see Table 11). Subsequent rows refer to specific causes.

Table B8

Likelihood of Increased Future Levels of LRTAP in the Absence of Regulatory Change Causing a Change in Forest Productivity in the Prairies/N.W.T. Region by 1994 and 2014[1]

Likelihood Scale: Most Likely 5 4 3 2 1 Most Unlikely

	- By 1994 -				- By 2014 -			
Item	*Mean*	*Std. Dev.*	*No. of Respondents*	*Range*	*Mean*	*Std. Dev.*	*No. of Respondents*	*Range*
1. **Decrease*** in forest productivity brought about by:	1.38	0.85	26	5 to 1	1.65	0.98	26	5 to 1
a. Reduced germination and seedling growth;	1.22	0.43	18	2 to 1	1.39	0.50	18	2 to 1
b. Increased tree susceptibility to pathogens;	1.37	0.60	19	3 to 1	1.58	0.69	19	3 to 1
c. Accelerated nutrient leaching from soils and foliage;	1.63	0.68	19	3 to 1	1.84	0.83	19	4 to 1
d. Mobilization of toxic metals;	1.47	0.51	19	2 to 1	1.68	0.67	19	3 to 1
e. Reductions in leaf biomass and eventually wood production;	1.22	0.43	18	2 to 1	1.50	0.51	18	2 to 1
f. Loss of sensitive species (e.g., hemlock, white spruce, sugar maple);	1.18	0.39	17	2 to 1	1.41	0.62	17	3 to 1
g. Reduced timber quality (e.g., through pest invasion);	1.17	0.38	18	2 to 1	1.39	0.61	18	3 to 1
h. Increased susceptibility to drought and other climatic stress;	1.50	0.69	20	3 to 1	1.95	1.10	20	5 to 1
2. **No change** in forest productivity brought about by:	3.52	1.40	27	5 to 1	3.44	1.37	27	5 to 1
a. Levels of pollutant too low to have an effect;	3.40	1.64	20	5 to 1	3.35	1.63	20	5 to 1
b. LTRAP in mixedwood situation leading to species productivity compensation[1];	1.63	0.96	19	4 to 1	1.68	0.95	19	4 to 1
c. Substitution of sensitive species by more tolerant species.	1.58	0.77	19	3 to 1	1.58	0.77	19	3 to 1
3. **Increase** in forest productivity brought about by:	1.31	0.79	26	4 to 1	1.27	0.67	26	3 to 1
a. Sulphur fertilization;	1.63	1.12	19	5 to 1	1.68	1.20	19	5 to 1
b. Nitrogen fertilization;	1.63	0.90	19	3 to 1	1.68	1.00	19	4 to 1
c. Sulphur and nitrogen fertilization (interactive).	1.53	0.84	19	3 to 1	1.58	0.96	19	4 to 1

[1]Respondents were asked to assume the following: (1) no substantive change in pollution control legislation, (2) no successful international agreement limiting transboundary pollution, and (3) moderate economic and population growth in the future.

[2]Long range transport of air pollutants in a mixedwood situation will cause decreased productivity in species A, which will be compensated for by an increase in productivity of species B leading to no net change.

*The initial row under each alternative outcome refers to the likelihood of a "decrease", "no change" or "increase" (see Table 11). Subsequent rows refer to specific causes.

Table B9

Likelihood of Increased Future Levels of LRTAP in the Absence of Regulatory Change Causing a Change in Forest Productivity in the British Columbia/Yukon Region by 1994 and 2014[1]

Likelihood Scale: Most Likely 5 4 3 2 1 Most Unlikely

	- By 1994 -				- By 2014 -			
Item	*Mean*	*Std. Dev.*	*No. of Respondents*	*Range*	*Mean*	*Std. Dev.*	*No. of Respondents*	*Range*
1. **Decrease*** in forest productivity brought about by:	1.48	0.92	25	5 to 1	1.80	0.96	25	5 to 1
a. Reduced germination and seedling growth;	1.33	0.49	18	2 to 1	1.50	0.62	18	3 to 1
b. Increased tree susceptibility to pathogens;	1.44	0.62	18	3 to 1	1.67	0.84	18	3 to 1
c. Accelerated nutrient leaching from soils and foliage;	1.56	0.70	18	3 to 1	1.78	0.88	18	4 to 1
d. Mobilization of toxic metals;	1.44	0.62	18	3 to 1	1.56	0.86	18	4 to 1
e. Reductions in leaf biomass and eventually wood production;	1.39	0.61	18	3 to 1	1.61	0.78	18	4 to 1
f. Loss of sensitive species (e.g., hemlock, white spruce, sugar maple);	1.22	0.43	18	2 to 1	1.39	0.50	18	2 to 1
g. Reduced timber quality (e.g., through pest invasion);	1.33	0.49	18	2 to 1	1.53	0.61	19	3 to 1
h. Increased susceptibility to drought and other climatic stress;	1.37	0.50	19	2 to 1	1.68	0.67	19	3 to 1
2. **No change** in forest productivity brought about by:	3.42	1.39	26	5 to 1	3.31	1.38	26	5 to 1
a. Levels of pollutant too low to have an effect;	3.42	1.64	19	5 to 1	3.37	1.64	19	5 to 1
b. LTRAP in mixedwood situation leading to species productivity compensation[1];	1.61	1.04	18	5 to 1	1.67	1.08	18	5 to 1
c. Substitution of sensitive species by more tolerant species.	1.44	0.70	18	3 to 1	1.44	0.70	18	3 to 1
3. **Increase** in forest productivity brought about by:	1.28	0.74	25	4 to 1	1.28	0.61	25	3 to 1
a. Sulphur fertilization;	1.28	0.57	18	3 to 1	1.28	0.57	18	3 to 1
b. Nitrogen fertilization;	1.50	0.86	18	3 to 1	1.56	0.86	18	3 to 1
c. Sulphur and nitrogen fertilization (interactive).	1.44	0.78	18	3 to 1	1.44	0.78	18	3 to 1

[1]Respondents were asked to assume the following: (1) no substantive change in pollution control legislation, (2) no successful international agreement limiting transboundary pollution, and (3) moderate economic and population growth in the future.

[2]Long range transport of air pollutants in a mixedwood situation will cause decreased productivity in species A, which will be compensated for by an increase in productivity of species B leading to no net change.

*The initial row under each alternative outcome refers to the likelihood of a "decrease", "no change" or "increase" (see Table 11). Subsequent rows refer to specific causes.

Table B10

Likelihood of Constant Levels of LRTAP Causing a Decrease in Forest Productivity by 1994 and 2014

Likelihood Scale: Most Likely 5 4 3 2 1 Most Unlikely

- By 1994 -

Region	*Mean*	*Std. Dev.*	*Number of Respondents*	*Range*
Atlantic provinces	3.08	0.93	26	5 to 1
Quebec/Ontario	3.29	0.98	28	5 to 1
Prairies/N.W.T.	1.41	0.89	27	5 to 1
British Columbia/Yukon	1.48	0.94	27	5 to 1

- By 2014 -

Region	*Mean*	*Std. Dev.*	*Number of Respondents*	*Range*
Atlantic provinces	3.54	1.07	26	5 to 1
Quebec/Ontario	3.61	1.10	28	5 to 1
Prairies/N.W.T.	1.59	0.93	27	5 to 1
British Columbia/Yukon	1.70	1.03	27	5 to 1

Table B11

Likelihood of Constant Levels of LRTAP Causing No Change in Forest Productivity by 1994 and 2014

Likelihood Scale: Most Likely 5 4 3 2 1 Most Unlikely

- By 1994 -

Region	*Mean*	*Std. Dev.*	*Number of Respondents*	*Range*
Atlantic provinces	2.15	0.97	26	5 to 1
Quebec/Ontario	1.96	0.92	28	5 to 1
Prairies/N.W.T.	3.69	1.38	26	5 to 1
British Columbia/Yukon	3.62	1.39	26	5 to 1

- By 2014 -

Region	*Mean*	*Std. Dev.*	*Number of Respondents*	*Range*
Atlantic provinces	2.00	1.00	25	5 to 1
Quebec/Ontario	1.81	0.96	27	5 to 1
Prairies/N.W.T.	3.54	1.45	26	5 to 1
British Columbia/Yukon	3.46	1.48	26	5 to 1

Table B12

Likelihood of Constant Levels of LRTAP Causing an Increase in Forest Productivity by 1994 and 2014

Likelihood Scale: Most Likely 5 4 3 2 1 Most Unlikely

- By 1994 -

Region	*Mean*	*Std. Dev.*	*Number of Respondents*	*Range*
Atlantic provinces	1.15	0.46	26	3 to 1
Quebec/Ontario	1.14	0.45	28	3 to 1
Prairies/N.W.T.	1.27	0.60	26	3 to 1
British Columbia/Yukon	1.31	0.62	26	3 to 1

- By 2014 -

Region	*Mean*	*Std. Dev.*	*Number of Respondents*	*Range*
Atlantic provinces	1.12	0.43	26	3 to 1
Quebec/Ontario	1.11	0.42	28	3 to 1
Prairies/N.W.T.	1.27	0.72	26	4 to 1
British Columbia/Yukon	1.27	0.67	26	4 to 1

Table B13

Likelihood of Decreasing Levels of LRTAP Causing a Decrease in Forest Productivity by 1994 and 2014

Likelihood Scale: Most Likely 5 4 3 2 1 Most Unlikely

- By 1994[1] -

Region	*Mean*	*Std. Dev.*	*Number of Respondents*	*Range*
Atlantic provinces	1.77	0.95	26	5 to 1
Quebec/Ontario	1.93	0.94	28	5 to 1
Prairies/N.W.T.	1.23	0.59	26	3 to 1
British Columbia/Yukon	1.23	0.59	26	3 to 1

- By 2014[1] -

Region	*Mean*	*Std. Dev.*	*Number of Respondents*	*Range*
Atlantic provinces	1.62	0.94	26	5 to 1
Quebec/Ontario	1.75	0.89	28	5 to 1
Prairies/N.W.T.	1.27	0.60	26	3 to 1
British Columbia/Yukon	1.27	0.53	26	3 to 1

[1]Productivity changes are based on the assumption that pollution levels will be reduced by 50% from present levels by 1994 and that this reduced level will be maintained indefinitely thereafter.

Table B14

Likelihood of Decreasing Levels of LRTAP Causing No Change in Forest Productivity by 1994 and 2014

Likelihood Scale: Most Likely 5 4 3 2 1 Most Unlikely

- By 1994 -

Region	*Mean*[1]	*Std. Dev.*	*Number of Respondents*	*Range*
Atlantic provinces	2.42	0.95	26	5 to 1
Quebec/Ontario	2.43	0.88	28	5 to 1
Prairies/N.W.T.	3.60	1.29	25	5 to 1
British Columbia/Yukon	3.60	1.32	25	5 to 1

- By 2014 -

Region	*Mean*[1]	*Std. Dev.*	*Number of Respondents*	*Range*
Atlantic provinces	2.50	1.03	26	5 to 1
Quebec/Ontario	2.39	0.99	28	5 to 1
Prairies/N.W.T.	3.64	1.29	25	5 to 1
British Columbia/Yukon	3.60	1.29	25	5 to 1

[1]Productivity changes are based on the assumption that pollution levels will be reduced by 50% from present levels by 1994 and that this reduced level will be maintained indefinitely thereafter.

Table B15

Likelihood of Decreasing Levels of LRTAP Causing Increase in Forest Productivity by 1994 and 2014

Likelihood Scale: Most Likely 5 4 3 2 1 Most Unlikely

- By 1994 -

Region	*Mean*[1]	*Std. Dev.*	*Number of Respondents*	*Range*
Atlantic provinces	2.04	1.00	26	4 to 1
Quebec/Ontario	2.14	0.85	28	4 to 1
Prairies/N.W.T.	1.26	0.54	23	3 to 1
British Columbia/Yukon	1.17	0.38	24	2 to 1

- By 2014 -

Region	*Mean*[1]	*Std. Dev.*	*Number of Respondents*	*Range*
Atlantic provinces	2.27	1.04	26	5 to 1
Quebec/Ontario	2.43	1.03	28	5 to 1
Prairies/N.W.T.	1.26	0.45	23	2 to 1
British Columbia/Yukon	1.21	0.41	24	2 to 1

[1]Productivity changes are based on the assumption that pollution levels will be reduced by 50% from present levels by 1994 and that this reduced level will be maintained indefinitely thereafter.

Appendix C

Selected Participant Comments

Introduction

For ease of exposition in the main text, attention was focused on the aggregate results of the survey. However, these aggregate results encompass a diversity of opinion among the respondents on the impacts of LRTAP on forests. Some of this diversity results from very different interpretations of the same information, while some opinions reflect a slightly different information base or perspective on the problem.

Throughout the survey, the respondents were encouraged to outline the reasons for their positions. As a result, many respondents made lengthy and detailed comments. In order to reflect the nature of the debate on different issues, a selection of these comments is presented in this Appendix. As far as possible, direct quotations of the various respondents are presented.

Forest Productivity Effect

Comments supporting a high likelihood of forest decline emphasized evidence from Germany, United States, and Quebec:

"There is ample evidence in Germany, where 50% of the forest is now found to be affected by the... (new type of forest death) syndrome, that acid deposition is the primary cause... This same syndrome is now seen in North America. In a study prepared for the 1984 German/American Scientific Exchange on forest dieback, Johnson, McLaughlin, Bruck, and Siccama reported an average reduction in growth, averaging 25% over the last two decades, of spruce and pine in an area extending from Maine to Tennessee. Because of the large geographical range, all previously known factors such as drought and insects can be eliminated as the primary cause."

"Although no comprehensive studies have been carried out in Canada, trees in eastern Canadian forests are showing similar symptoms and Lise Robitaille of the Quebec Government has found a 39% reduction over five years in the growth of maple in the Beauce region where serious dieback of this species is observed."

The validity of this interpretation, however, was seriously questioned by a number of respondents because of both lower pollution levels in Canada and other possible causes for observed declines:

"...acid deposition, to seriously affect forest growth via soil processes... requires inputs at higher levels and over longer duration than experienced in most parts of Canada. The possibility for secondary pollutants to affect forest growth in Canada also appears to be less acute than in central Europe and the U.S., as pollutant loads in provinces affected by long range transport are lower than in these countries."

"...I would be cautious about extrapolating growth reductions in Germany and the eastern U.S. to Canadian forests given (a) a likelihood of lower dry deposition of SO_2, NOx and ozone in eastern Canada, and (b) the mechanisms responsible for growth reductions are unknown. Although some of the maple decline in Quebec is unexplainable, forest pests (tent caterpillar, etc.) have been identified as causal agents for some of the damage..."

"...the 39% loss in diameter growth (of the maples in Quebec) over 5 years was established in relation to 20 years previously, (and) this loss of growth is also due in large part to an outbreak of forest tent caterpillar and climatic variation and there is not, at this time, any relationship established between this loss of growth and acid precipitation or atmospheric pollutants..."

Further, concerns were expressed regarding the applicability of the German findings in the Canadian context.

"...patterns of pollution, physiographic features of the land and forest growth in the United States and central Europe are different from Canadian conditions, making it impossible to apply directly by us the results of research from these countries."

At the same time, some respondents indicated that other "causes" of forest decline may themselves be related to air pollution:

"...A chronic and compounded reduction in vigor due to air pollution stress could intensify a host of secondary effects like weakened resistance to drought, insect infestations, and disease. In addition, pollution effects might be compounded by impeding the recovery of the forest ecosystem from natural periodic stresses like drought and insect outbreaks..."

"...while pollution is still regarded as a causative factor (in Europe) of forest decline, the mechanism may be more complex than previously thought. The interactions of pollution stress with other factors give rise to many more 'damage functions' than we imagined."

With respect to possible increases in forest productivity resulting from LRTAP, there was much more consensus among the respondents that this is unlikely, at least in the long term:

"Although nitrogen deficiencies have been identified in eight eastern Canadian forests, a small additional annual input of nitrogen (less than 5 kg/ha) is unlikely to supplement the nitrogen supply to the forest significantly... The sulphur requirement of the vegetation is much lower than nitrogen; sulphur fertilization is unlikely to increase forest productivity."

"Data from point source studies (Gordon and Gorham 1963) do not indicate any increase in increment in trees growing between 'moderate' and 'not obvious' damage categories, and no increase within the 'not obvious' category area relative to any other forest area of similar land type and stand composition."

"Experience in Germany, and now in southern Sweden, shows that initial gains from nitrogen fertilization are lost as calcium and magnesium are leached from the soil."

"Recent evidence from work in Alberta strongly suggests both an increase and decrease in forest productivity... Any increase in productivity... may be shortlived."

Future Pollution Levels

There was considerable difference of opinion among the respondents on future pollution levels in the absence of regulatory change. One respondent felt that all the mean projected pollution levels were significant underestimates requiring "that industry by itself decide to reduce pollutant emissions." On the other hand, one respondent drew the relatively large projected increases in NO*x* and O_3 into question citing the "(high) cost of petroleum products" and the likelihood of decreasing average disposable income. Another respondent explained that NO*x* pollution "may not grow as fast (as projected) because (of the) saturated automobile market..."

One respondent interpreted the mean projections for western Canada as indicating "an expectation of increased industrial activity" which he does not believe will occur. However, another respondent noted that this increased industrial activity need not be located in western Canada. Increased industrial activity in Asia, Mexico, etc. "will significantly and immutably contribute to increased worldwide atmospheric loading. This will cause the prairies, etc. and parts of the Rocky Mountains to receive their shares."

Finally, several respondents argued that the mean projections for sulphur emissions were too low. Because of the U.S commitment to energy self-sufficiency and the relative cost advantage, these respondents expect far greater use of coal for energy production in the future.

The Timing of Impacts

The aggregate results reflect an overall opinion that current or increased levels of pollution in the future will adversely affect forests within the next one or two decades. Similarly, a 50% reduction in pollution levels over the next 10 years is considered, on aggregate, likely to prevent these adverse effects.

However, two respondents emphasized the long time lags between pollution levels and effects on the forests. One respondent questioned whether any impacts would be felt at all within the near term, while the other respondent questioned any near-term benefits from reduced pollution levels:

"Twenty years is too short a time for any impacts of acid deposition to be manifested in any form of productivity change. According to some scientists (Ulrich), mere leaching of nutrients from foliage cannot cause a decrease in productivity. If the roots absorb sufficient quantities of nutrients to replenish those leached, the trees will not suffer or show any symptoms. So if the present level of pollution continues, it may take longer than 100 years to affect the soil (sufficiently) to cause any effects on productivity."

"When an ecosystem has been modified or altered by a stress such as air pollution, there is a certain momentum to this change. It is difficult to alter the direction of this momentum overnight. It will take many years for acidified ecosystems to reach a new equilibrium. Realistically, we are looking at many years after a 50% decrease in air pollution before we see results."

A more pessimistic view was expressed when another respondent observed that anything less than 100% reduction in LRTAP would be inadequate:

"Reducing the present pollution problem by a factor of 2 will not eliminate the problem. It only buys time."