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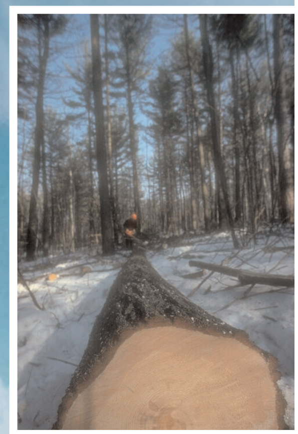

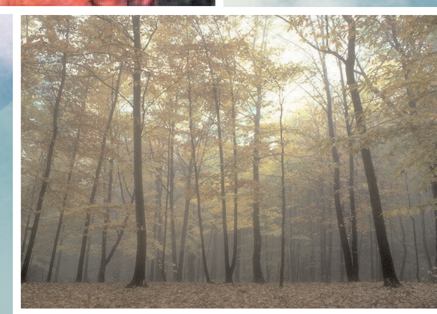

Climate Change Impacts and Adaptation:
A Canadian Perspective

Forestry

Prepared by the Climate Change Impacts and Adaptation Directorate
Natural Resources Canada
October 2002

Taking action on climate change
Together we can do it.

Canada

Preface

There is strong consensus in the international scientific community that climate change is occurring and that the impacts are already being felt in some regions (see, for example, the recent Third Assessment Report of the Intergovernmental Panel on Climate Change). It is also widely accepted that even after introducing significant measures to reduce greenhouse gas emissions, some additional degree of climate change is inevitable, and this will have significant economic, social and environmental impacts on Canada and Canadians.

It is possible to reduce our vulnerability to climate change. An effective response involves both the reduction of greenhouse gas emissions and adaptation to the impacts resulting from a changing climate. Reducing greenhouse gas emissions will decrease the amount of climate change, as well as the rate of change, so that effective adaptation can occur. Adaptation refers to activities that minimize the negative impacts of climate change, and position us to take advantage of new opportunities that may be presented.

This chapter is part of the report *Climate Change Impacts and Adaptation: a Canadian Perspective*. The report, which will be completed in spring 2003, includes a series of chapters that present brief summaries of impacts and adaptation research published over the past five years that relates to key sectors in Canada. Results of research supported by the Government of Canada's Climate Change Action Fund (CCAF) are highlighted in boxes within each chapter of the report.

The forestry chapter focuses on the impacts of climate change on forests in Canada, the consequences of these changes for the forestry sector, and potential adaptation options. While this chapter considers only forestry issues, it must be recognized that climate change impacts, as well as adaptation decisions in the forestry sector will be influenced by, and have implications for, other sectors (e.g. tourism and recreation, water resources). As such, a complete assessment of impacts and adaptation options must therefore take into consideration issues raised within other chapters of this report.

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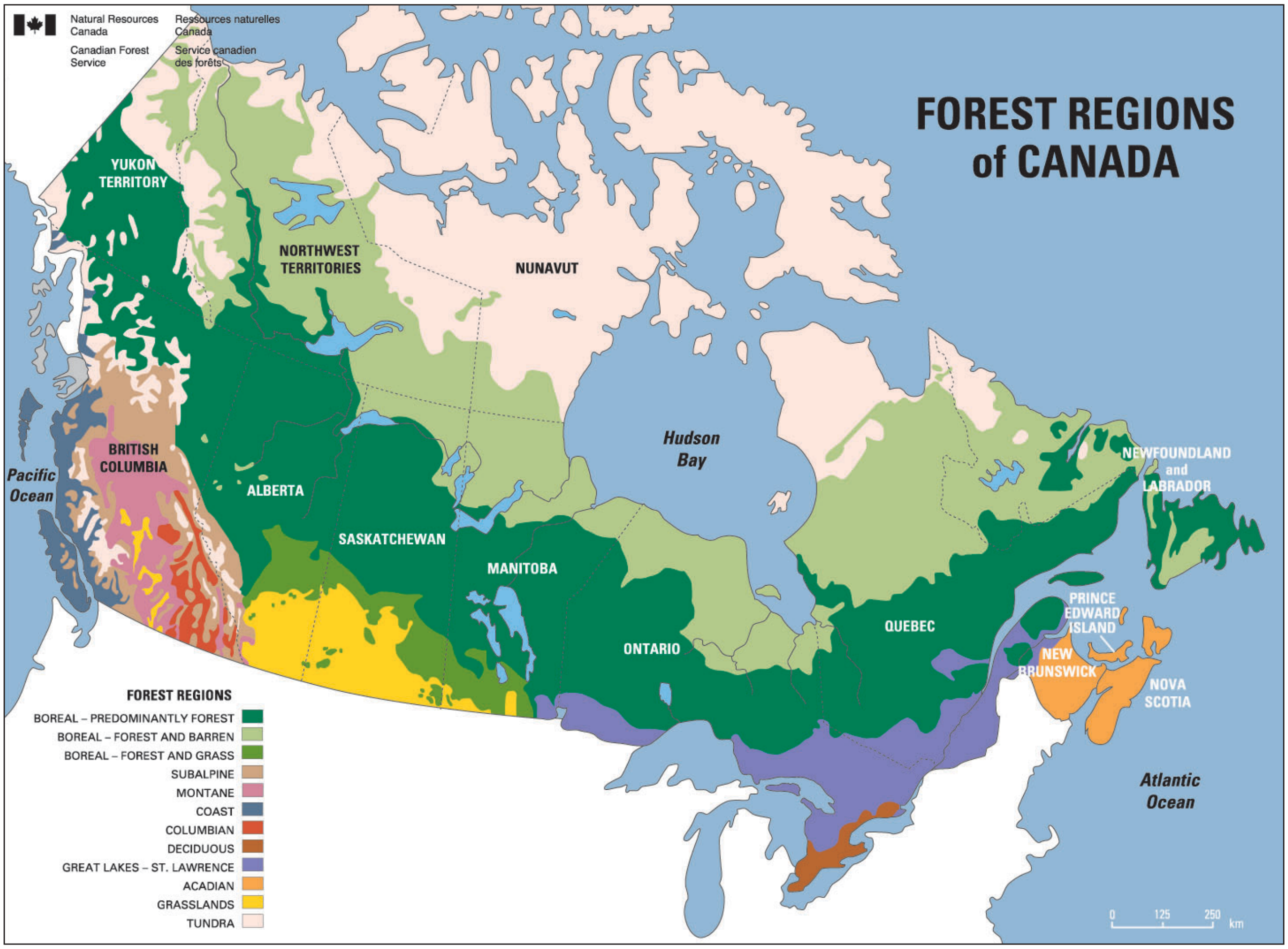
“For centuries, forests have been an intrinsic feature of Canada’s society, culture and economy, and they will continue to be an immensely important part of our lives.” [1]

Canada contains more than 400 million hectares of forested land, which accounts for almost half of our total landmass and approximately one-tenth of the world’s total forest cover.[1] As such, forests are a vital component of our country’s economy and culture. Boreal forests are the dominant forest type, spanning the complete width of the country (Figure 1).

Many communities across Canada are highly reliant on the forestry sector, which provided direct employment for over 370 000 Canadians in 2000.[1] Approximately 51% of Canada’s 234.5 million hectares of commercial forest (land capable of producing commercial tree species that can be sustainably harvested) are currently managed for timber production.[1] Each year about one million

FIGURE 1: Distribution of forest types in Canada.[1]



hectares of this commercial forestland are harvested, primarily to manufacture lumber, plywood, veneer, wood pulp and newsprint.[1] Non-wood forestry products also contribute to the Canadian economy.

Forests also impart numerous non-market benefits. They provide aesthetic value, and are important for many recreational activities, such as camping, hiking and snowmobiling. Forests also reduce soil erosion, improve air and water quality, and provide habitat for over 90 000 different species of plants, animals and micro-organisms.[1] Furthermore, forests are a vital component of aboriginal culture and heritage, providing food, medicinal plants and resources for many First Nations and Métis communities.

Climate is one of many variables that affects forest distribution, health and productivity, and has a strong influence on disturbance regimes. According to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), globally averaged surface air temperatures are projected to increase by 1.4 to 5.8°C by the year 2100,[2] with significant consequences for most elements of the global climate system. The net impact of such climate changes on forestry and forest-dependent communities in Canada would be a function of a wide range of biophysical and socio-economic impacts that would be both positive and negative. To date, research in Canada and internationally has tended to focus primarily on the response of individual species and ecosystems to changing climate. In contrast, the potential social and economic implications of climate change for the Canadian forest sector have received far less attention. Reflecting these trends, this review emphasizes the potential biophysical impacts of climate change on forests while recognizing the importance of expanding our capacity to address socio-economic impacts as well.

In addition to changes in the climate, forests will also be stressed by other factors such as land cover and land use changes, related to both human activity and natural processes. When these variables are considered in conjunction with limitations imposed by the uncertainties of climate models, especially regarding future changes in precipitation patterns, it is difficult to project the impacts of climate change on forests at the regional and local levels. Although research is ongoing to address these issues, understanding the vulnerability of both forests and forestry practices to climate change is essential for forestry management planning. Appropriate adaptation will help reduce the negative impacts of climate change while allowing the forest sector to take advantage of any new opportunities that may be presented.

Previous Work

"Climate change has the potential to enormously influence the future health of Canada's forested ecosystems." [3]

In their summary of research as part of the Canada Country Study, Saporta et al.[4] concluded that climate change would have a range of impacts on Canadian forests. They summarized that higher temperatures would generally improve growth rates, while an increase in the frequency and severity of moisture stress and forest disturbances would create problems in some areas. Elevated atmospheric CO_2 concentrations may also affect forests by improving the efficiency of water use by some plants, which could lead to increases in forest productivity. The actual nature and magnitude of the impacts will vary, depending on such factors as forest type, location and species characteristics. For example, forests in continental areas are expected to experience increased drought stress, whereas increased wind and storm damage are likely in coastal regions.

The rate and nature of projected climatic changes will be important, especially with respect to shifts in species distributions. As temperature increases, species are expected to migrate northward and to higher altitudes. Species located near the southern edges of their current range and those with poor dispersal mechanisms would be the most threatened by these migrations, and local extinctions are possible.

The forestry industry would need to adapt its operations to deal with the changing conditions. New technologies, introduction of new tree species and relocation of forestry operations are potential adaptation options. The rate, magnitude and location of climate change would greatly influence the success of these adaptations.

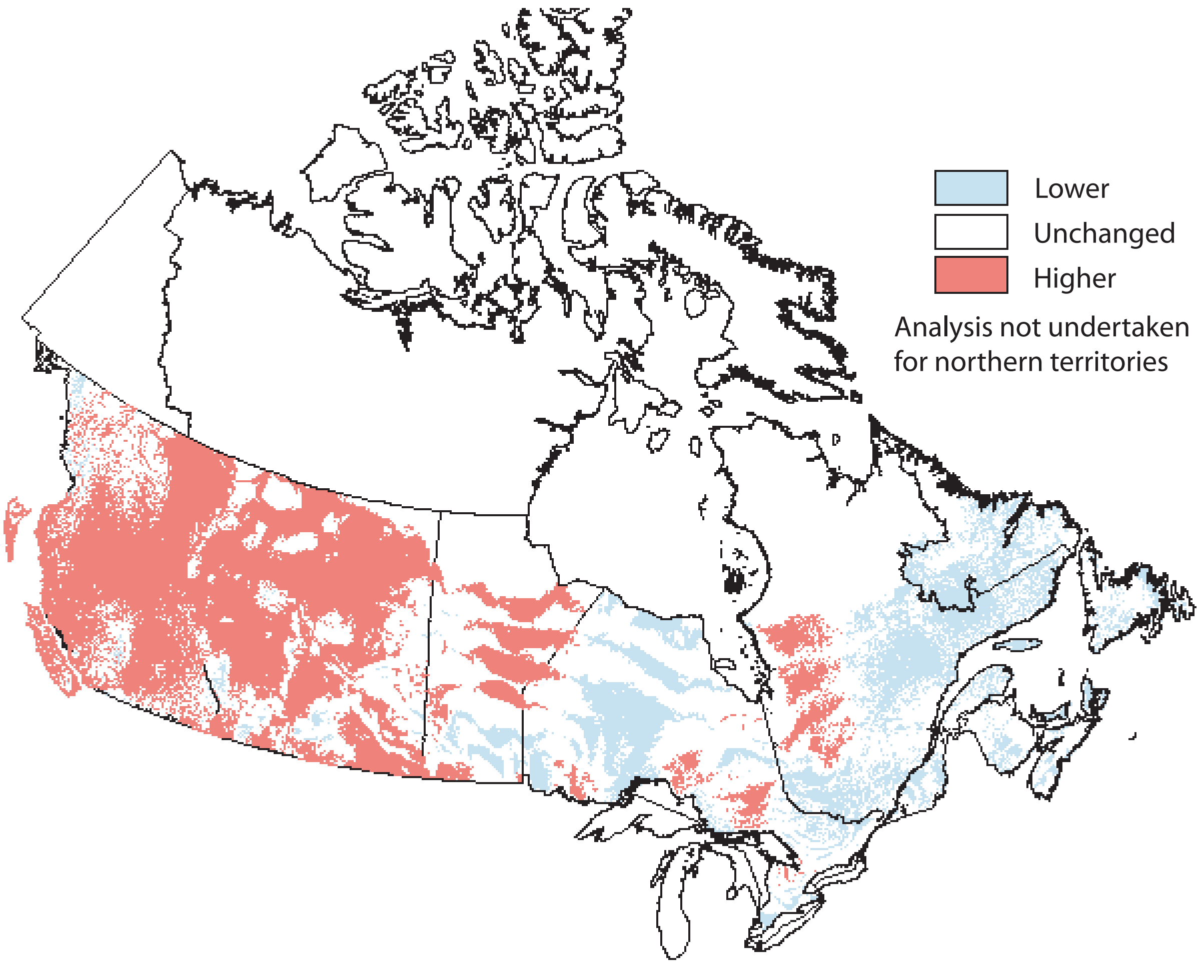
Impacts

Impacts on Forest Growth and Health

"Changes in climatic conditions affect all productivity indicators of forests and their ability to supply goods and services to human economies." [(5)]

Researchers expect that even small changes in temperature and precipitation could greatly affect future forest growth and survival,[(6)] especially at ecosystem margins and threshold areas. Over the last century, Canada has warmed by an average of 1°C.[(7)] During the same time period, plant growth at mid to high latitudes (45°N and 70°N) has increased and the growing season has lengthened.[(8)] Historic warming has also had an impact on tree phenology. For example, in Edmonton, Alberta, trembling aspen has begun to bloom 26 days earlier over the past 100 years,[(9)] and the bud break of white spruce in Ontario appears to be occurring earlier.[(10)] Plant hardiness zones also appear to have shifted in response to recent changes in climate, with the most significant changes occurring in western Canada (Figure 2).[(11)]

FIGURE 2: Changes in plant hardiness between 1930-1960 and 1961-1990 (modified from reference [11]).



Climate models project that future warming will be greatest during the winter months. This trend is evident in the historic climate record for most of the country. For example, over the past century, winter temperatures in the Canadian Rockies have warmed about twice as much as spring and summer temperatures.[12] Higher temperatures in the winter would have both positive effects on forests, such as decreased winter twig breakage,[13] and negative effects, such as increased risk of frost damage.[10] Although warmer winters would increase the over-winter survival of some insect pests, reduced snow cover could increase the winter mortality of others.[14]

Higher winter temperatures may also increase the frequency and duration of midwinter thaws, which could lead to increased shoot damage and tree dieback (references 15 and 16; *see* Box 1). A decrease in snow cover could further increase tree dieback due to frost-heaving, seedling uplift[17] and increased exposure of roots to thaw-freeze events.[18]

Climate change would impact future moisture conditions in forests through changes in both temperature and precipitation patterns. As the temperature increases, water loss through evapotranspiration increases, resulting in drier conditions. Higher temperatures also tend to decrease the efficiency of water use by plants. In some areas of Canada, future increases in precipitation would help offset drying caused by higher temperatures.[20] In other regions, however, decreases in precipitation will accentuate the moisture stress caused by warming. Changes in the seasonality of precipitation and the occurrence of extreme events, such as droughts and heavy rainfalls, will also be important. For example, tree-ring analysis of aspen poplar in western Canada revealed that reduced ring growth was associated with drought events, whereas growth peaks followed periods of cool, moist conditions.[18]

Forest characteristics and age-class structure also affect how forests respond to changes in moisture conditions. Mature forests have well-established root systems and are therefore less sensitive to changes in moisture than younger forests and post-disturbance stands, at least in the short term.[5] In addition, certain tree species and varieties are more moisture or drought tolerant than others.

BOX 1: Are winter thaws a threat to yellow birch?[19]

In the past, large-scale declines of yellow birch have been documented in eastern Canada. Studies indicate that winter thaws and late spring frosts may partially explain the diebacks. Winter thaws decrease the cold hardiness of birch, thereby increasing the vulnerability of the affected trees. The effect of a winter thaw on birch seedlings is shown in the photograph below. Winter thaw events can also cause breakdowns in the xylem of yellow birch, making it more difficult for water to pass from the roots to the branches. Future climate changes are expected to result in more frequent and prolonged winter thaws, and the likelihood that birch dieback may worsen.

The effect of thaw on shoot dieback. The top photo is the control (not exposed to thaw), whereas the bottom photo shows yellow birch seedlings that were exposed to thaw.

For example, bur oak and white fir are better able to tolerate drought conditions than most tree types.[21]

While numerous studies have investigated the impacts of elevated CO_2 on forest growth and health, the results are neither clear nor conclusive.[5] Although researchers generally agree that higher CO_2 concentrations improve the efficiency of water use by some plants (at elevated CO_2 concentrations, plants open their stomata less, thus reducing water loss through transpiration), diverse results have been found concerning the overall effects on plant growth. For example, higher CO_2 concentrations have been found to increase the growth of various types of poplar,[22, 23] but have little to no effect on the growth of Douglas fir,[24] aspen and sugar maple.[25] The differing results between studies could relate to the species studied, individual tree age, the length of the study period and differences in methodology. It is also important to note that some researchers suggest that any positive response of plants to enhanced CO_2 concentrations may decrease over time, as plants acclimatize to elevated CO_2 levels.[5]

The uncertainties concerning how trees will respond to elevated CO_2 concentrations make it challenging to incorporate this factor into impact assessments. Additional complications arise from the possibility that other anthropogenic emissions will affect forest growth. For example, ozone (O_3), a pollutant that causes visible damage to tree species,[26] has been shown to offset the potential benefits of CO_2 on tree productivity.[26, 27] On the other hand, some suggest that nitrogen oxides, which are released through fossil fuel combustion and high-intensity agriculture, may lead to enhanced forest growth,[28] especially in nitrogen-limited ecosystems. Another study found that these growth enhancement factors (e.g. CO_2 fertilization, nitrogen deposition) actually had minimal influence on plant growth relative to other factors, particularly land use.[29]

Overall, the impacts of climate change on forest growth and health will vary on a regional basis, and will be influenced by species composition, site conditions and local microclimate.[12] In the aspen forests of western Canada, forest productivity may increase due to longer frost-free periods and elevated CO_2 concentrations,[18] although an accompanying increase in drought stress could create problems. Productivity in northeastern Ontario may also increase under the combined effects of higher temperatures, increased precipitation, and a longer growing season.[30] In contrast, some researchers suggest that climate warming could have a negative impact on the physiology and health of forest ecosystems in the Great Lakes–St Lawrence region.[31]

Impacts on Tree Species Migrations and Ecosystem Shifts

"Our forest ecosystems will be in a state of transition in response to the changing climate, with primarily negative impacts." [32]

Climate change may result in sometimes subtle and non-linear shifts in species distributions.[5] As conditions change, individual tree species would respond by migrating, as they have in response to past changes in climate. There is concern, however, that the rapid rate of future climate change will challenge the generation and dispersal abilities of some tree species.[33,34] Successful migration may be impeded by additional stresses such as barriers to dispersion (habitat fragmentation) and competition from exotic species,[35, 36, 37] and changes in the timing and rate of seed production may limit migration rates.[34]

It is generally hypothesized that trees will migrate northward and to higher altitudes as the climate warms. The warming of the last 100 years has caused the treeline to shift upslope in the central Canadian Rockies.[12] Temperature, however, is not the sole control on species distribution, and temperature changes cannot be considered in isolation. Other factors, including soil characteristics, nutrient availability and disturbance regimes, may prove to be more important than temperature in controlling future ecosystem dynamics. The southern limit of the boreal forest, for example, appears to be influenced more by interspecies competition[38] and moisture conditions[39] than by temperature tolerance. The distribution of trembling aspen in western Canada is also largely controlled by moisture conditions.[40]

Predictions of future changes in species distributions are exceedingly complicated, and results from available studies vary greatly. Predictions of migration rates in northern forests by 11 leading ecologists varied by more than four orders of magnitude.[41] This could be related to the fact that predictions are often derived from models, which require a number of assumptions to be made. For example, many models assume that seeds of all species are uniformly available, and that environmental conditions do not fluctuate between regions, leading to overestimation of future species diversity and migration rates.[42] Models also generally do not account for the potential role of humans in assisting species migrations. Model projections should therefore be viewed as indicative of trends, rather than conclusive of magnitude.[43]

Some key results of recent studies that combined historical trends or climate simulations with ecosystem models are listed in Table 1.

It is important to note that species will respond individually to climate change and that ecosystems will not shift as cohesive units. The most vulnerable species are expected to be those with narrow temperature tolerances, slow growth characteristics[49] and limiting dispersal mechanisms such as heavy seeds.[45] For example, since trembling aspen has better seed dispersal mechanisms than red oak and jack pine,[50] it may be more successful at migrating in response to climate change. Differing species response to anthropogenic emissions may also affect competitive ability,[51] with potentially significant impacts on forest ecosystem functioning.[49]

TABLE 1: Recent research results of forest migrations.

Region	Scenario	Key Predictions
Western North America[44]	1%/year compound increase in CO_2	• Shifts in ranges in all directions (N/E/S/W) • Significant ecosystem impacts • Changes in species diversity
Ontario[45]	$2xCO_2$ scenario	• Great Lakes forest types will occupy most of central Ontario • Pyrophilic species (e.g., jack pine and aspen) will become more common • Minimal old-growth forest will remain • Local extinctions will occur
Central Canadian treeline[46]	Gradual warming (based on historical analysis)	• Initial increase in growth and recruitment • Significant time lag between warming and northward expansion of boreal forest
New England, U.S.A.[47]	$2xCO_2$ scenario	• Stable ecotone with no dieback • Northward ecotone migration at a rate of less than 100 m per 100 years
Northern Wisconsin, U.S.A.[48]	Gradual warming over next 100 years	• Loss of boreal forest species in 200–300 years
Eastern U.S.A.[35]	$2xCO_2$ scenarios	• Dramatic changes in forest type distribution • Loss of spruce fir forest types in New England • Large decline in maple-beech-birch forests • Large increase in oak-pine forest types

Impacts on Disturbances

"Increases in disturbances such as insect infestations and fires can lead to rapid structural and functional changes in forests." [5]

Each year, approximately 0.5% of Canada's forests are severely affected by disturbances, such as fire, insects and disease.[1] These disturbances are often strongly influenced by weather conditions and are generally expected to increase in the future in response to projected climate change.[4]

Cumulative impacts arising from the interactions between disturbances are likely. For example, an increase in drought stress, is expected to increase the occurrence and magnitude of insect and disease outbreaks.[30] Similarly, an increase in defoliation by insect outbreaks could increase the likelihood of wildfire.[52] The interaction between fire and spruce budworm in Ontario is described in Box 2. In addition to tree damage, changes in the disturbance regime would have long-term consequences for forest ecosystems, such as modifying the age structure and composition of plant populations.[30]

BOX 2: Interactions between spruce budworm and wildfire in Ontario.[53]

Wildfires and spruce budworm (SBW) outbreaks are widespread disturbances in the boreal forest. Fleming et al.[53] examined historical records to investigate the interactions between these disturbances in Ontario, and estimate how they will be affected by future climate changes. Spruce budworm outbreaks are thought to increase the occurrence of wildfires by increasing the volume of dead tree matter, which acts as fuel for fires. The researchers documented a disproportionate number of wildfires occurring 3 to 9 years following spruce budworm outbreaks, with the trend being more pronounced in drier regions such as western Ontario, where wood fuels tend to decompose more slowly. The study concluded that drier conditions induced by climate change would cause wildfires to increase in stands with SBW defoliation, as well as increase the frequency and intensity of SBW outbreaks.

Spruce bud worm: dorso-lateral view of mature larva

Forest Fires

"In most regions, there is likely to be an increased risk of forest fires…." [5]

Forest fires are a natural occurrence and necessary for the health of many forest ecosystems. Indeed, without fire, certain tree species and ecosystems of the boreal forest could not persist.[54] However, fires can also lead to massive forest and property damage; smoke and ash generated by fires can create health problems, both locally and at great distances; and evacuations forced by fires have a wide range of social and economic impacts. Average annual property losses from forest fires exceeded $7 million between 1990 and 2000, while fire protection costs average over $400 million per year.[55]

Studies generally agree that both fire frequency in the boreal forest and the total area burned have increased in the last 20 to 40 years.[56, 57, 58]

There is, however, less agreement among studies that examine longer term records, with both decreases[59,60] and increases[61] reported, reflecting differences in location, timeframes and study methodologies. It is also important to note that, although large fires (over 1000 hectares) account for only 1.4% of forest fires in Canada, they are responsible for 93.1% of the total area burned.[55] Hence, caution is required when trying to compare studies examining changes in fire frequency and area burned.

Fire season severity is generally projected to increase in the future due to climate change (Table 2). Reasons for the increase include a longer fire season, drier conditions and more lightning storms.[62, 63]

TABLE 2: Forest fire predictions.

Region	Prediction
Eastern boreal forest[59]	• Fewer forest fires in future (based on historical analysis)
Canada[64]	• Increase in forest fire danger • Great regional variability (based on Forest Fire Weather Index)
Western Canada[58]	• Increase in strength and extent of fires (based on RCM[1] projections)
North America[65]	• General increase in forest fire activity • Little change or even a decrease in some regions (based on GCM 2xCO_2 projection)
Alberta[66]	• Increase in fire frequency (based on GCM 2xCO_2 projection)
Southwestern boreal forest, Quebec[67]	• Decrease in fire frequency (based on GCM 2xCO_2 projection)
Ontario[68]	• Increase in forest fire frequency and severity (based on Forest Fire Weather Index)
Canada[62]	• Increase in fire activity • Longer fire season • Increase in area of extreme fire danger (based on GCM 2xCO_2 projection)

[1] RCM, regional climate model

There is relatively high uncertainty associated with most studies of climate change and forest fires, due largely to our limited understanding of future changes in precipitation patterns. Where precipitation increases, forest fire frequency may experience little change or even decrease.[3] It has also been shown that warm weather and dry conditions do not necessarily lead to a bad forest fire season. This was exemplified in 2001: despite the extreme heat and dryness, wildfire frequency was down and total area burned was the lowest on record.[69] Vegetation type will influence changes in future fire frequency and intensity. For example, conifers are more likely to experience intense fires than are deciduous or mixed-wood stands. Hence, species migrations in response to changing climate would also affect future fire behaviour by changing the fuel types.[70] Some other factors that influence fire seasons include wind, lightning frequency, antecedent moisture conditions and fire management mechanisms.

Insect Outbreaks

Insect outbreaks are a major problem across Canada, with resulting timber losses estimated to exceed those from fire.[71]

In certain regions, defoliation by pests represents the most important factor controlling tree growth.[72] The response of insects to climate change is expected to be rapid, such that even small climatic changes can have a significant impact. Insects have short life cycles, high mobility, and high reproductive potentials, all of which allow them to quickly exploit new conditions and take advantage of new opportunities.[14]

Higher temperatures will generally benefit insects by accelerating development, expanding current ranges and increasing over-winter survival rates.[14] For example, insect pests that are not currently a problem in much of Canada may migrate northward in a warmer climate. Warmer conditions may also shorten the outbreak cycles of species such as the jack pine budworm, resulting in more frequent outbreaks,[73] and increase the survival of pests like the mountain pine beetle, that are killed off by very cold weather in the late fall and early spring.[74] However, an increase in extreme weather events may reduce insect survival rates,[14] as may a decrease in winter snow cover.

Climate change would also have indirect effects on forest disturbance by pests. For example, extended drought conditions may increase the sensitivity of trees to insect defoliation,[3] as would ecosystem instability caused by species migrations. Projected increases in anthropogenic emissions (e.g., CO_2, O_3) may further reduce tree defences against insects and diseases.[75, 26] Climate change may also affect insect outbreaks by altering the abundance of insect enemies, mutualists and competitors. For example, warmer weather may have differing effects on the development rates of hosts and parasitoids,[34] as well as the ranges of predators and prey.[76] This could alter ecosystem dynamics by reducing the biological controls on certain pest populations.

Extreme Weather

The frequency and severity of extreme weather events, such as heavy winds, winter storms and lightning, are projected to increase due to climate change.

The impact of extreme climate events on forests and the forest sector was clearly demonstrated by the 1998 ice storm that hit eastern Ontario, southern Quebec and parts of the Maritime Provinces. Damage from the ice storm in areas of Quebec was comparable to that of the most destructive windstorms and hurricanes recorded anywhere.[77] Long-term economic impacts have been evident in the maple sugar industry, with almost 70% of the Canadian production region affected by the storm.[78] Researchers are still working to quantify the actual costs.[79] Ice storms are not uncommon events, but the intensity, duration and extent of the January 1998 event was exceptional.[78] Nonetheless, such storms may become more frequent in association with milder winters in the future.[3]

Wind damage can result from specific events, such as tornadoes and downbursts, or from heavy winds during storms. In the Great Lakes area, downbursts are a key wind disturbance that can affect thousands of hectares, with both immediate and long-term impacts.[80] Heavy winds can also cause large-scale forest destruction through blowdown. For example, a heavy storm in New Brunswick in 1994 felled 30 million trees, resulting in losses of $100 million.[81] Factors such as tree height, whether or not the tree is alive, and stand density affect whether a tree is just snapped or completely uprooted by heavy winds.[82] Wind events may also have consequences for other forest disturbances, such as fires and insect outbreaks. For example, researchers have found that spruce beetle reproduction is favoured in blowdown patches.[83]

A warmer climate may be more conducive to extreme wind events, although there is much uncertainty on this issue.[84] Given the localized nature of these events, and the fact that wind phenomena are generally poorly understood, reliable modelling of the frequency of future wind events is not available at this time.[80]

Social and Economic Impacts

The biophysical impacts of climate change on forests will translate into many different social and economic impacts (Table 3), which will affect forest companies, landowners, consumers, governments and the tourism industry.[85]

The magnitude of socio-economic impacts, such as those listed in Table 3, will depend on 1) the nature and rate of climate change; 2) the response of forest ecosystems; 3) the sensitivity of communities to the impacts of climate change and also to mitigation policies introduced to address climate change; 4) the economic characteristics of the affected communities; and 5) the adaptive capacity of the affected group.[86]

Exports of forest products are an important component of the Canadian economy, valued at $47.4 billion in 2001.[1] A greater degree of warming at higher latitudes may mean that Canadian forests experience greater impacts on productivity as a result of climate change than forests of many other countries.[87] However, because of uncertainty regarding the magnitude and even the direction of many of these impacts, it is extremely difficult to assess Canada's future competitive ability in international markets. If Canadian forests were to experience faster

TABLE 3: Examples of socio-economic impacts of climate change.[85]

Physical Impact	Socio-economic Impacts
Changes in forest productivity	Changes in timber supply and rent value
Increased atmospheric greenhouse gases	Introduction of carbon credit-permit mitigation policies that create a carbon sequestration market
Increased disturbances	Loss of forest stock and non-market goods
Northward shift of ecozones	Change in land values and land use options
Change in climate and ecosystems	Economic restructuring leading to social and individual stress and other social pathologies
Ecosystem and specialist species changes	Changes in non-market values
Ecosystem changes	Dislocation of parks and natural areas, increased land use conflicts

tree growth and greater wood supply[88] and global timber shortages occur as predicted, due to population and economic growth,[89] Canada's forest industry could benefit. Climate change may require changes in international trade policies and the pricing of forest products,[90] which are generally based, at present, on the assumption of a stable climate.

First Nations are extremely concerned about the impacts of climate change on Canada's forests.[91] Since more than 90% of reserves are located on forested lands, forests play a vital economic and cultural role for many First Nations communities.[1] The projected impacts of climate change on forests, especially with respect to increased disturbances and species migrations, could threaten the sustainability of some of these communities.

Adaptation

"Many of the forest management activities required to address climate change are already part of current actions. In the context of climate change, it is the location and intensity of these problems that will change and challenge the sector's ability to cope and adapt." [92]

While individual tree species would respond independently to climate change through migration and physiological changes, there are many different ways in which the forest sector may adapt. Some forest managers may take a 'wait and see' approach, dealing with changes as they occur, but a strong case can and should be made for the importance of planned adaptation, in which future changes are anticipated and forestry practices (e.g., silviculture, harvesting) are adjusted accordingly.

Anticipatory adaptation takes climate change into account during the planning process. It is especially important when the rotation periods are long,[93] as the species selected for planting today must be able to not only withstand, but hopefully thrive in, future climates.[94] Although appropriate anticipatory adaptation should reduce losses from climate change, uncertainties regarding the timing, location, and magnitude of future change hinder its inclusion in forestry management.[95, 96] Uncertainties regarding future changes in precipitation patterns, and the resultant impacts on productivity and disturbance regimes, are especially challenging. To address these issues and encourage the inclusion of climate change into forestry management decision-making, some suggest the use of model simulations,[93] whereas others advocate increased communication between researchers and forest managers (*see* Box 3).

BOX 3: Promoting adaptation in the forest industry.[97]

Interviews and workshops conducted with representatives from the forest management sector were used to determine ways to facilitate adaptation to climate change. Key findings included:

- There is a need for more scientific information on the impacts of climate change.
- Research results need to be presented at scales (both space and time) that are relevant to forest management planning.
- Mechanisms for communicating climate change information are required.
- Forest managers must be involved in determining adaptation options.

The overwhelming message was a need for improved communication between the scientific research and forest management communities. This is considered critical to facilitating development of effective adaptation strategies.

Forestry management has a large influence on forest growth, health and composition.[98] Forests that are subject to management activities are generally considered to be less vulnerable to the impacts of climate change than forests that are not managed, due to the potential for adaptation.[5] Some characteristics of managed forests may also render them better able to cope with disturbances. For example, during the 1998 ice storm, highly managed fruit trees grown in orchards experienced much less damage than less structured stands of sugar maples.[78] Management activities, such as the use of subsequent salvage cuttings, may also reduce the degree of long-term damage arising from disturbances such as ice storms.[99]

Maintaining forest health and biodiversity is an important adaptation mechanism, which builds upon existing initiatives for sustainable forest management, such as those listed in Table 4. Criteria for sustainable forest management, as outlined in the Montreal Process of the United Nations Conference on Environment and Development, include conservation of biodiversity, maintenance of forest productivity, maintenance of forest ecosystem health, and conservation of soil and water resources.[100] Forests that are managed for these criteria would generally be less vulnerable to disturbances and hence more resilient to climate change. For example, healthy forest stands have been shown to exhibit a stronger and faster recovery from insect disturbances than stressed stands,[72] while the conservation of biodiversity and forest integrity would aid in successful species migrations.[43]

TABLE 4: Initiatives for sustainable forest management.

Program/Initiative	Purpose
Canada's National Forest Strategy	Presents a strategy for achieving sustainable forest management at the national scale
Canadian Standards Association Forest Certification System	Evaluates companies and government agencies with respect to their practice of sustainable forest management
Forest Management Agreement	Commits companies to comply with agreements that allocate volume and forest management responsibilities (e.g., replanting, habitat protection)

Sustainable forest management provides a framework into which climate change adaptation can be effectively incorporated. Potential impacts of both climate change and climate change adaptations could be assessed with respect to the sustainability criteria described above, in much the same way as managers currently evaluate the impacts of management activities such as harvest schedules and building roads. In this way, adaptation options for climate change can be developed to fit within existing forest land-use planning systems, rather than being viewed as a new and separate issue.

In some cases, to help preserve forest sustainability, forest managers may assist in tree regeneration. Regeneration may involve replanting native tree species or introducing new species, including exotics and hybrids. It has been suggested that assisted regeneration could be used in the southern boreal forests of western Canada if drier conditions hinder the ability of conifers to regenerate naturally.[101] In beach pine forests of British Columbia, genotypes may also need to be redistributed across the landscape in order to maintain forest productivity in the future.[6] There are many issues related to the use of non-native species, the most important of which concerns the potential for unforeseen consequences, such as accompanying pest problems or loss of native species due to new competitive interactions.

Forest managers may also assist in the migration of forests, by introducing carefully selected tree species to regions beyond their current ranges. In cases such as the Boreal Transition Ecozone, forests may prove to be an ecologically and economically viable alternative to marginally productive agriculture.[102] New forest cover in this area may be established through either natural forest succession or planting of commercial tree species.[102] Similar to human-assisted regeneration, there are many concerns regarding assisted migration, due largely to the potential for unpredictable outcomes.

In some cases, biotechnology may play an important role in adaptation to climate change. For example, by adding or removing one or more genes from a species, scientists can develop strains that are better adapted to specific conditions, such as droughts, and more resistant to potential threats, including insect outbreaks and diseases.[103] Plant hybrids can also be developed with these goals in mind. Hybrid poplars have been successfully introduced in western Canada.[104]

Dealing with Disturbances

"Losses due to possible forest decline and modified fire and insect regimes, as well as drought stress in some areas, could challenge the adaptive capacity of the industry." [92]

Adjusting to shifts in disturbance regimes may be an important aspect of climate change adaptation. Although focus is generally placed on an increased frequency of disturbances, a decrease in disturbances would also require adaptation. For example, a longer fire cycle in eastern Canada would increase the amount of overmature and old-growth stands, which would require alternative management practices.[59]

Where fire frequency increases, protection priorities may require adjustments so that burns are prevented from damaging smaller, high-value areas.[62] Recent work conducted in the Prairie Provinces promotes protection of such areas through the use of 'firesmart landscapes' (*see* Box 4). Increased monitoring, improved early warning systems, enhancing forest recovery after fire disturbances, and the use of prescribed burning are other adaptation options to deal with changes in forest fire regimes.[105]

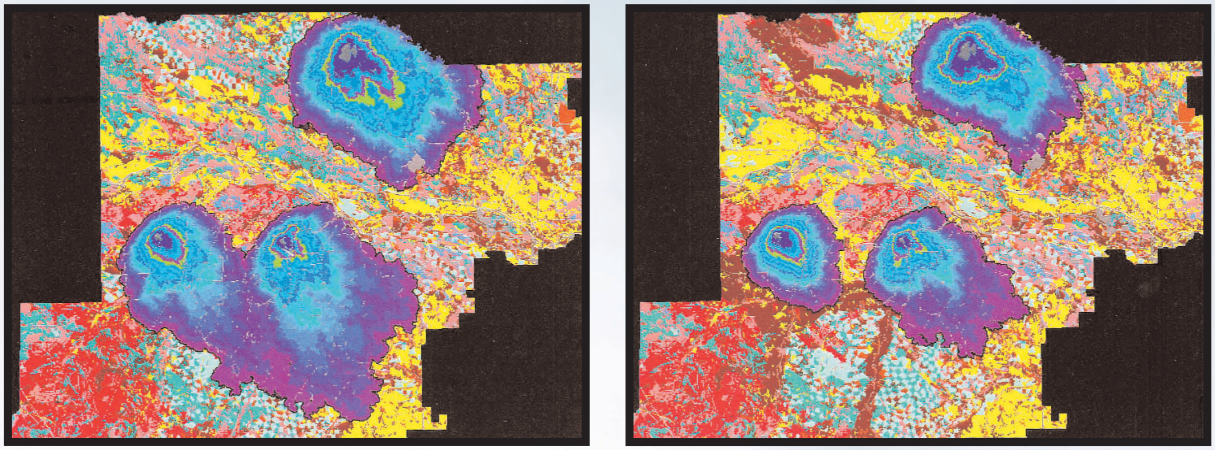
Prescribed burning has also been recommended as one potential adaptation option for reducing forest vulnerability to increased insect outbreaks.[105] Several other methods to address future insect outbreaks have also been suggested. For example, nonchemical insecticides can be applied to reduce leaf mortality from insects, thereby allowing the trees to still be harvested at a later date.[107] Another nonchemical insect control option being investigated is the use of baculoviruses. These viruses attack specific pest species, such as the spruce budworm, with minimal consequences for other species and the environment.[108] Adjusting harvesting schedules, so that those stands most vulnerable to insect defoliation would be harvested preferentially, represents yet another method for addressing increased insect outbreaks.[107]

Changes in forest fire regimes as a result of climate change would necessitate adjustments in fire management systems. Future changes in fire occurrence would affect budgets, staffing, technologies, equipment needs, warning mechanisms and monitoring systems.[105] Anticipating these changes and increasing interagency cooperation could help to minimize costs and ease the transitions.

Studies on the impacts of past extreme climate events, as well as the response of the forestry sector to these events, can assist in understanding and improving the degree of preparedness for the future. For example, researchers are investigating how the management of woodlots and plantations can be used to reduce vulnerability to ice storms,[79] and are developing decision-support tools to assist forest managers in dealing with damaged tree stands.[109]

BOX 4: Reducing fire extent with fire-smart landscapes.[106]

Many studies suggest that forest fires will increase in future due to climate change. To reduce fire-related losses in the forestry industry, Hirsch et al.[106] advocate the incorporation of 'fire-smart landscapes' into long-term forest management planning. Fire-smart landscapes use forest management activities, such as harvesting, regeneration and stand tending, to reduce the intensity and spread of wildfire, as well as fire impacts. For example, species with low flammability (e.g. aspen) could be planted adjacent to stands of highly flammable, valuable and highly productive conifers to protect them from large burns. Model simulations suggest that such treatments could substantially reduce the size of forest fires.



Size of three simulated fires on current (left) and hypothetical fuel treatment landscape (right) after a 22 hour fire run. Note the reduction in area burned using the 'fire-smart' management approach.

In addition to reducing losses from forest fires, the study suggests that these fuel treatments may also increase the total annual allowable cut.

Social, Economic and Political Considerations

In evaluating adaptation options, it is necessary to consider the social, economic and political implications of each adaptation. For example, although relocation of forestry operations in response to species migrations is commonly cited as an appropriate adaptation option, several factors may limit its feasibility. Communities, especially First Nations and Métis, tend to have cultural and economic ties to the land and may be unwilling, or unable, to relocate. In addition, moving industrial infrastructure and entire communities would be expensive, with no guarantee of subsequent profits, or that cultural ties to the land would persist in the same way. Furthermore, policies and agreements limit the mobility of many aboriginal communities, potentially limiting the viability of relocation as an adaptation option.[85]

An important component of adaptation is determining who will do the adapting. The forest industry, different levels of governments, communities and individuals would all need to adjust their practices to deal with the impacts of climate change on forests. As these groups will perceive climate change risks and their adaptive capacity in different ways, adaptive responses will vary. In some cases, differing perceptions of risk and adaptation may lead to increased tension between the various groups. Conflicting priorities and mandates could also lead to future problems.

Before implementing adaptation options, the potential impacts on all stakeholders need to be considered. For example, although introducing exotic commercial tree species or hybrids may be desirable to address some climate change impacts, it may not be considered socially and/or ethically acceptable among some or all of the stakeholders involved.

Knowledge Gaps and Research Needs

To date, climate change research in Canada related to forestry has focused primarily on biophysical impacts, such as growth rates, disturbance regimes and ecosystem dynamics. Much less attention has been devoted to socio-economic impacts and the ability of forest managers to adapt to climate change. Canadian studies that have examined adaptation to climate change in the forestry sector emphasize the importance of involving forest managers and other stakeholders throughout the research project, and ensuring that study results are released in formats that are relevant and useful for forest managers. This includes developing recommendations at the appropriate spatial and temporal scales.

Research needs identified within the literature cited in this report include the following:

Impacts

1) Studies on the long-term interactive effects of climate and other environmental changes on forests.

2) Better understanding of the capability of tree species to respond to change through migration, and the potential consequences for ecosystem dynamics, communities and the forest industry.

3) Additional work on disturbance regimes, including the interactive impacts of disturbances (e.g., fire and pests) and the incorporation of these impacts into models.

4) Impacts of climate change on biodiversity, and the role of biodiversity in ecosystem functions.

5) Increased understanding of the potential range of impacts on market and non-market forest values, the critical thresholds for change, and the linkages between science, policy and forest management.

6) The development of methodologies to synthesize and integrate results of research on the impacts of climate change on forests.

Adaptation

1) Improved understanding of the impacts of active forest management on ecosystems, such as the effects of reintroducing species to disturbed ecosystems.

2) Studies focusing on the social and economic impacts of different adaptation options.

3) Studies that explore options to reduce both short- and long-term vulnerability of forests to fire and insect disturbances.

4) Improved understanding of the adaptive capacity of forest managers and other stakeholders, as well as factors that influence decision making.

5) Research on new opportunities for forestry, such as enhancing the commercial value of forests in northern areas and the potential role of biotechnology.

6) Studies on how climate change can be better incorporated into long-term forest planning, including improved communication of knowledge and research.

Conclusion

Climate change can cause fundamental changes in forest ecosystem dynamics. However, results of numerous studies examining the impact of climate change on forests vary greatly, depending on the factors considered and the assumptions made. For example, studies that incorporate higher temperatures, enhanced CO_2 concentrations and increased precipitation tend to project increased forest productivity. If increased disturbances (fires, insect outbreaks) and the ecosystem instability induced by species migrations are included in the study, negative impacts are usually suggested.

In addition to the direct and indirect impacts of climate change on forests, other factors, such as land use changes, will affect the ability of both forests and the forest industry to adapt. To assess overall vulnerability, all these factors need to be considered, as should the capacity to implement adaptation options. Due to uncertainties in climate models and our incomplete understanding of ecosystem processes, it is unlikely that the precise predictions of climate change impacts on forestry are attainable. This does not constrain our ability to adapt, but instead emphasizes the need to maintain or increase forest resiliency. Climate change should be incorporated into long-term forest planning, so that potential mismatches between species and future climatic and disturbance regimes are minimized. These measures will assist in reducing the vulnerability of forests to climate change.

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