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1987

ECONOMIC IMPACTS OF ACID RAIN ON FOREST, AQUATIC AND AGRICULTURAL ECOSYSTEMS IN CANADA

1 INTRODUCTION

Air pollutants can be divided into primary pollutants, SO_2 and NO_x, and secondary pollutants, primarily ozone, O_3, acid deposition and peroxy-acetyl Nitrate (PAN). Primary pollutants affect regions near the source of emission. Secondary pollutants, formed by the oxidation of sulphur dioxide and nitrogen oxides with atmospheric hydrocarbons, can affect regions far from the source of emission.

Canadian researchers in the mid-fifties began to suspect that air pollutants were causing aquatic, forestry and agricultural damages. It was not until the mid-seventies that researchers began to estimate the costs of these damages.

The major areas affected were southwestern Ontario and Eastern Townships of Quebec. Other regions of Canada exihibted little or no damage. Despite the limited area affected, air pollution impact is significant because the affected area contains the highest population, largest number of lakes, and intensive forestry and agricultural production.

This paper is restricted, of necessity, to a review of the economic impacts of acid rain on aquatic, forest and agricultural ecosystems of Canada.

2 FOREST ECOSYSTEM IMPACTS

In recent years the forest sector has received considerable attention from those interested in acid rain impacts. The scientific thinking about the impacts of acid deposition on forests has undergone significant change during the 1980's.

In the early 1980's, there was no visible sign of forest damage attributable to acid deposition. It was suggested that rather than being harmful, acid deposition might benefit North American forests as a result of atmospheric inputs of nitrogen to nitrogen deficient forest soils. However, it was recognized that these were

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AAEA paper, 1987

short-run effects that could give way to long-run adverse effects as continued acid inputs increased the leaching of nutrient cations, causing these to be the limiting nutrients to the forest (Forster, 1984a).

By the mid-eighties declines in forest production were noted in Europe and North America. Six hypotheses have emerged to explain the observed forest die-back: 1) gaseous air pollutant attack; 2) soil acidification and heavy metal toxicity; 3) magnesium deficiency; 4) excess nitrogen; 5) general stress, and, 6) drought. These hypotheses may be grouped into two explanatory categories. One suggests a direct damage mechanism to the forest canopy; the other an indirect mechanism operating through modifications in soil quality. The implications of these alternative explanations are quite different and scientific inquiry is aimed at determining which explanation(s) is valid.

In the spring of 1984, Ontario maple syrup producers complained of sugar maple damage which they suggested was caused by acid rain. Sugar maples in the Eastern Townships of Quebec also showed signs of damage, and acidic inputs were naturally suspected as causal agents. Aerial surveys revealed 28% of Quebec maple stands showed signs of decline in 1984, spreading to 52% in 1985 (Lanken), and possibly 85% more recently (Des Granges). Attention in Canada has focussed on the sugar maple, but decline has also been noted in numerous other tree types (Lanken).

While ozone (a gaseous pollutant) is known to be responsible for substantial amounts of forest damage in various U.S regions, it is believed that ozone levels are not high enough in Canada to be implicated in the observed forest damage in Ontario (Martin); however, there are "phytotoxic" concentrations in the Eastern Townships of Quebec (Rennie), so an ozone mechanism for Quebec cannot be dismissed.

The knowledge concerning the Ontario sugar maple situation is reported in Linzon, 1986. This study of the affected region revealed that decline was most evident in older trees that had either been previously tapped or otherwise wounded. Soil nutrient deficiencies were not implicated, although Foster *et al*, 1986, found that atmospheric inputs of sulphate and nitrate did contribute to cation leaching in the soils of a maple-birch forest in Central Ontario. Support for the soil acidification and heavy metal toxicity explanation was found, according to Linzon, since the Muskoka soils were acidic and had elevated aluminum (Al) concentration. Furthermore, the declining trees had suffered extensive root death, and their fine root systems had higher Al concentrations than the healthy trees. Consistent with decline scenarios in other countries, the growth rates of "healthy" trees has been declining since the mid to late 1950's.

Drought, insect defoliation and root infections were also implicated in the observed decline. After tent caterpillar attacks healthy trees were able to resume normal growth while declining trees did not. Now, as this paper is being written, some of the forests of Muskoka are again being defoliated by caterpillars.

Few studies exist on the economics of forest decline owing to acid deposition, given the state of scientific enquiry. Crocker and Forster assumed an 5% growth reduction (attributed to acid deposition by the National Academy of Sciences) to suggest an annual loss of $197 million in commercial forest wood products and a further $1.3 billion loss due to recreation and wildlife habitat disruption.

The 5% loss estimate generally agrees with Canadian forest estimates (Fraser *et al*). Using a Delphi survey technique, which is based upon expert opinion, they estimated declines in growth due to long-range transported air pollutants in the Atlantic and Quebec/Ontario regions of 3% and 5%, respectively, for 1975-1985, projected to be 5% and 7%, respectively, for 1985-1995. On the other hand, Woodman and Cowling have suggested that "... air pollution stress may simply increase the mortality of pollution-sensitive trees enough that resistant trees will grow more rapidly because of their improved competitive edge."

For the maple syrup industry, the total loss in Quebec has been put at $89 million by the Union des Producteurs Agricoles (Penner). While syrup from the sugar maple may be threatened, white birch and yellow birch may provide substitute sources. White birch has the widest distribution of any tree species in Canada (Jones and Alli), and the availability of such substitutes will lessen sugar industry losses, provided these species are not as sensitive to the same atmospheric contaminants as the sugar maple.

3 AQUATIC ECOSYSTEM IMPACTS

The physical impacts of acidification are most clearly demonstrated and understood in aquatic ecosystems. Acidification of water bodies may affect all forms of aquatic life as well as the quality of drinking water, with subsequent effects on commercial fisheries, recreational fishing and human health.

More is known about the qualitative responses than the quantitative relationships between pH and aquatic biomass. The literature frequently concentrates on threshold concepts where either entire species or large blocks of species disappear either through mortality, reproductive failure or relocation. Knowledge is correlated with field observations and, in some cases, is based upon experimental acidification. The consensus of aquatic biology research is that acidification leads to a reduction in species richness (Stokes).

Specific impacts on fish include mortality, reproductive failure, reduced growth, skeletal deformity and increased uptake of heavy metals (Haines). Research has shown that there is a relationship between the reproduction of certain species and pH level. For example, Walleye cease to reproduce when pH is between 6.0 to 5.5 (Beamish).

Newcombe suggests reductions ranging from 5% to 52% in many species of aquatic biota at pH 6.5. However, there is no consistent relationship between pH and biomass changes for the phytoplankton community (Havens and De Costa), and amphibians are relatively insensitive to increased acidity, with many capable of surviving in solutions of pH 4.0 to 4.5 (Pierce). At pH values of 5.0 to 7.0, however, there is evidence that many species suffer as much as 50% mortality, and that acid sensitive species are replaced by insensitive ones.

Aquatic birds are not likely to be affected directly by increased water acidity, but they may be affected by acidity-induced alterations in the food chain. Species richness of fish-eating birds is correlated with pH (Nilsson and Nilsson). As the food chain is disrupted, the birds may switch to other resources and other water bodies (Singer and Fischer). McNichol *et al* report that the common goldeneye preferred acidified lakes, while the carrying capacity for loons and mergansers reduced as a result of loss of fish, thus concluding "lake acidification has varied and opposite impacts on different waterfowl species depending on feeding habits". Similar issues may arise for mammals. Birds and mammals may suffer from increased body burdens of toxic metals. This could have subsequent implications for human health as well. The area of surface water at risk from acidification in Canada is shown in Table 1.

One method of reducing acidification of water bodies is to lime the waterways. Forster (1985) calculated an annual liming cost for Eastern Canada of $112 million dollars. This estimate assumed that a 3 year buffering action could be obtained at a cost of $100 per hectare. An estimate of $20 per hectare was added as the monitoring cost. The Forster estimate considered only those highly sensitive areas receiving sulphate deposition in excess of 20 kg/ha/yr.

The aquatic members of Work Group 1 of the Memorandum of Intent believed that a sulphate deposition rate of 20 kg/ha/yr would protect all but the most highly sensitive areas. The most sensitive group could only tolerate acid depositions of 11 kg/ha/yr or less, although the U.S. members dissented on such an estimate. From Table 1 it is seen that there are roughly 5.9 million ha of surface waters that are highly sensitive and receiving at least 10 kg/ha/yr. and a further 1.7 million ha that are moderately sensitive and receiving at least 20 kg/ha/yr. Thus the total area likely to require liming is 7.6 million ha. which, assuming $100 per ha for 3 years of buffering, totals $760 million or $253 million annually[1], to which monitoring costs should be added. Where highly sensitive areas receiving 10-20 kg/ha/yr. are involved, $100/ha may be low since those areas may be less accessible, requiring more expensive technology, such as helicopters .

Watt, studying Nova Scotia salmon rivers, concluded that liming was not an economic solution since cost far exceeded estimated benefits. The total cost estimate for a 20 year period was $95 million, which included capital cost for roads, silos, annual spreading, operation costs and monitoring. The project aim was to provide an enhancement of 12,000 salmon over current catch. The average cost per restored salmon worked out to $400, while the average value per landed salmon was less than $100. On the other hand, Watt argued that liming may still be desirable to maintain genetic diversity or genetically unique salmon stocks, thus the benefits of genetic diversity cannot be adequately captured by simple cost-benefit analysis.

Forster (1985) pointed out that there are technical problems with liming since existing fish may be killed by remaining heavy metals. Booth *et al* found that whole-lake liming does not stop acid and aluminum pulses caused during spring snow melt which could adversely affect near-shore spawning, offsetting the benefits of liming. However, whole-lake liming did improve whole-lake water quality so that trout re-stocking was successful.

A major concern for the acidification of water bodies is the impact on recreational fishing. Forster used a consumer surplus range of $50 - $100 per fishing day to give an estimated loss of $52 - $104 million in 1981 to Canadian recreational fishing. Minns and Kelso suggest an upper bound of projected future losses to recreational fishing in Eastern Canada of 2 million angler days and $90 million per year in addition to the already existing losses of 2.24 million angler days and $53.2 million in Ontario and Quebec, about $40 million higher than Forster's upper bound.

The Minns-Kelso estimate is based on gross expenditure changes per angling day rather than on changes in consumer surplus. Minns and Kelso estimate significantly larger angling day losses due to acidification than Forster because they assume that anglers who had fished in previously non-acidic waters cease to angle. This elimination of substitution response exaggerates losses.

Forster argued that considering only the consumer surplus losses to recreational fishing caused by acidification would result in underestimating the losses. The fishing activity should be seen as part of a broader recreational experience based upon aquatic resources. The general recreationalist places value on living things in the ecosystem. It is hard to know how individuals value changes in species diversity per se. Forster reports on a contingent valuation study performed for the Ontario Ministry of the Environment that attempted to determine Willingness to Pay (WTP) values to prevent acidification of Ontario's water bodies. Respondents were asked to reveal their WTP values for improving water quality from various levels of pollution to the relatively clean water standard referred to the Ontario Environment Quality Level. The WTP values had a strong correlation with respondent income. Table 2 gives the average WTP values by income class and change in environmental quality.

Using the data in Table 2 to estimate a simple linear inverse demand function relating willingness to pay (WTP) to change in environmental quality (EQ) and income Y, the following equation is obtained:

$$WTP = -151.11 + 32.41 * EQ + 11.04 * Y.$$

The EQ and Y parameters estimates are significant at the 1 percent level, the R^2 is .80 and the F-statistic for the regression is 34.68 which is significant. The equation suggests that average individual WTP is increased by $32.41 for each potential unit decrease on the environmental quality ladder. Each increase of $1000 in income will result in individual WTP increasing $11.04.

A general discussion of the limitations of the study can be found in Forster, 1985. The major limitations seem to be: 1) the study suggested that the general level of Ontario environmental quality would deteriorate -- we now know that the area at risk is much smaller; 2) the bids were not obtained in an iterative bidding game but were first responses -- the questionnaire was quite long and iterative techniques would have certainly led to interview fatigue; 3) It is not clear if the respondents were reporting individual or household WTP.

Forster assumed that households in Eastern Canada would be willing to pay $100 per year on average to preserve environmental quality in the impacted region. This value is in line with estimates for the U.S. Using the 1981 population estimates, this produced an aggregate WTP of $560 million for Eastern Canada.

Neuman reports that surveys between 1980 - 1985 reveal that 50% of Canadians and 70% of Ontarions would be willing to pay higher prices or higher taxes to control acid rain. Over half of these groups were prepared to pay more than $100.

4 AGRICULTURAL SYSTEM

Most researchers have identified ozone as the air pollutant which has the greatest effect on crop production[2]. This section will present some of the findings on the economic impact of ozone on Ontario agriculture.

As early as the mid-fifties, researchers were already suspecting that increased ozone level was causing weather flecks on tobacco (Walker). In the mid-sixties attention began to be focussed on the impact of ozone on white beans. However, those studies mainly concentrated on establishing conformity between field symptomatology and controlled treatments, with little assessment of quantity or quality effects on agricultural output.

Agricultural scientists did not begin to study the economic consequences of elevated ozone levels until the mid-seventies, when it was estimated that tobacco yield losses owing to this pollutant were approximately .73% (about $1,117,500 in 1973 prices)(Gayed), while white bean losses were put at 35%, or $42.00/acre (Curtis).

A more recent and comprehensive analysis of change in production and associated economic effects related to ozone was undertaken by Linzon, who divided Ontario into five regions by ozone level. Only two regions, with concentrations above 0.04 ppm, were considered to be suffering from ozone damage. Linzon estimated change in production using the following formula:

$$\Delta \rho = \frac{P_c \cdot \%L}{100\% - \%L}$$

where %L = percent loss in production;

P_c = current production

$\Delta \rho$ = Change in production owing to lower ozone

Combining estimated yield reductions for 15 crops with existing cropping patterns and returns for the period 1978-80 to production in the high ozone regions, Linzon estimated overall revenue losses in the range of $9 - $23 million[3], representing between .9% - 2.2% of cash receipts. Potatoes, tobacco, white beans, soybeans and wheat were found to experience the greatest impact. The impact on farm incomes could be potentially four times greater than Linzon's estimates because, in the absence of ozone damage, farmers could have augmented returns with very little increase in costs. Thus, in the worst scenario, farm incomes have been reduced by almost 9% because of elevated ozone concentration.

Linzon's approach is a static analysis which provides a useful first indication of the maximum effect of ozone on Ontario crops. However, it does not account for changes which the farmer might make, such as switching to less ozone sensitive cultivars or altering the crops grown.

Moving beyond purely static analyses, Adomait developed a dose-response function for white bean yields in Ontario. The study employed data from ozone antioxidant trials over four years to develop a) ozone dose and yield response models for white beans; and b) an economic model of farmer behavior. The best dose-response function was found to result when percentage change in yield was regressed on three variables: ozone level above 160 milligrams per cubic meter per hour; August-July rainfall; and average August temperature. It was found that between 1976 - 1979 the mean yield loss was about 13%.

The above estimates were then combined with a model estimating the area planted in white beans and known price data to generate supply curves used to calculate producer surplus and revenue losses. The results indicated that average short-run losses were 15% of real average white bean income, totalling $3.3 million, based on 1979 dollars. Long-run losses were calculated as 12% of average income, totalling $2.2 million. The authors concluded that the slightly lower long-run values suggest that farmers adjusted behavior in an attempt to avoid losses associated with declining yields.

In a further attempt to overcome the limitations of static analysis, a study is now being undertaken at the Department of Agricultural Economics and Business of the University of Guelph which seeks to estimate the extent to which areas in southwestern Ontario planted in specific crops are a function of ozone levels and returns to alternative crops[4]. Data for selected crops and counties for the period 1965 - 1983 are used in the regressions. Because ozone values are not available prior to 1975, a dummy variable is included to capture the effect of missing data.

Preliminary results suggest that the area devoted to specific crops in each county can be explained by ozone levels and returns per unit of land, lagged one year. The results are consistent with field experiments which indicate that corn is not sensitive to ozone, and that soybeans are less sensitive to ozone than are white beans.

The above results were used to estimate differences in actual area planted in corn, soybeans and white beans and the area which would have been planted if 1981 - 1983 economic and yield conditions and 1965 ozone levels prevailed (Figure 1). For example, the results indicate that in Elgin County the area devoted to corn and white bean was 9000 and 3000 acres less than it would have been had 1965 ozone levels prevailed. At the same time the area devoted to soybeans was 12,000 acres more than it would have been under 1965 conditions. Generally, the results indicate that in four counties the area planted in white beans declined, while in two counties it increased. In almost all counties more area is now devoted to corn and soybeans than would have been if 1965 ozone levels still obtained.

The foregoing confirms Adomait's finding that farmers adjust their behavior to minimize losses caused by adverse economic and environmental conditions. To date good county level estimates of production costs for specific crops are lacking for Ontario, making an accurate assessment of the economic impact of changing cropping patterns difficult. However, provincial estimates (OMAF) of average variable production costs indicate that, based on the area changes shown in Figure 1, gross margins are generally greater than they would have been under 1965 ozone conditions.

These tentative results should not be taken to mean that high zone levels have increase farm income. Rather, they are an indication that varietal changes coupled with altered cropping patterns have counteracted the negative impacts of elevated ozone concentration. With more detailed data it might still be possible to conclude that farmers could realise even greater incomes if ozone levels were reduced.

The future aim of the Guelph study will be to collect the data required to assess more accurately the impact of ozone on Ontario agriculture.

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Table 1: Impacted Regions at Risk from Acid Deposition in Eastern Canada

Region	Sulphate Deposition (kg/ha/yr)	Area (km²) High Sensitivity	Area (km²) Moderate Sensitivity
Ontario	10-20	11,254	4,124
	20-40	8,452	1,890
	>40	408	98
Quebec	10-20	20,474	2,532
	20-40	10.137	730
	>40		456
Maritimes	10-20		
	20-40	8,719	13,447
	>40		

Source: United States-Canada, Memorandum of Intent, 1983.

Table 2: Average Willingness to Pay to Prevent a Deterioration in Environmental Quality by Income Group*

Income	Change in Ladder Position 8 to 7	8 to 6	8 to 4	8 to 2
< 10,999	55	84	74	90
11,000-19,999	65	75	88	120
20,000-29,999	108	136	186	246
30,000-34,999	191	225	288	421
35,000 +	301	369	528	668

* The numbers in the Table are the average dollar values for the given income group for a given change.

Source: ARA Consultants, 1982.

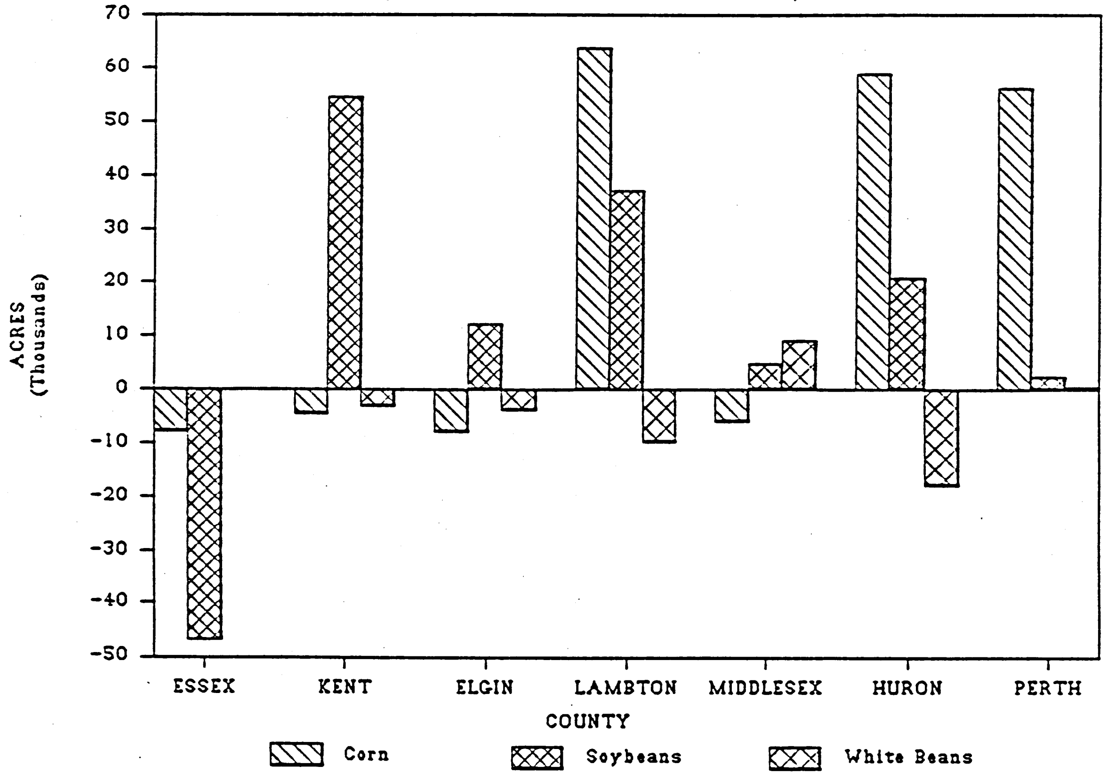
Table 3: Estimated Yield Losses for Selected Ontario Crops Due to Ozone Damage (Linzon, Table 4)

Crop	Ozone Region 5		Ozone Region 4	
	Average	Range	Average	Range
White Beans	12	(6-18)	7	(4-11)
Potatoes	8	(4-12)	5	(3-8)
Onion	8	(4-12)	5	(3-8)
Sweet Corn	8	(4-12)	5	(3-8)
Lettuce	8	(4-12)	5	(3-8)
Radish	8	(4-12)	5	(3-8)
Spinach	8	(4-12)	5	(3-8)
Rutabages	8	(4-12)	5	(3-8)
Tomato	5	(3-8)	2	(1-3)
Cucumber	5	(3-8)	2	(1-3)
Green bean	5	(3-8)	2	(1-3)
Soybean	3	(2-4)	*	(*)
Grape	3	(2-4)	*	(*)
Wheat	3	(2-4)	*	(*)
Tobacco	1	(.5-1.5)	.6	(.3-.9)

* No expected damages of losses.

FIG 1: GAINS OR LOSS BECAUSE OF OZONE

(1981-83 Returns - 1965 Ozone Levels)



End Notes

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1. Minns and Kelso suggest a range of annual liming costs of $75-$172 million depending on the extent of liming. The upper bound is for treatment to all lakes with pH less than 6. The discrepancy between this estimate and Forster's cannot be resolved, owing to a lack of detailed information on the assumptions used by Minns and Kelso.

2. Forster, 1984, found the economic impact of SO_2 and NO_x to be greater than that of ozone. This result may be attributed to the reliability of the agricultural research data used in performing the economic analysis. Forster noted in 1987 that by usin U.S. National Acid Precipitation Assessment Program data his assessment of losses in Ontario dropped from $105 million to approximately $2.4 million.

3. Forster, 1984, in a static analysis, also calculated the losses owing to ozone to be $23 million.

4. It is hypothesized that the area devoted to a given crop are a function of the ozone levels and returns of the year prior to planting. Therefore, ozone and returns are lagged one year.