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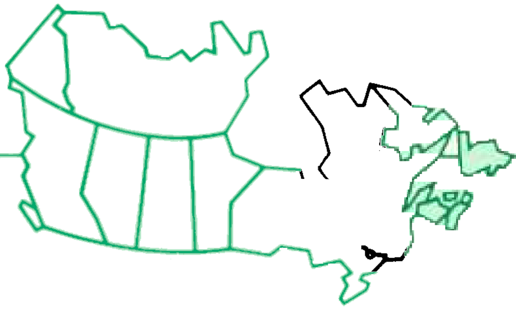
Acid Rain Control: Potential Commercial Forestry Benefits to Canada

G. Alex Fraser



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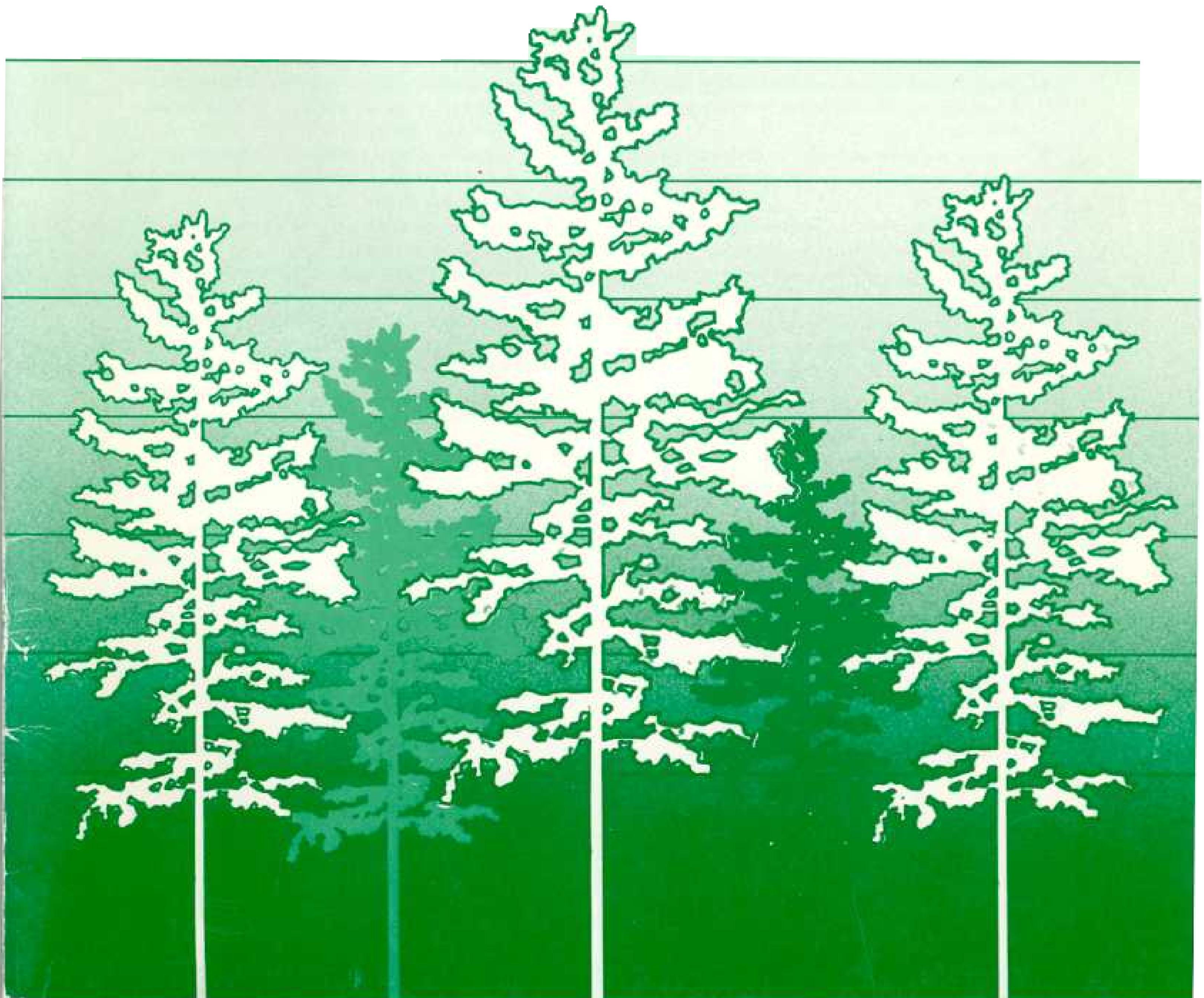

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Forestry Canada is the main focus for forestry matters in the federal government. It provides national leadership through the development, coordination, and implementation of federal policies and programs to enhance long-term economic, social, and environmental benefits from the forest sector for Canadians.

Forestry Canada is a decentralized organization with six regional forestry centres, two national research institutes, and seven regional sub-offices located across Canada. Headquarters is located in the National Capital Region in Hull, Quebec.

In support of its mandate, Forestry Canada carries out the following activities:

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- compiles, analyzes, and disseminates information about national and international forest resources and related matters
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Forêts Canada

Forêts Canada est l'organisme principal en matière de foresterie à l'intérieur du gouvernement fédéral. Chef de file sur le plan national, il assure la préparation, la coordination et la mise en œuvre des politiques et des programmes fédéraux dans le but d'améliorer les avantages économiques, sociaux et environnementaux à long terme offerts aux Canadiens par le secteur forestier.

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Contents

Abstract

The overall impact of acid rain on Canadian forests and the effectiveness of alternative pollution control programs in preventing forest damage are highly uncertain. However, a survey of scientific experts, carried out by Forestry Canada, sheds considerable light on the potential effects. Firstly, the results of this survey are used to identify the risk of forest damage without further pollution controls, and the expected forest productivity benefits of two alternative pollution control programs. Secondly, the relationship between these forest productivity changes and the future commercial timber harvest is explored. Finally, the social and economic benefits of the two pollution control programs are estimated.

Résumé

L'incidence globale des pluies acides sur les forêts du Canada et l'efficacité des programmes de lutte contre la pollution axés sur la prévention des dommages causés aux forêts sont extrêmement incertaines. Toutefois, une enquête menée auprès de spécialistes scientifiques par Forêts Canada jette un éclairage cru sur les incidences possibles. En premier lieu, les résultats de l'enquête servent de matière première à une analyse du risque d'endommagement qui pèse sur les forêts si nulle autre mesure de lutte contre la pollution n'est prise ainsi que des avantages que devraient avoir sur la productivité forestière deux nouveaux programmes de lutte contre la pollution. En deuxième lieu, nous examinons les rapports entre ces changements au niveau de la productivité forestière et la future récolte commerciale de bois d'eouvre. Enfin, nous faisons une estimation des avantages sociaux et économiques des deux programmes de lutte contre la pollution.

Executive Summary

This study develops a preliminary estimate of the commercial forestry benefits resulting from long range air pollution control. Specifically, two alternative pollution control options are evaluated against a base case in which no further pollution control measures are implemented. The first program of additional controls and regulations simply maintains long range air pollution at recent (1984) levels into the indefinite future. This program can prevent projected increases in pollution levels without further controls. The second program of controls and regulations is much more extreme and can achieve a 50% reduction in long range air pollution levels by 1994 and can maintain these new lower pollution levels into the indefinite future.

The overall impact of long range air pollution on Canadian forests and the efficacy of alternative pollution control programs is highly uncertain. Definitive knowledge on the subject will require extensive scientific research for some years. Meanwhile, a survey of scientific experts on air pollution/forestry impacts sheds considerable light on the "potential" effects. In the first part of this study, this information is used to derive an estimated range of forest productivity benefits for the two alternative pollution control programs.

The results of this analysis indicate that the expected productivity benefits of regulatory option 1 (constant pollution levels) are relatively modest. In Eastern Canada, about a 2–3% increase in forest productivity over the base case is expected by the year 2014. In Western Canada, only a negligible 0.6–0.7% increase in forest productivity is expected during this time. The expected benefits of regulatory option 2 (50% reduction in pollution levels) are much more substantial, particularly in the East. By 2014, a 9.5% and a 13.2% increase in forest productivity is expected in the Atlantic provinces and Quebec/Ontario, respectively. In the West, expected benefits range from a 1.4 to a 2.2% increase in forest productivity.

In the second part of this study, the relationship between these forest productivity changes and the future harvest rate is investigated. The nature of the forest productivity change and the role of management responses are identified as important considerations. On the basis of several key assumptions, the productivity effects are translated into a set of harvest rate adjustment factors. Applying these adjustment factors to current harvest rates generates a stream of future harvests with and without pollution control.

The results of this analysis indicate that the harvest rate benefits of the two pollution control options increase dramatically with time. Under both regulatory scenarios, projected harvests are only slightly above the base case (no regulatory action) by 1994. However, the difference in projected harvests increases consistently with time as growth reduction affects the system. Under regulatory scenario 2 (50% reduction in pollution levels), there is a projected difference greater than 10 million m^3 nation-wide by the year 2064.

In the final section of the report, the expected social and economic benefits of long range air pollution control are estimated with a relatively simple economic model. Specific simplifying assumptions include constant product prices regardless of changes in market clearing quantities, and constant capital and labor inputs to process the growth rate induced difference in harvest rates.

The results of this analysis indicate significant long-term economic benefits from pollution control. Under regulatory scenario 1 (constant pollution levels), total national benefits exceed \$100 million (1983) per annum by the year 2034 and reach a final level of \$182 million (1983) per annum by the year 2064. Under regulatory scenario 2 (50% reduction in pollution levels), total national benefits exceed \$100 million (1983) per annum by the year 2004 and reach a final level exceeding \$800 million (1983) per annum. Social benefits under regulatory scenario 1 eventually include approximately 1200 person-years of employment and exceed \$34 million (1983) per annum in salary and wage payments. Under regulatory scenario 2 the totals exceed 5500 person-years of employment and \$150 million (1983) per annum in salary and wage payments. The majority of all benefits are expected to accrue to Quebec and Ontario.

The risk of forest damage without controls and the potential size of the benefits from controls appear to rationalize significant pollution control expenditures. In general terms, this supports recent Canadian government policy initiatives aimed at reducing future pollution emissions.

1.0 Introduction

This study develops a preliminary estimate of the commercial forestry benefits resulting from the control of long range air pollution.[1] Specifically, two alternative pollution control programs are evaluated against a base case in which no further pollution control measures are implemented. First, a program of additional controls and regulations is evaluated, which can maintain long range air pollution at recent (1984) levels into the indefinite future. This program can prevent projected increases in pollution levels without further controls. Second, a more extreme program of controls and regulations is evaluated, which can reduce long range air pollution levels 50% by 1994 and can maintain these new lower pollution levels into the indefinite future. These control programs were not chosen because they accurately reflect actual pollution control initiatives on the part of Canadian and/or American governments, but because they reflect a subjective assessment of the feasible range of policy options. However, it is noteworthy that the base year for the analysis is 1984, and since that time the Canadian government has taken several important initiatives to reduce pollution levels.[2]

At the outset, it is useful to outline the rationale for the particular framework used in this study and clarify its relation to other work in this area. First, the focus is on the "benefits of pollution control" rather than the "costs of pollution damage" to avoid confusion in terminology. Costs are usually equated with expenditures made to implement an action. In the context of pollution control, this means the dollars expended to purchase scrubbers or implement other technological improvements to reduce pollution emissions. In this framework, the avoidance of pollution damage is a benefit of pollution control. Second, the intended purpose of the study is to help decision makers select an appropriate pollution control strategy. Much of the previous analysis and commentary on long range air pollution has focused on estimating the "current damage" to the forest (Crocker and Forster 1986). Although the information is interesting, this approach to the problem is not particularly useful from a decision-making perspective. For example, if the damage that has already occurred is partly or largely irreversible, then knowledge of current damage has little relevance for future policy.[3] The damage represents a "sunk cost" to society which is not susceptible to a policy prescription. The more relevant question from a public policy perspective, and the one addressed in this study, is the extent to which "future damage" can be avoided and the nature and extent of the pollution control measures required.

Even in the context of forestry, this analysis is only a partial benefit evaluation. Noncommercial forestry values, which may be influenced by pollution control, are unevaluated. This is partly because of difficulties in estimating nonpecuniary values, but also in the interest of keeping an already complex subject reasonably focused. In addition, commercial forestry is narrowly defined in the study to mean the harvesting and processing of timber into lumber, pulp and paper, and other common forest products. Annual tree-cropping activities, such as maple sugar or fruit production, are also unevaluated now because limited time and resources precluded their investigation.

2.0 Study Outline

The basic framework of the study is as follows. In section 3.0, the potential physical damage to forests due to long range air pollution is investigated. A survey of expert scientists in the field of air pollution and forest interactions, conducted by Forestry Canada in 1984, sheds considerable light on

[1]Long range air pollution is defined in this study to include five key pollutants that may adversely affect forest productivity (SO_2, SO_x, NO_x, O_3, and heavy metals.) A more popular generic term for long range air pollution, or more accurately one of the effects of long range air pollution, is "acid rain."

[2]The effect of the Canadian initiatives on "total" pollution levels depends on American policy responses. The American government to date has not followed the Canadian lead on this issue.

[3]In the specific context of forestry, this may be important. Many experts believe that forest damage has already occurred and that it is not completely reversible within 30 years (see Fraser et al. 1985).

the nature and extent of potential forest productivity changes under alternative pollution level scenarios. This survey identifies potential percentage changes in forest productivity both with and without further pollution control actions. The differences in productivity define the physical benefits of the control actions. The estimated pollution responses and the benefits associated with pollution control do not reflect actual measurable impacts resulting from controlled scientific experimentation and sampling. Rather, the information reflects the aggregated opinions of expert scientists in the area of forest/air pollution interactions. Until there is more precise data, it is the best information available now in a Canadian context.

In section 4.0 of the study, the relationship between the percentage changes in forest productivity under the alternative pollution scenarios and future commercial harvest rates is investigated. This relationship depends on both the nature of the forest damage and the policies and action of forest managers. The effect of physical damage on harvest rates is often indirect and lagged over a considerable time period. In this section, future harvest rates are projected both with and without pollution control actions. The difference in harvest rates defines the harvest rate benefits of the control actions.

In section 5.0 of the study, the social and economic benefits of long range air pollution control are estimated. Technically, a correct evaluation of economic efficiency or allocative benefits should incorporate the implications of potential price changes to consumers as well as net revenues to producers as a result of the harvest rate changes. This type of analysis requires detailed modeling of both demand and supply sides of the market, and unfortunately, it proved infeasible with the limited time and resources available. Therefore, several simplifying assumptions are made to facilitate estimation. Regarding social benefits, the study only examines the difference in potential employment levels and wages.

3.0 Pollution Control and Forest Productivity

The overall impact of long range air pollution on forests is highly uncertain. Although circumstantial evidence points to long range air pollution as a primary cause of forest decline in West Germany, adequate information does not exist to conclusively prove this negative relationship. In Canada, the evidence is even more tentative. The overall level of pollutants is lower, and the mix of pollutants is considerably different from that in central Europe. Present and future levels of pollution may or may not adversely affect forest productivity in Canada. In fact, some experts believe that an increase in forest productivity is possible due to the fertilization effects of certain pollutants. Definitive knowledge on the subject will require extensive scientific research for some years.

Meanwhile, a survey of scientific experts carried out by Forestry Canada sheds considerable light on the potential effects of long range air pollution (Fraser et al. 1985). Using an iterative series of four questionnaires, this survey solicited expert opinion on the nature and extent of future forest productivity changes and the likelihood of alternative forest productivity effects under several different pollution level scenarios. The results of this survey are the basis for estimating the benefits of pollution control.

3.1 Base Case

The starting point for evaluating an action is the consequence of inaction. To estimate the benefits of pollution control, it is necessary to project conditions without pollution control. In the Forestry Canada survey of scientific experts,[4] the respondents were asked to estimate "the most likely

[4]Specifically, the respondents were asked to assume: a) no substantive change in pollution control regulation, b) no successful international agreement limiting transboundary pollution, and c) moderate economic and population growth in the future. Then the respondents forecast continuing increases in the level of all key pollutants that may adversely affect forests. For more detail on the forecast level of specific pollutants see Fraser et al. 1985.

Table 1. Estimated percent change in future forest productivity under base case assumptions (Fraser et al. 1985, Table 14, p. 23)

Region	Mean (%)	SD (%)	Number of respondents	Range (%)
		by 1994		
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/NWT	-0.78	1.25	24	-5.0 to 0.0
B.C./Yukon	-0.86	1.66	24	-7.5 to 1.0
		by 2014		
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/NWT	-1.63	2.40	25	10.0 to 0.0
B.C./Yukon	-2.30	3.32	25	15.0 to 0.0

percentage change in forest productivity" due to long range air pollution assuming the absence of any additional pollution control measures. These predictions form a base case from which alternative states of the world can be evaluated.

Aggregated responses regarding the probable impact of long range air pollution, given a base case world, are provided in Table 1. The mean figures represent the average estimated percentage impact of long range air pollution on regional forest productivity. Standard deviations, numbers of respondents, and response ranges are included to indicate of the degree of consensus among experts regarding forest/long range air pollution interactions.

The results in Table 1 strongly suggest that unless further efforts are made to control long range air pollution, reductions in forest productivity can be expected throughout Canada. The most pronounced reductions are expected in Eastern Canada. In Quebec/Ontario and the Atlantic provinces, average productivity reductions of 7.4 and 4.5%, respectively, are predicted by the year 1994 and 11.5 and 8.4%, respectively, by the year 2014. In Western Canada, long range air pollution induced reductions in forest productivity are expected to be relatively low. The average predicted decline by 1994 is less than 1% for both the Prairies/Northwest Territories and British Columbia/Yukon regions. However, the predicted declines reach 1.6 and 2.3%, respectively, by the year 2014. It is noteworthy that in spite of the range of opinion among scientific experts, all of the average figures are statistically significantly different from zero at a 95% confidence level.

3.2 Regulatory Scenario 1

The first pollution control scenario evaluated in the Forestry Canada survey resulted in "constant pollution levels." The respondents were asked to assume that regulatory action was taken that maintained pollution at recent (1984) levels into the indefinite future. (Regulatory actions were left unspecified. The respondents were simply asked to assume that regulation was effective in maintaining constant pollution levels.) The respondents were then asked, as in the base case, to provide an estimate of the most likely percentage change in forest productivity. Table 2 reports the average estimated productivity change together with standard deviations, number of respondents, and response ranges.

The difference between regulatory scenario 1 and the base case is the avoidance of projected future increases in pollution levels. However, Tables 1 and 2 are very similar. Although there is some marginal downward shifting in the estimated amount of forest productivity decline, substantial productivity reductions are still predicted. Once more, the most pronounced effects are expected in

Table 2. Estimated percent change in future forest productivity under regulatory scenario 1 assumptions (Fraser et al. 1985, Table 17, p. 25)

Region	Mean (%)	SD (%)	Number of respondents	Range (%)
		by 1994		
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/NWT	-0.47	0.83	23	-2.5 to 0.0
B.C./Yukon	-0.66	1.26	23	-5.0 to 1.0
		by 2014		
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/NWT	-0.93	1.37	23	- 5.0 to 0.0
B.C./Yukon	-1.64	2.31	23	- 10.0 to 0.0

Table 3. Estimated percent change in future forest productivity under regulatory scenario 2 assumptions (Fraser et al. 1985, Table 19, p. 27)

Region	Mean (%)	SD (%)	Number of respondents	Range %
		by 1994		
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/NWT	-0.14	0.47	22	-2.0 to 0.0
B.C./Yukon	-0.11	0.62	22	-2.5 to +1.0
		by 2014		
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/NWT	-0.16	0.68	22	- 3.0 to +0.5
B.C./Yukon	-0.07	1.24	22	- 5.0 to +2.0

Quebec/Ontario and the Atlantic provinces. Productivity decreases of 5.3 and 3.2%, respectively, are predicted by the year 1994, and 8.7 and 6.1%, respectively, by the year 2014. The average predicted losses by 1994 for the Prairies/Northwest Territories and British Columbia/Yukon regions are again less than 1% and this time are not statistically significantly different from zero at a 95% confidence level. However, small reductions of 0.9 and 1.6% predicted for the year 2014 are statistically significant.

3.3 Regulatory Scenario 2

The second pollution control scenario evaluated in the Forestry Canada survey reflects a much more vigorous pollution control strategy. The respondents were asked to assume that regulatory action was taken that reduced pollution by 50% by 1994 and that this new lower pollution level could then be maintained into the indefinite future. Table 3 reports the average estimated productivity changes, standard deviations, number of respondents, and response ranges for this scenario.

The results here are very different from both the base case and regulatory scenario 1. First, a small increase in forest productivity is expected in both the Atlantic provinces and Quebec/Ontario by 1994 and a more significant increase is expected by the year 2014. In effect, eastern Canadian forests are expected to partially recover from existing adverse pollution effects. Second, throughout Western Canada, expected forest productivity losses are negligible and statistically insignificant.

3.4 Forest Productivity Benefits of Regulatory Action

The "expected" forest productivity benefits of regulatory actions are the differences between the expected changes under the base case and under each regulatory scenario. To provide an estimate of the benefits likely to result from the two regulatory options, the probability distributions in Tables 1 and 2 and Tables 1 and 3 were pooled using standard statistical techniques. The estimated benefits of regulatory scenario 1 (constant pollution levels) and regulatory scenario 2 (50% reduction in pollution levels) are presented in Tables 4 and 5, respectively. In addition to the pooled standard deviation for the estimates and the number of respondents, an associated 95% confidence interval is reported for each regional benefit estimate.[5] This interval indicates the diversity of opinion among experts on the forest productivity impacts of long range air pollution. The size of the interval can be directly attributed to uncertainty regarding both the effects of air pollution and the efficacy of controls.

Table 4 shows that the expected productivity benefits of regulatory option 1 are relatively low. In the West, negligible (less than 1%) benefits are expected by both 1994 and the year 2014. In the East, the expected benefits are somewhat more substantial but still remain less than a 3% increase in forest productivity over the base case by the year 2014. The only statistically significant result at 95% confidence is Quebec/Ontario by the year 1994. Zero (no effect) is contained within all of the other confidence intervals.

Table 4. Benefits of regulatory scenario 1

Region	Mean (%)	SD (%)	Number of respondents	95% Confidence interval
		by 1994		
Atlantic provinces	+1.31	2.22	44	+2.66 to -0.04
Quebec/Ontario	+2.15	3.21	50	+3.98 to +0.32
Prairies/NWT	+0.31	1.06	47	+0.95 to -0.33
B.C./Yukon	+0.20	1.48	47	+1.98 to -0.69
		by 2014		
Atlantic provinces	+2.26	4.09	44	+4.[illegible]1 to -0.29
Quebec/Ontario	+2.80	5.50	50	+5.[illegible]3 to -0.33
Prairies/NWT	+0.70	1.97	48	+1.[illegible]5 to -0.45
B.C./Yukon	+0.66	2.88	48	+2.[illegible]4 to -1.02

[5] The confidence interval is derived assuming "independent" mean estimates of productivity change under each pollution scenario. On this basis, the pooled variance for two means is:

$$S^2 \text{ pooled} = \frac{[n_1 - 1] S^2_1 + [n_2 - 1] S^2_2}{n_1 + n_2 - 2}$$

and the confidence interval for the difference in means is:

$$\text{Confidence Interval}_{(1-a)} = \overline{Y}_1 - \overline{Y}_2 \pm t_{a/2} (S_P) \left(\frac{1}{n_1} + \frac{1}{n_2}\right)^{1/2}$$

Table 5. Benefits of regulatory scenario 2

Region	Mean (%)	SD (%)	Number of respondents	95% Confidence interval
		by 1994		
Atlantic provinces	+5.03	2.21	43	+6.39 to +3.64
Quebec/Ontario	+7.89	3.57	50	+9.99 to +5.79
Prairies/NWT	+0.64	0.96	46	+1.28 to +0.07
B.C./Yukon	+0.75	1.27	46	+1.51 to -0.01
		by 2014		
Atlantic provinces	+9.55	4.07	43	+12.66 to +6.44
Quebec/Ontario	+13.21	5.57	47	+16.49 to +9.93
Prairies/NWT	+1.47	1.81	47	+2.04 to +0.90
B.C./Yukon	+2.23	2.57	47	+3.74 to +0.72

The procedure in footnote 5 on page 11 is likely to give a relatively conservative bias to the confidence intervals. Since the base data are estimates by individual survey respondents of productivity change, the means may be correlated. In this case, the use of the somewhat rarer paired t-test for the difference between means may be appropriate. The use of a paired t-test could be expected to narrow the estimated confidence intervals.

Table 5 shows that the expected productivity benefits of regulatory option 2 are much more substantial. Expected benefits for the Quebec/Ontario region are a 7.9% increase in forest productivity over the base case by 1994 and a 13.2% increase by the year 2014. The 95% confidence interval for this region ranges from 9.9 to 16.5% productivity increase by the year 2014. In the Atlantic region, estimated benefits range +12.7% to +6.4% over the base case with expected benefits of +9.6% by 2014. The expected benefits for the West are of course low. In both British Columbia/Yukon and the Prairies/Northwest Territories regions, expected benefits are less than a 1% increase in forest productivity over the base case by 1994. Somewhat more substantial but still small benefits are expected by the year 2014. However, all benefits except those estimated for British Columbia/Yukon by 1994 are statistically significant at a 95% confidence level.

In summary, there is a reasonably strong consensus among experts that significant benefits in forest productivity would be realized from 50% reduction in long range air pollution levels. Even the pessimistic lower limits of the scenario 2 confidence intervals, imply 6% and 10% increases in forest productivity over the base case by the year 2014 in the Atlantic provinces and Quebec/Ontario, respectively. There is also reasonable consensus among experts that simply maintaining long range air pollution at current levels will generate few benefits. The projected increases in forest productivity under scenario 1 generate only marginal increases in forest productivity over the base case in all regions of the country. Also, the estimated benefits are almost without exception not significantly different from zero at a 95% confidence level.

4.0 Forest Productivity and the Harvest Rate

The previous section reported the average and range of estimated productivity benefits from the two pollution control alternatives. The next step in the evaluation process involves determining the implications of this for the flow of timber harvests. Although a definite relationship exists between forest productivity and harvest rate, this relationship is not necessarily direct or immediate. The change in harvest rates as a result of pollution control depends on the nature of the forest productivity change and the response of management agencies. In the following sections, these two issues are

Table 6. Estimated distribution of forest productivity effect between mortality and growth reduction (Fraser et al. 1985, Table 15, p. 24)

Region	Mortality (%)	Growth reduction (%)
	by 1994	
Atlantic provinces	20	80
Quebec/Ontario	24	76
Prairies/NWT	12	88
B.C./Yukon	14	86
	by 2014	
Atlantic provinces	26	74
Quebec/Ontario	28	72
Prairies/NWT	15	85
B.C./Yukon	18	82

discussed in some detail and a set of plausible assumptions is developed. In subsequent sections, these assumptions are used to project future harvests both with and without pollution control measures. For ease of exposition, throughout this analysis we focus on the average estimated productivity effects of each pollution level scenario.

4.1 Nature of the Productivity Change

Based on evidence from point source pollution studies and the forest damage in Central Europe, which is believed to be pollution related, any forest productivity loss can be expected to result from two types of forest damage (Gorham and Gordon 1960). First, there may be a widespread reduction in forest growth and yield. Second, there may be a mortality of certain sensitive tree species. In the Forestry Canada survey, the scientific experts were asked to estimate the distribution of potential productivity loss between these two categories. The mean results are presented in Table 6.

In the Atlantic region, tree mortality is expected to account for about 20% of any forest productivity loss by 1994. By 2014, this proportion increases to approximately 26%. In the Quebec/Ontario region, mortality is expected to account for about 24% of any forest productivity loss by 1994 and approximately 28% by 2014. Throughout the West the proportionate share of mortality is expected to be considerably lower. The mean proportionate share of mortality ranges from a low of 12% on the Prairies by 1994 to a high of 18% in British Columbia by 2014.

4.2 Management Responses to Tree Mortality

In the case of tree mortality, several different assumptions regarding management responses are possible. One assumption, which is favored by several European analysts, is that short-term commercial harvests will be increased to salvage wood from the moribund trees (O.F. Hall and E.Niesslein, Status of Atmospheric Damage to Forests in West Germany, Virginia Polytechnic Institute and State University, unpubl. ms., 1985; E. Niesslein, Economic and Political Consequences of Waldsterben, Frieburg University, interim report, Feb. 1985). In effect, they project a short-term increase in timber supply followed by a long-term reduction in harvests. However, even with salvage harvesting, this projected increase need not occur. For example, in 1984 the West Germans indicated that scheduled harvests were being partially delayed to compensate for salvage harvesting. Damaged timber can be substituted for undamaged timber with no net change in short-run timber supplies.[6]

In the Canadian context, salvage harvesting is unlikely to play the same major role. Forest management is much less intensive than in Europe and the forest is far less accessible. Consequently, salvage harvesting is likely to be the exception rather than the rule. One alternative is to assume that the harvest will be reduced by the amount of mortality at the expected date of stand maturity. Thus, pollution-induced mortality could be modeled as implying a substantial reduction in harvests in either the near or far future depending on the age class and maturity of the damaged timber. However, this procedure ignores possible management substitution for the damaged stand. In the year during which the damaged stand was scheduled to mature, the next most desirable stand is likely to be cut in place with all other stands promoted accordingly. In this way, the effects of mortality are more likely to be diffused throughout the entire forest and over the entire rotation. This approach parallels the methods proposed by Van Wagner (1979) for dealing with forest fire damage evaluation in Canada.

4.3 Management Response to Growth Reduction

A direct relationship between forest productivity loss due to growth reduction and the harvest rate seems appropriate; however, a closer examination reveals several complicating factors. Under a sustained yield management system, reduced forest growth will work its way through the allowable cut calculation, but even in a "normal" forest[7] the full impact of growth reduction on harvest rates will not be felt until the end of a full rotation. Each tree represents an inventory of growth over its total life cycle. An immediate reduction in allowable cuts to reflect the full pollution-induced growth reduction would be an overreaction. It would ignore the fact of normal growth before pollution damage occurred. In a normal forest, the growth reduction would cause a gradual decline in actual yields over the full rotation. In Canada, where a large proportion of the present forest inventory is mature and overmature, the relationship between reduced growth and harvest rates is even less immediate. Since the growth rates on mature and overmature timber are presumably low or nonexistent, a reduction in growth for this portion of the inventory is hardly relevant. In an idealized case where the entire inventory is mature or overmature, cuts could be maintained throughout an entire rotation before declining as second growth begins to be harvested. Pollution impacts may simply exacerbate or cause a future decrease in harvests rather than affect present harvest levels.

4.4 Harvest Rate Adjustment Factors

In summary, first, pollution-related forest productivity loss (or gain) is likely to be due to both "mortality" and "growth" effects. Second, the mortality effect in Canada is more likely to result in a small reduction in the flow of harvests rather than a large reduction at a discrete time or a short-run increase in harvest due to salvage harvesting. Third, forest productivity losses due to growth reduction in Canada are likely to have an initially mild and overall lagged effect on harvest rates.

Bearing this in mind, the following specific assumptions and procedures have been used to translate the productivity effects of section 2 into harvest rate adjustment factors. First, productivity change is distributed between tree mortality and growth reduction based on the Forestry Canada survey results. Second, a direct relationship is assumed between tree mortality and the harvest rate. Thus, an x % productivity loss due to pollution-induced mortality is assumed to result in an immediate x % reduction in the harvest rate. In effect, mortality is assumed to result in an equal annual loss in

[6] This strategy can obviously work only if damage is not extensive. Effective salvage requires harvesting within 1–2 years of death. If mortality exceeds the scheduled harvests during this period then the substitution process will clearly break down.

[7] A normal forest is defined in the forestry literature as one that has several equal-sized stands ranging from a newly replanted area to a mature stand ready for harvesting. In theory, it represents a managed forest after a full rotation.

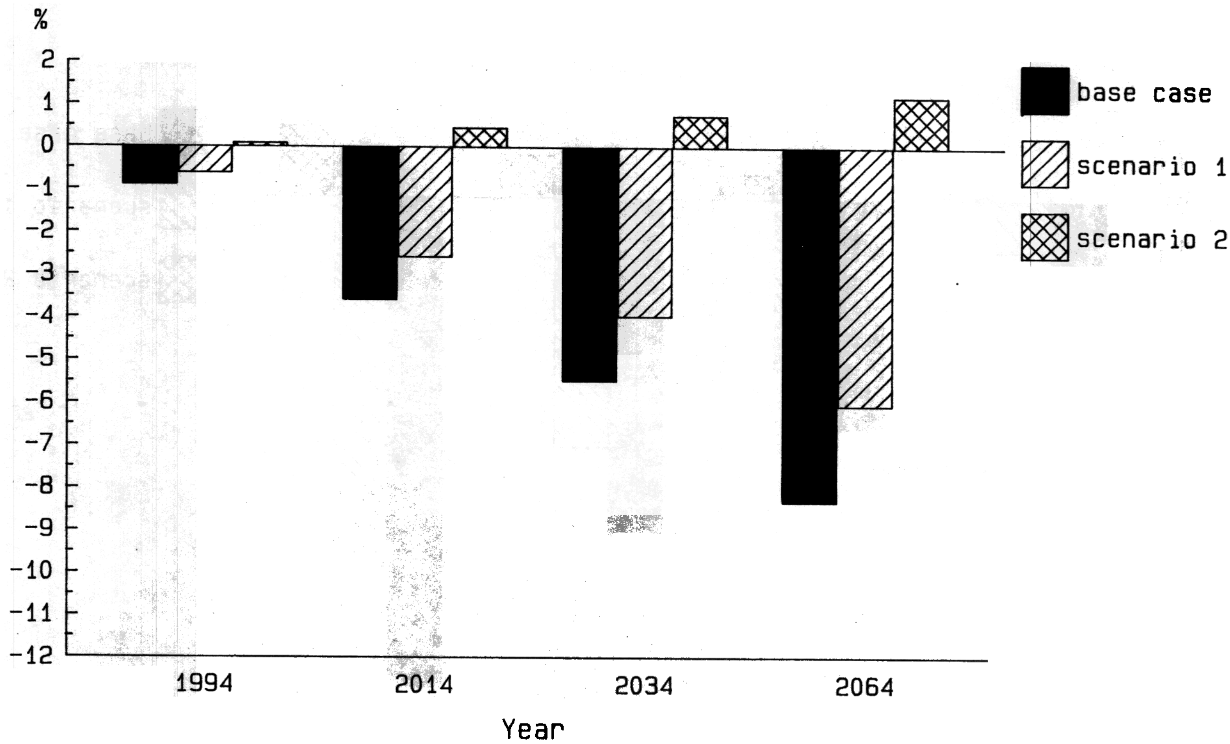

Figure 1. Atlantic provinces harvest adjustments.

harvests over the entire rotation. Third, it is assumed that it takes 50 years for growth reduction to fully affect harvest rates.[8] The full effect is gradually introduced in a direct line fashion during this period.

The implications of these assumptions for the four Canadian regions are outlined in Figures 1-4. These reflect the estimated decline (or increase) in harvest rates (in percent) for selected years under the base case and the two regulatory scenarios. For example, in the Atlantic region under the base case (that is, no further pollution control actions), harvests in 1994 are projected to be 0.9% below the level attained with no forest productivity change. This loss is projected to increase to 8.4% by the year 2064. For Quebec/Ontario the equivalent figures are -1.8% and -11.5% for 1994 and 2064, respectively.

[8] Fifty years may be insufficient to introduce the growth reduction effect. Rotation ages in Canada generally exceed 50 years; however, productivity change is estimated only up to the year 2014 and the situation may deteriorate beyond that time. Introducing the growth reduction effect over 50 years is intended as a compromise.

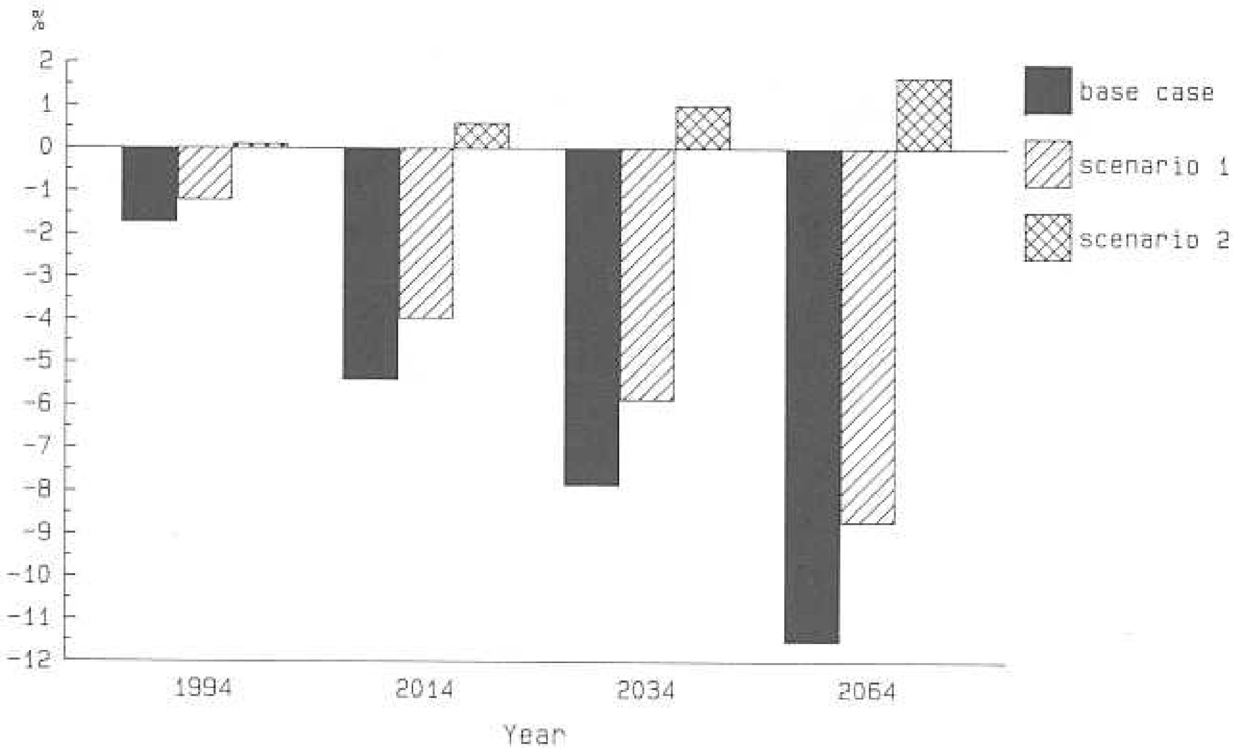

Figure 2. Quebec/Ontario harvest adjustments.

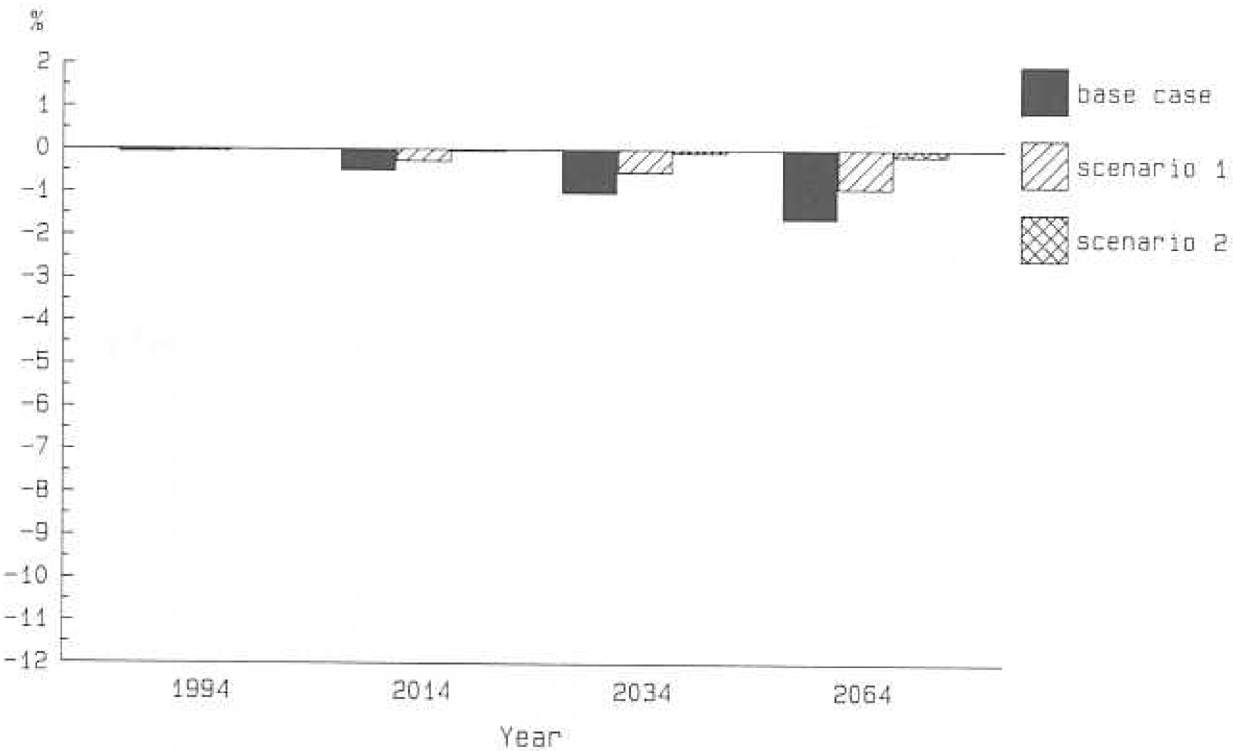

Figure 3. Prairies/NWT harvest adjustments.

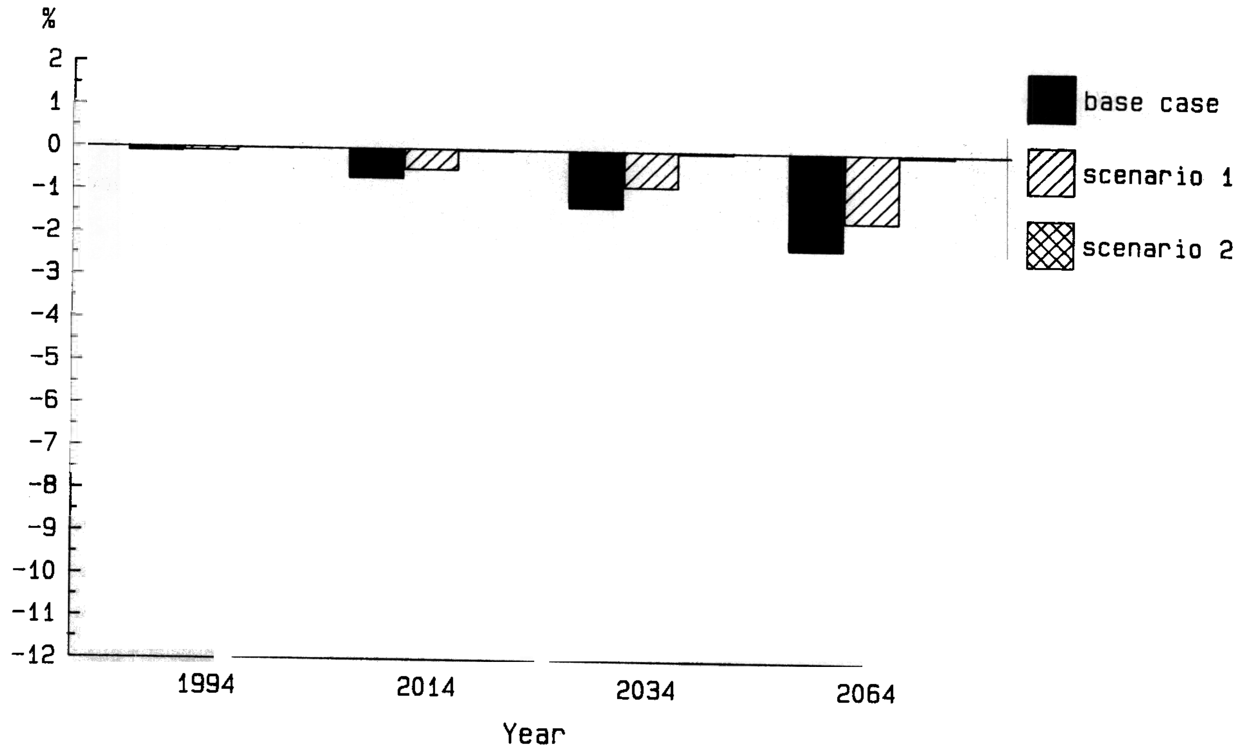

Figure 4. British Columbia/Yukon harvest adjustments.

4.5 Harvest Projections

The future of Canadian timber supply is uncertain and controversial even without long range air pollution impacts. In the last three decades, Canadian harvests have increased dramatically and calculated annual allowable cuts indicate a surplus available for further expansion within this management constraint. However, this surplus may be more apparent than real (F.L.C. Reed and Associates 1978). Allowable cut calculations have tended to focus on the physical availability of timber with less attention to its economic viability. Much of the apparent surplus is poor quality wood located in inaccessible or environmentally sensitive areas which may never be harvested. Canadian harvests may actually decline in the next several decades as the old growth timber stocks are liquidated and replaced with lower volume second growth forest.

For projection purposes, we have used the relatively conservative assumption that harvests will be maintained at current (annual average 1981–85) levels throughout the country without pollution-induced productivity changes.[9] Estimates of future harvests under the base case and the two regulatory scenarios are presented in Figures 5–8 for each region of the country.

Without further pollution controls (base case), harvests are projected to decline in each region of the country. Maintaining pollution at current levels (regulatory scenario 1) does little to change this situation. In contrast, reducing pollution levels by 50% (regulatory scenario 2) has a much more dramatic impact. Not only are harvests generally maintained in all regions but harvests are projected to increase to some extent in the East.

[9] This assumption was selected to facilitate exposition. However, the harvest rate benefits of pollution control are the "differences" in harvests with and without pollution control. Consequently, alternative assumptions regarding the future Canadian timber harvest will have only a marginal effect on estimated benefits.

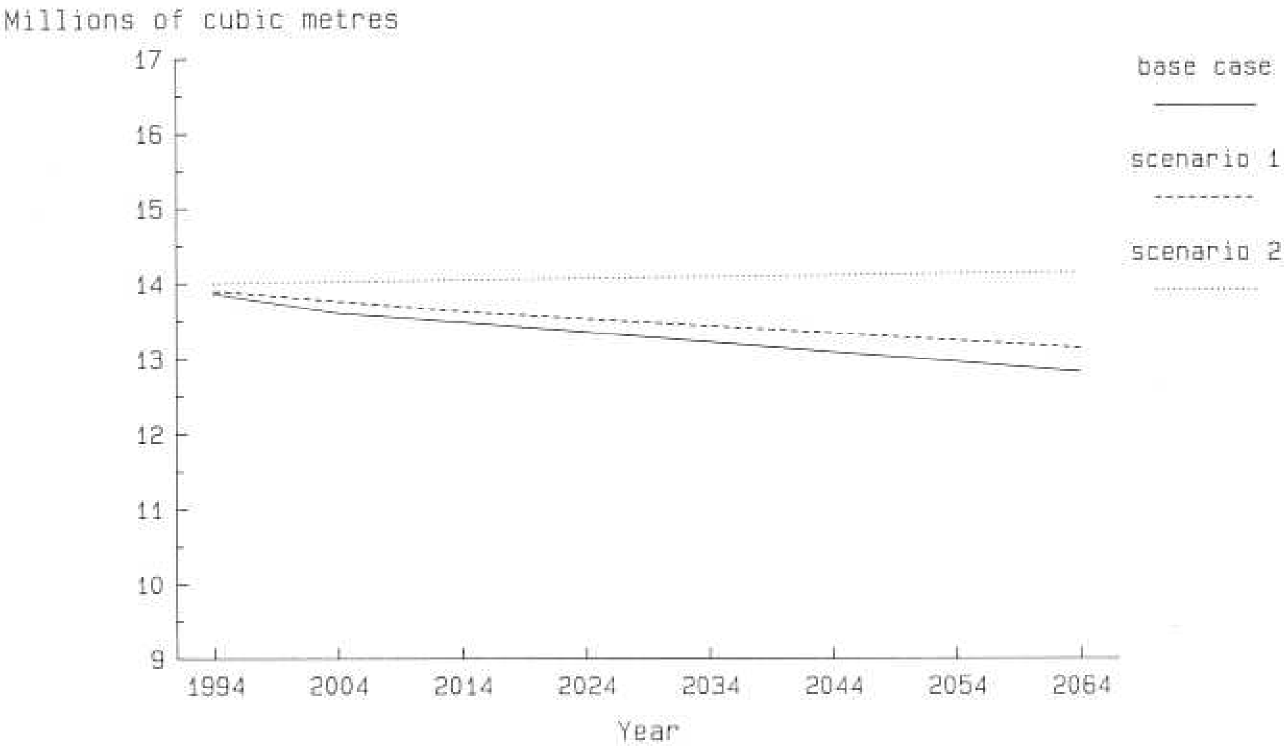

Figure 5. Atlantic provinces total harvest.

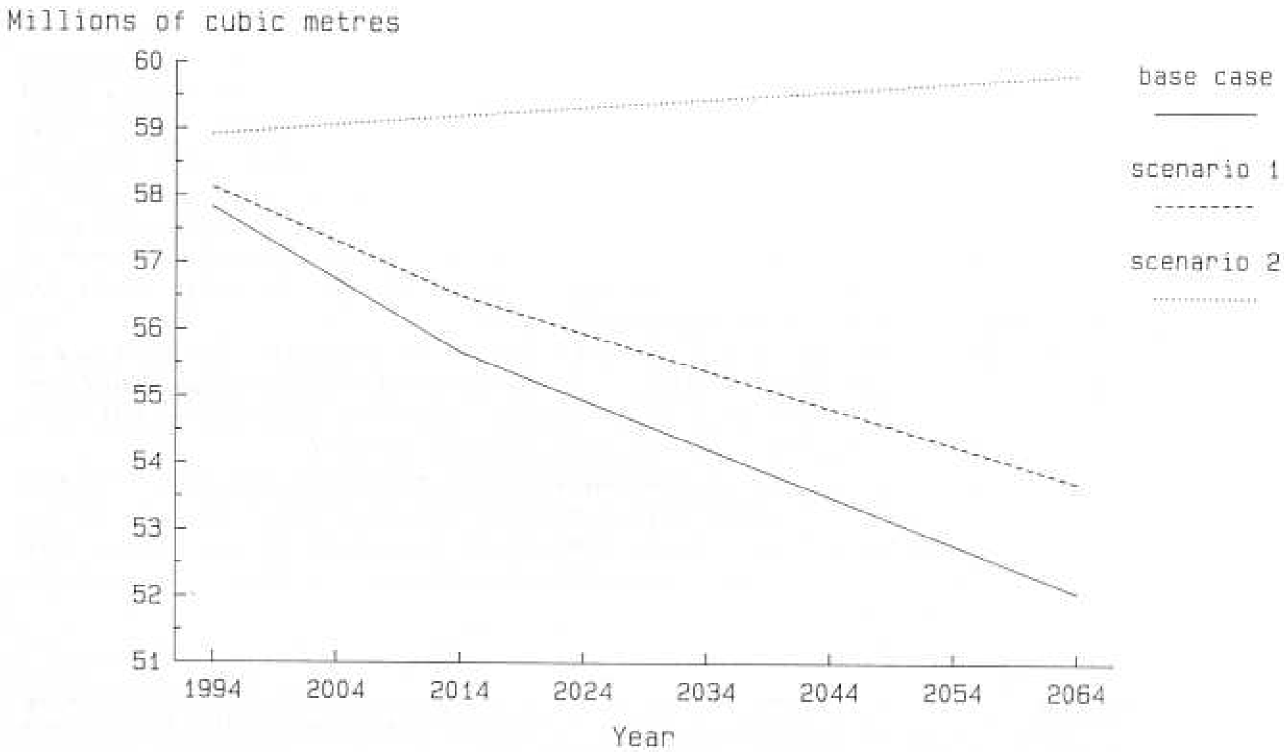

Figure 6. Quebec/Ontario total harvest.

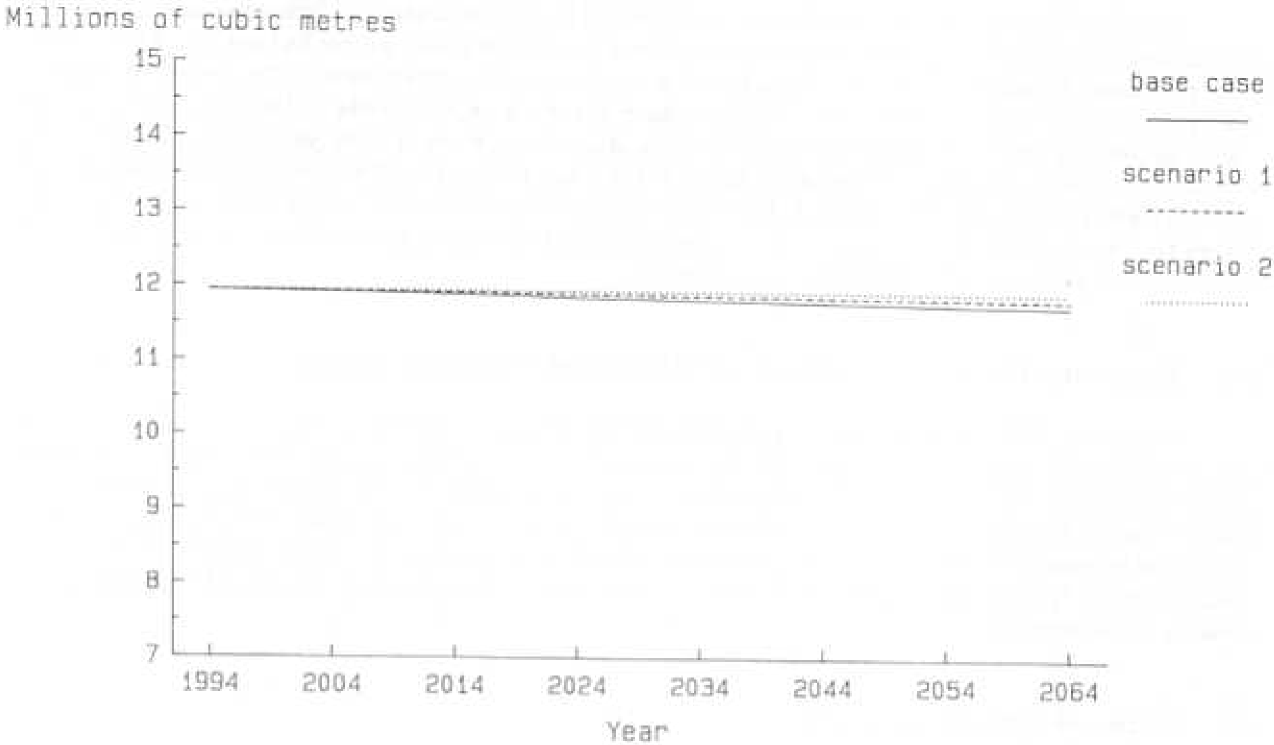

Figure 7. Prairies/NWT total harvest.

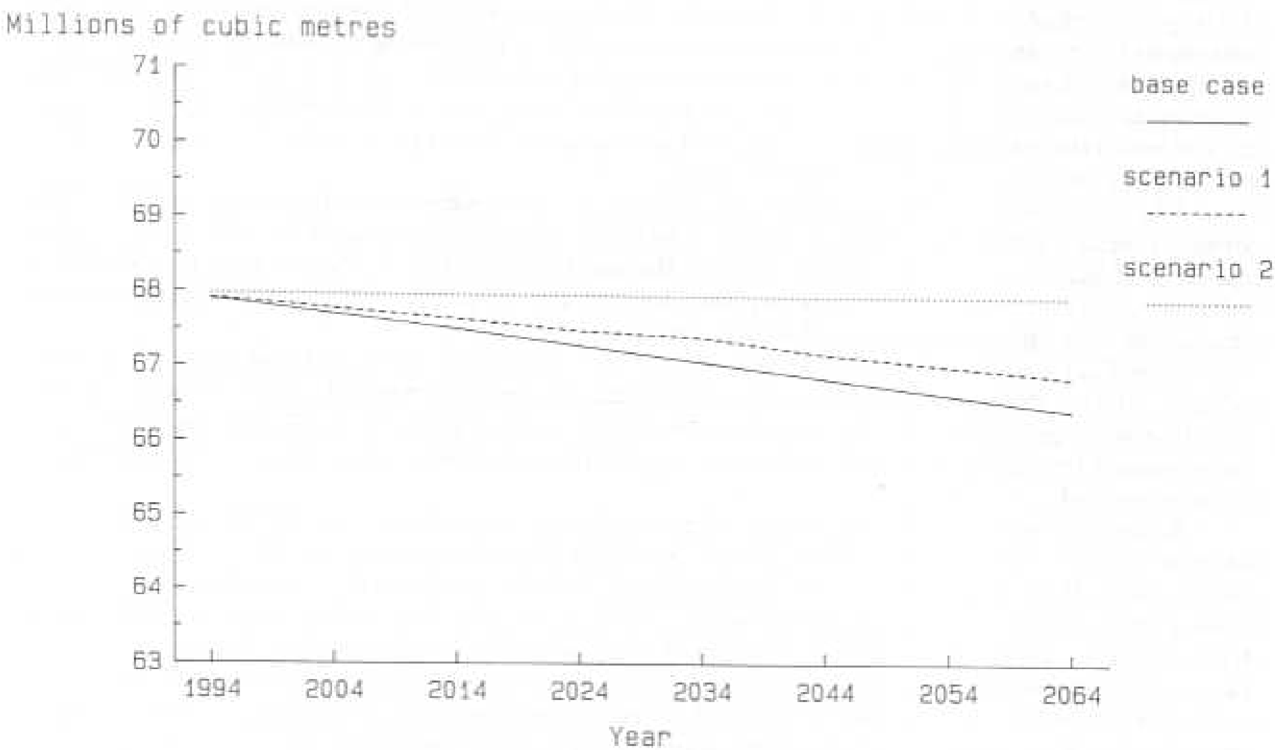

Figure 8. British Columbia/Yukon total harvest.

The difference in the projected volumes of timber harvested under the base case and each of the regulatory scenarios represents the harvest rate benefits of each pollution control option. Even with a 50% reduction in pollution levels, these benefits are low in the short term. The projected harvest under regulatory scenario 2 is only slightly above the base case in 1994. However, the benefits increase consistently as growth reduction begins to affect the system. By the year 2064, differences in projected harvest volume are greater than 7 million m^3 in the Quebec/Ontario region and approximately 1.3 million m^3 in the Atlantic provinces. Even in the British Columbia/Yukon region where the forest productivity impacts of long range air pollution are expected to be slight, a difference in harvest rates of about 1.5 million m^3 is projected.

5.0 Social and Economic Benefits of Long Range Air Pollution Control

In section 3.0, estimates of the potential forest productivity benefits from two long range air pollution control options were reported. In section 4.0, the implications of forest productivity for future harvest levels were explored. Expected harvest rates were then projected under the base case and the two pollution control scenarios investigated. Based on the difference in harvest rates, the social and economic benefits of the two pollution control options can be estimated. The initial analysis focuses on the "expected" benefits of control. Subsequently, the potential range and distribution of benefits are discussed.

5.1 Economic Efficiency Benefits

The conceptually correct measure of the economic efficiency benefits of pollution control is the net change in consumer and producer surplus (United States-Canada Memorandum of Understanding on Transboundary Air Pollution; final report, sections 7 and 8, January 1983; Kneese 1984). Pollution control causes the supply schedule for forest products to shift outward relative to a noncontrol strategy. As illustrated in Figure 9, this shift implies a lowering of product prices which benefits consumers by increasing the difference between consumer willingness to pay and the actual payment required (that is, consumer surplus). An analogous effect may be felt by producers. To the extent that pollution control facilitates a lower average cost production, producer net revenues will be increased. Depending on the elasticity of demand, this producer surplus effect may be partly or even largely offset by market price declines (Kneese 1984)(see Fig. 9).

The consequences of pollution control for consumer and producer surplus cannot be determined without specifying both demand and supply schedules. This implies a need for relatively complex modeling of both demand and supply sides of the market as well as rather complete modeling of different supply effects. This modeling was beyond the scope of this study. Instead, several simplifying assumptions are made to facilitate calculation.

Specifically, it is assumed that the change in market clearing quantities induced by both pollution control options are insufficient to change market prices. Implicitly, it is assumed that the Canadian forest products industry is a price taker on forest product markets. Given this assumption, the estimated impact on producer net incomes approximates the total economic efficiency benefits of pollution control.

Several options exist for approximating the change in producer net income as a result of pollution control actions. For example, if total harvesting and processing costs are fixed regardless of output levels, then final product price could be used to value the difference in output levels. This approach has often been used in the literature to value pollution impacts on agricultural harvests (Kneese 1984). At the other extreme, if all production costs are variable with industry output, then the residual between product price and the unit costs of production would represent the difference in producer net income. In a competitive market for standing timber, the price charged by the resource owner for the right to exploit the timber (the stumpage rate) theoretically represents this residual.

The approach used here assumes that the appropriate option for estimating the effect on producer net income varies with the nature of the difference in production. Specifically, it follows from

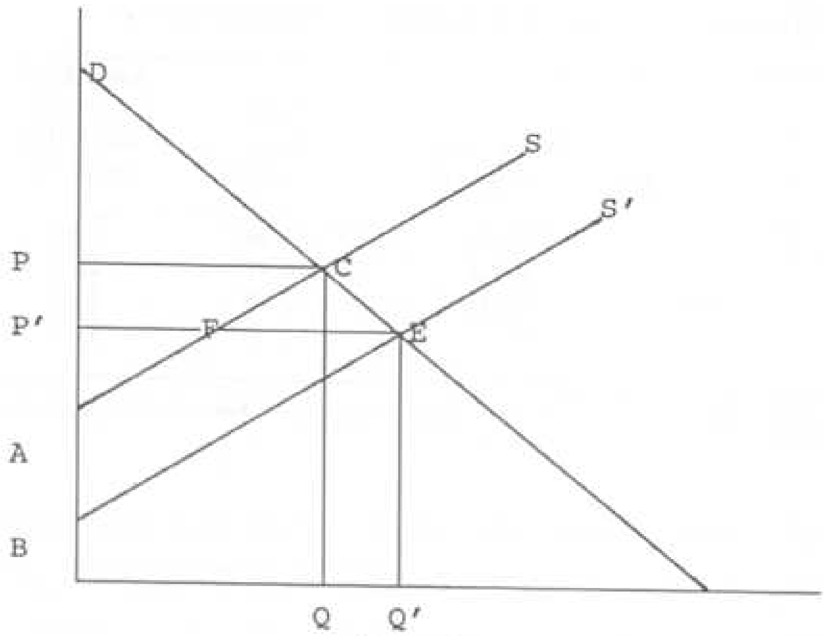

Figure 9.
The initial market equilibrium establishes price P and market clearing quantity Q. At this point, consumer surplus is defined as the area above the price line and under the demand schedule (that is, area PDC). Producer surplus is defined as the area above the supply schedule but below the price line (that is, area PAC). Pollution control is assumed to shift the supply schedule from S to S'. At this point, a new market equilibrium is established at price P' and market clearing quantity Q'. At this new lower price, consumer surplus is increased by the area P'PCE. The impact on producer surplus is somewhat more complex. Producer surplus is increased by the area AFEB, but this gain is partially offset because of the new lower price. The area P'PCF is lost to producer surplus. The total net gain to both consumers and producers is indicated by the area ACEB. (United States–Canada Memorandum of Understanding..., 1983)

the earlier discussion that a part of the difference results from the harvest of more trees due to the avoidance of mortality. For this portion of the difference in harvests, the increased revenues with pollution control are likely to be partially offset by increased harvesting and processing costs. For this reason, the real (1983 dollars) average regional stumpage rate has been chosen to value the mortality-induced difference in harvest rates. The case of growth increase is somewhat more complex. Numerous empirical studies indicate that smaller trees are more costly to harvest and process (Cooney and Haley 1982; Dobie 1966); thus, additional producer benefits are likely due to decreasing average production costs. For this reason, stumpage plus the average real value (1983 dollars) added during 1981–85 has been used to estimate the benefits from the growth-induced difference in harvest rates.[10] The specific values used in the analysis are outlined in Table 7. The expected economic benefits of the two regulatory scenarios are presented in Table 8.

[10] Implicitly this assumes that equivalent capital and labor is used to harvest and process the trees regardless of the size differences, while energy and other material and service inputs vary proportionately with output. An identical number of trees are assumed to be harvested and processed. The only significant difference is the size of the trees and the resulting quantity of final output. However, the assumption is not meant to be taken literally. The use of price to value the output difference assumes a zero elasticity of total harvesting and processing costs regarding output while stumpage assumes an elasticity of one. The use of value added is intended to represent an elasticity of total costs between these two extremes. This agrees with the empirical studies noted.

Table 7. Selected average real values ($) per unit of harvest (1983 dollars)

Region	Stumpage[a]	Wages and salaries[b]	Total value added[b]	Assumed value of mortality impacts	Assumed value of growth impacts
Atlantic provinces	2.85	36.89	63.58	2.85	66.43
Quebec/Ontario	2.39	61.48	114.27	2.39	116.66
Prairies/NWT	1.37	33.55	63.46	1.37	64.83
B.C./Yukon	3.17	35.14	56.31	3.17	59.48

[a] Internal files, Economics Branch, Forestry Canada.
[b] Statistics Canada, Canadian Forestry Statistics (1981–1985), catalogue number 25-202 (annual), Minister of Supply and Services Canada, Ottawa, Ontario.

Table 8. Expected economic efficiency benefits ($) of long range air pollution control (1983 dollars)

	1994	2004	2014	2024	2034	2044	2054	2064
				Scenario 1				
Atlantic provinces	108.30	3 681.48	4 153.07	6 550.25	8 803.17	11 131.07	13 453.27	15 778.32
Quebec/Ontario	717.00	23 533.07	46 463.41	65 012.35	84 144.59	102 693.53	121 825.77	140 374.71
Prairies/NWT	4.11	463.40	859.23	2 220.66	2 933.79	3 582.09	4 230.39	4 684.20
B.C./Yukon	44.38	1 754.95	3 471.86	7 100.14	14 063.22	14 773.06	18 460.42	22 085.93
Total	**873.79**	**29 432.90**	**54 947.57**	**80 883.40**	**109 944.77**	**132 179.75**	**157 969.85**	**182 923.16**
				Scenario 2				
Atlantic provinces	407.55	9 598.11	15 872.12	26 102.34	36 133.27	45 854.85	56 394.42	66 624.64
Quebec/Ontario	2 617.05	86 231.37	169 945.62	268 059.07	366 167.74	465 095.42	563 906.44	662 834.12
Prairies/NWT	13.70	932.28	1 850.86	3 990.25	5 546.17	7 037.26	8 463.52	9 695.29
B.C./Yukon	237.75	6 189.50	12 200.73	25 107.89	37 658.17	50 148.97	63 115.61	75 190.05
Total	**3 276.05**	**102 951.26**	**199 869.33**	**323 259.55**	**445 505.35**	**568 136.50**	**691 879.99**	**814 344.10**

As before, the expected benefits of regulatory scenario 1 (maintaining constant pollution levels) are relatively modest although total national benefits still exceed $100 million (1983) per annum by the year 2034, and reach a final level of approximately $183 million (1983) per annum by the year 2064. The expected benefits of regulatory scenario 2 (50% reduction in pollution levels) are more dramatic, exceeding $100 million (1983) per annum within 20 years and reaching a final level greater than $800 million (1983) per annum. As expected, the major benefits are projected to accrue to Quebec and Ontario. Between 75 and 80% of the benefit stream accrues to these two provinces depending on the specific pollution control scenario. Benefits to the Atlantic provinces are surprisingly modest given that this region is the next most heavily affected by long range air pollution. In contrast, the benefits projected to accrue to the British Columbia/Yukon region are surprisingly large given the minimal forest productivity effects expected in this area. This latter result is primarily due to the large forest sector in British Columbia, and the relatively high productivity of British Columbia's forests. Even minor impacts on forest productivity can imply substantial economic losses in this region.

5.2 Expected Social Benefits

Economic efficiency focuses on the change in the net value of goods and services produced in the economy. Control of long range air pollution may have other important beneficial impacts. For example, one clear implication of pollution control is the maintenance of a larger forest sector in the Canadian economy. In isolation, this may be unimportant. In the long term, wages and employment that do not exist in the forest industry may be generated elsewhere in the economy. However, this different pattern of employment and population distribution could be less socially desirable. The nature of forest industry production requires the industry be near the resource base. Forest industry employment tends to be located in the rural and less developed regions of the country where it is often the predominant and sometimes only economic activity in many communities.

In these specific areas, there may be no viable alternative to the forest industry. To forgo employment and income may represent a total net loss implying slow growth and economic stagnation. Particularly in local areas, the implications could include high levels of unemployment for extended time periods, and a considerable waste of human resources. The avoidance or mitigation of these problems may be a significant benefit from long range air pollution control.

To indicate this potential benefit, Table 9 outlines an estimate of the direct employment and income impacts of the two pollution control options for selected years. Like economic efficiency benefits, the employment and wage impacts can be expected to vary according to the nature of the output difference. Mortality-induced differences in the harvest level tend to directly reduce employment and income in the forest sector. However, growth-induced differences in harvest levels are likely to have a lesser impact on employment or income in the sector. In fact, the specific assumptions used to estimate economic efficiency benefits imply that equivalent labor is used to harvest and process the trees regardless of size differences.

Therefore, the estimates in Table 9 are based on average labor input and wage and salary expenditures per unit of production, applied to the mortality-based difference in harvest rates alone. The specific unit values used represent 5-year averages from 1981 to 1985.

Based on these assumptions, social benefits peak quickly relative to the economic efficiency

Table 9. Expected wage and employment impacts of long range air pollution control

Region	1994 wages (1983$)	Person-years	2004 wages (1983$)	Person-years	2014 wages (1983$)	Person-years
			Scenario 1			
Atlantic provinces	1 402	54	2 213	85	3 025	116
Quebec/Ontario	18 444	662	23 178	832	27 850	1 000
Prairies/NWT	101	4	235	9	403	15
B.C./Yukon	492	14	1 652	48	2 881	84
Total	**20 439**	**734**	**27 278**	**974**	**34 159**	**1 215**
			Scenario 2			
Atlantic provinces	5 275	202	9 112	349	12 838	492
Quebec/Ontario	67 321	2 417	99 536	3 573	131 321	4 714
Prairies/NWT	335	12	604	22	872	32
B.C./Yukon	2 636	77	5 974	174	9 312	271
Total	**75 567**	**2 708**	**115 226**	**4 118**	**154 343**	**5 509**

benefits. Under regulatory scenario 1 (constant pollution levels) an annual gain of approximately $34 million (1983) in salaries and wages is projected by 2014 and more than 1200 person-years. Under regulatory scenario 2 (50% reduction in pollution levels), equivalent figures are approximately $154 million (1983) and more than 5500 person-years. Like economic benefits, the major share of social benefits is expected in Quebec and Ontario. Between 80 and 85% of the national benefits accrue to these two provinces depending on the particular pollution control scenario.

5.3 Range and Distribution of Potential Benefits

The discussion in this section focuses on the "expected" social and economic benefits of pollution control. Although this represents the best estimate based on available information, as outlined in section 3, there is considerable uncertainty both regarding the effects of long range air pollution on forests and the efficacy of different pollution control strategies. Expected benefits summarize a broad range of potential effects and this uncertainty should be clearly understood by decision makers.

The potential range of forest productivity benefits is identified in Tables 4 and 5. A parallel range of potential economic efficiency and employment benefits can be derived for both pollution control options. Also, other uncertainties are added with the socioeconomic calculations. The major social and economic impacts of long range air pollution can be expected many years in the future. It is unlikely that the market values of forest products or stumpage rates will remain unchanged during this period. Increasing scarcity of timber and technological advance in both harvesting and processing are likely to increase all measures of value. Regarding social benefits, technological advance in the forest industry is labor saving and will likely cause employment and wage impacts to decline. On the other hand, the trend towards further processing of raw materials in the Canadian economy will likely cause employment and wage impacts to increase. All of this uncertainty regarding future trends will tend to further increase the range of potential benefits.

Finally, this analysis does not discuss the distribution of benefits between consumers and producers. The present estimates technically represent projected impacts on producer net incomes assuming that increased harvests are insufficient to influence price levels. Producer prices will more likely fall because of pollution control measures. To the extent that this occurs, the economic benefits will be shared by consumers and producers of forest products.[11] This is not simply a technical concern, but one that has major political ramifications. Canada is largely a producer of forest products for foreign markets and the United States is the largest consumer. In short, a significant proportion of the projected economic benefits may represent benefits not to Canada but to American consumers of Canadian forest products. The importance of this for international negotiations on pollution control is obvious.

6.0 Conclusions

There is considerable uncertainty among experts regarding both the impact of long range air pollution on Canadian forests and the effectiveness of different control strategies. Based on present scientific knowledge, precise estimates of forest damage cannot be derived. However, there is a reasonably strong scientific consensus that forest productivity will decline without additional pollution control measures. In this study, results from a survey of scientific experts were used to develop a preliminary estimate of the size and range of forest productivity benefits from two alternative pollution control programs.

Based on several key assumptions, future harvests were projected both with and without control

[11] Callaway et al. (1986) used an econometric model of the U.S. forest products market to assess the economic impact of 10–20% reductions in the radial growth of U.S. northeastern and southeastern forests. The authors concluded that "... consumers of wood products bear the brunt of damages. Moreover, a substantial proportion of these losses represent transfers of economic surplus from consumers to producers and timber owners as physical damage levels were increased."

measures. The results indicate that the harvest rate benefits of the two pollution control options increase dramatically with time. Under both regulatory scenarios, projected harvests are only slightly above the base case (no regulatory action) by 1994. However, the difference in projected harvest rates increases consistently with time as growth reduction begins to affect the system. Under regulatory scenario 2 (50% reduction in pollution levels), there is a projected difference greater than 10 million m^3 nation-wide by the year 2064.

The socioeconomic analysis indicates that the eventual benefits, particularly under regulatory scenario 2, are substantial. Total national benefits for this pollution control option exceed $100 million (1983) per annum by the year 2004 and reach a final level greater than $800 million (1983) per annum. Estimated employment and wage impacts for this scenario exceed 5500 person-years and $154 million (1983) per annum, respectively.

The risk of forest damage without controls and the potential size of the benefits from controls appears to rationalize significant pollution control expenditures. In general terms, this supports recent Canadian government initiatives to reduce future pollution emissions. However, it is worth emphasizing that this study does not directly examine the viability of the pollution control options investigated. No information is presented on the costs of pollution control and these costs may or may not be large relative to the benefits identified here. On the other hand, this study represents only a partial benefit evaluation, even in the area of forestry. Other benefits in such areas as fisheries, human health, and the recreational and aesthetic values of forests may provide an equally strong and additional rationale for pollution controls.

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Statistical Apppendices

Table A1. Harvest rate adjustment (%) under alternative pollution control regimes by decade (Cont'd)

	1994	2004	2014	2024	2034	2044	2054	2064
				Base Case				
Atlantic Provinces								
Mortality	-0.92	-1.55	-2.18	-2.18	-2.18	-2.18	-2.18	-2.18
Growth reduction	0.00	-0.72	-1.44	-2.39	-3.33	-4.28	-5.22	-6.17
Total	**-0.92**	**-2.27**	**-3.62**	**-4.57**	**-5.51**	**-6.46**	**-7.40**	**-8.35**
Quebec/Ontario								
Mortality	-1.75	-2.46	-3.17	3.17	-3.17	-3.17	-3.17	-3.17
Growth reduction	0.00	-1.13	-2.26	-3.48	-4.70	-5.92	-7.14	-8.36
Total	**-1.75**	**-3.59**	**-5.43**	**-6.65**	**-7.87**	**-9.09**	**-10.31**	**-11.53**
Prairies/NWT								
Mortality	-0.09	-0.17	-0.24	-0.24	-0.24	-0.24	-0.24	-0.24
Growth reduction	0.00	-0.14	-0.27	-0.58	-0.79	-1.00	-1.21	-1.39
Total	**-0.09**	**-0.31**	**-0.51**	**-0.82**	**-1.03**	**-1.24**	**-1.45**	**-1.63**
B.C./Yukon								
Mortality	-0.12	-0.27	-0.41	-0.41	-0.41	-0.41	-0.41	-0.41
Growth reduction	0.00	-0.15	-0.30	-0.62	-0.94	-1.26	-1.58	-1.89
Total	**-0.12**	**-0.42**	**-0.71**	**-1.03**	**-1.35**	**-1.67**	**-1.99**	**-2.30**
				Scenario 1 — Constant Pollution Levels				
Atlantic Provinces								
Mortality	-0.65	-1.12	-1.59	-1.59	-1.59	-1.59	-1.59	-1.59
Growth reduction	0.00	-0.51	-1.02	-1.72	-2.41	-3.11	-3.80	-4.50
Total	**-0.65**	**-1.63**	**-2.61**	**-3.31**	**-4.00**	**-4.70**	**-5.39**	**-6.09**
Quebec/Ontario								
Mortality	-1.24	-1.82	-2.40	-2.40	-2.40	-2.40	-2.40	-2.40
Growth reduction	0.00	-0.80	-1.60	-2.55	-3.49	-4.44	-5.38	-6.33
Total	**-1.24**	**-2.62**	**-4.00**	**-4.95**	**-5.89**	**-6.84**	**-7.78**	**-8.73**
Prairies/NWT								
Mortality	-0.07	-0.11	-0.14	-0.14	-0.14	-0.14	-0.14	-0.14
Growth reduction	0.00	-0.08	-0.16	-0.29	-0.41	-0.54	-0.66	-0.79
Total	**-0.07**	**-0.19**	**-0.30**	**-0.43**	**-0.55**	**-0.68**	**-0.80**	**0.93**
B.C./Yukon								
Mortality	-0.10	-0.20	-0.29	-0.29	-0.29	-0.29	-0.29	-0.29
Growth reduction	0.00	-0.11	-0.22	-0.45	-0.67	-0.90	-1.13	-1.35
Total	**-0.10**	**-0.31**	**-0.51**	**-0.74**	**-0.96**	**-1.19**	**-1.42**	**-1.64**

Table A1. Harvest rate adjustment (%) under alternative pollution control regimes by decade (Concluded)

	1994	2004	2014	2024	2034	2044	2054	2064
	Scenario 2 — 50 % Reduction in Pollution Levels							
Atlantic Provinces								
Mortality	-0.10	0.21	0.31	0.31	0.31	0.31	0.31	0.31
Growth reduction	0.00	0.08	0.16	0.31	0.45	0.60	0.74	0.89
Total	0.10	0.29	0.47	0.62	0.76	0.91	1.05	1.20
Quebec/Ontario								
Mortality	0.11	0.29	0.46	0.46	0.46	0.46	0.46	0.46
Growth reduction	0.00	0.07	0.14	0.35	0.56	0.78	1.00	1.22
Total	0.11	0.36	0.60	0.81	1.02	1.24	1.46	1.68
Prairies/NWT								
Mortality	-0.01	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02
Growth reduction	0.00	-0.02	-0.04	-0.06	-0.08	-0.10	-0.12	-0.14
Total	-0.01	-0.04	-0.06	-0.08	-0.10	-0.12	-0.14	-0.16
B.C./Yukon								
Mortality	-0.01	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02
Growth reduction	0.00	-0.01	-0.02	-0.02	-0.03	-0.04	-0.04	-0.05
Total	-0.01	-0.03	-0.04	-0.04	-0.05	-0.06	-0.06	-0.07

Table A2. Projected harvests (1000 m³) under alternative pollution control regimes by decade

	1994	2004	2014	2024	2034	2044	2054	2064
Atlantic Provinces								
Base Case	13 859	13 670	13 482	13 349	13 217	13 084	12 953	12 820
Scenario 1	13 897	13 760	13 623	13 525	13 428	13 331	13 234	13 136
Scenario 2	14 002	14 029	14 054	14 075	14 094	14 115	14 135	14 156
Quebec/Ontario								
Base Case	57 820	56 737	55 654	54 936	54 219	53 501	52 783	52 065
Scenario 1	58 120	57 308	56 496	55 937	55 384	54 825	54 271	53 712
Scenario 2	58 915	59 062	59 203	59 327	59 450	59 580	59 709	59 839
Prairies/NWT								
Base Case	11 939	11 913	11 889	11 853	11 827	11 802	11 777	11 755
Scenario 1	11 942	11 927	11 914	11 899	11 884	11 869	11 854	11 839
Scenario 2	11 949	11 945	11 943	11 940	11 938	11 936	11 933	11 930
B.C./Yukon								
Base Case	67 894	67 691	67 493	67 276	67 058	66 841	66 623	66 413
Scenario 1	67 908	67 765	67 629	67 473	67 323	67 167	67 011	66 861
Scenario 2	67 969	67 956	67 949	67 949	67 942	67 935	67 935	67 928

Table A3. Expected harvest rate benefits (1000 m³) of long range air pollution control by decade

	1994	2004	2014	2024	2034	2044	2054	2064
Regulatory Scenario 1 — Constant Pollution Levels								
Atlantic Provinces								
Mortality	38	60	82	82	82	82	82	82
Growth	0	30	59	95	129	164	199	234
Total benefits	38	90	141	177	211	246	281	316
Quebec/Ontario								
Mortality	300	377	453	453	453	453	453	453
Growth	0	194	389	548	712	871	1035	1194
Total benefits	300	571	842	1001	1165	1324	1488	1647
Prairies/NWT								
Mortality	3	7	12	12	12	12	12	12
Growth	0	7	13	34	45	55	65	72
Total benefits	3	14	25	46	57	67	77	84
B.C./Yukon								
Mortality	14	47	82	82	82	82	82	82
Growth	0	27	54	115	183	244	306	367
Total benefits	14	74	136	197	265	326	388	449
Regulatory Scenario 2 — 50% Reduction in Pollution Levels								
Atlantic Provinces								
Mortality	143	247	348	348	348	348	348	348
Growth	0	112	224	378	529	683	834	988
Total benefits	143	359	572	726	877	1031	1182	1336
Quebec/Ontario								
Mortality	1095	1619	2136	2136	2136	2136	2136	2136
Growth	0	706	1413	2254	3095	3943	4790	5638
Total benefits	1095	2325	3549	4390	5231	6079	6926	7774
Prairies/NWT								
Mortality	10	18	26	26	26	26	26	26
Growth	0	14	28	61	85	108	130	149
Total benefits	10	32	54	87	111	134	156	175
B.C./Yukon								
Mortality	75	170	265	265	265	265	265	265
Growth	0	95	191	408	619	829	1047	1250
Total benefits	75	265	456	673	884	1094	1312	1515