SUSTAINABLE FOREST MANAGEMENT NETWORK
RÉSEAU DE GESTION DURABLE DES FORÊTS

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Climate Change and Forest Management in Canada: Impacts, Adaptive Capacity and Adaptation Options

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Martin Moroni | Reg Parsons | David Price | John Stadt

A STATE OF KNOWLEDGE REPORT

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Foreword

The State of Knowledge program was launched by the Sustainable Forest Management Network (SFMN) to capture the knowledge and wisdom that had accumulated in publications and people over a decade of research. The goal was to create a foundation of current knowledge on which to build policy, practice and future research. The program supported groups of researchers, working with experts from SFMN partner organizations, to review literature and collect expert opinion about issues of importance to Canadian forest management. The priority topics for the program were suggested by the Network's partners in consultation with the research theme leaders. Each State of Knowledge team chose an approach appropriate to the topic. The projects involved a diversity of workshops, consultations, reviews of published and unpublished materials, synthesis and writing activities. The result is a suite of reports that we hope will inform new policy and practice and help direct future research.

The State of Knowledge program has been a clear demonstration of the challenges involved in producing a review that does justice to the published literature and captures the wisdom of experts to point to the future. We take this opportunity to acknowledge with gratitude the investment of time and talent by many researchers, authors, editors, reviewers and the publication production team in bringing the program to a successful conclusion.

Jim Fyles
Scientific Director

Fraser Dunn
Chair of the Board

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Executive Summary

Climate change is already affecting Canada's forests and will continue to do so for the foreseeable future. Impacts observed to date include changes in forest fire regimes, large-scale insect outbreaks, droughts in central Canada, severe windstorms in Atlantic Canada and shorter periods of frozen soil. Climate change will affect forest growth rates, the distribution of tree species, the rate of ecosystem processes and the ability to carry out forest operations. These impacts will in turn affect forest-dependent communities, often in ways similar to those already seen in the current industry downturn.

Forest managers agree that climate change is real and that it is an important issue that needs to be dealt with. Some are already implementing short term adaptations, although these are often not for future climate change but simply adaptations to current climatic variability. A small number of Canadian companies have also developed forest management plans that explicitly include consideration of climate change.

Canada's forest sector has a generally high capacity to meet forest management challenges through technical adaptations, due in part to the high levels of education and professionalism among forest managers. Technical and scientific capacity related specifically to climate change varies widely, however, and is generally low. Forest managers, planners and policy-makers often feel ill-equipped to evaluate, plan or implement a possible course of action related to climate change.

A major constraint is lack of appropriate information on climate change at scales relevant to decision making and planning. Also, there will be thresholds of climate change impacts beyond which adaptation will be extremely difficult, and it is a major research and management challenge to identify those thresholds.

Institutional barriers are often significant constraints to adaptation. Forest policy generally assumes a constant physical environment, yet it is clear that this assumption will be incorrect in the future. Forest policy will need to evolve in ways that help the sector deal more effectively with uncertainty, surprise and novel conditions, including the effects of climate change. Also, current policy often prevents local autonomy in decision-making, yet it is at the local level that adaptation takes place. Forest managers in an uncertain future will increasingly need the ability to make innovative and locally relevant decisions related to climate change adaptation.

Anticipatory and planned adaptation can reduce potential negative impacts of climate change and allow managers to take advantage of beneficial impacts. Structured assessments can help determine areas of vulnerability (or opportunity), and can help identify possible adaptation actions and strategies. In some cases options can be implemented now that reduce current climate vulnerability while also building adaptive capacity for the future ("no-regrets" options).

Forest management planning is a logical mechanism for including climate change considerations in decision-making. Managers should begin to incorporate climate change thinking into current long-term planning exercises. An effective approach is one referred to as "embedded science", in which scientists work closely with forest managers throughout the lifespan of a planning exercise to integrate scientific information with management planning. This approach has been found to be not only effective but also personally and professionally rewarding for those involved. It can also help build capacity in participants. Continuing education programs through professional and industry bodies can also help build capacity.

One challenge with incorporating climate change into planning is the need for a view of the future in a particular area under a rapidly changing climate combined with other socioeconomic changes. Decision support models and science-based projections may help but they are likely subject to wide margins of error. A complementary approach is scenario construction, in which the question is not "what will happen?", but rather, "what would you do if this happened?"

Policy-makers should review existing forest management policy and determine the extent to which it can accommodate surprise and uncertainty. Particular attention should be paid to the principles of sustainable forest management (SFM) and how they might be modified under an uncertain future that includes climate change. Similarly, forest certification systems and the Criteria and Indicators of SFM need to be reviewed and modified to recognize the uncertainties associated with climate change and to increase adaptive capacity among forest managers. Finally, planning guidelines should be developed to provide direction on how to integrate climate change considerations into forest management plans.

Priorities for research include better models for projecting future ecosystem impacts and wood supply, further work on modifying seed transfer zones and assisted migration of more suitable tree populations, improved models for projecting future species distributions, and a better understanding of how frozen soil conditions will change under a warming climate. We need to develop methods to assess and improve resiliency to increased disturbance pressure. Social science research in the area of economic impacts assessment, preference rankings of environmental impacts, perceptions of risk, institutional effectiveness, and adaptive capacity assessments are needed. Most important, we need a new transdisciplinary approach that accounts for cumulative impacts, interrelationships among a range of change agents, and dynamic and non-linear systems.

1.0 Introduction

1.1 Issues and objectives

The forested portions of Canada are expected to experience greater impacts of climate change than many areas of the world (Field et al. 2007). Of particular concern to Canadian forest managers are impacts such as:

- increased frequency and intensity of fires (Flannigan et al. 2005),
- increased outbreaks of forest pests, both insects and disease (Johnston et al. 2006),
- increased frequency of drought leading to forest dieback, particularly on the southern fringe of the boreal forest (Hogg and Bernier 2005), and
- changes to growth and amount of harvestable wood volume (Johnston and Williamson 2005, Girardin et al. 2008).

Some of these and other potential biophysical impacts are already being observed, but in many cases we lack the details needed to identify specific adaptation options (Johnston et al. 2006). The ways in which forest management institutions will be required to adapt to these impacts are poorly understood, yet critical to successfully coping with climate change.

Assessing adaptive capacity may help identify and address sources of vulnerability in forest-dependent social and economic systems

Adapting to climate change will need to become a part of forest management and planning in Canada. We need further assessment of the ability of Canada's forest management enterprise to adapt to climate change impacts – i.e. its adaptive capacity (Johnston and Williamson 2007). Assessing adaptive capacity may help us to identify and address sources of vulnerability in forest-dependent social and economic systems. Such information could also be useful in helping us develop policies to improve the adaptive capacity of forestry stakeholders and to assist them in identifying realistic adaptation options.

This report addresses both the impacts of climate change and the adaptive capacity of forest management, with somewhat more emphasis on the latter, as impacts have been detailed in several recent reviews (e.g. Johnston et al. 2006, Lemmen et al. 2008, Lemprière et al. 2008, Williamson et al. 2009). Our objectives were as follows:

- To review current understanding of climate change impacts on Canadian forests and forest management;
- To assess the adaptive capacity of forest managers and forest management institutions in Canada;
- To determine how forest management must change in order to cope effectively with climate change (adaptation).

A particular objective was to obtain and present insights from Canadian forest managers and other practitioners. While the scientific literature has covered climate change impacts to some extent, data on adaptive capacity and adaptation activities are rare in the forest science field. Although adaptation is occurring, it is generally not documented and therefore requires discussions with practitioners who are beginning to consider these activities. For these reasons we invested a great deal of time in discussing climate change impacts, adaptive capacity and potential adaptation options with practitioners. (See Table 1.)

1.2 Policy context

In Canada, most forest resources are publicly owned. Provincial and territorial governments manage Crown forest lands under legislation that prescribes responsibilities of provincial or territorial regulators and the forest industry.

Rights to harvest wood are granted to forest companies through forest management agreements (FMAs) or other licensing arrangements. These stipulate harvest levels and activities the companies must undertake (e.g., submission of forest management plans; reforestation of harvested areas; protection of fish and wildlife habitat). In general, forest companies are required to establish one or more wood-using facilities to make use of the timber harvested from the FMA area. Thus the companies manage both the forest landscape and the industrial facility. Provincial regulators exercise oversight of forest companies by requiring long term (e.g., 20-year) forest management plans, as well as enforcing regulations under forest management legislation.

Forest management plans usually assume a constant physical and policy environment – yet climate may change dramatically within current rotations.

Current forest management policy in Canada generally assumes a relatively constant environment. For example, long-term wood supply analyses may be done on a 200- or 300-year time horizon in which stand dynamics are represented but a stable climate is assumed. Forest management plans usually assume a constant physical and policy environment. Yet scientific evidence increasingly indicates that the climate may change dramatically within the rotation of existing forest stands (50-100 yr). These changes need to be considered and incorporated now into long-term planning. In addition, recent work has shown that existing forest policy institutions may lack the flexibility to accommodate the innovation required by climate (or other) change in future decades (Haley and Nelson 2007, Johnston et al. 2010).

Adaptation has not generally been a high priority in climate policy in Canada.

Climate policy in Canada has emphasized greenhouse gas emission reductions (i.e. mitigation) much more than climate change impacts and adaptation. Similarly, federal and provincial funding for climate change has been mostly oriented to mitigation efforts, with relatively little support for adaptation-related activities. (Some exceptions are reviewed in Section 2.5 below). However, at the 2007 United Nations Climate Change Conference in Bali the need for adaptation was given a higher profile, which has resulted in more work in this area recently. As climate change impacts become increasingly clear, adaptation will likely become a higher priority. Reports such as this one will help increase forest managers' understanding of the need to begin thinking about adaptation.

1.3 Methods

The project made use of two complementary approaches. The first was a literature review, primarily on climate change impacts on forest ecosystems and the ability of forest management to adapt to these impacts. Much of the impacts component was adapted from a new report by Williamson et al. (2009), which forms a report complementary to this one. The adaptive capacity component draws heavily from a project recently completed for NRCan's Canadian Climate Change Impacts and Adaptation Program, in which adaptive capacity of forestry stakeholders in the Boreal Plain Ecozone was assessed through interviews and group discussions (Johnston et al. 2008). We also drew on other recent works on climate change and

Table 1 List of organizations contributing to the State of Knowledge report through interviews and discussions[1]

British Columbia	British Columbia Ministry of Forests and Range
Alberta	Alberta-Pacific Forest Industries Inc. Millar-Western Ltd. Government of Alberta, Sustainable Resource Development
Saskatchewan	Mistik Management Domtar Saskatchewan Independent Forest Operators of Saskatchewan Government of Saskatchewan, Saskatchewan Environment, Forest Service Saskatchewan Environmental Society Council of Saskatchewan Forest Industries
Manitoba	Louisiana-Pacific Tembec Manitoba
Ontario	Ontario Ministry of Natural Resources
Quebec	Abitibi-Consolidated, Grand-Mère Ministère des Ressources naturelles et de la Faune Abitibi-Consolidated, Baie-Comeau Université Laval
New Brunswick	Fundy Model Forest AV Nackawic Inc. (formerly St. Anne Nackawic Pulp Mill)
Prince Edward Island	Government of Prince Edward Island, Department of Natural Resources
Nova Scotia	Nova Forest Alliance (Model Forest) Natural Resources Canada, Canadian Forest Service (Acadian Forest) Bowater Mersey Paper Company Federation of Nova Scotia Woodland Owners StoraEnso Port Hawkesbury Government of Nova Scotia, Department Of Natural Resources Pictou Landing First Nation Confederacy of Mainland Mi'kmaq (Tribal Council)
Newfoundland and Labrador	Western Newfoundland Model Forest Government of Newfoundland and Labrador, Department of Natural Resources, Forest Resources Branch Kruger (Corner Brook Pulp and Paper) Abitibi-Bowater Grand Falls Indian and Northern Affairs Canada
Yukon[1]	Champagne and Aishihik First Nation Alsek Renewable Resource Council Government of Yukon, Department of Energy, Mines and Resources, Forest Management Branch Government of Yukon, Department of Environment Environment Canada, Canadian Wildlife Service Natural Resources Canada, Canadian Forest Service Parks Canada Yukon Conservation Society Canadian Parks and Wilderness Society (Yukon) Kluane Ecological Monitoring Project Yukon College Council of Yukon First Nations Northern Climate ExChange Canadian Climate Impacts and Adaptation Research Network

[1] All discussions in the Yukon were part of a PhD project carried out by Aynslie Ogden and supervised by John Innes at the University of British Columbia.

forest management. These include a report on climate change and forest management prepared for BIOCAP Canada's Research Integration Program (Johnston et al. 2006), work by Aynslie Ogden and colleagues in the Yukon Territory on climate change and forest management planning (Ogden and Innes 2007a,b; 2008), and the Canadian national climate change assessment (Lemmen et al. 2008). In addition, we have taken some preliminary results from a national project currently being done under the auspices of the Canadian Council of Forest Ministers which is examining the impacts of climate change on Canadian forests, its effects on forest management, an assessment of adaptive capacity and recommendations for policy-makers.

In addition to a literature review, we held nearly 60 meetings with forest managers across Canada (Table 1). They shared their observations of climate change impacts, the degree to which climate change was part of their operational and planning activities, how they view their ability to successfully adapt to climate change, and what they see as the barriers to adaptation. We used a list of questions (see Appendix) to generally guide the discussions, but did not prevent anyone from bringing up any other related points they wished to. In setting up these consultations, we often made use of contacts and practitioners known to the Sustainable Forest Management Network's partner organizations and academic partners. In some cases, organizations were consulted through other projects or activities, and relevant results were included in this report as well.

We generally held the discussions with groups of five to eight individuals, as we found that a one-on-one interview would have been too formal, especially given the relative newness of the thinking around climate change. In addition, our experience was that meeting in small groups allowed ideas to develop through the course of the discussions, with one thought triggering others among the group members. Our goal was not to record the details of each person's contribution, but rather to distil the general points and identify common themes among managers. We were careful not to attribute any aspect of the discussion to any individual, company or government agency.

We were primarily interested in general conclusions that seem to be relevant across the Canadian forest sector. We also wished to compare and contrast a general "industry" perspective with that of "government" without being specific about identity. Discussions were recorded based on written permission of the participants, purely for the purposes of later transcription of the discussions. The text and details of the discussions will not be made public. While not all jurisdictions were examined explicitly, we feel the findings represents a wide cross-section of forest management agencies, forest industry and forest-related non-governmental organizations across the country.

2.0 Findings

2.1 Conceptual framework

Assessing a system's vulnerability to climate change can be a useful step toward anticipating and planning for risks and impacts, both positive and negative (Williamson et al. 2007). A vulnerability assessment approach was therefore adopted as the underlying conceptual framework for this project. This approach to examining impacts and adaptation to climate change was developed by the Intergovernmental Panel on Climate Change in their Third Assessment Report in 2001 (Smit and Pilifosova, 2001), and adapted to the forest management context by Johnston and Williamson (2007).

Assessing a system's vulnerability to climate change can help anticipate and plan for risks and impacts, both positive and negative.

A system's **vulnerability** to climate change is a function of the **impacts**[1] of climate change on the system (e.g., a forest ecosystem or the forest sector in general) and of the system's **adaptive capacity**. Adaptive capacity is the ability of a natural or human system to adapt to the impacts of climate change. In biological systems, adaptive capacity is based on potential for genetic adaptation, physiological adjustment, migration, etc. For human systems, adaptive capacity is determined by such factors as access to technology, availability of resources, social and human capital and management of information (Moser et al. 2008).

Vulnerability can be assessed in the context of either current or future climate scenarios. Adaptation measures can then be identified that will reduce vulnerability by reducing potential negative impacts and/or by improving adaptive capacity.

The following sections combine a review of recent literature with results of discussions with forest managers in various parts of Canada. We address various aspects of climate change impacts and adaptation:

- Climate change impacts on forests and the forest sector;
- Adaptive capacity of forest management organizations or individuals, i.e., ability to implement adaptation options;
- Adaptation options that forest managers may consider in planning for climate change;
- Current programs and activities related to forestry and climate change;
- Studies from Europe and the U.S.

[1] Climate change impacts are a function of exposure to climatic conditions (e.g., temperature, precipitation) and a system's sensitivity or degree of response to the exposure (e.g., a forest's sensitivity to drought).

2.2 Impacts of climate change on the forest sector[2]

Climate change is affecting or will have future effects on a number of components and values associated with Canada's forest sector:

- Forest productivity and management (e.g., timber supply and revenues, planning, operations, ability to achieve objectives),
- Forest industry profitability (i.e., the ability to earn a competitive return on investment),
- Forest-based communities (e.g., jobs, income, social well-being, social and cultural ties to surrounding forest landscapes), and
- Supply of forest-based public goods and services to Canadian society (e.g., wildlife habitat, special places, clean air and water, productive soils, biodiversity, recreation and tourism opportunities, aesthetics).

Uncertainty about the impacts of climate change on the forest sector is higher than uncertainty about impacts on forest ecosystems.

Impacts will vary in magnitude and direction, depending on location and time horizon. It is difficult to make precise and unambiguous predictions about impacts, especially in the long-term. Because uncertainty accumulates at each step, uncertainty about the impacts of climate change on the forest sector is higher than uncertainty about impacts on forest ecosystems. However, it is possible to make some general inferences about how climate change may affect Canada's forest sector and to identify important implications for forest management.

Several reports provide detailed regional assessments of climate change impacts.

In this section we provide a general summary of the impacts of climate change on Canadian forests and forest management. Several recent publications provide more detailed regional assessment of climate change impacts; see for instance reports by Lemmen et al. (2008), Lemprière et al. 2008 and Williamson et al. (2009).

2.2.1 Impacts on forest ecosystems

Climate change is already affecting Canada's forests. The most visible impacts are changes in the frequency and severity of disturbances such as fires, drought, severe storms, and damaging insect and disease attacks.

The current unprecedented outbreak of the mountain pine beetle in western Canada, the recent spruce bark beetle outbreak in the Yukon, the Dothistroma needle blight outbreak in northwestern British Columbia, aspen dieback in the Prairies, and unprecedented fire activity in the western boreal forest and the Yukon have been linked, at least in part, to recent climate change.

More subtle effects are also being observed. For example, the length of the growing season is increasing, bud burst in sugar maple is occurring earlier, the flowering period of aspen is occurring earlier, and tree lines are moving upward in elevation.

Impacts on forest ecosystems include changes in frequency and severity of fires, drought, pests and diseases.

These examples show that impacts of climate change are already occurring and they provide a basis for beginning to understand how future climate change will affect Canada's forests. In many cases a range of factors will converge to affect forest landscapes, as in the "island forests" of Saskatchewan (Box 1).

2.2.2 Forest management

Forest management refers to the use, manipulation, management, and modification of forests and forest land to achieve social, economic, and environmental

[2] Parts of this section are excerpted from Williamson et al. (2009).

BOX 1

Saskatchewan's "island forests"

The "island forests" in central Saskatchewan are isolated areas of forest cover surrounded by agricultural land. They tend to occur on wind-blown sand deposits that are somewhat higher in elevation, thereby receiving slightly higher amounts of precipitation and sustaining forest cover, largely jack pine. A recent review of the combined impacts of climate change and disturbance agents (Johnston and Williamson 2010) suggests that these forests may already be showing signs of climate change impacts, and will probably be severely affected in the future.

The number of days with minimum temperatures below -39°C has declined in the past three decades, and will likely decline further with a warming future climate. This temperature threshold limits the reproduction of mountain pine beetle and the parasitic plant dwarf mistletoe, both pests of jack pine. An additional factor leading to the area's high vulnerability is the age of the forest. Nearly 60% of the forest is more than 70 years old, and 24% is between 50 and 70 years old. These age classes are the most susceptible to pests such as mistletoe and mountain pine beetle.

The island forests occur largely on soils with poor water-holding capacity. The future climate is expected to be drier than at present, making this area highly susceptible to droughts (Hogg and Bernier 2005). This will add to the likelihood of forest decline due to pests, as well as to declining tree growth. Modelling analysis for the island forests has indicated that future moisture availability may become similar to that currently in southern Saskatchewan (e.g. Swift Current), and that tree growth could decline by up to 30%. Finally, the older age-classes and increased likelihood of drought will promote more frequent high-intensity forest fires.

These areas may serve as an "early warning system" for the first signs of climate change impacts. They may also serve as living laboratories for work on climate change impacts and adaptation responses.

objectives. As noted earlier, most forest land in Canada is publicly owned. Management of such land for timber production is planned and carried out by forest companies in accordance with provincially (or territorially) dictated guidelines. Forest management generally includes aspects of forest inventory and mapping, growth and yield estimation, resource and timber supply analysis, land and forest management planning, zoning, public consultation, maintaining environmental standards, valuation and trade-off analysis, harvesting, reforestation and other silvicultural activities, and forest protection from fire or insect pests.

Climate change and its impacts will likely affect the ability of Canadian forest managers to achieve management objectives (Mote et al. 2003; Ogden and Innes 2007b). The implication is that forest management objectives and the means used to achieve them may need to be modified.

Timber supply

Climate change has changed current timber supply and will continue to change it in the future. Supply may change due to increased fire or pest activity, temperature or moisture effects on tree growth, and impacts of ice-storms or heavy snowfalls).

Effects on local timber supply may be positive or negative.

At local scales, effects on timber supply may be positive or negative, depending on location, time frame, and human adaptation (Johnston and Williamson 2005). Several interrelated factors will determine the net impact of climate change on timber supply. They include the impacts of climate change on forest land area, growth, disturbance patterns, silvicultural activities, regeneration success, species composition and regulatory constraints. Changes in timber supply may lead to changes in forest sector profitability and modes of operation.

Impacts on harvest revenues may affect ability to pay for reforestation and other silvicultural operations.

Woods (2008) provides a conceptual model that links climate change impacts, forest stand growth, and economic benefits of timber harvest. The final harvest volume, and hence revenues, are a function of how climate change (and other factors) have affected growth through the rotation. Revenues, in turn are re-invested in reforestation. Regeneration can be significantly affected by climate change and the likelihood of it reaching the free-to-grow stage. In early stand development the ability to reach free-to-grow is affected by climate change, which in turn will determine the future development of the stand and the final volume at harvest. This will again determine revenues available for reforestation, etc. In this way it is clear that climate change affects not only the stand throughout its rotation but also the forest in the longer term as it determines management options and economic benefits, part of which will fund good forest management and silviculture.

Payments to governments through stumpage fees could also be affected, with implications for some government budgets.

Also, timber harvesting from public lands provides revenues to provincial and territorial governments in the form of stumpage fees. As timber supply is directly dependent on the health of forests, these revenues are also vulnerable to climate change impacts. This issue is of particular concern to provinces and territories with less diverse economies that depend rather heavily on those revenues to be able to deliver programs and services to the public (hence the attempts of the BC government to mitigate losses of timber supply due to the mountain pine beetle epidemic). Loss of provincial and territorial revenues due to climate change impacts on timber supply may affect the general public in ways that are different from how climate change will affect forest companies and forest-dependent communities. Also, in the case of forest-dependent communities, loss of provincial/territorial revenues may exacerbate their already vulnerable position.

The magnitude of socioeconomic impacts resulting from changes in timber supply will depend partly on how fast these changes occur. If changes are gradual, forest managers, the forest industry, and forest-based communities will probably be able to adapt and adjust. Even slow and gradual changes in timber supply will certainly be significant over time, however, and should be considered today in forest management planning.

For industry, a key consideration is the degree to which changes in timber supply jeopardize fixed capital investments. If timber supply under climate change continues to meet the requirements of an existing mill over its life-span, then the net impacts may be relatively small, assuming that delivered wood costs do not increase significantly. It will thus be possible to adjust and adapt technologies and capital assets to the new forest conditions.

The most significant socioeconomic impacts will be felt where changes in timber supply occur over a short time period.

The most significant socioeconomic impacts will be felt where changes in timber supply occur over a short time period. The experience with the mountain pine beetle in British Columbia shows that climate change factors can contribute to significant changes in timber supply in a relatively short period of time (Box 2). Such large swings in local timber supply, and the associated changes in production and employment compressed within a relatively short time frame, can result in significant challenges to communities, forestry companies, and provincial and territorial revenues.

BOX 2

Changes in annual allowable cut (AAC): the Vanderhoof example

The AAC of the Vanderhoof Forest District in the Prince George Timber Supply Area changed rapidly from its traditional level of around 2 million m^3 around the year 2000 to around 6.5 million m^3 to facilitate salvage of beetle-killed pine (Pederson 2004). Under a worst-case projection, harvest in the Vanderhoof Forest District could drop to about 1 million m^3 per year by 2020 once the salvage phase is completed, then gradually recover to 1.75 million m^3 by 2070 (Pederson 2004).

Sustainable forest management

The effects of climate change on Canada's ability to achieve objectives for sustainable forest management are of concern. For example, climate change will almost certainly lead to changes in species composition and distribution over time; maintaining current species and ecosystems and age-class distributions will likely not be feasible (Hebda 1998). Climate change will affect the long term ability of forested ecosystems to maintain ecological functions and processes; the forest sector may need some fundamentally new approaches to address this issue (Hamann and Wang 2006).

Climate change is already resulting in shorter winter harvest seasons. This may result in increased building of forest roads and/or more harvesting on unfrozen ground, both of which have implications for soil and water quality.

Finally, the expected increases in landscape-scale disturbances (e.g. fire, insects) have the potential to release into the atmosphere significant quantities of carbon that is currently stored in forest ecosystems (e.g. Kurz et al. 2008).

Forest operations

Warmer winters and shorter seasons with frozen ground will likely affect harvesting, hauling and other forestry operations. Flexibility in harvest scheduling will become increasingly important as frozen ground conditions become less reliable and extreme weather events (e.g., heavy precipitation, flooding) prevent access to some sites. Changes to seasonal harvest operations are already becoming significant in some areas (Box 3).

Forest companies have few options to deal with decreases in frozen-ground conditions. In the short term, more harvesting can be done on summer ground, but eventually timber supply in summer-access areas will run out. Some have suggested building more permanent roads, but such projects are expensive. In addition, the current provincial forest management policy in many jurisdictions is to minimize permanent road construction and to rehabilitate temporary roads once harvest activities are complete. Specialized equipment (e.g., high-flotation tires) is available but expensive and can only be used for a short time each year. In addition, some of these technologies require additional maintenance. This also adds to costs.

BOX 3

Impacts on frozen-ground harvest operations

Discussions with forest companies in Saskatchewan indicate that changes to seasonal harvest operations are already becoming significant. During the winter of 2005–2006, frozen-ground conditions did not occur until January. Harvest operations normally scheduled for frozen soils ("winter ground", i.e., sites that are inaccessible in summer, too wet, or prone to soil compaction) were reallocated to drier sites ("summer ground").

Future projections for warmer winters and more precipitation (early snows insulate the ground and limit freezing) suggest that the duration of frozen-ground conditions will continue to shorten (Barrow et al. 2004). Declines in frozen-ground conditions are a potentially large problem in many boreal forest regions, especially in areas with a high proportion of wetlands that cannot be reached in summer (Johnston 2007).

General remarks

The sensitivity of forests to climate change and the potential for widespread impacts on the societal benefits from forests mean that climate change considerations should start to be incorporated into all aspects of forest management in Canada (Mote et al. 2003; McKinnon and Webber 2005; Lazar 2005; Ogden and Innes 2007b).

One of the first priorities is to enhance our ability to estimate future impacts and incorporate these into timber-supply analysis and long-term plans. Second, because climate change has major implications for our ability to achieve current forest management objectives, the forest management sector will need to start reviewing those objectives as well as the means to achieve them. Ogden and Innes (2007b) provide a thorough overview of adaptation options that forest managers might consider.

2.2.3 Impacts related to global markets

Earlier we discussed the implications of climate change for timber supply and forestry operations. This section discusses ways that the Canadian forest industry might be affected by changes in global markets for forest products due to climate change.

Canada is the world's leading exporter of forest products. Forest products are a major export commodity for Canada and thus of importance to the Canadian economy; the forest sector contributed $31.5 billion to Canadian GDP in 2007 (Natural Resources Canada 2008).

Climate change may lead to a net increase in global timber supply, but may decrease benefits to North American producers.

Sohngen and Sedjo (2005) suggested that climate change will lead to a net increase in global timber supply. Forests in some regions of the world may decline whereas forests in other regions may increase. Climate change is generally expected to lead to an overall increase in the global supply of forest products, and a restructuring of the global trade in forest products. Some countries will gain more than others, leading to shifts in the comparative advantages of exporting countries.

Sohngen and Sedjo (2005) concluded that climate change will significantly decrease economic benefits to North American producers. The decrease in benefits will be significant in the early part of the 21st century as a result of a decline in relative prices and in the relative market share held by North American producers. Producers in the southern hemisphere will likely benefit from climate change throughout the century.

Canada's forest product producers may be uniquely vulnerable to market impacts compared to their counterparts elsewhere.

Perez-Garcia et al. (2002) provided country-specific predictions of the market impacts of climate change up to 2040. Of the countries included in the analysis, Canada is the only one for which the impacts on producers are predicted to be negative. Moreover, these negative impacts are predicted to be substantial. The analysis suggests that Canada's producers of forest products are uniquely vulnerable to market impacts relative to their counterparts elsewhere in the world.

The structural changes predicted to result from climate change will occur alongside a host of other changes that are simultaneously affecting markets for forest products. These include technological changes, trade disputes, changes in exchange and interest rates, and changes in consumer tastes and preferences, to name just a few. It may therefore be difficult to isolate the effects of climate change from other market influences. It may also be difficult to develop and implement specific adaptation measures in response solely to the market impacts of climate change.

Canada's market share in traditional commodity lines has, in some cases, already started to decline for reasons unrelated to climate change, e.g. high labour and wood costs. The very countries whose products are now replacing Canadian products in the global market are those that are expected to be significant beneficiaries of climate change (i.e., countries in South America and Oceania) (Perez-Garcia et al. 2002). Adaptation should, therefore, be based on consideration of the combined impacts of climate change and other market factors.

It may be necessary to increase the adaptive capacity of Canadian firms by identifying, removing, or reducing institutional barriers that limit Canada's ability to adapt and compete in global markets. Proposals include developing new value-added products and niche markets, improving efficiency, and reducing costs. These will require a strong commitment to technology development and innovation. They will also require a commitment to identifying and reducing institutional barriers that impede the ability of the forest industry to produce products at competitive costs and to adapt and evolve in response to changing market conditions (Haley and Nelson 2007).

2.2.4 Forest-based communities: impacts and vulnerability

The impacts of climate change will not be evenly distributed across Canadian society. Some segments of society face higher risks because of their location, their association with climate-sensitive environments, and their economic, political, and cultural characteristics (Davidson et al. 2003, Williamson et al. 2007). Rural, resource-based communities are of particular concern (Standing Senate Committee on Agriculture and Forestry 2003).

Forest-based communities face the same kinds of impacts and risks associated with climate change that non-forest-based communities face. These include potential health effects, impacts on infrastructure, and exposure to extreme weather events. However, forest-based communities face additional factors that add to their overall vulnerability to climate change (Williamson et al. 2007), including:

- strong ties to the surrounding climate-sensitive forest landscape,
- increased risks owing to expected increases in wildfire activity (in some locations),
- potential changes in local wood supply, and
- changes in the relative competitiveness of local firms.

These factors can have significant impacts on local economies, particularly where there is a heavy dependence on the forest-products sector.

Davidson et al. (2003) identified five socioeconomic factors that further contribute to the heightened levels of vulnerability of Canadian forest-based communities:

- adaptive-capacity constraints (e.g., small and undiversified economies and overspecialized local labour forces with skill sets that are not transferable to other sectors),
- potential for larger scale institutional responses to environmental issues and climate change that ultimately affect small, rural, resource-based communities,
- lack of consideration of climate change in forest management decisions and forestry institutions that may ultimately lead to higher impacts manifesting at the community level,
- potential misperception of the risks of climate change, and
- an increase in multiple, simultaneously occurring, and interacting risks (e.g. climate change plus market downturns).

Forest-based communities tend to be more vulnerable to climate change than other types of communities.

Forest-based recreational opportunities will change due to changes in water availability, wildlife distributions and snow cover, with economic implications for some communities. The ability of Aboriginal communities to carry out traditional activities will also change as the forest types and water bodies around them are altered.

In short, the combined effects of higher potential impacts and lower adaptive capacity mean that forest-based communities tend to be more vulnerable to climate change than other types of communities; Aboriginal communities may be particularly vulnerable (e.g., see Lemmen et al. 2008).

Systematic and structured assessments of vulnerability at a community level can help individuals and communities identify significant factors that currently contribute to their vulnerability, or that may do so in the future (Williamson et al. 2006). Williamson et al. (2007) described a framework and approach with which to do this (e.g., Figure 1); they note that such approaches should be tailored to each community.

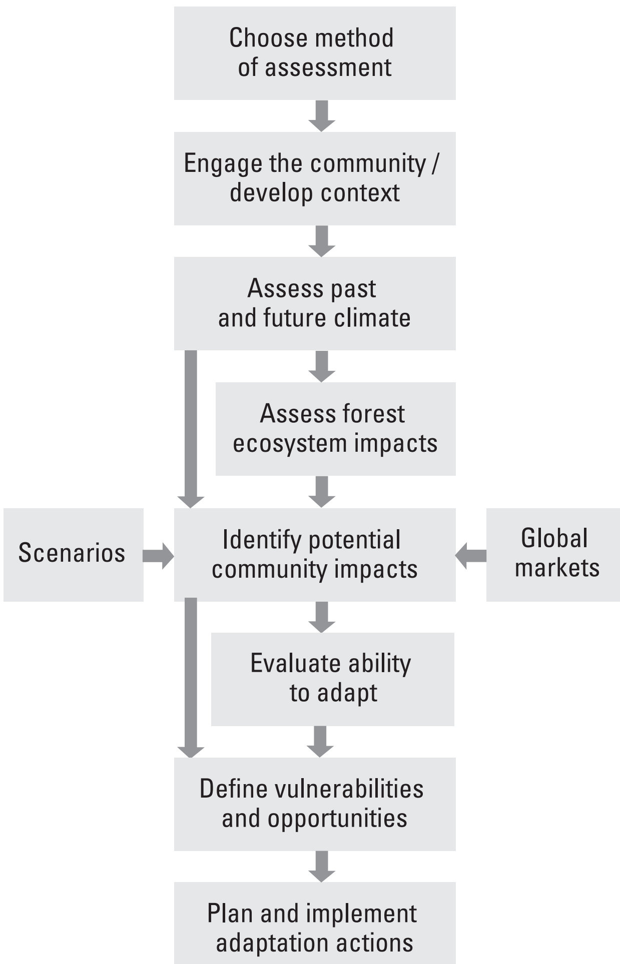

Figure 1. Conceptual model for vulnerability assessment of forest-based communities. Adapted from Williamson et al. (2007).

A case study assessing potential biophysical and socioeconomic impacts of climate change on the forest-based community of Vanderhoof in central British Columbia was described by Williamson et al. (2008). The Vanderhoof example (Box 4) highlights ways in which forest-based communities are uniquely exposed, sensitive, and therefore potentially vulnerable to climate change.

BOX 4

Case study: assessing climate change impacts in Vanderhoof, BC

The Vanderhoof area is currently significantly affected by the mountain pine beetle outbreak in British Columbia. This outbreak is partly due to recent climate change. The mountain pine beetle is having a major impact on the natural forest capital that helps support the Vanderhoof economy. The immediate impact is a large increase in local harvesting to accommodate salvage of beetle-killed timber. Once salvage activities have ended, harvest rates in the area are expected to decline below historical levels.

For the longer term, a scenarios analysis approach was adopted. Four scenarios were developed, based on different assumptions about future climate and socioeconomic conditions. Results suggested that in the longer term (up to 2050), forest productivity will actually increase under the climatic scenarios that could occur in Vanderhoof, although harvests are not expected to recover to the levels that occurred in the year 2000. However, fire risk in the area is also expected to increase, and this may offset some of the expected recovery in forest productivity.

The experience of Vanderhoof shows that the effects of climate change can be immediate and significant. An additional risk factor for communities that depend on the forest industry could be reduced profitability of traditional forest products due to climate-induced changes in global timber supply (see previous section) and/or operational changes such as reduced winter harvest. A useful first step for communities is to assess how they are potentially vulnerable to climate change.

KEY QUESTIONS FOR FOREST-BASED COMMUNITIES

Some key questions that forest-based communities might consider include the following:

- How is the local climate changing, and what kinds of future changes in climate are expected in the local area?
- What are the potential implications in terms of extreme weather and other hazards such as forest fires and floods?
- Given the expected change in hazard risk, are local emergency preparedness measures adequate?
- What types of manufactured assets (buildings, equipment, infrastructure) and natural assets (forests, agriculture, water) currently support the local economy?
- How will these assets be affected by the changing climate and by the changing global economy?
- Can the community modify the mix of assets on which it depends in order to reduce its vulnerability to climate change (e.g., diversification, substitution of less vulnerable forms of capital for natural capital)?
- Does the community have sufficient capacity to adapt?
- How can the community strengthen its capacity to adapt?

2.2.5 Public and common-property goods and services

Public and common-property goods and services associated with forests include:

- clean air and water,
- productive soils,
- wildlife,
- protection and preservation of biodiversity,
- existence value (i.e., the knowledge that certain species or ecosystems continue to exist),
- bequest value (i.e., the knowledge that we are preserving natural capital for future generations),
- provision of aesthetically pleasing vistas, and
- provision of outdoor recreation opportunities.

Forest-based public and common-property goods and services are vulnerable to climate change because they are closely linked to the health of forests.

Outdoor recreation is an important forest-based service. Canadians spent 225 million days on various outdoor recreation activities in 1996 (Duwors et al. 1999). Forested areas accounted for 195 million user days, or 86% (Williamson et al. 2002). Outdoor recreation is sensitive to climate (Johnston et al. 2006). For example, Browne and Hunt (2007) found that climate change will probably have a net positive effect on summer outdoor recreation activities in Ontario because of lengthened season and higher temperatures. Winter-based activities, however, will decrease due to shorter seasons.

Biodiversity encompasses species diversity, genetic diversity, and the diversity of ecosystems (Gray 2005). Changes in ecological diversity will have important socioeconomic impacts. Many of the psychological non-use values of forests (e.g., option value, bequest value, existence value, intrinsic value) are associated or closely aligned with biodiversity and ecological diversity (Hauer et al. 2001). Ecological diversity will probably change considerably this century in response to not only climate change but also human activities such as changes in and fragmentation of land use (Gray 2005).

Varrin et al. (2007) considered the effects of climate change on representative species in Ontario. They noted that the risks will vary by species, depending on species-specific traits and on the nature of changes in interrelations between species. Risks will be the highest for species with small geographic ranges, with small populations, with specialized habitat requirements, with low genetic variability, with limited dispersal ability, and with a southern range boundary located in Canada.

KEY POINTS

Impacts of climate change

- Impacts of climate change will be variable across the country, underlining the need for regional and local vulnerability assessments.
- Forest productivity will change as climate change affects forest ecosystems. Productivity may increase or decrease depending on local site factors, species composition and the potential for management interventions.
- In the short term, changes in disturbance regimes, especially forest fires and insect outbreaks, may have

more important impacts than changes in productivity and species composition.

- It is essential that vulnerability assessments and adaptation planning be done within the context of sustainable forest management.
- Vulnerability assessments must be carried out for and with forest-based communities, including Aboriginal communities, as well as for forest management.

2.3 Adaptive capacity of Canadian forest management

According to the Intergovernmental Panel on Climate Change (Smit and Pilifosova 2001), the capacity to adapt to climate change is determined by:

- Awareness of the issue and perception of urgency;
- The range of technological options available to decision makers;
- Economic resources;
- Institutional factors (e.g., design and structure, flexibility, ability to efficiently allocate resources to adaptation, degree of autonomy in making adaptation choices);
- Human and social capital of adaptors: skills, education, experience, networks;
- Knowledge and access to information;
- Ability to manage risk.

In this section we identify and discuss features, assets and institutional factors that influence (positively and negatively) the ability of Canadian forest managers to adapt to climate change. Most of this section is based on discussions with forest managers and other forestry stakeholders (Table 1). We include many findings first reported in Johnston et al. (2008), confirmed or supplemented by observations from across Canada.

2.3.1 Awareness and understanding, perception of urgency

The Canadian forest sector has a high general level of understanding of climate change, and sees it as a serious issue . Forest managers are acutely aware of exposure to climate change, and of the sensitivity of forests to current climate and climate variability. The question among managers is not whether climate change is real, but what local impacts will be and what adaptation actions should be taken.

Information is often lacking at the scales needed for forest management planning and operations.

However, information on impacts is often unavailable at the temporal and spatial scales needed for planning and operations. Downscaling climate data and ecosystem modelling techniques could partially address the need for such information. However, they require fairly sophisticated expertise and have large uncertainties associated with them.

Also, climate change is only one source of change affecting the forest sector. Others include demographic shifts in rural populations, effects of global market forces on the forest industry, local and national political change, and changes in society's expectations of the values and benefits available from the forest. The integration of climate change with these other agents of change is a challenge for forest managers, given high levels of uncertainty and current economic instability and poor market conditions.

2.3.2 Technological options

Forest managers generally have access to technology that is sufficient and appropriate under current conditions. Managers also felt that future climate change could be accommodated with current technology up to a threshold of change beyond which adapting would be difficult and eventually impossible if climate change impacts continue. A major challenge for climate researchers is to determine what these thresholds are, especially given that the nature of the thresholds will vary geographically and with respect to different aspects of forest management (e.g. impacts of disturbance, shifts in species ranges, changes in operating conditions etc.).

International discussions have identified a range of temperature changes that represent "tipping points" beyond which severe impacts may occur (e.g.

Ramanathan and Feng 2008). One value often cited is a 2° C rise in mean annual temperature, which would likely result in rapid and irreversible melting of the Greenland ice cap (Lenton et al. 2008). However, it is extremely difficult to determine how these large-scale changes would translate into local impacts on Canadian forest ecosystems, and how they would affect forest management.

Current technology may be able to accommodate climate change up to certain thresholds of change; such thresholds are difficult to determine.

In discussing the role that additional or different technology might play in adaptation, the primary concern was cost relative to its utility. For example, high-flotation tires on skidders may allow operations during unfrozen conditions in some cases (Lemmen et al. 2008). However, forest managers expressed the concern that this option is expensive, can require additional maintenance, and may only be required sporadically. Therefore the expense would be difficult to justify.

Cost is also a prime concern for the use of genetic modification to produce tree varieties better adapted to future conditions. This is especially the case in the boreal region, given slow growth rates and low return on investment for this technology. Public acceptance of genetically modified organisms (GMOs) is still a problem in agriculture and forestry, and most companies will not pursue a policy that leads to social and political controversy.

Modifying seed transfer zones is of significant interest.

On the other hand, there is significant interest among government regulators in modifying seed transfer zones, which stipulate the source (provenance) of seed used for regeneration. The current concept is to restrict the use of seed to the area from which it was collected. Managers are now beginning to look at seed zones relative to where suitable locations may occur in the future, so that seed is "matched" to the future climate. The BC Ministry of Forests and Range has recently modified its seed transfer zone policy to increase the elevation limits for seed in mountainous areas in anticipation of warmer conditions (BCMoFR 2008b). A major research need is to make better use of existing provenance test data to develop climate-based seed transfer zones for Canada's commercial tree species. In addition, new provenance tests should be established for species that have not been tested (McKenney et al. 2009).

Technology may have an important role in allowing new species to be used for forest products. Tree species ranges are expected to shift as climate change unfolds (Hamann and Wang 2006, McKenney et al. 2007), resulting in the replacement of traditional commercial species with new ones. In some cases the changes could be significant, e.g. the replacement of conifers with deciduous species under a future with more forest fire activity (e.g. the replacement of spruce with aspen in boreal mixedwood stands, Williamson et al. 2009).

Companies that are able to implement new technology to provide new products will have enhanced adaptive capacity. However, investment in the forest sector is currently low (FPAC 2007a). It is unlikely that investment in new facilities and equipment will occur in anticipation of future species availability, given high capital costs and large uncertainty.

2.3.3 Availability of economic resources

Availability of resources for adaptation, especially financial resources, is extremely limited in the Canadian forest sector today. Tens of thousands of forest-industry jobs have been lost in the past 10 years and many mills have closed across the country (NRCan 2008). It was made very clear in our discussions that most forest managers in industry are focused on day-to-day survival and do not have time to consider climate change and adaptation, even in cases where they know this will be important in the future.

One of the by-products of the economic downturn is lack of investment in innovation. Furthermore, Canada has below-average rates of private investment in research and development compared to other

OECD countries (Industry Canada 2007). The forest industry in Canada has also been the victim of high exchange rates, competition with low-cost offshore producers and rapidly increasing costs of energy, further reducing our capacity to adapt to future climate change (FPAC 2007a). Finally, most forest products facilities are long-lived and require very large capital investments. This makes it difficult to adjust rapidly to changes in the natural or economic-political environment.

2.3.4 Key institutions

Our discussions indicated overwhelmingly that institutional factors are the most important elements limiting adaptive capacity among forest managers. While the financial position of the forest industry is also important, the general perspective is that this is a temporary problem and part of the business cycle. In constrast, institutional barriers are seen as being long-term and an inherent part of the forest sector's structure and governance, making them difficult to change. In addition, the solutions are seen as requiring political change which may make them more difficult to implement.

Our discussions indicated that institutional factors are the most important elements limiting adaptive capacity among forest managers.

Various institutions can or do play a role in strengthening the capacity of Canada's forest sector to adapt to climate change:

- Industry-related institutions,
- Regulatory institutions (e.g., government),
- Non-governmental bodies,
- Multisectoral institutions, and
- Research institutions.

We discuss some such institutions below.

Industry organizations

Forest industry managers indicated that industry organizations are important to them as source of credible information. The Forest Products Association of Canada (FPAC) was mentioned specifically as their first stop for gathering information. FPAC works with companies to facilitate dialogue and work toward reforms in areas such as business (exchange rates, industry restructuring and competition policy, regulatory environment, etc.) and environment (air quality, environmental effects monitoring, climate change, species at risk). In addition, FPAC works with government to develop more efficient systems for international trade, streamline regulatory requirements and enhance investment. It also works with environmental nongovernmental organizations in developing large-scale conservation plans, e.g. the Canadian Boreal Initiative.

Working with FPAC to develop industry-relevant information on climate change impacts and adaptation options would be a good way to bring information to companies from a source they trust. An example of a previous successful initiative is the large amount of work FPAC has done on helping companies reduce greenhouse gas emissions. The forest industry in Canada has reduced these emissions by 44% since 1990 while increasing production by 20%, largely through the use of cogeneration based on forest residues (FPAC 2007b).

Forest management plans

Most jurisdictions in Canada require some type of long-term forest management plan. Our experience in other projects and our discussions with industry managers indicate that the forest management planning function provides an excellent vehicle for considering climate change impacts and adaptations. These plans have relatively long time horizons (e.g., 20 or 25 years) and a generally strategic focus. This means that climate change can be considered at temporal and spatial scales consistent with the current state of understanding of climate change impacts. In addition, the plans are required under most provincial legislation, so this is an activity the companies will be undertaking regardless and is not a separate activity that would add additional cost to their operations.

This provides an important example of "mainstreaming" climate change adaptation, as recommended by the recent Canadian National Climate Change Assessment (Lemmen et al. 2008). Smit and Wandel (2006, p. 285-286) note the importance of mainstreaming in the following:

"One of the fundamental findings from this work is that it is extremely unlikely for any type of adaptive action to be taken in light of climate change alone… Practical climate change adaptation initiatives are invariably integrated with other programs, and often aim to enhance adaptive capacity."

Three examples of forest management plans that have included climate change impact and adaptation components are noted below (Box 5). Each of these plans has been submitted to provincial regulators.

While these efforts were a success in that climate change considerations were included in the final submitted plan, each was done in an ad hoc manner with no common guidelines; there was no consistency among efforts and no common understanding of how best to address climate change impacts and adaptation.

Forest management planning provides an excellent vehicle for considering climate change impacts and adaptations.

We advocate the development of **planning guidelines** that could be used across all jurisdictions to help integrate climate change impacts and adaptations into forest management plans. These would necessarily be general in order to accommodate variability among jurisdictions and biophysical conditions, but could be developed in a way that would be helpful to both industry and government planners.

The "embedded science" approach can help forest managers and planners incorporate scientific analyses into forest management plans. General guidelines should also be developed.

We also support the concept of **"embedded science"** (Van Damme et al. 2008). In this approach, scientists from government or academia work closely with company managers and planners in incorporating scientific analyses into the forest management plans. This collaboration is established at the beginning of the planning cycle so that the direction and approach used by the scientists is collaboratively developed by researchers and practitioners and is therefore likely to support the objectives of the plan. Companies vary widely in their science capacity and their interest in such an arrangement, so we would not expect that this would work in all planning projects. But where the interest and capacity exist, it can be a very rewarding experience for both scientists and industry staff (e.g. Van Damme et al. 2008).

A particular challenge in forest management is the fact that effects of decisions taken today will persist for several decades. This is especially true in slow-growing

BOX 5

Examples of forest management plans that address climate change

- **Louisiana-Pacific** in southwestern Manitoba: scenarios dealing with future fire activity, forest productivity and forest carbon budgets were developed by a group of government and university scientists working closely with the company. The plan also included a range of other scientific investigations including a very advanced, spatially-explicit biodiversity analysis under several future harvest scenarios (Louisiana-Pacific 2009).
- **Mistik Management** in northwestern Saskatchewan: the plan included analyses of forest productivity, fire activity and likelihood of winter frozen ground conditions under several future climate scenarios (Mistik Management 2009).
- **Millar-Western**: several future scenarios integrated the effects of climate change, oil and gas development and demographic change across their Forest Management Agreement area in central Alberta (Van Damme et al. 2008).

forest regions (e.g. the boreal). In contrast, decisions in agriculture about what crops to plant or what management practices to follow can be made annually or sometimes more frequently. The outcome of forest management decisions is difficult to predict even under current assumptions about a stable climate. It will be all the more difficult to predict given the high likelihood of a different climate occurring in the next few decades. The lack of ability to determine the correct long-term decision limits the adaptive capacity of forest managers. It also points to the need for climate sensitive tree growth models that could help managers envisage future forest conditions (Girardin et al. 2008).

Corporate culture and adaptive capacity

An interesting relationship has been found between corporate culture and adaptive capacity (Van Damme 2008). Certain corporate characteristics, such as the strength of leadership, willingness to innovate and having a future orientation vs. maintenance of the status quo, may enhance capacity to adapt to climate change. Companies vary widely in the extent to which they exhibit such characteristics. In many cases where such qualities are evident, they result from the influence of specific individuals and reflect their personal values. While positive, these attributes may disappear when an individual leaves the company. The issue becomes how to institutionalize these progressive attitudes and make them a part of corporate culture rather than just a function of specific individuals.

> **An issue is how to make progressive attitudes – willingness to innovate, having a future orientation – a part of corporate culture.**

Regulatory institutions

As indicated earlier, most forestry-related legislation in Canada is determined and enforced by provincial or territorial forest management agencies that regulate activities of the forest industry on Crown forest land. Institutional barriers to adaptive capacity among provincial regulators are related to forest policy that usually assumes a forest that remains substantially the same over time. Policy is generally based on what has worked in the past rather than anticipating what is likely to happen in the future. This is particularly a problem with climate change given the uncertainty about future conditions. This may make it difficult for provincial regulators to accept innovative ideas proposed by forest managers and planners. This is especially the case if the proposed alternative lies far outside of accepted practice.

> **Future conditions are uncertain. Regulatory systems should allow for flexibility and innovation.**

There is also much discussion in the forest sector currently regarding the need for change in the forest tenure system. Long-term agreements may reduce the adaptive capacity of both industry and provincial regulators by "locking in" levels of harvest or other aspects of forest management, and may prevent adaptation options from being implemented (Haley and Nelson 2007). Innovative forest management practices may be difficult to apply given relatively inflexible tenure agreements.

Similarly, agreements that stipulate both an industrial wood-using facility and management of large forest landscapes may reduce adaptive capacity in that the company must maintain a range of specialists and staff for both mill and forest management, rather than focusing on one aspect or the other. A tenure agreement that is specific to the forest landscape, rather than requiring both forest management and a mill, will likely result in agreements with companies that specialize in forest management. These companies are more likely to allocate the resources to carry out effective adaptation.

Finally, forest managers will require the flexibility to make local decisions based on their needs for adaptation. This flexibility is not always available under current regulatory and tenure systems. Industry based forest managers do not feel that they currently have the authority to modify management practices at local scales in anticipation of local climate change effects. In fact there may be a disincentive in trying innovative approaches because of the risk that new approaches that are outside of the scope of current standards could be rejected by the regulators.

Organizations and standards promoting sustainable forest management

A number of non-governmental bodies have emerged that support the principles and application of sustainable forest management (SFM). Forest certification bodies have developed standards for forest management that stipulate how SFM is to be achieved, and will certify a company's products as having come from a sustainably managed forest estate (Box 6).

BOX 6

Certification for sustainable forest management

Canada has three certification standards for sustainable forest management:

- Forest Stewardship Council,
- Sustainable Forestry Initiative,
- Canadian Standards Association.

Over 134 million ha of forest land have been certified (FPAC 2007c). Certification is often required by buyers of forest products (e.g. IKEA, Home Depot), and is increasingly sought by consumers at the retail level. The forest industry now sees certification as essential to continued market access. The updated CSA standard for sustainable forest management (Z809-08; CSA 2008) includes a discussion about how climate change can be considered within the Criteria and Indicators framework.

While certification standards promote sustainable forest management, it is unclear to what extent they support or help develop adaptive capacity for climate change. In general they assume a relatively unchanging forest, and they tend to support the protection and maintenance of existing species and habitats. The standards indicate little about how forests may change or how practices may need to adapt to new conditions.

We advocate the incorporation of climate change considerations into forest certification standards. This would necessarily be at a fairly general level but would provide guidance to companies on how to address the critical questions about likely impacts, vulnerability and adaptation options. Some steps have already been taken in this direction. For instance the new version of the CSA standard for SFM (Z809-08, Sustainable Forest Management) has provision for exploring climate change impacts and adaptation (CSA 2008).

Sustainable forest management in Canada is guided by the Criteria and Indicators (C&I) framework as defined by the Canadian Council of Forest Ministers (CCFM 2003). This framework is generally used as a backward-looking instrument, i.e. as a checklist or report card indicating how forest management has performed in maintaining the values represented by the criteria (Box 7). None of the criteria as written deals with future change, in either the natural or the socio-economic environment.

BOX 7

Sustainable forest management Criteria and Indicators: the CCFM framework

The Canadian Council of Forest Ministers has developed a framework that defines sustainable forest management and provides a basis for measuring progress toward sustainable forest management (CCFM 2003). The framework is based on six criteria, each associated with several indicators. The basic criteria are:

1) biological diversity,
2) ecosystem condition and productivity,
3) soil and water,
4) role of forests in global ecological cycles,
5) economic and social benefits, and
6) society's responsibility.

Climate change has the potential to affect each of these (Ogden and Innes 2007b).

Sustainable forest management standards should consider climate change.

We feel the CCFM's framework for SFM could be adapted to provide an already accepted vehicle for identifying biophysical climate change impacts, socio-economics impacts and adaptive capacity.

An excellent example of this approach is given by Ogden and Innes (2007b). They used the criteria from the Montreal Process, which differ somewhat from those adopted by CCFM. For each criterion they propose a range of climate change impacts and adaptation options that can be implemented at either the strategic or operational level. This approach could be adapted to the CCFM framework. The framework could then be used in forest management planning across the country, increasing the adaptive capacity of the forest sector.

Canada's national forest strategies

Several Canadian national forest strategies have been produced since 1983. These have evolved over the past 20 years, increasingly emphasizing sustainable forest management and the need for sustainable communities as well as forest ecosystems. In 2008 the CCFM produced "A Vision for Canada's Forests: 2008 and Beyond" (CCFM 2008). This document was based on initial discussion papers by the National Forest Strategy Coalition followed by extensive cross-country consultation. The vision document identifies two key themes: transformation in the forest sector, and climate change impacts and adaptation. We highlight this because we feel it is good evidence that the issue of climate change is firmly entrenched among stakeholders in the forest sector. Climate change will be a high priority as discussion proceeds toward implementation of the strategy vision. This should significantly enhance the adaptive capacity of the forest sector.

The issue of climate change appears to be firmly entrenched among stakeholders in the forest sector.

Model forests

Canada is known internationally for the model forest program, which was an outcome of the Environmental Summit at Rio de Janeiro in 1992. A model forest is a community-based partnership organized around the desire to develop and implement sustainable forest management practices. The partnership identifies local issues, develops innovative and locally-relevant SFM practices, and provides a forum for sharing results, resolving conflicts and ensuring equality of benefits among the partners (Gilbert 2008). The model forest program began in Canada, which now has 14 model forests. The International Model Forest Network was established in the mid-1990s, and now includes approximately 50 model forests on every continent except Antarctica.

The model forest program is well placed to support and develop adaptive capacity among forestry stakeholders.

In the past several years, climate change has become a top priority for the model forest system, both domestically and internationally. Many Canadian model forests now have local projects dealing with climate change, and the Canadian Model Forest Network has funded a number of national initiatives that address climate change across several model forests. The International Model Forest Network recently held a meeting of over 160 individuals from 33 countries representing all the model forests around the world. Through a group prioritization exercise, participants identified the main theme areas in which they would like to work in partnership, and climate change was in the top three. The model forest program is well placed to help support and develop adaptive capacity among forestry stakeholders, both in Canada and other countries.

Research institutions

In a rapidly-evolving field like climate change, access to research results, and the integration of researchers and practitioners is essential. Practitioners recognize the value of research but generally do not have the time or capacity to review peer-reviewed publications. The concept of embedded science (Van Damme et al. 2008) has proven to be a very successful model for integrating scientists and practitioners through involvement in forest management plans. Practitioners gain insight into the scientific method and see the results of research first-hand. Scientists gain a detailed understanding of practitioners' needs and the real-world constraints that often limit research to focused, applied questions.

Collaboration and communication between researchers and practitioners is vital. Interaction with policy-makers is important as well.

Organizations such as the SFM Network, the CCFM Climate Change Task Force and others in which researchers interact with policy-makers are also important in setting research priorities. We also advocate the creation of a virtual national centre of excellence on climate change and forest management. Practitioners need a well-recognized "one-stop shop" where they can go to get credible, applied science related to impacts and adaptation guidance. In particular, research that integrates the biophysical and social sciences is needed to support forest management decision-making.

2.3.5 Human and social capital[3] (e.g., skills, education, networks)

The forestry profession has a long history in Canada, with the first professional schools established in the early 1900s. The profession has strong governance in the form of professional societies in virtually every province, some with legal rights to approve management plans and other forest management activities. Professional societies enforce standards for education and ethical practices and provide incentives for continuing education. Research in forest science and management is taking place in professional schools and government institutions across Canada. This has resulted in one of the most advanced and technically sophisticated forest management communities in the world. Canada's forestry profession has developed a strong set of principles regarding sustainable forest management. At the basic level of forest management, the adaptive capacity of the forestry profession in Canada is high.

While adaptive capacity of the forestry profession is generally high, lack of scientific capacity is an important constraint to planning for climate change.

In some parts of the country (e.g., boreal plains), discussions with both industry and government managers indicated that lack of capacity was an important constraint to planning for climate change. Forest companies and management agencies vary widely in their expertise; some employ several Ph.D.-level scientists while others have very little advanced scientific capacity. Compounding the lack of scientific capacity is the fact that current information on climate change impacts is generally not available at spatial and temporal scales relevant to forest management planning and operations.

Regulators that lack scientific capacity may be unable to review forest management plans that contain climate change analyses.

[3] **Human capital** is a measure of the skills, education, experience and knowledge of individuals and groups. The collective amount of human capital within a group is an important measure of the capacity of that group to adapt to some external change.

Social capital measures the size, density and characteristics of an individual's or organization's network. High levels of social capital may facilitate improved access to information, collective actions and responses and access to resources that an individual or organization would not otherwise have access to. Trust is an important feature of functioning networks.

In organizations with scientific capacity, available information can be modified (e.g. downscaling of global model results, use of ecosystem simulation models) so that it becomes more relevant. However, most organizations would need to seek outside expertise for these kinds of analyses. In addition, government agencies that lack scientific capacity may be unable to review forest management plans that contain climate change analyses.

We also heard that companies and especially government regulatory agencies are chronically understaffed; this further reduces adaptive capacity. In some cases, forest managers work for small companies in isolated rural locations, further reducing their access to relevant information on impacts and adaptation.

Finally, most forest companies today are focused on surviving an economic downturn, increased competition from off-shore producers and large-scale restructuring in the industry. Even companies that take climate change seriously and have scientific capacity find it difficult to address this issue when day-to-day survival is their primary concern.

Forestry organizations can provide information and continuing education.

Social capital provides other ways to enhance adaptive capacity (Williamson et al. 2007). Industry forest managers identified FPAC as an important organization that provides both technical and political support to companies; information from FPAC was seen as credible and relevant. As noted earlier, this would suggest FPAC as a good organization to partner with in order to engage and educate the forest industry about climate change impacts and adaptation.

The provincial professional forestry associations and the Canadian Institute of Forestry (CIF) have continuing education programs that could (or do) play a role in communicating climate change information relevant to the forest sector. The CIF's innovative web-based ("webinar") series has already highlighted climate change and will include further sessions on this topic in the future. Most provincial professional associations require their members to pursue an active continuing education program; such programs are essential to maintaining adaptive capacity.

2.3.6 Information and information management

Information availability

Availability and interpretation of relevant information clearly affects the adaptive capacity of forest managers, planners and policy-makers. Information generation and accessibility have been touched on elsewhere in the report.

Availability and interpretation of relevant information is essential.

We recap some points here, together with some additional observations:

- Much information exists on climate change (e.g., IPCC assessment reports, Canadian National Climate Change Assessment, other sources), but...
- Information is often lacking at scales useful for local decision-making.
- Some information could be obtained by downscaling existing climate data, but this requires fairly sophisticated expertise and has large uncertainties.
- Modelling can help, but also has limitations.
- Lack of scientific capacity can sometimes limit the ability of planners to interpret and use existing data.
- "Embedded science" can help to generate and share relevant information.
- We need to develop general guidelines to help incorporate climate change considerations into forest management plans.
- Some frameworks already in use could be adapted to help consider climate change explicitly in forest management planning and operations (e.g., forest certification standards, CCFM's SFM framework).

Role of modelling

There is a generally high level of uncertainty about the direction, magnitude, and timing of future impacts of climate change (Spittlehouse 2005; Williamson et al. 2006). Effective adaptation will require the use of models that simulate how forests may be affected by future climate change and how they might respond to various adaptation measures. We need to improve such models and incorporate their results into decision-support tools and forest management planning. (We discuss this further in section 3.3). At the same time, we must acknowledge the limitations of models and recognize that climate change will probably result in events that cannot be anticipated. A complementary approach is scenario construction, in which the question is not "what will happen?", but rather, "what would you do if this happened?"

Information sharing within and between organizations

The larger organizations generally have adequate knowledge-sharing mechanisms. These can include in-house training sessions, newsletter and periodic meetings. However, corporations vary in their culture of sharing information. Some leaders see knowledge as power and will only share with those who will not use it against them. In a culture that places little value on new information or new ways of thinking, innovation will be stymied and adaptive capacity will be limited.

Various agencies (e.g., CCFM, NRCan/Canadian Forest Service, Ontario Ministry of Natural Resources) have produced, or are producing, reports on climate change impacts, adaptive capacity, and adaptation options. Many of these publications are readily accessible through the internet. We expect that relevant climate-related information will increasingly be available through these and other sources, including FPAC and other industry bodies, government agencies, and research networks.

Many publications are available through the internet.

2.3.7 Risk management

Forest companies, like any other, engage in risk management as a part of normal business practice. However, some aspects of forest management make risk management more difficult. For example, the commitment to long-term decisions makes it difficult to change the species in a forest stand once they have been established. If an insect outbreak occurs, expensive treatments after the fact are usually the only viable option (spraying pesticides, salvage harvesting), rather than, say, changing to less susceptible tree species. With respect to the impacts of climate change, the rate of change expected under future climate scenarios is likely to exceed the rotation period of many commercial tree species.

Diversification may help manage risk.

One basic risk management approach in business is to diversify the portfolio of assets held. In a forestry context this could mean diversifying the mix of tree species grown or the provenances planted. However, forest managers are constrained by the natural environment (i.e. only certain species will grow in a given location). They are also limited by policy which usually stipulates that whatever species is harvested must be re-planted. These constraints may limit the ability to diversify the species mix on the landscape. In addition, some managers focus on doing what has worked in the past and do not consider planting different species. Diversifying product lines could be another strategy, as mentioned earlier.

KEY POINTS

Adaptive capacity of Canadian forest management

- Awareness of climate change as an important issue for forest management is increasing in Canada, although site-specific impacts and adaptation options are not yet well understood.
- Availability of technological options for adaptation is variable; cost is often a limiting factor.
- Investment in innovation in the Canadian forest sector is generally low, limiting the ability to develop innovative solutions to climate change impacts. In addition, resources are often lacking to support vulnerability assessments and adaptation planning.
- Institutional barriers are an important limitation to implementing adaptation options. Analyses of current policy could help identify features likely to hinder adaptation.
- Canadian forest management has a number of institutions that increase adaptive capacity, e.g. FPAC, the model forest network, forest certification programs, the national forest strategy, professional associations, and others.
- Research capacity related to forest management is high in Canada but to date has not addressed climate change in a comprehensive manner. Mobilizing this capacity through a concerted effort on climate change impacts and adaptation research would provide great benefits to Canada's forest sector.
- There is a lack of scientific capacity relative to understanding and dealing with climate change in the Canadian forest sector, and also a lack of information at spatial and temporal scales relevant to forest management planning and decision-making.
- New modelling tools will assist in better understanding the impacts of climate change and the role of potential management interventions in adaptation activities.

2.4 Adaptation options

The rate of climate change that will be faced by Canada's forest sector and the consequent impacts have no historical analogue. Canada's forest sector will need to adapt (Lazar 2005; McKinnon and Webber 2005; Lemprière et al. 2008) and it will need to do so without the benefit of prior experience.

Some useful guiding principles or adaptation strategies include the following (from Peterson 2008):

1) Increase landscape diversity;
2) Maintain biological diversity;
3) Plan for post-disturbance management, e.g. reforestation;
4) Implement early detection & rapid response;
5) Manage for realistic outcomes (prioritize projects with high probability of success; abandon hopeless causes);
6) Incorporate climate change in restoration (reduce emphasis on historical references; reduce use of guidelines based on static relationships, e.g., plant associations);
7) Develop climate-smart regulations, policies;
8) Anticipate big surprises (expect longer droughts, larger fires, species extirpations, major changes in ecosystem function; use scenario planning to develop potential responses).

Some examples of possible adaptation options are listed in Table 2. For further discussion, see for instance Spittlehouse and Stewart (2003) and Ogden and Innes (2007b). Note that general adaptation recommendations must be tailored for specific landscapes and operational conditions.

Table 2 **A summary of possible adaptation options for Canadian forest management**[1]

Plant alternative genotypes or new species in anticipation of future climate if data are available to support the decision
Agree on standardized climatic scenarios for analysis
Modify seed transfer zones to recognize potential changes in climate
Develop technology to use altered wood quality and size and non-traditional species
Consider increasing the amount of salvage logging in response to increased fire and insect outbreaks
Include climatic variables in growth and yield models and incorporate the effects of climate change into long-term timber supply analysis and forest management plans
Incorporate climate change into land use and forest management plans and consider the possibility of land use change at specific locales (forest to agriculture and vice versa)
Shorten rotation length
Develop fire-smart landscapes and communities
Plan landscapes to minimize the spread of insects and diseases
Adopt risk assessment and adaptive management principles
Diversify society's portfolio of forest assets
Develop alternative harvesting systems and implement alternative harvesting practices
Include climate change considerations when planning, constructing, or replacing infrastructure
Prepare for variable timber supply
Engage the public in a dialogue on forest values and management under a changing climate
Maintain connectivity in a varied, dynamic landscape
Monitor to determine when and what changes are occurring
Redesign or implement institutions that facilitate cost-effective and economically efficient adaptation and that provide forest managers with the tools necessary to achieve forest management objectives
Modify objectives for sustainable forest management and the means we use to achieve them
Prepare for reduced winter harvest
Prepare for increases in wildfire activity

[1] Adapted from Williamson et al. (2009).

2.5 Current activities and programs across Canada

The following section provides an overview of current activities and programs dealing with climate change impacts and adaptation in different parts of Canada.

While climate change is not generally recognized in current forest policy and planning in Canada, there are some notable exceptions. Perhaps the most advanced provincial program is British Columbia's Future Forest Ecosystem Initiative, described below. A few forest companies, too, have incorporated climate change considerations into their forest management plans, as noted earlier, though in general such efforts are at a fairly preliminary stage.

British Columbia's Ministry of Forests and Range (BCMoFR) established the Future Forest Ecosystem Initiative (FFEI) in 2005. It is developing scenarios of climate change, analyzing climate change impacts on forest ecosystems, and reviewing current policy to determine how it needs to change in order to facilitate adaptation (Spittlehouse 2008). Individual projects include a province-wide assessment of vulnerability (Don Morgan, personal communication) and local projects such as the Kamloops Future Forest Strategy (Box 8).

BOX 8

The Kamloops Future Forest Strategy

This initiative involves a detailed analysis of climate change impacts to ecosystems and policy review in the vicinity of Kamloops BC. The area (approximately 6000 km^2) includes a variety of overlapping management objectives, a diversity of ecosystem types, and significant anticipated impacts from climate change (BCMoFR 2008a). Specific objectives include:

- Clarify intent and overlap from the various plans and strategies for the Kamloops Timber Supply Area;
- Assess management options based on the desired future condition;
- Provide management options based on climate change scenarios;
- Mitigate risks to environmental values to ensure objectives for timber and other values are not jeopardized;
- Identify data gaps and uncertainties; and
- Provide a template for managing multiple objectives in a changing environment.

The climate and ecosystem analyses of the Kamloops Timber Supply Area have been completed. Resource specialists (timber, water conservation, wildlife, etc.) are now interpreting these impacts with regard to the effects on forest resources (BCMoFR 2008a).

Finally, BCMoFR has recently updated seed transfer guidelines to increase elevation limits for seed transfer by 100 to 200 m in order to anticipate the effects of warming in mountainous environments. These took effect 01 April 2009 (BCMoFR 2008b).

Alberta is in the final stages of completing a province-wide vulnerability analysis on climate change. It includes information about impacts of climate change on forest ecosystems and a review of adaptive capacity and adaptation options. Alberta's Sustainable Resource Development ministry (SRD) is working with the Alberta Forest Genetics Resources Council and the BC Ministry of Forests and Range in analyzing historical provenance test data in order to identify populations that are resistant to drought and pests. Current work is focused on white spruce (Rweyongeza et al. 2007a) and lodgepole pine and jack pine (Rweyongeza et al. 2007b). They are considering modifying seed transfer zones to accommodate the impacts of future climate change, and are developing a provincial gene conservation program (Leonard Barnhardt, personal communication).

Saskatchewan has allocated funding for a preliminary analysis of the impacts of climate change. It may do further analysis of adaptation options in the future. A portion of the impacts analysis will include existing information on the impacts on forest ecosystems in the province.

The government of **Manitoba** has established a number of new initiatives that will assist in adapting to climate change (Jocelyn Baker, personal communication). The new Forest Health Protection Act will allow regulations and management strategies to be developed for new potential pests that might migrate to Manitoba forests as a result of a changing climate (e.g., emerald ash borer, mountain pine beetle). Manitoba's Forestry Branch has provenance trials across the province, testing seed sources from different areas of Manitoba. These trials could allow for monitoring of the impacts of climate change on tree growth trends, and could play an important role in the development of appropriate adaptation strategies, such as moving southern seed sources farther north.

The **Ontario** Ministry of Natural Resources (OMNR) has established a Climate Change Strategy and Action Plan, comprising nine strategies (OMNR 2006):

1) Gather and use knowledge in support of informed decision-making about climate change. This includes research on the impacts of climate change on Ontario's ecosystems and natural resources.
2) Use meaningful spatial and temporal frameworks to manage for climate change. The basis for determining impacts will be a land classification system for Ontario's ecosystems.
3) Gather information about natural and cultural heritage values and ensure that this knowledge is used as part of the decision-making process established to manage for climate change impacts.
4) Use partnerships to marshal a coordinated response to climate change.

5) Ensure [the OMNR] corporate culture and function work in support of efforts to combat rapid climate change. The Ministry of Natural Resources will support the people engaged in the management of climate change issues.
6) Establish on-site management programs designed to plan ecologically, manage carbon sinks, reduce greenhouse gas emissions, and develop tools and techniques that help mitigate the impacts of rapid climate change.
7) Think and plan strategically to prepare for natural disasters and develop and implement adaptation strategies.
8) Ensure policy and legislation respond to climate change challenges
9) Communicate. OMNR will raise public understanding and awareness of climate change through education, extension, and training programs.

In 2007, Ontario established the Expert Panel on Climate Change Adaptation, made up of 11 leading scientists and environmental experts. The government has asked the panel for its recommendations on the path forward.

Quebec's climate change research and applications program is carried out through Ouranos, a consortium of 14 partners that include the Quebec government, the federal government and several university research institutes. Ouranos is also the national centre for developing regional climate models for Canada, i.e. models with a spatial resolution of 40-50 km. Ouranos has an impacts and adaptation program with a component on forestry resources. Its focus is on forest productivity, the impacts of changes in natural disturbance and impacts of climate change on deciduous species and forest soils. Adaptation to climate change through changes in forest management is also part of the program (Ouranos 2008).

In addition, the Quebec Ministry of Natural Resources and Wildlife started a vulnerability study on the effects of climate change on the forest and the forest sector in 2008. In its first year, study plots were established in the field to measure the effects on tree growth of heating the soil and watering specific trees. Another field study involves displacing soil samples from north to south to see the way they behave in a warmer climate. A review of literature is being completed on the silvics of 40 tree species to identify key vulnerability factors to climate for these species. Using inventory data, a study is underway dealing with relations between growth of trees and climate (Michel Campagna, personal communication).

New Brunswick has a substantial program dealing with climate change mitigation. It is implementing a Crown Land forest biomass policy, examining options for using abandoned farmland for agriculture and forestry carbon sequestration, working with the Federal government to ensure that forest management carbon offset credit opportunities in New Brunswick are fully recognized, and collaborating with Federal government and other agencies on forest carbon sequestration and carbon sinks. In the area of impacts and adaptation, New Brunswick is undertaking initial analysis to integrate climate change considerations into the forest management plan for 2012-2017. It is also assessing opportunities to enhance monitoring and suppression of forest fires and forest pests (Mike Bartlett, personal communication).

Prince Edward Island is undertaking a study of the impacts of climate change on the island's tree species in cooperation with Dr. Charles Bourke of the University of New Brunswick Faculty of Forestry.

The **Yukon** has completed a study of the impacts of climate change on the major tree species (Nitschke 2009). Further work on impacts and adaptation is on-going.

The **Northwest Territories** is undertaking a review and update of its forest management policy and will be incorporating climate change considerations in the new policy.

Federal and Canada-wide initiatives

The **Canadian Council of Forest Ministers** established a new project on climate change in March 2008, based on direction from the Premiers at the Council of the Federation meeting in January 2008. The project will comprise a national analysis of current understanding of the impacts of climate change, forest sector adaptive capacity and adaptation options. The project is structured around three components:

- Phase 1 is a study of tree species adaptation. It includes a review of current information on potential genetic adaptation and physiological adjustments, and species-level information on climate change and insects and disease.

- Phase 2 will include an ecosystem-level analysis of climate change impacts on ecosystem processes such as large-scale disturbance, nutrient cycling, etc.
- Phase 3 will focus on forest management and policy with an emphasis on assessing adaptive capacity, developing a framework to assist forest managers in carrying out vulnerability analyses, and policy recommendations for building adaptive capacity and identifying adaptation options.

Phases 2 and 3 will be addressed through an Adaptation Policy Assessment as described by Füssel and Klein (2006). These authors show how biophysical impacts, adaptive capacity assessment and policy recommendations can be combined in an integrated analysis that will provide the basis for facilitating and implementing adaptation actions. The CCFM project is expected to be completed by mid-2011.

Natural Resources Canada recently announced a new program to establish **Regional Adaptation Collaboratives (RAC)**. The goal is to catalyze action to reduce vulnerability to climate change, by advancing adaptation planning and decision-making (Natural Resources Canada 2009). The RACs program will support focused collaboration at the regional level among government, non-government decision-makers, and technical experts to facilitate regional adaptation planning and decision-making. Six regional collaboratives are planned. Primary responsibility for organization and administration will be taken by the provincial jurisdictions.

The **Canadian Model Forest Network** comprises 14 model forests across Canada. A model forest is a community-based partnership organized around the desire to develop and implement sustainable forest management practices. The partnership identifies local issues; develops innovative, locally-relevant SFM practices; and provides a forum for sharing results, resolving conflicts and ensuring equality of benefits among the partners. Many of the Canadian MFs have local projects dealing with climate change, and the Canadian MF Network has funded several national initiatives that address climate change across several model forests, e.g. a project on climate change and forest-dependent communities that was completed in 2007 (Williamson et al. 2007).

The **Canadian Forests Genetics Resources Program (CONFORGEN)** was formed in 2006. CONFORGEN aims at increasing collaboration on forest genetic resources among different provinces of Canada. They are producing a web site in which information on the genetic conservation status of Canada's tree species will be available.

2.6 Studies from Europe and the U.S.

We can also learn from activities and programs in other parts of the world. For instance a pan-European assessment called 'SilviStrat' (Kellomäki and Leinonen 2005) explored the impacts of climate change on forest productivity, carbon storage and biodiversity. In general they found that forest productivity and carbon storage increased in northern and central Europe but declined in southern Europe due to drought impacts. They recommended planting new species that are drought-tolerant and frost-tolerant as an adaptation strategy. They also recommended increased intensity of thinning in areas where productivity was likely to increase. In general they found that the current policy environment would support adaptation except in cases where policy limited the ability to introduce new species.

A pan-European assessment recommended planting trees that are drought-tolerant and frost-tolerant.

Another study, the ATEAM project (Advanced Terrestrial Ecosystem Analysis and Modelling) examined the impacts of climate change on the provision of ecosystem services across Europe using a formal vulnerability assessment framework (Schröter et al. 2005). Among other services, the study considered forest production and carbon storage. They found that forest growth and carbon storage are expected to increase through the mid-21st century but would decline after that due to an increase in soil respiration, although this depended on the climate scenario considered. They also found that forest management activities accounted for 60 to 80% of the forest growing stock change between the years 2000 and 2100, climate change explained 10 to 30% of the difference, and land use change had the smallest impact of 5 to 22%.

The U.S. Climate Change Science Program is currently producing a wide array of reports on climate change impacts and adaptation. One deals with the effects of climate change on agriculture, land resources, water resources, and biodiversity (Backlund et al. 2008) and contains a section on forests. The impacts are summarized as follows:

- Climate change has very likely increased the size and number of forest fires, insect outbreaks, and tree mortality in the interior west, the Southwest, and Alaska, and will continue to do so.
- Rising CO_2 will very likely increase photosynthesis for forests, but the increased photosynthesis will likely only increase wood production in young forests on fertile soils.
- Warmer temperatures and nitrogen deposition have very likely increased forest growth where water is not limiting and will continue to do so in the near future.
- The combined effects of expected increased temperature, CO_2, nitrogen deposition, ozone, and forest disturbance on soil processes and soil carbon storage remain unclear.

Another report deals with adaptation options for climate-sensitive ecosystems and resources (Julius and West 2008). They summarize their management recommendation for forests as follows ("agency" refers to the U.S. Forest Service):

- Integrate consideration of climate change across all agency planning levels;
- Reframe the role of uncertainty in land management: manage for change;
- Nurture and cultivate human capital within the agency;
- Develop partnerships to enhance natural resource management under a changing climate;
- Increase effective collaboration across federally managed landscapes;
- Establish priorities for addressing potential changes in populations, species, and community abundances, structures, compositions, and ranges, including potential species extirpation and extinction under climate change;
- Reduce current stressors (e.g. air pollution);
- Develop early detection and of climate change impacts and rapid response systems for post-disturbance management.

3.0 Implications and recommendations

3.1 Implications for management

Climate change has implications for forest managers and planners in both industry and government bodies. Key points and recommendations are noted below.

Analyse vulnerability

Forest managers can learn much from an analysis of their current vulnerabilities under today's climate. Structured approaches to vulnerability assessment exist (Smit and Pilofosova 2001, Johnston and Williamson 2007). By working through such frameworks and adopting a collaborative ("embedded science") approach with scientists, forest managers can make significant progress in understanding and reducing current vulnerability, while also positioning themselves to minimize the negative impacts of future climate change.

Implement "no-regrets" options

Forest managers should identify and implement regionally-specific no-regrets options, i.e., actions that would be beneficial even if climate change didn't occur. Such activities as fire hazard reduction around communities and important infrastructure (fire-smart practices) have been widely adopted across many jurisdictions and provide both protection from fire today and a reduction of fire hazard under future climate conditions. Establishment of new provenance trials and analysis of data from existing trials will help shed light on what provenances may do well under future climate conditions. Managers may consider planting small stands of non-local or exotic species in order to observe how they respond to climate change over the next few decades. Of course current biodiversity policy and related concerns will need to be recognized.

Build capacity - learn about climate change

Capacity building related to the impacts of climate change and available adaptation options needs to be supported in industry and government. Bodies such as the Canadian Institute of Forestry, the provincial professional associations, the Forest Products Association of Canada and others have education programs that could be used to educate managers about the climate change issue. An embedded science approach can also have the added benefit of capacity building where managers and scientists are able to work closely together.

Use sustainable forest management practices; consider climate change

Managers and policy makers should carefully review the principles of sustainable forest management (SFM) and satisfy themselves that these are being observed in practice. To the extent that these principles are incorporated in day-to-day practice, forest managers will be in the best position to begin planning for climate change. Managers can then build on SFM in developing more specific information on climate change impacts and adaptation options. A particular need is for increased monitoring of forest ecosystems to detect early sign of climate change impacts.

"Mainstream" climate change considerations (include in regular activities)

Managers should consider ways in which climate change considerations can be "mainstreamed" into existing forest management practices. The examples related to forest management planning outlined above have been shown to be effective, in spite of the lack of consistent approaches and guidelines for undertaking the analyses. Other opportunities for mainstreaming include incorporation of climate change thinking into tree improvement programs, road layout and construction, stream crossings and others.

KEY POINTS

Recommendations for managers

- Analyse and address sources of vulnerability.
- Implement "no-regrets" options - e.g., fire-smart practices, provenance trials.
- Build capacity - learn about climate change.
- Encourage collaboration - e.g., "embedded science" approach.
- Implement sustainable forest management practices.
- Include climate change considerations in regular activities ("mainstreaming"), e.g.,
  - forest management plans
  - tree improvement activities
  - road planning.
- The future will be full of surprises; we should position ourselves to deal with them (flexibility, innovation, adaptation).

3.2 Implications for policy

Policies will need to evolve to accommodate uncertainty; flexibility is needed.

Accommodate uncertainty – encourage innovation and adaptation

Climate change will require innovation in forest management in ways that are not predictable. In this environment, forest management policy needs to be flexible to accommodate uncertainty and surprise. Flexible policies will allow forest managers to make decisions locally based on their expertise and judgment. Overly-prescriptive centrally-planned regulatory approaches will not be successful in an environment where adaptation is carried out locally. Further, policy-makers should understand how innovation occurs and how to support and encourage the development and adoption of new techniques for sustainable forest management.

Allow more flexibility in regulatory systems; encourage collaboration

On-going discussions about reform of regulatory policy should also consider how the need to accommodate environmental change may contribute to new designs for forest management systems. One important component of these discussions should be about ways in which forest managers in industry, government and nongovernmental organizations can work together in a more collaborative fashion. Large uncertainty exists around climate change, and the potential impacts are potentially severe. All members of the forest sector must work together closely to develop solutions in a collaborative environment.

Develop guidelines to help planners consider climate change

Planning guidelines should be developed that could be used to provide guidance on how climate change considerations could be integrated into forest management plans. These would necessarily be general in order to accommodate variability among jurisdictions and biophysical conditions, but could be developed in a way that would be helpful to both industry and government planners.

Review principles and criteria for sustainable forest management

The general principles of SFM have been defined and adopted by most of the forest management community. However, there is no comprehensive understanding of how SFM needs to be modified in order to help managers adapt to climate change. SFM generally assumes a stable climate; while it is not clear how the climate will change in the future, it is clear that this assumption will be wrong. Policy makers should review the principles of SFM and ask how they need to be different under an uncertain future that includes climate change. Similarly, forest certification systems and the Criteria and Indicators of SFM need to be reviewed and modified in ways that recognize the uncertainties associated with climate change and that can help support increased adaptive capacity among forest managers.

3.3 Implications for research

Given the uncertainties related to climate change impacts and potential adaptation options, a wide range of research needs can be identified. Some of the most pressing are identified here.

Improve models – climate, ecosystem processes, disturbances

Information on climate change impacts is not generally available at temporal and spatial scales relevant to decision-making. Recent advances in regional climate modelling (e.g. Plummer et al. 2006) and downscaling climate data (e.g. McKenney et al. 2006) contribute to a better understanding of local climate change. However, ecosystem process models are needed to translate the climate change information into impacts such as changes in growth, effects on water availability and changes in species distributions. In addition, models dealing with large landscape scale disturbances (e.g. forest fires, insects) are essential.

Model climate effects on growth and yield

A major question related to future climate change is the effect on growth and yield. Current research is ambiguous on this point, with most indicating that it will depend on the local details of climate, and availability of water and nutrients (e.g. Johnston and Williamson 2005, Girardin et al. 2008). Further work is needed on climate-sensitive growth and yield models, since current approaches assume a constant climate.

Understand climate effects on plant species distribution and adaptation

More work is needed on climate envelope modelling for species distributions (McKenney et al. 2007) and on how ecological land classification units may shift on the landscape (Hamann and Wang 2006, Schneider et al. 2009) . Use of dynamic global vegetation models will help produce a comprehensive view of how vegetation and ecosystem processes may change under future climate (Neilson et al. 2005).

Early attempts are being made in changing seed transfer policies (BCMoFR 2008b) and using provenance test data in designing potential assisted migration approaches. However, this work is at an early stage and much more needs to be done. Establishment of new provenance tests and analysis of data from existing tests will yield much useful information on how species may adapt to future climate change.

Identify biotic and abiotic thresholds

Implementation of adaptation options will reduce the impacts of climate change to a certain degree. However, there will be a level of climate change beyond which adaptation will be increasingly ineffective. It is a major research challenge to identify thresholds beyond which adaptation will not be successful. These thresholds will be likely comprise both biophysical and socio-economic aspects and in many cases will be difficult to identify.

Investigate abiotic changes – e.g., duration of frozen-ground conditions

In addition to ecological modelling, there is a need to explore how the abiotic environment may change in the future. Of particular concern to forest managers in Canada is the effect of a warming climate of the length of frozen ground conditions. In many parts of the country forest operations are carried out on frozen soil, either to protect the soil from disturbance or because the sites are too wet in the summer for access. If the length of frozen conditions is significantly shorter, major impacts to harvest scheduling and access will occur. However, as very little research has been done on this topic, it would significantly benefit planning for the future to expand the work.

Promote collaboration on forest management and climate change; consider a national centre of excellence

The formation of a national centre of excellence on forest management and climate change could help facilitate a broader understanding of climate change impacts and adaptation. This could be a real or a "virtual" institute in which scientists and managers collaborate on sharing information, developing analytical frameworks and undertaking joint analyses for industry and jurisdictions across the country.

Include social science research; develop a transdisciplinary approach

Social science research is needed in the area of economic impacts assessment, preferences rankings of environmental impacts, perceptions of risk, institutional effectiveness, and adaptive capacity assessments. Most important, a new transdisciplinary approach is needed, one that accounts for cumulative impacts, interrelationships among a range of change agents, and dynamic and non-linear systems (e.g. Pohl 2005).

4.0 Conclusions

We provide the following conclusions from our discussions with forest managers across Canada:

- Climate change is affecting the forested landscapes of Canada and will continue to do so for the foreseeable future. Forest managers agree that climate change is real and that it is an important issue that needs to be addressed.
- Impacts already observed include changes in forest fire regimes, large-scale insect outbreaks, droughts in central Canada, severe windstorms in Atlantic Canada, and shorter periods of frozen soil in winter. These impacts will affect forest growth rates, the distribution of tree species, the rate of ecosystem processes and the ability to carry out forest operations.
- Impacts on forest ecosystems will in turn affect the forest industry and forest-dependent communities, in ways similar to those already seen in the current industry downturn.
- Some short term adaptations are already being implemented by forest managers, although in most cases these are simply measures taken in response to individual weather events rather than an adaptation in anticipation of climate change.
- The Canadian forest sector's capacity to adapt is generally high when considering technical forest management adaptations. There are high levels of education and professionalism among forest managers, and the standards for sustainable forest management (SFM) in Canada are among the highest in the world.
- Technical and scientific capacity related to climate change impacts and adaptation varies widely across forest management organizations, with a few having high levels and the majority with low capacity.
- Lack of appropriate information on the impacts of climate change is one of the constraints preventing managers from implementing adaptation measures. In general, information on climate change impacts is not available at spatial and temporal scales relevant to decision-making and planning.
- There will be a threshold of climate change impacts beyond which adaptation will be extremely difficult and it is a major research and management challenge to identify those thresholds.
- Institutional barriers are an important problem constraining adaptation actions. Forest policy generally assumes a constant physical environment, yet it is clear that this assumption will not apply in the future. Forest policy will need to evolve such that it can effectively deal with uncertainty, surprise and novel conditions in order to cope with climate change.
- Adaptation takes place locally, and forest managers in an uncertain future will need increasing ability to make innovative, locally relevant decisions related to adaptation. To the extent that current policy prevents this local autonomy in decision-making, it will be inappropriate under future climate change.
- Policy instruments that define and guide SFM in Canada have been strongly adopted by the forest management community (e.g. forest certification,

Criteria and Indicators of SFM, etc.). However, they are generally used to assess how management has performed (i.e. looking backward) rather than as a guide to how management should evolve in the future (i.e. looking forward). Given the wide acceptance and use, these instruments should be modified to support future planning for climate change adaptation.

- Other guidelines should be developed to assist forest managers in incorporating climate change into forest management plans. A national effort at developing guidelines for climate change planning should be a high priority.

KEY MESSAGES

- Climate change is already affecting forested landscapes in Canada.
- Climate change will affect forest productivity, forest sector profitability, forest-based communities, and society at large.
- Vulnerability assessments (e.g., of a sector, a company or a community) can help anticipate and plan for climate change impacts.
- Forest managers see the need to address climate change, but capacity related to climate change impacts and adaptation varies widely.
- Adaptive capacity can be enhanced by access to relevant information and training.
- Institutional barriers are important constraints to adaptation; flexibility is needed.
- Forest policy must evolve to accommodate change and uncertainty.
- Forest policy should permit local autonomy in decision-making.
- Guidelines should be developed to help forest managers and planners address climate change.
- Forest management plans and SFM standards should consider climate change impacts and adaptation.
- Appropriate information is needed at scales relevant for local planning.
- Communication and cooperation are needed between researchers, forest industry managers and planners, and policy-makers.

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Appendix

Questions used to guide discussions on climate change with forest managers

Part A. The state of forest management in Canada

One of the main purposes of this study is to understand factors that contribute to, or limit the ability of forest management and forest managers to adapt and prepare for climate change. However, climate change is only one of many issues that are - and will in the future - impact forest management in Canada. For the first few questions we would like to ask you about major events or changes that are affecting forest management in your FMA.

1) What are the major issues, challenges and/or changes currently affecting forest management in your region and in Canada?
2) What will be the major issues, challenges and/or changes affecting forest management in the next 20 to 30 years?
3) How concerned are you about climate change in comparison to other issues affecting forest management?

Part B. Recent climate change

A useful approach for discussions about future climate change is to begin with a discussion of current climate and/or recent trends in climate and how forest managers have adapted to these changes in the past.

4) Do you feel the climate in your area has changed over the last 20 – 40 years and if so how have these changes impacted forest management in your area?
5) Have you, your company or your organization made specific changes to adapt to these changes and if so please describe them?

Part C. Future climate change impacts on forest outputs and forest management

The purpose of this section is to identify important climate change factors for forest management and to obtain information about ways that climate change might affect forests, forest outputs, and forest management in your area.

Note: specific impacts on forest management and forest operations resulting from changes discussed in this section will be discussed in the next section of questions.

6) Please discuss the kinds of climate changes that may be particularly important from a forest management perspective in your area.

For example:
- Increase in climate variability
- Increase in extreme weather including high winds
- Shorter winters
- Etc.

7) How might forests and forest outputs in the area be impacted by climate change between now and the year 2050 and what are the main implications for forest management?

For example:
- Increase (decrease) in wildfire activity and other disturbances
- Regeneration failure
- Change in quantity and quality of wood supply
- Increased uncertainty in wood supply (increased risk)
- Change in delivered wood costs
- Change in ability to achieve non-timber related forest management objectives
- Etc.

Part D. Potential ways that forest managers might adapt to climate change

In this section we would like the respondents to identify and discuss various types of strategies and actions that they think could be taken to adapt to climate change in their specific context. They should not be confined to discussion of only those actions that are allowed under current tenure arrangements but should be allowed to think outside the box.

8) What are some strategies and/or ways that you would recommend or consider adopting in order to reduce the impacts of future climate change and what are some of the things that the forest management community in Canada in general needs to do in order to adapt?

Part E. Assessing current capacity to adapt

The purpose of this section is to identify and discuss features, assets and institutional factors that influence (positively and negatively) the ability of Canadian forest managers to adapt to climate change. According to the Intergovernmental Panel on Climate Change, the capacity to adapt to climate change is determined by:

- Awareness,
- The range of technological options available to decision makers,
- Economic resources (or wealth of decision makers),
- Institutional design and structure (i.e. flexibility, able to efficiently allocate resources to adaptation, degree of autonomy of adaptation choices),
- Human and social capital of adaptors,
- Ability to manage risk, and
- Knowledge and access to information (adequacy of current knowledge and management of new knowledge and information).

Awareness / perceptions of urgency:

9) Do you feel that climate change is real?

10) How concerned are you about climate change and why?

11) How urgent is it that forest managers begin to address climate change in decision making and in planning?

12) Do you feel that the local effects of climate change on forest ecosystems are well understood by forest managers in your area?

Science and technology:

Climate change implies significant uncertainty. Lack of knowledge or tools about possible future impacts (e.g. effects on growth and yield) may be limiting the ability of forest managers to adapt.

13) Does uncertainty and lack of tools about future impacts prevent you as a forest manager from implementing changes in how you manage forests in anticipation of climate change and if so how? (i.e. What knowledge and tools would you need that you do not already have in order to begin adapting to climate change?)
14) Is there sufficient capacity (financial, skills, researchers, etc) to develop and implement innovative ways of managing forests in response to climate change?

Economic resources, institutions and governance:

Adaptation will require funding and financial resources. It will also require that forest managers, forest based companies and forest land owners (i.e. provinces) have an incentive to invest in adaptation. Incentives are usually defined in the context of current institutional designs. Incentives may be in the form of rewards (e.g. financial return) or sanctions (e.g. penalties for not following a particular rule).

15) In your view, does the financial state of the Canadian forest industry in anyway limit or constrain our ability to begin adapting to climate change?
16) What would be required in order for companies to justify making investments in adaptation?
17) Forest companies operating on public lands have certain responsibilities under their tenure arrangements. Which of these responsibilities will be impacted by climate change?
18) Do companies have the ability within current tenure systems to adapt in a way that company responsibilities are not compromised and what are the barriers (if any)?

Risk management:

Climate change will likely result in increased risk relative to timber supply, infrastructure, forest management investments (e.g. plantations) and relative to other objectives (e.g. wildlife, sustainable forests, multiple use). An increase in risk has an economic cost. It also means that foresters may need implement new approaches in order to manage risk (e.g. through portfolio diversification, shorter rotations, hedging, etc).

19) In what ways does climate change have implications for risk relative to forestry objectives?
20) Do you have the ability to manage risk in your current setting?
21) If you could manage risk better, what risk management strategies would you employ?

Human capital:

Human capital is a measure of the skills, education, experience and knowledge of individuals and groups. The collective amount of human capital within a group is an important measure of the capacity of that group to adapt to some external change.

22) Do Canadian forest managers possess the knowledge, skills, education, experiences and general abilities appropriate for adaptation? How could this be improved? (e.g. forestry curriculums, forestry extension, professional development and training)

Social capital:

Social capital measures the size, density and characteristics of an individual's or organization's network. High levels of social capital may facilitate improved access to information, collective actions and responses and access to resources that an individual or organization would not otherwise have access to. Trust is an important feature of functioning networks.

23) Please identify and describe the forestry related groups, associations or organizations (e.g. professional foresters, CIF, forestry association, etc.) that you are a member of.

24) How important are these networks to you in terms of solving forest management related problems.

25) Is there a need for a specific climate change and forestry network to share information and knowledge about climate change impacts and adaptation?

Information management:

Information management pertains to the effectiveness of policy makers, regulatory agencies, companies, professional organizations and research organizations in obtaining, developing, managing and communicating information about climate change. This includes the processes by which information is acquired, assessed and communicated. This contributes to increased awareness of climate change, more confident decision making and better informed decision makers.

26) Do you think existing systems for acquiring and assessing information regarding climate and climate change in forest management are adequate and if not how would you change them?

27) Do you think there is a need to reassess the measures and indicators we use to assess sustainable forest management (e.g. certification and Criteria and Indicators)?

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August 2007

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- Canadian Institute of Forestry
- Forest Ecosystem Science Cooperative, Inc.
- Forest Engineering Research Institute of Canada (FERIC)
- Fundy Model Forest
- Lake Abitibi Model Forest
- Manitoba Model Forest
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