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FORESTS AND GLOBAL WARMING

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TABLE OF CONTENTS

PAGE

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FORESTS AND GLOBAL WARMING

INTRODUCTION

Forests cover almost one-half of Canada's land mass, an area representing about 10% of the world's forested land. They have a vitally important place in this country's environmental mosaic and strongly influence climate, watersheds, wildlife and fisheries habitats. Canada's forests also have a profound cultural and heritage value for Canadians. In 1989, a national poll showed that three-quarters of Canadians "…see the forest as a national treasure, to be held in trust for future generations."[(1)]

Forests are as important to Canada's economic health as they are to the country's environmental integrity. The forest sector is a major provider of employment and a major source of revenue for governments, both federal and provincial. It follows, then, that appropriate management of the forest resource, including its protection and regeneration, is essential to the national well-being.

The "greenhouse effect," which is predicted to result in a significant degree of global warming over the next several decades, is real. Indeed, it is the greenhouse effect that keeps the overall average temperature of the globe at about +15ºC. Without this phenomenon, the earth would have an overall average temperature of -18ºC, resulting in a climate that would be too cold and harsh for most of the life forms that characterize the rich biological diversity of the earth today. The greenhouse gases which contribute to the heating of the globe include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO), and the chlorofluorocarbons (CFCs).

The relationship of Canada's forests to climate change and global warming is significant on several levels. Some 50% of the anticipated global warming will be caused by CO_2, a ubiquitous gas which is an integral component of the growth cycle of forests. Healthy,

(1) Environics Research Group Limited, *1989 National Survey of Canadian Public Opinion on Forestry Issues – Final Report*, Prepared for Forestry Canada, Toronto, May 1989, p. 9-10.

growing forests remove carbon dioxide from the atmosphere and store it as organic carbon in wood fibre. Standing forests, therefore, act as dynamic reservoirs of CO_2 which can affect the concentration of atmospheric carbon dioxide. The reverse of this beneficial biotic activity is the fact that, collectively, forests represent a massive potential source of carbon dioxide emissions.

Canada's forests are believed to be roughly in balance with the global carbon cycle, removing about as much carbon from the atmosphere as they contribute. Therefore, Canadian forests will be able to moderate the onset of global warming through sequestration of atmospheric carbon only to the extent that forest stands can be increased in size.

If significant climate warming occurs, the phenomenon will exert an important, perhaps crucial, impact on Canada's forest resources. A warmer climate and higher future concentrations of CO_2 in the atmosphere will affect the growth, survival, and reproduction of trees in Canada's forests, perhaps even changing the nature, and extent of those forests. Such changes would have a dramatic, and possibly very negative, impact on the Canadian economy, should the harvestable stock of trees be seriously affected under a future climate regime.

CANADA'S FORESTS

To understand the significance of global warming for Canada's forests, and the possible impacts of climate change, it is necessary to know something of the types of forests that grow in this country. The three principal types of forest around the world are related to climate regimes. These are the equatorial and tropical region forests; the temperate-zone forests; and those forests associated with colder climates. It is this last type that predominates in Canada.

Most Canadian forests lie within the cold-climate boreal belt, the northern circumpolar region which includes Alaska, the Soviet Union (Siberia), Finland, Sweden, and Norway.(2) Temperate-zone forests, more common to parts of the United States, extend into Canada in milder areas along the Pacific coast and in southwestern Ontario. In southern Ontario, the hot, humid summers have allowed the development of a deciduous forest. Moving north through Quebec and Ontario toward the cold-climate boreal forest, one passes through a transitional mixed-wood forest where coniferous and deciduous trees exist in about equal proportions. In British Columbia, a forest dominated by conifers has developed in the cool, temperate maritime climate of the Pacific coast.

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(2) The word "boreal" means related to, or growing in, the northern parts of the northern hemisphere.

Canada's predominant boreal forest is principally composed of coniferous trees, such as pine, spruce, larch and fir. This forest, which represents about 80% of Canada's total forested area, forms the basis of much of the forest industry in Canada. The tree species in this region established themselves some 10,000 years ago after the retreat of the last ice-sheets. These trees have evolved to grow and reproduce in a climate characterized by an extended and very cold winter interval. A change in the climate, therefore, could have profound effects on the growth and reproduction of conifers and could affect the species composition of this region.(3)

THE FOREST ENTERPRISE

Canada's economy has benefited enormously from the forest resource. Currently, the annual value of shipments from the forest sector exceeds $40 billion. The forest products industry is the largest single industrial sector in Canada, generating an annual trade surplus of almost $20 billion. Canada is the world's largest exporter of forest products and accounted for 21% of total world trade in 1987.(4) In 1988, the forest sector contributed 3.6% to Canada's gross domestic product.

It has been estimated that the forestry sector provides direct or indirect employment for some 800,000 to one million Canadians. For some 350 Canadian communities, many in northern, rural areas, the forest industry is virtually the only source of economic activity. In many other cities and towns, the industry is very important to the economic base. If this resource were to be intensively managed, as it is in some Scandinavian countries, it has been suggested that the forestry enterprise might continue to form not only a major part of Canada's economic activity, but could possibly even be expanded in the future.(5)

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(3) C.R. Stanton, "Forest," The Canadian Encyclopedia, Second Edition, Volume II, Hurtig Publishers, 1988, p. 810.

(4) J.S. Maini, "Anticipated Climate Change and Forests," Forestry Canada, Background Notes for Presentation to the Standing Committee on Environment, 21 November 1989a.

(5) House of Commons, *Forests of Canada: The Federal Role*, Report of the Standing Committee on Forestry and Fisheries, Sub-Committee on Forestry, Bud Bird, M.P., Chairman, November 1990, p. 2.

FORESTS AS A CARBON SINK

Carbon dioxide (CO_2) is produced by the combustion of organic carbon compounds, for example in the burning of wood or fossil fuels. It is also a principal by-product of the respiration of living organisms, trees included. In a simplified description of respiration, organic carbon molecules, such as sugars, are combined with oxygen to release energy for life's functions and carbon dioxide is produced as a waste product. The decay of plant material in the presence of oxygen will also release CO_2.

Carbon dioxide is removed from the earth's atmosphere by plants through photosynthesis, a complex series of reactions that combines CO_2, water and energy from the sun to produce organic carbon compounds and oxygen. Without photosynthesis, life on earth essentially would cease to exist. Photosynthesis is carried out by terrestrial and aquatic chlorophyll-bearing ("green") plants. The world's forests collectively form a major locus of photosynthetic activity and therefore play an important part in the earth's carbon cycle and in the global-warming equation.

As a tree increases in size it accumulates CO_2 from the atmosphere, converting it into the complex organic compounds in wood. As long as the tree is alive and growing, that carbon will remain in storage; hence the description of forests as a "sink" or reservoir for atmospheric carbon. Forest soils store even larger amounts of organic carbon than do forest stands. There are also large areas of peat deposits, rich in organic carbon, throughout the northern coniferous forest zone.

The most effective and efficient fixation of atmospheric carbon occurs in the early years of a forest stand when the trees are growing rapidly. At the early stage of growth, trees accumulate more carbon through photosynthesis than they release through respiration. As the stand ages, however, the amount of carbon released through respiration increases. Eventually, the balance will shift to a net loss of carbon to the atmosphere as the sum of carbon emitted through respiration and decay exceeds that sequestered by photosynthesis.

Ultimately, when the stand reaches advanced age and the trees begin to die, the balance will shift predominantly to carbon loss. This observation does not mean, however, that old-growth forests should be cut and replanted with seedling trees for the purpose of increasing the carbon sink. Old-growth forests have intrinsic ecological and cultural values, and a considerable body of evidence indicates that they should be left intact.

Once a tree is cut, some of the carbon may be released back to the atmosphere fairly quickly as the small limbs, bark, foliage, etc., are discarded and burned, or allowed to decay on the forest floor. Similarly, a tree burned in a forest fire will quickly release a large quantity of carbon dioxide, together with a mixture of other gases.

If the tree is used in construction or in other relatively permanent products, the carbon will remain trapped in the wood, perhaps for decades or centuries. If, however, the wood is burned as fuel, or is converted into papers or chemicals which have a limited temporal use-cycle, all of the tree's accumulated carbon may be emitted to the atmosphere in a relatively short period of time.

The issues of reforestation and deforestation are very important in a consideration of global warming. Reforestation refers to the replanting of trees in a commercial forest after harvest. Deforestation occurs when forested land is converted to other permanent uses, such as agriculture or settlement. Deforestation thus contributes to increasing concentrations of atmospheric CO_2, partly through a reduction in global photosynthetic activity, and partly through the release of the carbon stored in the forest biomass. Most of the world's attention to deforestation is focused on tropical countries, particularly the rainforest of Brazil.

FOREST MANAGEMENT

Forest management is essential to maintain a healthy, productive forest for commercial, recreational, and ecological reasons. In the context of global warming, forest management gains additional importance because a well-managed, vigorously growing forest will sequester carbon more efficiently than a poorly managed stand. Efficient forest management can be a part of the solution to the developing global-warming scenario, particularly the prompt regeneration of harvested areas, either through planting or by natural means, and the reduction of losses of stands to wildfire, insects and disease. The extensive commercial harvesting of trees and the loss of trees from other causes in the developed countries, Canada included, has not always been followed by adequate replanting of stock.

In an appearance before the House of Commons Standing Committee on Environment, Dr. J.S. Maini of Forestry Canada stated that there are 244 million hectares (ha) of inventoried productive forest land in Canada. Of this total, 7%, or 17 million ha, were classified as "NSR" in 1989. Land that is classified as NSR is:

> … not satisfactorily (or sufficiently) restocked (or revegetated), productive forest land that has been denuded and has failed partially or completely to regenerate naturally or to be artificially regenerated. The regeneration must contain a minimum number of well-established, healthy trees free-to-grow, sufficient to produce a merchantable timber stand at rotation age.[6]

The key component of this definition is that the trees must form a commercial stand in order not to be regarded as NSR. Although most of these NSR lands are not currently supporting stands of trees of commercial quality, they are covered by foliage of some sort which is sequestering some atmospheric carbon. Dr. Maini informed the Committee that, while reforestation of these 17 million ha would make only a modest contribution to the global carbon balance, it could be a significant factor in Canada's national carbon balance.[7]

In their appearance before the Standing Committee on Environment, Forestry Canada officials stated that the situation with Canada's NSR lands has improved recently: "… during the last five years, through cost-shared programs with the provinces, we have spent about $1 billion in reforestation programs and have planted about 1.3 billion seedlings, and almost 1 million hectares have been treated in the country."[8] The question of NSR backlog remains, however. In 1988, for example, there was a shortfall of 198,000 hectares of forest land that were not regenerated after harvest, either by seeding or through natural processes.[9]

Forestry Canada's testimony to the Environment Committee also stated that the federal government would participate with the provinces in replanting the NSR backlog, "… provided the provinces and the industry look after the current cutters."[10] The Director of Forestry Development for Forestry Canada suggested that if no more NSR lands were created, and if funding through federal-provincial forestry agreements were directed totally at backlog,

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(6) J.S. Maini (1989a).

(7) *Ibid*.

(8) J.S. Maini, House of Commons, Minutes of Proceedings and Evidence of the Standing Committee on Environment, Issues No. 22, 21 November 1989b, p. 22:11.

(9) Forestry Canada, 1991-92 *Estimates, Part III Expenditure Plan*, p. 26.

(10) J.S. Maini (1989b), p. 22:16.

then, with "… a sustained level of planting the backlog could probably be rehabilitated within 10 or 20 years.[(11)]

In the context of forest management and the restocking of NSR lands, the matter of federal-provincial forestry agreements is important. Most of Canada's forested areas fall under provincial jurisdiction. The principal type of federal-provincial forestry agreement in Canada is the "Federal-Provincial Forest Resource Development Agreements" (FRDA) which are administered by the federal and provincial governments. In 1989, there were FRDAs between the federal government and the governments of Newfoundland, Nova Scotia, Prince Edward Island, Ontario, Saskatchewan, Alberta, and British Columbia. The federal government also signed agreements other than FRDAs with New Brunswick, Quebec and Manitoba.

Most of the federal-provincial forestry agreements have now expired, including the FRDAs with Ontario, Saskatchewan and Alberta (31 March 1989) and those with Newfoundland and British Columbia (31 March 1990). The non-FRDA agreements with Quebec and Manitoba have also expired. New agreements were signed with Nova Scotia and New Brunswick near the end of March 1990. In February 1991, it was announced that a new FRDA had been negotiated between the federal government and British Columbia. New agreements with the other provinces are currently under negotiation.

FORESTS AND FIRE

Fire in a forested area, whether wildfire or controlled burning, has an obvious relevance to the global warming issue: fires result in the rapid liberation of large amounts of CO_2 and smaller amounts of other gases, including methane, a much more potent greenhouse gas than carbon dioxide. Destruction of forest stands will also reduce the total amount of photosynthesis and therefore contribute to an increase in atmospheric concentrations of CO_2.

It is incorrect, however, to conclude that fires are entirely destructive and negative events in the forest environment. The boreal forest has evolved with fire as a frequent and significant environmental factor:

(11) John Forster, House of Commons, Minutes of Proceedings and Evidence of the Standing Committee on Environment, Issue No. 22, 21 November 1989, p. 22:17.

> The overwhelming impact of wildfires on ecosystem development and forest composition in the boreal forest is readily apparent and understandable. Large contiguous expanses of even-aged stands of spruce and pine dominate the landscape in an irregular patchwork mosaic, the result of periodic severe wildfire years and a testimony to the adaptation of boreal forest species to natural fire over millenia. The result is a classic example of a fire dependent ecosystem, capable, during periods of extreme fire weather, of sustaining the very large, high intensity wildfires which are responsible for its existence.(12)

A. Wildfire

Forest fires, particularly in areas remote from human settlement, can cover enormous areas. The so-called Great China Fire in the early spring of 1987 on the China-USSR border burned over 1.1 million hectares. At the same time there were much larger fires burning in the boreal forests of Siberia in the USSR, some covering an area of 2 million ha. In total, up to 50 fires in Siberia in 1987 are estimated to have consumed approximately 10 million hectares of forest.

Forest fire incidence in Canada has been extensively studied, and detailed fire statistics have been collected since 1920. The data show that the annual fire frequency has increased steadily over the last six decades, from about 6,000 fires annually in the 1930-1960 period, to almost 10,000 fires annually during the 1980s. The increasing numbers of fires have been ascribed to the impact of a growing Canadian population and increased forest use, as well as to an expanded capability for detecting fires in more remote areas.

The number of fires does not necessarily give an indication of the area burned, and in fact that area fluctuates tremendously each year. From 1920 to 1960, the area burned by forest fires in Canada actually decreased; however, it increased dramatically during the 1980s, primarily as a consequence of periods of short-term extreme fire weather in western and central Canada. The annual average number of fires and area burned in Canada for the 1980-1989 period were 9,618 and 2.44 million ha, respectively. In 1989, the worst fire year on record, there

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(12) Brian J. Stocks, "The Extent and Impact of Forest Fires in Northern Circumpolar Countries," Chapman Conference on Global Biomass Burning: Atmospheric, Climatic, and Biospheric Implications, Williamsburg, Virginia, 19-23 March 1990 (in press). [unless otherwise indicated, the data presented below are from this paper]

were more than 11,000 fires in Canada and the burned area was greater than 6.4 million hectares.[13]

As of September 1990, the 1990 fire season in Canada was described as "average," with 9,057 fires being reported.[14] Total hectarage, at 839,570 ha in lost stands, was well below the average for the 1980-1989 period. Much of the hectarage lost in 1990 was in Western Canada, with the Yukon and Northwest Territories and Saskatchewan accounting for 51.6% of the total area burned. Manitoba, which was the location of enormous fires in 1989, recorded 482 fires and a total of 16,794 ha burned. As is typical in forest fire scenarios, a relatively small number of fires accounted for the bulk of the area burned: in 1990, 4% of the fires burned 54.6% of the hectarage.

The relationship between forest fires and multiple uses of the forest by Canadians is reflected in the statistics on causes of fires: some 65% of fires are caused by human activities and the remainder, 35%, by lightning. However, this latter cause accounts for 85% of the area burned because such fires occur randomly and in more remote areas. This delays detection of the fire and makes access difficult for fire-fighters, thereby frustrating quick initial attack and allowing the fire to become well established before mitigation efforts can be brought to bear.

Forest fire fighting in Canada has become a highly developed activity, and this is reflected by the fact that the vast majority of fires are controlled early; only 2-3% of forest fires in Canada grow larger than 200 ha and these fires account for 97-98% of the total area burned. Over the past seven decades, the percentage of smaller fires has increased steadily while the percentage of larger fires has declined, a tribute to the success of fire-management programs.

In many jurisdictions in Canada decisions have been made to allow fires in low-priority areas to run their course, priority being defined on the basis of human values assigned to the forest resource. In Ontario in the 1980s, this resulted in an increased number of larger fires in such areas. The decision has been based partly on economic considerations; remote fires are extremely expensive to fight.

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(13) Brian J. Stocks, "Global Warming and the Forest Fire Business in Canada," Canada/United States symposium on the Impacts of Climate Change and Variability on the Great Plains; Calgary, Alberta, 11-13 September, 1990b (in press).

(14) Forestry Canada, Personal Communication, February 1991.

Also, fire, as stated earlier, is a natural component of the boreal ecosystem and plays a dynamic role in forest reproduction and renewal. It should also be noted that when a forest burns in a wildfire, not all of the organic carbon stored in the trees is released to the atmosphere. The portion of the tree below ground (the root system), estimated to comprise about 30% of the total biomass, typically does not burn.

Also, it is estimated that on average only about 20% of the above-ground portion of the tree actually burns, the rest remaining as soil organic matter, or as long-lasting charcoal.(15) Therefore, given that fire in the boreal forest makes a positive contribution to forest renewal, it is possible that forest fires might ultimately result in a net accumulation of carbon in biomass.

Before the onset of very favourable conditions for fire in the last decade, it was generally believed that damage from fires would continue to decline in this country with improved forest fire management and control. That this has not happened is a portent of what might take place should fire conditions continue to worsen under a new climate regime.

There is now a general awareness within the scientific, and even the political, community that the global burning of biomass has a significant impact on the composition of the atmosphere and on climate warming. While most world attention is focused on the destruction of forests and biomass burning in tropical regions, research is also underway to determine the impact of biomass burning in the northern hemisphere. For several years, Canada and the United States have been cooperatively studying the behaviour and atmospheric environmental impact of large-scale fires in Canada's boreal forest zone.

One result of this research has been the characterization of smoke chemistry associated with fires in the boreal forest. When combined with fire statistics, the data have been used to generate estimates of the contributions of northern hemisphere forest fires to trace gases in the earth's atmosphere. Of the total amount of carbon released during a fire in the boreal forest, 89% is in the form of CO_2 and 9% is carbon monixide. The remaining 2% is released as methane (CH_4) or non-methane hydrocarbons. The following figures, expressed as grams of gas released per kilogram of carbon burned, have been estimated: carbon dioxide, 1500 g/kg; carbon monoxide, 150 g/kg; methane and total non-methane hydrocarbons, 15 g/kg.

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(15) W. Seiler and P.J. Crutzen, 1980: quoted in Christopher P. Da Silva, "Role of the Canadian Forests in the CO2 Issue," Canadian Climate Centre, Environment Canada, 1 May 1982, p. 18.

By combining these figures with statistics on the area of forest burned in the northern circumpolar region, estimates have been derived for total trace gas emissions from the region's forest fires. Approximately 70 Teragrams (Tg = trillion grams, or 1 million tonnes) of carbon are consumed in fires annually, on average. This equates to releases of 105 Tg of carbon dioxide; 10.5 Tg of carbon monoxide; and 1.1 Tg of both methane and non-methane hydrocarbons.

These figures have to be viewed in the context of total global emissions of greenhouse gases from biomass burning. The most recent estimate of global biomass burning indicates that 2,000-5,000 Tg of carbon are released each year, the primary contributors being savannah (tropical grassland) burning and the deforestation of tropical areas. Thus, forest fires in the northern circumpolar region contribute about 1.4-3.5% of the carbon released worldwide through biomass burning, assuming that the various estimates are accurate.(16)

Forestry Canada has been developing estimates of the carbon balance of Canada's forest lands; that is, the balance between the carbon released from the forest through respiration, wildfire, commercial harvest, the impacts of insects, disease and other disturbances, and the amount of carbon sequestered by foliage from the atmosphere. Obviously, this is an enormous, and enormously difficult, proposition, given the immense hectarages involved and the large number of species of trees and other plants.

Nonetheless, the carbon balance of Canadian forests has been estimated, using data from 1986. This work indicates that Canada's forests had a total carbon inventory of 225 billion tonnes, and that there was an excess of carbon accumulation over carbon emissions of 116 million tonnes. Two points should be kept in mind, however. First, the amount of net carbon accumulation for the reference year is very small in relation to the total stored in the forest – just over 0.05%. Second, a change in forest conditions, such as the very severe fire situation that developed in 1989, would change the balance to that of a net carbon source. For these reasons, Canada's forests are assumed to be roughly in balance with the global carbon cycle.(17)

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(16) Paul J. Crutzen and Meinrat O. Andreae, "Biomass Burning in the Tropics: Impact on Atmospheric Chemistry and Biogelchemical Cycles," *Science*, Vol. 250, 21 December 1990, p. 1669-1678. (Also, quoted in Brian J. Stocks, 1990b.)

(17) Forestry Canada, Personal Communication, March 1991.

B. Slashburning

In the context of the burning of forest biomass, it is appropriate to consider the matter of slashburning, also known as “prescribed fire,” which is used in silvicultural programs to prepare harvested forest sites for replanting. Prescribed burning of slash wood residue and litter on the forest floor after harvest releases significant quantities of carbon dioxide and other gases to the atmosphere.

The practice is well-established in British Columbia and Ontario, with the former being by far the greater user of the technique. In British Columbia, prescribed burning takes place on more than 100,000 ha each year - 137,596 ha in 1989, burning on just over 73,000 ha of which was for silviculture purposes. The remaining hectares included large areas for range and wildlife habitat improvement. In Ontario, the total prescribed burned area averages less than 10,000 ha per year, mostly in the boreal forests of northern Ontario, away from major population centres.(18)

Slashburning for silviculture has been practised in B.C. since the early 1900s and is currently regulated in the province by the B.C. Forest Service under a permit system. For silviculture, slashburning is carried out “to reduce fire hazard, facilitate planting, provide a favourable environment for seedlings, and to eliminate diseases such as dwarf mistletoe.”(19) As well as releasing smoke and greenhouse gases, the practice may also have other negative impacts, including possible reduction of long-term nutrient supply and soil organic matter at the site, and elimination of beneficial micro-organisms.(20)

Significant quantities of CO_2 are released directly through slashburning; however, if this material is not burned, it will eventually decompose on the forest floor and release its carbon through biological, rather than physical, processes. The time scale will be longer, but the result will be similar. It must also be kept in mind that prescribed burning for silviculture, like wildfire in the boreal forest, is followed by regeneration of the forest stand.

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(18) Bruce D. Lawson, “Where There Is Fire, There’s Smoke: A Global View of B.C.’s Prescribed Burning,” Presentation at Panel Discussion on Smoke Management, Southern Interior Fire Management Committee, Cranbrook, B.C., 2 June 1990, p. 2.

(19) Forestry Canada, “Does Slashburning Increase Atmospheric Carbon Dioxide Levels?,” *Focus on Forestry*, June 1990, p. 1.

(20) Peter Fuglem, “Prescribed Burning in British Columbia,” B.C. Forest Service, Unpublished Note, 19 July 1990.

The new forest will sequester atmospheric carbon, converting it into wood through photosynthesis. Whether the amount of carbon recovered by the new managed forest will ultimately be greater than, less than, or equal to that recovered by an unmanaged forest will depend on a number of factors. However, it is certain that the total contribution of CO_2 to the atmosphere from slashburning will be significantly less than that suggested by emission levels alone.

IMPACTS OF GLOBAL WARMING ON FORESTS

The discussion of the possible impacts on Canada's forests of increases in global temperature and climate change must commence with a clear recognition that there are enormous uncertainties associated with the various scenarios that have been advanced. However, there is a good consensus within the scientific community that some warming of the earth is probable and that regional climates will change in the future. The boreal forest, which forms the basis of much of Canada's forest resource and the industry it supports, is very sensitive to climate change:

> The structure and function of the boreal forest ecosystem is more clearly dependent on climate than many other ecosystems. Many characteristics of the boreal forest, including tree physiology and productivity, vegetation zones, fire, and insects and diseases are inextricably linked to climate.(21)

With a doubling of carbon dioxide in the atmosphere (the "2 x CO_2" scenario), the earth's surface temperature might increase by 1.5-4.5˚C; this could happen by 2030 under a "business-as-usual" scenario, or as early as 2015 under a high-emission scenario. The effects will be even more severe in northern regions, particularly in Ontario and Quebec: temperature increases of "perhaps up to ten degrees or more are expected in parts of the boreal forest."(22) This level of warming occurring over the next century would represent a rate of climate change

(21) E.E. Wheaton and T. Singh, "Exploring the Implications of Climatic Change for the Boreal Forest and Forestry Economics of Western Canada," *Climate Change Digest*, CCD 8902, Environment Canada, 1989, p. 2.

(22) Forestry Canada, *Strategic Plan for Research on Climate Change 1990-1995*, Science Directorate, 21 March 1990, p. 1.

ten times more rapid than forest trees and ecosystems have experienced during the past 10,000 years.(23)

The effect of climatic change on Canada's ecosystems is currently the subject of research at Environment Canada using a "climate-ecosystem response model" which permits the development of ecological scenarios under various climate regimes. In January 1990, the department published a report on the "ecoclimatic provinces" of Canada under current conditions and under the warmer climate anticipated in 2050.(24) Table 1, taken from this report, lists the projected real changes, while Figures 1 and 2 illustrate the current and projected ecoclimatic provinces on a map of Canada.

Table 1
Ecoclimatic Provinces of Canada

	Area of Canada (%)		
Ecoclimatic Province	Current	Future	Change
Arctic	26	20	- 6
Subarctic	20	8	-12
Boreal	29	15	-14
Cool Temperate	4	15	+11
Moderate Temperate	<1	5	+ 5
Grassland	5	12	+ 7
Transitional Grassland	0	8	+ 8
Semi-Desert	0	2	+ 2

Source: Brian Rizzo, "The Ecosystems of Canada in 2050: a Scenario of Change," *State of the Environment Reporting*, Newsletter No. 5, Environment Canada, January 1990, p. 4-5.

For forestry, the most dramatic changes will be in the size and location of the boreal forest ecoclimatic province. The boreal forest, currently occupying a wide swath that sweeps across Canada from Newfoundland to the Rocky Mountains and Alaska, making up some 82% of Canada's forested area, is projected to shrink by 14%. At the same time, the cool temperate and moderate temperate climatic zones, currently covering only small southern areas of Canada, will grow to 15% and 5% of Canadian territory, respectively. Similarly, the grassland zone is projected to expand to 12% of total area from its current 5%.

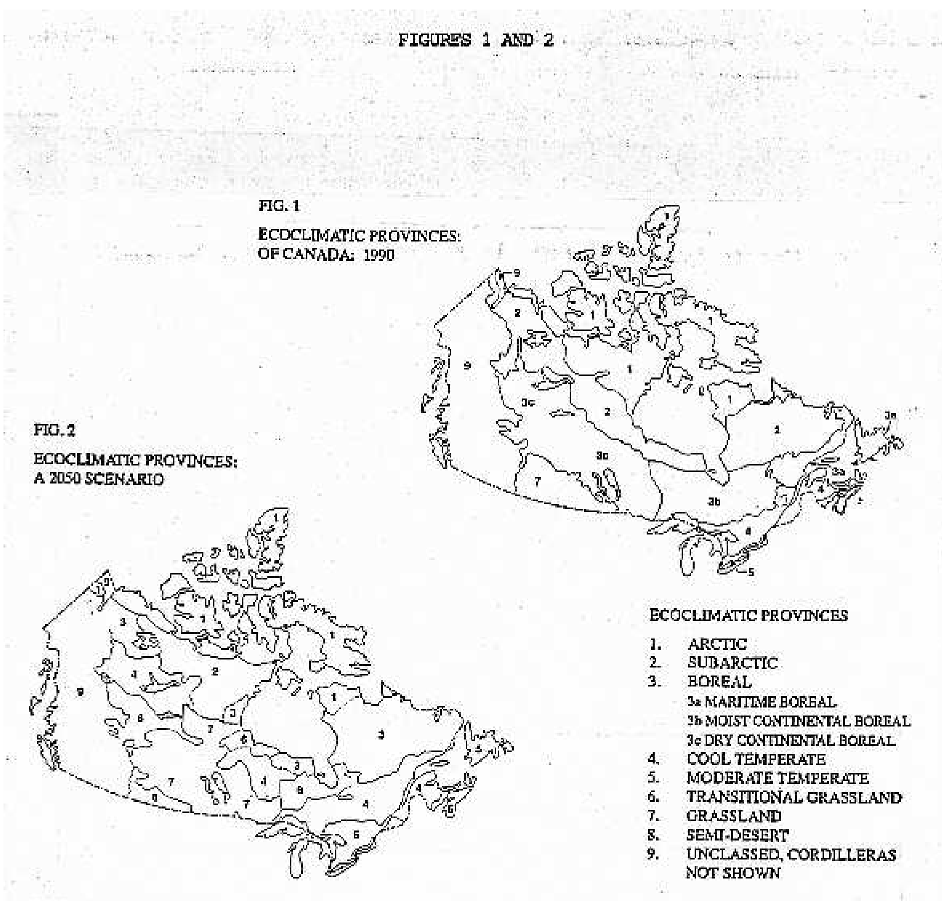
(23) J.S. Maini (1989b), p. 22:8.

(24) Brian Rizzo, "The Ecosystems of Canada in 2050: a Scenario of Change," State of the Environment Reporting, Newsletter No. 5, Environment Canada, January 1990, p. 4-5.

In rough terms, the climatic zone favouring the boreal forest will move much farther north and the temperate climate zone, which supports a deciduous forest, will expand northwards from its current restricted area in the southeast of Canada. The ecoclimate of Newfoundland will change from maritime boreal to moderate temperate, an ecoclimatic zone currently found only in southern Ontario.

Dr. J.S. Maini of Forestry Canada gave the Environment Committee a rough estimate of the impact of climate warming on Canada's forests:

> One of the things we have projected in Canada is that for everyone degree centigrade change in temperature, the belts of forests, the boreal forests, the hardwood forests, the mixed wood forests, are likely to shift about 100 kilometres.(25)



Source: Brian Rizzo, "The Ecosystems of Canada in 2050: a Scenario of Change," *State of the Environment Reporting*, Newsletter No. 5, Environment Canada, January 1990, p. 5.

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(25) J.S. Maini (1989b), p. 22:9.

The Intergovernmental Panel on Climate Change (IPCC) provides the following, more detailed projection, based on computer simulations:

> Under the GISS 2 x CO_2 climate scenario the circumpolar boreal forest could shift some 500-1000 km northwards … The southern boundary of the Canadian boreal forest could shift some 470-920 km north, and the northern boundary some 80-720 km north … Under the GFDL scenario, however, the respective potential shifts could be 250-900 km and 100-730 km northward. Projected losses of potential boreal forest sites in the Canadian south could amount to 170 million ha, while gains in the north could amount to 70 million ha…, a net loss of 100 million ha.(26)

The time frame involved in a change in the type of forest is open to speculation. Although the climate in a particular region may become altered, it could take many decades, or even longer, for the species composition of a forest to change. A dramatic event such as a forest fire could, however, hasten such a change.

There are a number of factors which will be brought to bear on the productivity of Canadian forests in a warmer climate. It is impossible to be specific about the effects of any of these factors, but for purposes of policy assessment and planning it is essential to be cognizant of them.

It has already been noted that there could be a change in the zonal climates in Canada, with large areas becoming more suitable for deciduous or mixed wood forests, or grasslands, rather than for boreal species. Some areas could see faster tree growth as a consequence of warmer climate. Similarly, there could be a "fertilizer effect" from higher atmospheric CO_2 concentrations which would increase a tree's photosynthetic rate, and therefore its rate of growth. It is not certain, however, that this will occur; the fertilizer effect of higher CO_2 concentrations has been demonstrated with seedling trees but it is not known if mature trees will respond in the same way.

Paradoxically, a warmer climate may result in an increase in winter damage to some tree species. If a warmer climate produces a decrease in snowfall, the frost may penetrate deeper into the ground and damage tree roots. This type of damage has already been implicated

(26) Intergovernmental Panel on Climate Change, Draft Report of Working Group 2, *Likely Impacts of Climate Change*, Chapter 2, Section 3.4.1, 1990. (GISS is an acronym for the Goddard Institute for space Studies; GFDL is an acronymfor the Geophysics Fluid Dynamic Laboratories.)

in the decline and death of hardwood trees in Canada. The current serious decline of sugar maple forests and other hardwood species in eastern Canada may be due, at least in part, to this phenomenon.(27)

Forest productivity is generally higher in warmer, moister climates. In some areas of Canada, moisture may well become a limiting factor in parts of the forest ecosystem where lower levels of precipitation accompany increased temperatures, bringing about a decrease in forest productivity. Also, while the warmer climate theoretically may move the forest zone farther north, the actual development of forests in more northern regions will be subject to the availability of appropriate soil conditions. It is also possible that some northern lands in the Canadian prairies, now marginal for agriculture, could become more productive. If agriculture begins to encroach on existing forest lands, land-use conflicts between agriculture and forestry could arise.

The matter of forest diseases and insects is another concern. The activities of some species of insect pests prevalent in the United States are restricted in Canada's colder climate. Insect populations will certainly change in number and type with climate warming, very possibly to the detriment of the forest resource. One possible future pest is the balsam woolly aphid, a sucking insect which attacks balsam fir and damages the wood quality by staining the cells and which may also cause tree mortality. The distribution of this insect pest is currently restricted by cold winter temperatures but the situation might change with global warming.

A second example is the eastern spruce budworm, an extremely serious insect pest which causes defoliation of a number of valuable conifer species, including balsam fir, white spruce, hemlock, and eastern larch. The budworm causes extensive tree damage and mortality in evergreen forests east of the Rock Mountains. In 1986, 25 million hectares of forest were dead or dying as a consequence of attacks by this insect.(28) Budworm epidemics are usually preceded by two to three years of warm, dry spring weather, a scenario that might become more typical with global warming.

Diseases in Canadian forests yearly extract a significant toll in tree damage and mortality. As is the case with insects, many of these root and stem diseases are limited in distribution and severity by low temperatures, a situation that could change with climate

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(27) J. Peter Hall, "How Will the Projected Changes in Canada's Climate Affect the Sustainability of our Forests?," Forestry Canada, unpublished paper, 3 January 1991, p. 9.

(28) *Ibid*., p. 14.

warming. If a warming climate causes forest ecosystems to become progressively less well-suited to their environments, increasing areas of forest will become stressed, a situation that typically renders trees more susceptible to attack by disease organisms, as well as by insect pests.

Forest ecosystems evolve very slowly, unlike grasslands or agricultural crops. Also, as was noted earlier, the pace of projected global warming will be unprecedented:

> … we should recognize that forests … are long living ecological entities. Many of our forests are 500, 700, 1,000 years old. In British Columbia there are many cases where you have forests more than 1,000 years old … the rate of (climate) change, which is likely to be 10 times more than what we have experienced over the last 10,000 years, is very crucial when we determine the likely impact on forests. Our forests have not had the experience of that kind of change.(29)

It was pointed out earlier that the tree species that now populate the Canadian boreal forest evolved in a cold climate. A warming of the climate could adversely affect their growth and reproduction. They would also be at a competitive disadvantage with respect to species that have evolved in a warmer climate. This might not have a major effect on standing stock but could have serious impacts on reforestation, whether accomplished through natural means or through human intervention.

While annual agricultural crop species can be improved and adapted fairly quickly to new environmental conditions through breeding programs, the same is not true for forest trees:

> In forestry, using the traditional breeding strategies it takes us 15 years before the trees even start flowering. So (to develop) the next generation of breeding of trees that are adapted to warmer or drier conditions … we really need a much longer lead time than agricultural people do.(30)

Reforestation programs in Canada and elsewhere are proceeding apace at a cost of hundreds of millions of dollars. While such programs are essential to the regeneration of growing stock for a variety of purposes, there is a potential flaw in the planning, should global warming become significant in the next century. Current reforestation efforts utilize seedlings

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(29) J.S. Maini (1989b), p. 22:8.

(30) *Ibid*., p. 22:1011.

whose genetic characteristics are selected and matched to the geographic locale and the present climate regime. As Maini has noted, the match between climate and genetic traits may not hold:

> In Canada, for example, seedlings being planted today, at considerable cost, will be only half their commercially harvestable age by the year 2030, when they could be growing in a very different climate. We need to develop strategies to protect this investment – for example, by developing technologies to harvest and use smaller trees.(31)

An important variable in the overall forestry equation, which could have an enormous impact on standing stock and thus on the future makeup of Canada's forests, is forest fire. The dramatic increase in the numbers of wildfires in Canada's forests in 1989, particularly in Manitoba, where huge areas of forest were burned, gave an indication of what can happen in the boreal forest under warm, dry climatic conditions. As was noted above, however, wildfire has been an integral part of the boreal forest ecosystem and the current mix of coniferous species in the boreal forest reflects the selective impact of past fires.

Under a warmer climate regime, wildfire may have a quite different impact. The conifers that now populate the boreal zone, and upon which much of Canada's forest industry is based, have evolved in, and become adapted to, a climate significantly cooler than that which is anticipated to lie 50 or 70 years in the future as a consequence of global warming. In a changed climate regime, wildfire could effect significant species change in the boreal forest:

> It can … be predicted that fire will act as a major agent in removing vegetation types that are no longer adapted to the changed climatic conditions, setting the stage for new combinations of plant species to invade burned areas.(32)

It is possible, then, that the character of the boreal forest could change fairly rapidly if wildfires become a major problem under a warmer climate regime. If major

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(31) J.S. Maini, "Forests: Barometers of Environment and Economy," in Constance Mungall and Digby J. McLaren (eds.), *Planet under Stress – The Challenge of Global Change*, Royal Society of Canada, 1990, p. 179.

(32) Ross W. Wein and Edward H. Hogg, "Climate Change Moisture Stresses on Northern Coniferous Forests," in G. Wall and M. Sanderson, eds., Climate Change: Implications for Water and Ecological Resources, Occasional Paper No. 11, Department of Geography, University of Waterloo, Ontario, 1990, p. 286.

conflagrations do become a common occurrence in the boreal forest, very large amounts of CO_2 and other gases will be liberated. Depending on their magnitude, these wildfires could frustrate efforts to reduce the concentration of CO_2 in the atmosphere through restrictions on combustion of fossil fuels and other mitigative measures.

CONCLUSION

The importance of forests to Canada, both in economic and environmental terms, is indisputable. A warmer global climate may well have profound effects on the Canadian boreal forest, and at least some of these effects will not be beneficial. Climate change will have many implications for Canadian society and it is clear that both mitigative and adaptive strategies and programs will have to be designed now for implementation as changing circumstances dictate.

With the state of current knowledge of climatic processes and climate change, it is not possible to predict the extent or rate of projected effects of anthropogenic origin. Given the large predictive uncertainties, the appropriate course of action for the Canadian forest sector is to develop policies and strategies that make good sense under the current climate regime but will also be appropriate in a warmer climate scenario.

Appropriate forest management programs based on sound science are essential whether the climate changes in the next century or remains substantially the same as it is now. The development of such visionary programs will require an increased and firm commitment of funds by industry and by provincial and federal governments.

The “business-as-usual” approach is not acceptable in the context of pollution control as it has become very clear that the anthropogenic emissions of greenhouse gases and other pollutants must be substantially reduced, both to prevent (or at least slow the rate of) possible global warming, and to reduce impacts on the biophysical environment and human health. Effective mitigative actions must be introduced on both a national and global scale.

The business-as-usual approach is also not appropriate for the management of Canada’s forest resource. Forest management policies more effectively geared to the sustainability of forests are needed. The programs that are developed out of such policies must optimize the economic and environmental potentials of Canada’s forests and must also be cognizant of the imminent possibility of climate change in the present boreal forest regions.

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