Adapting Forest Management to the Impacts of Climate Change in Canada

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Table of Contents:

FIGURES

TABLES

Executive Summary

This report identifies a range of ways that climate change may impact human and economic systems (e.g. market impacts, land use change, availability and cost of raw material supply, change in habitat and our ability to preserve ecosystems in fixed boundary parks, etc). It does not however focus on the role of Canadian forests in sequestering carbon, as this has been covered in detail elsewhere (e.g. Bhatti *et al*. 2006). The report also considers factors that may influence our capacity to adapt. These factors include inherent features and properties of social systems (such human capital and social capital), policy and institutional factors, and awareness and processes by which risk perceptions are socially constructed. The ultimate goal is to isolate the most vulnerable systems and regions, and to understand why these systems and regions are vulnerable so that impacts of climate change on vulnerable elements of Canadian society can be reduced. This report provides a synthesis of conceptual approaches that can be used to assess vulnerabilities. Our challenge in a forestry context is to apply the concepts to provide a more informed view of sources of vulnerability so that we can inform policy.

Exploring Futures. In order to obtain an accurate understanding of the real long-term effects of climate change, we need to understand the interaction and interrelationships between human and environmental systems through integrated assessments. Integrated Assessments could provide a more holistic analysis of the regional impacts dimension of climate change by including both modeling and non-modeling approaches. The use of climate, ecosystem and social-economic models are integral to impacts and adaptation research. Although the accuracy and sophistication of the various models is rapidly increasing, there are significant barriers that presently restrict our ability to forecast future conditions in a reliable way.

Changing Forests. Due to the wide variety of climatic, topographic and ecosystem types, as well as differences in forest management approaches and land ownership patterns it is difficult to assess the vulnerability of Canada's forests to climate change. General assumptions of expected climate change impacts on Canada's forests derived from our understanding of forests vulnerability to current climate, as well as initial modeling results include: <u>Forest Productivi</u>ty: Generally net primary productivity is expected to increase under warmer temperatures if water and nutrients are not limiting; higher temperatures will generally result in a longer growing season. <u>Forest Distribution and Composition:</u> Species will likely redistribute probably resulting in some new plant communities with no current analogue; wildlife species associated with various forest types will shift as their habitat changes, or in some cases disappear. <u>Forest Disturbances:</u> Forest fires are expected to be more frequent, of higher intensity and burn over larger areas in the prairie and northern regions of Canada; eastern Ontario and Quebec may experience a decline in the rates of fire disturbance due to increased summer precipitation, insect outbreaks are expected to be more frequent and severe in Canada, both in terms of current native species and invasive exotics.

Impacts on the Forest Sector. Forests provide for many values, including primary life-support values (e.g. provision of habitat) and secondary benefits (e.g. economic) drawn off by humans. Climate change poses a risk to both the values and benefits that are associated with forests. Canada's forest industry may be at risk due to its reliance on an export-based forest economy through long run structural change in global forest products markets. Market impacts will be particularly important for provinces like British Columbia and Quebec where forest products exports make a significant contribution to provincial GDP. Forest-based communities are particularly vulnerable to climate change due to their reliance on the forests for jobs, tax-base, social, cultural ties and economics. Relevant information on vulnerability at a community level is a key requirement for successful adaptation. Outdoor recreation and nature-based tourism will be impacted to some degree by climate change due to the direct relationship between quality of experience, product and weather and climate. Climate change has a number of important policy and planning implications for protected areas in Canada. Protected area managers will have to accept the autonomous response of natural systems and will need to employ planned adjustments to moderate potential risks or to benefit from opportunities associated with climate change.

Forest Management and Policy. The combination of long growth cycles and future changes in growing conditions that are likely to occur within the current rotation means that climate change will have important implications for choices we make today. With a few exceptions climate change is not currently considered in decisions and long-term forest management plans in Canada. Climate change is notably absent in both the academic forest-based policy literature and within current federal and provincial forest policies themselves. Current forest policy does not contain provisions for climate change impacts and adaptation, and often have built-in policy rigidities such as prescribed Annual Allowable Cut rules that prevent the necessary operational changes to account for climate change.

Adaptation. Although we do not have a clear view of the future climate and forest, or of the vulnerability of species and society, it is critical to begin the process of developing adaptation strategies now. Adaptation must address the biophysical and socio-economic impacts and will require changes in forest policy to allow implementation.

Recommendations. The following 5 key recommendations should be considered to help the Canadian forest sector reduce its vulnerability to climate change: (1) Enhance our capacity to undertake integrated assessments of system vulnerabilities at various scales, (2) Increase resources for basic climate change impacts and adaptation science, (3) Review forest policies, forest planning, forest management approaches and institutions to assess our ability to achieve social objectives under climate change, (4) Develop an enhanced capacity for risk management, and (5) Maintain or improve our capacity for communications and networking.

1 Introduction

1.1 Yesterday's Emissions – Today's Problem

In December 2005, the skidder used to haul logs out of the north Saskatchewan bush had been stuck in the mud/bog for nearly a week. Harvesting operations had halted. The company wasn't able to send in a front-end loader to pull the skidder out, the ground was too soft to support any heavy equipment. The harvesting company had never experienced anything like this in the 20 years they had been winter logging in their Forest Management Area (FMA). However, over the past 10 years the Chief Forester with the company had noticed that the ground they logged and traveled on had become successively softer each winter. The Forester contemplated the company's future if they were unable to access the timber in their FMA of which a majority fell within winter-access only areas. He considered their options; road building for summer logging wouldn't comply with provincial policies on limiting road access into forested areas, heli-logging wasn't feasible and purchasing special equipment to travel over the boggy forests of the north Saskatchewan was beyond the financial resources of the company. The company's ability to adapt to the situation was limited. The timber from this FMA made up a majority of the supply destined for a local mill that employed a large number of residents of a nearby town. The implications of shutting down harvesting operations in the area would further impact the region as a large percentage of its tax base came from local harvesting operations. This could spell financial disaster for the company if the warm winter temperatures continued past this year, and would put the community's future in question.

The situation described above represents a 'real-world' operational and management issue with potentially severe socio-economic consequences that is currently facing logging companies and forest-based communities. The problem is characterized by a gap in knowledge of climate change impacts, as well as a lack of planning for climate change in forest management, forest policy and community planning. A lack of understanding about the vulnerabilities of the forest sector to climate change poses a serious threat to the environmental, economic and social health of the country. Further compounding the problem is the absence of awareness and/or concern of the climate change issue among the forest policy makers, forest managers and community leaders.

1.2 Implications for Canada's Forests

Canada's forests serve an important role in the country's overall environmental, social and economic health. Canada is home to ten percent of the world's forests, covering nearly half of the country's landscape and home to two-thirds of its wildlife. With twenty percent of the world's freshwater, Canada's forests also have a key role in fresh water protection. The forest industry, a strong financial contributor to the Canadian economy and the gross domestic product, brings in about $80 billion annually and in 2004 contributed $34.5 billion to the Canadian trade balance. Further, over 300 communities are economically dependent on the forest industry (Natural Resources Canada. 2004). Additionally the forests of Canada provide a diversity of recreational opportunities and are an important source of resources for the First Nation populations of the country.

High latitude ecosystems such as those contained within Canada's vast forests are expected to be affected by climate change to a greater extent than the global average, adding an additional stress to our resources and protected areas.

There is growing evidence that environmental changes caused by elevated atmospheric carbon dioxide (CO_2) and its potential effects on global climate will alter the forest ecosystems of Canada. Climate change has the potential to influence Canada's forest ecosystems through altered natural disturbance regimes, species distribution and forest productivity. Forests are highly dependent on climate in their function and structure, species can survive only in narrow temperature ranges so a sustained increased in temperature may cause significant changes in species distribution. Further complicating the issue is the fact that increasing atmospheric CO_2 may increase weather variability, and this may be just as important as projected changes in average temperatures and precipitation for Canada's forest regions (Stennes *et al.* 1998). This has raised concern over what impacts a changing climate will have on the multitude of social, economic and ecological values that Canadians associate with the nation's forests. To date a majority of climate change forest research activities and budget expenditures in Canada have been oriented towards studies on carbon inventories and the potential of forests to offset greenhouse gas emissions. As a result, there are severe knowledge gaps surrounding the expected impacts of climate change on Canada's forests and our ability to assess sector vulnerability and develop adaptation strategies is limited (Mckinnon and Webber 2005). Understanding the forest sector's vulnerability to climate change will be essential for continued sustainable forest management in Canada.

Canada's forests have been the center of national attention for quite some time now, dominating discussions around Canada's international commitments (e.g. Kyoto Protocol) to reducing greenhouse gas emissions. Forests have the potential to sequester atmospheric carbon and store it for long periods of time, making it an attractive solution to the climate change mitigation problem. However, recently Canada's forests have dominated headlines across the country for a very different yet related reason. Recent large-scale disturbances in Canada's forest have highlighted the close relationship between forests and climate, and perhaps are indicative of a changing climate. These events have had widespread environmental, social and economic costs that have impacted Canadians in very real and significant ways.

Photo by: Leslie Manning, Canadian Forest Service

British Columbia's Mountain Pine Beetle Epidemic

"British Columbia is currently experiencing the largest recorded mountain pine beetle outbreak in North America. This forest health epidemic is a catastrophic natural disaster and is causing widespread mortality of lodgepole pine, the Interior's most abundant commercial tree species. The epidemic puts forest values at risk and threatens the stability and long-term economic well being of many communities" (Government of British Columbia, 2005, p.3). "Only if a period of extremely cold weather (e.g. -20C in the fall or -40C in late winter) occurs throughout the affected area can the epidemic be stopped. As a result, it is likely the epidemic will only be over once it has infested most of the mature pine in B.C. Ministry of Forests modeling data predict that at the current rate of spread, 50 per cent of the mature pine will be dead by 2008 and 80 per cent by 2013". (Government of British Columbia, 2005, p.3)

Ice Storm of 1998

The impact of this (1998) ice storm ranks among that of the most damaging windstorms and hurricanes recorded in forested landscapes anywhere. The event doubled the amount of precipitation experienced in any prior ice storm. The scale of biomass transfers to the forest floor in ice storms indicates a significant role in structuring forests and driving forest succession. Changes in the frequency and intensity of ice storms, e.g., as a result of global climate change, could have important implications for the forests of the region. (Hooper, *et al.* 2001).

Photo by: USDA Forest Service

Photo by: Canadian Forest Service

British Columbia 2003 Forest Fire Storms

Another recent effect of a warmer and drier climate has been its impact on the number of large, uncontrollable forest fires in Canada. The province of British Columbia experienced three consecutive years of drought conditions culminating in an extraordinary fire risk and extreme fire behaviour in 2003. The Firestorm 2003 emergency had significant impacts on British Columbia communities, testing the resilience and resourcefulness of British Columbians.

The summer of 2003 was the worst ever for forest fires in British Columbia. Abnormally hot, dry weather resulted in over 2,500 wildfire starts over a vast area, mostly in the Interior of the province. Interface fires, which occur in places where wildland meets urban development, were at an all-time record high. The interface fires of the summer of 2003 destroyed over 334 homes and many businesses, and forced the evacuation of over 45,000 people. The total cost of the Firestorm is estimated at $700 million. (Filmon *et al.* 2004).

The implications of a changing climate for Canada's forest sector is not something that will be experienced at some point in the distant future, we are witnessing its effects today.

2 Climate Change

2.1 Impacts and Adaptation

There is growing evidence that the earth's climate is changing at an unprecedented rate. The amount of carbon dioxide in the atmosphere has increased by over 25% in the last 200 years. Already, global temperatures are almost 0.7 degrees C above those a century ago, with the 10 warmest years all occurring since 1983 and seven of them since 1990. This is a rate of warming greater than any in the last 10,000 years. The rate of warming has been even greater in northern, continental regions such as the western Canadian Boreal forest, where temperatures have increased nearly 2°C since the late 1940s (Hogg *et al.* 2005). The year 1998 was the warmest on record since 1860, capping off a consecutive 20-year warming trend, according to the World Meteorological Organization (Houghton *et al.* 2001).

Almost every part of southern Canada, from coast to coast, was warmer at the end of the twentieth century than it was at the beginning. Northwestern Canada has also seen strong warming over the past 50 years, but the Northeast has become cooler. Most of Canada has become wetter, with increases in precipitation ranging from 5% to 35%. Because of increased precipitation, Canada was generally snowier at the end of the twentieth century than at the beginning. Over the past 50 years, however, higher spring temperatures have reduced the proportion of precipitation falling as snow in some parts of southern Canada. Sea surface temperatures have risen substantially on Canada's west coast but appear to have changed little on the east coast. (Canadian Council of Ministers of the Environment 2003).

If current trends continue, the amount of carbon dioxide in the atmosphere will double (from current levels) during the 21st century, with further increases thereafter. Other greenhouse gases will also increase during the 21st century. An increase in atmospheric greenhouse gases will translate into a potential change in surface temperatures, precipitation, and wind patterns.

Until recently international and national discussions regarding climate change have focused almost exclusively on the mitigation of climate change through a reduction of greenhouse gases emissions. The mitigation issue has driven initiatives such as the United Nations Framework Convention on Climate Change [1](UNFCCC) and the Kyoto Protocol. The Convention sets an ultimate objective of stabilizing greenhouse gas emissions at a level that would prevent dangerous anthropogenic (human induced) interference with the climate system. Recently, a number of nations have approved an addition to the treaty: the Kyoto Protocol, which has more powerful (and legally binding) measures.

Research and international policy development focused on climate change mitigation is undeniably critical, and will serve to help the nations of the world become more sustainable in terms of development. However it is understood that mitigation efforts such as a reduction in GHG emissions will only translate into a delay in accumulation of greenhouse gases in the atmosphere. "Stabilization of CO2 emissions at near-current levels will not lead to stabilization of CO2 atmospheric concentration" furthermore, "After stabilization of the atmospheric concentration of CO2 and other greenhouse gases, surface air temperature is projected to continue to rise by a few tenths of a degree per century for a century or more" (IPCC 2001). At the recent 11th Session of the United Nations Conference of the Parties to the Climate Change Convention (COP 11[2]), there was formal recognition by the Parties that adaptation to climate change and its adverse effects is an issue of high priority for all countries. Furthermore the Parties recognized and encouraged activities relating to impacts, vulnerability and

[1] The UNFCCC is an international treaty that resulted from the United Nations Conference on Environment and Development in 1992 in Rio de Janeiro, Brazil.
[2] Held in Montreal, November 28 - December 9, 2005

adaptation to climate change undertaken by Parties and relevant international and regional organizations and institutions.

2.2 Global and Regional Climate Models

The earth's atmospheric system is large and chaotic, making future system states difficult to predict. The development of Global Circulation Models (GCM) over the past 20 years has provided a tool for simulating past, current and future climate. Major climate change assessments, e.g. the IPCC Third Assessment Report (IPCC 2001) are based on GCM projections of climate up to 2100. The fact that GCMs operate at global scales means that the ability to provide projections of the future climate at scales relevant to forest managers (e.g. landscape) is limited; for example, the horizontal grid cell spacing for the Canadian GCM is approximately 400 X 400 km, and the model does not recognize meso-scale topography or lake influences (e.g. the Great Lakes). An alternative approach is to use Regional Climate Models (RCM), which provide data at higher resolution, e.g. 45 X 45 km for the Canadian GCM. RCMs use CGM data as boundary conditions, and so cannot be run in isolation (Laprise *et al.* 2003).

The highest resolution scenario data are from downscaled climate products. Downscaling is a process of using a range of methodological techniques (such as regional climate models, statistical downscaling, spatial and temporal analogues, and the simple application of 'climate change factors' to a reference climate) to provide more detailed climate change scenarios at the regional or local level, which is the spatial scale at which most climate change impact assessments are conducted. Downscaling techniques can also be used to provide daily scenario data rather than the monthly scenarios that are commonly available from GCMs (Nicholls and Scott, 2006). In this approach, intermediate values for climate variables are interpolated statistically between the grid cells of GCM output. A variety of downscaling methods have been developed, among which one of the most advanced is the new products recently published by researchers at the Canadian Forest Service (McKenney *et al.* 2004, Price *et al.* 2004). These products provide climatic data at a 10 X 10 km resolution and take into account the effects of elevation as well as interpolation between GCM grid points. Coverage is available for nearly all of North America and comprises both observed climate surfaces as well as future scenarios from four GCMs (Canadian, UK, Australian and European Community) and two (Special Report on Emission Scenarios (SRES) emission scenarios (A2 and B2). The A2 scenario family describe a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in a continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines. The B2 scenario represents a world in which the emphasis is on local solutions to economic, social and environmental sustainability, with a continuous increase in population and intermediate economic growth. Here we briefly review the current GCMs and RCMs available for climate change impacts studies, being mindful that the expertise of the project team does not lie in this area.

We use the Canadian GCM Version 2 (CGCM2) as an illustration of the current state of the art. It is one of the more respected models globally, and for example was one of two GCMs used for the recent US Climate Change Assessment that contained a forestry component (Mcnulty & Aber 2001). It was also among those used in the IPCC Third Assessment Report (IPCC 2001). The model was developed in the late 1990s and is described in Flato and Boer (2001). It is a fully coupled model, linking the atmosphere, ocean and land surface. The atmosphere is modeled on a grid of points approximately 400 km X 400 km over the entire earth's surface. It simulates the exchanges of energy and moisture among grid cells at an hourly time step. It also simulates these exchanges among 10 vertical levels in the atmosphere and 29 vertical levels in the ocean at each grid point. It has a simplified land surface scheme that also simulates the fluxes of energy and moisture between the atmosphere and land surface. CGCM2 produces output for 25 climatic variables including various measures of temperature, pressure, wind speed, precipitation and humidity.

The model has been used to simulate both past climate (Kim *et al.* 2002) and future climate for the IPCC analyses out to 2100 (Flato & Boer 2001). Future climate is simulated through running different emissions scenarios, each reflecting unique assumptions about driving forces on emissions such as demographics, socio-economic development and technological change. The IPCC analysis was based on a "medium" assumption of future CO_2 emissions, known as the IS92a scenario. CGCM2 has more recently been run under a number of emissions scenarios taken from the IPCC Special Report on Emissions Scenarios (Nakicenovic and Swart 2000), which provide a range of some 40 emission scenarios varying in their assumptions about technological development, fossil fuel use and social cohesiveness. Figure 1. shows the results of the runs using both the IS92a and SRES (A2 and B2) scenarios. Output from the first generation Canadian GCM (CGCM1) is also shown for comparison.

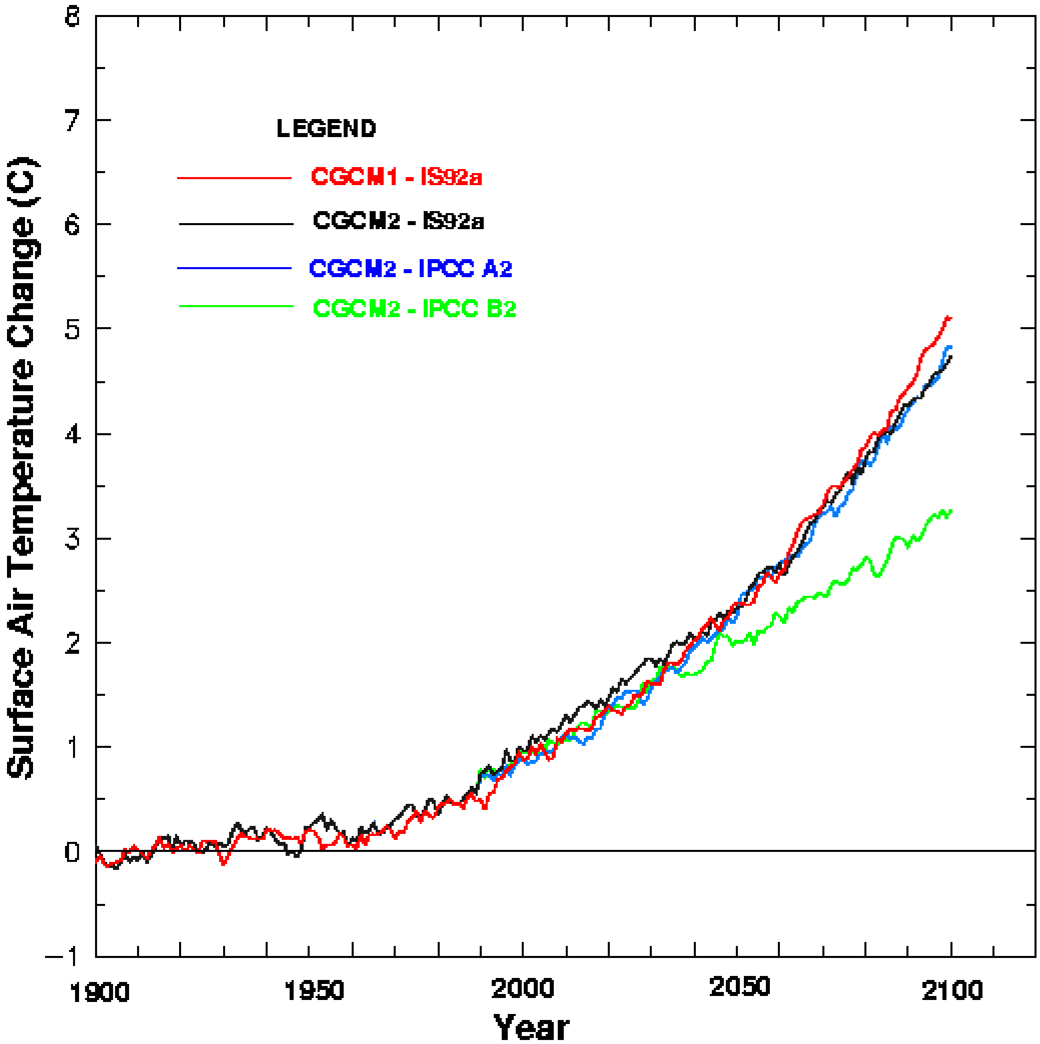

Figure 1. Global annual average surface temperature change, relative to 1900-1929 average as produced by CGCM1 and CGCM2 for various forcing scenarios. From Canadian Climate Centre for Modeling and Analysis web site: http://www.cccma.bc.ec.gc.ca/models/cgcm2

Regional climate models are a type of downscaling known as dynamical downscaling. In this approach, a high resolution climate model, typically *ca.* 50 x 50 km grid spacing, is run using a GCM to set the boundary conditions. The Canadian RCM is one of the world's leading examples, and is run at *ca.* 45 x 45 km grid using the CGCM2 to provide lateral forcing data. The model is run on a grid that covers all of Canada including the high arctic, and extends south into the United States to approximately 33 degrees latitude. Climate variables available as output are similar to those available from the GCM. The first published account of the CRCM is given by Laprise *et al*. (1998) and that of the current version by Laprise *et al.* (2003).

A third alternative is to use downscaled climate products. Price *et al.* (2004) and McKenney *et al.* (2004) describe a set of downscaled products that cover all of North America at a 10 x 10 km grid spacing. These data include historical and future scenarios generated by four GCMs, each with two SRES emissions scenarios (A2 and B2), covering the period from 1961 to 2100. Wang *et al.* (2006) have developed an easy-to-use software system for generating historical and future scenario data that is interpolated for any set of points chosen by the user. It is also possible to derive downscaled data using statistical relationships between local and regional station data, which are then applied to GCM scenarios (e.g. Wilby *et al.* 2002).

2.3 Ecosystem Models

Ecosystem effects of environmental change (e.g. warming, precipitation changes, increased CO_2) occur over large temporal and spatial scales and may have subtle and complex effects. The ability to experiment on whole ecosystems to determine these effects is limited, although the Free Air Carbon dioxide Enrichment (FACE) experiments are an important step in that direction (Long *et al*. 2004). In addition, environmental change will likely bring novel circumstances that have no analogue under current conditions (e.g. doubling of CO_2 concentrations). For these reasons, models that simulate ecosystem function are an important way in which the effects of environmental change can be determined.

Models currently in use to determine the effects of climate change on forests can be divided into three groups: gap models, stand level biogeochemistry models, and dynamic global vegetation models (DGVM). We conclude this section with a detailed look at one of the DGVMs currently in use in Canada.

Gap models are based on an assumption of maximum biomass growth rate for a given tree species, which is then constrained by limitations in resource availability (light, moisture, nutrients) due to competing individuals and abiotic factors (e.g. drought). These models simulate the growth and reproduction of a tree species in a relatively small area (a “gap”) which is then scaled up to larger landscapes. There is a long history of gap model development for a wide variety of tropical, temperate and boreal forests (see Shugart 1998 for a review of gap models, and Bugmann *et al.*, 2001, for reviews of how they may be used to address climate change impacts).

Stand-level biogeochemistry models simulate ecosystem processes (photosynthesis, transpiration) that result in tree biomass growth, death and organic matter decomposition, with fully-implemented nitrogen, carbon and water cycles. Well-known examples include PnET (Photosynthesis and Evapotranspiration, Aber *et al.* 1997) and Biome-BGC (Thornton *et al.* 2002).

The most recent development in forest ecosystem modeling is the use of Dynamic Global Vegetation Models (DGVM). These are a class of ecosystem models that attempt to provide comprehensive descriptions of global terrestrial ecosystems (i.e., including dynamic interactions among vegetation competition, biogeochemistry and biophysical processes), simulated at the scale of a “large-landscape” (typically 10-100 km gridcells). Widely considered state-of-the-art, DGVMs are generally designed with the intention that they be fully integrated into global circulation models (GCM) to simulate exchanges of water vapour, energy and trace gases between vegetation and atmosphere. Hence, these models are invariably rather complex, even though their representation of many vegetation processes is necessarily relatively simplistic. The outputs of these models are important diagnostic ecosystem variables[3], including evapotranspiration and runoff, vegetation composition, and carbon balance

[3] Any aspect of the environment (temperature, fertility, etc.) that is likely to have a direct influence on forest productivity.

indicators such as Net Primary Productivity[4] (NPP) and Net Biome Productivity (NBP). The data obtained by calculating NPP can be used as the basis for:

- Estimating the impact of both natural disturbances and management activities on forest productivity;
- Assessing the effects of climate change on Canadian forests;

One such model is the Integrated BIosphere Simulator of Foley *et al*. (1996) which is currently being used by David Price and colleagues at the Canadian Forest Service (CFS) Northern Forestry Centre to project ecosystem-level responses to future climate across North America. This work forms part of the VINCERA ("***V***ulnerability and ***I***mpacts of ***N***orth American Forests to ***C***limate Change: ***E***cosystem ***R***esponses and ***A***daptation") project involving research groups from the UK and the USA as well as Canada. Examples of other DGVMs include the Lund-Potsdam-Jena (LPJ, Gerber *et al*. 2004) and MC1 (Bachelet *et al.* 2001).

2.4 Integrated Assessments

"Human actions both affect and are affected by changes in terrestrial ecosystems. For example, changes in ecosystems occurring as a result of climate change will affect human activities, and humans will respond through various adaptations. These will in turn feed back to and result in further changes in the terrestrial ecosystems." (Hauer *et al.* 2001.p.39). Therefore, in order to obtain an accurate understanding of the real long-term effects of climate change, we need to understand the interaction and interrelationships between human and environmental systems. Impact assessments that are narrowly based on biophysical responses to climate change may result in misleading estimates of long-term impacts.

"Each component of the integrated environmental-economic system is complex, and the level of complexity increases when the individual components are linked for integrated assessment. There are two important implications of this situation. First, assessment models should explicitly recognize uncertainty as well as the stochastic nature of climate change (Smith 1982). Second, because future responses will be the result of action and feedback loops between atmospheric, terrestrial and human socioeconomic and political systems, the ability to forecast the impacts of climate change will require the integration of dynamic models of atmospheric, biosphere, and economic systems, with full recognition of the complexity of the integrated systems and the generality of the result of these types of models." (Hauer *et al.* 2001.p.39).

"Integrated assessment models (IAM) generally include some combination of general circulation, ecological and economic models. The motivation for developing IAMs is to provide input into policy making for mitigation and adaptation and to allocate scarce resources for climate change research (Dowlatabadi 1995). Bruce *et al*. (1996) suggested that integrated assessment offer a number of benefits, including coordination of assumptions from different disciplines and introduction of feedbacks among disciplines." (Hauer *et al.* 2001. p.39). The wide variety of IAMs that have been developed were reviewed by Dowlatabadi (1995), Bruce *et al* (1996), Lindner *et al.* (2002), and Binkley and van Kooten (1994).

There are two prominent non-Canadian examples of comprehensive multi-sectoral integrated assessment efforts based on scientific analysis and modeling: 1. The United States assessment and 2. The European Union assessment. The United States assessment is described in Parson *et al*. 2003. The European Union Assessment is described in Schroter *et al.* 2005. Forest sector specific assessments are components of these large national assessments. The forestry components of these two assessments are described in McNulty and Aber (2001) and Kellomaki and Leinonen (2005).

[4] Net Primary Productivity (NPP) is measurement of plant growth obtained by calculating the quantity of carbon absorbed and stored by vegetation. NPP is equal to photosynthesis minus respiration. It is sometimes expressed in grams of carbon per square metre per year. It is a major component of the carbon cycle and is a useful tool for measuring forest productivity.

The use of integrated assessment approaches in Canada is at a preliminary stage. Cohen (1997) discusses an approach for integrated assessment (IA) of climate change impacts in the north. Cohen (1997, p. 281) notes, "IA needs to recognize the multi-objective and multi-stakeholder aspects of vulnerabilities, risks, and potential responses to climate change. IA could provide a more holistic analysis of the regional impacts dimension of climate change by including both modeling and non-modeling approaches, and incorporating institutional and stakeholder issues that do not readily lend themselves to economic analysis." Ohlson *et al.* (2005) present a conceptual approach to climate change assessment in forest management based on identification of vulnerabilities, impacts and adaptation; this paper is a summary of much of what was presented at the Forestry C-CIARN workshop in Winnipeg (2003). Spittlehouse and Stewart (2003) and Spittlehouse (2005) reviewed climate change impacts on forest management and provide one of the few detailed discussions of adaptation options for forest managers. Hauer *et al*. (2001) focus on the social and economic dimensions of climate change impacts and adaptations in forest management. The Canadian Senate Standing Committee on Agriculture and Forestry held hearings and solicited public input on climate change in Canada. Several member of the Forestry C-CIARN network provided oral and written comments and a comprehensive written submission was provided by the Forestry C-CIARN coordinator. The development and application of an integrated assessment approach to assess national and regional forest sector vulnerabilities is a high priority.

3 Forest Ecosystems

3.1 Ecosystem Effects

Short-term effects of climate change may be seen in increased rates of disturbance (see following section). Longer-term effects of climate change will be manifested in changes to tree growth and hence the volume of timber available for harvest. Forest productivity is determined by a number of environmental factors, most of which will be affected by climate change. The most important of these are temperature, moisture availability, nutrient availability and atmospheric CO_2 concentration. Recent research has shown a variety of responses to changes in these factors, including long-term increases in growth, short-term increases followed by acclimation, and negative impacts on growth.

Temperature

Higher temperatures increase the rate of both carbon uptake (photosynthesis) and carbon loss (respiration), so the effect of higher temperatures will depend on the net balance between these processes (Amthor & Baldocchi 2001). Most of the literature suggests that respiration may increase but the increases are likely to be small; this will vary among species, season, and site conditions. Both photosynthesis and respiration have been shown to adjust to a change in environmental conditions (acclimation), so any increases may be short-lived. Finally, changes to photosynthesis have been shown to be highly dependant on nutrient availability (especially nitrogen) and on water availability (Baldocchi & Amthor 2001). Generally, net primary productivity is expected to increase under warmer temperatures if water and nutrients are not limiting (Norby *et al.* 2005)

Soil warming experiments have shown increases in growth and nitrogen availability. Experimental soil warming in northern Sweden (64ºN) in Norway spruce stands showed increased basal area growth, and also showed that the addition of fertilizer and water dramatically increased volume growth relative to warming alone (Stromgren & Linder 2002). In a wide-ranging review of other soil warming experiments, increased rates of nitrogen availability have been found in nearly all locations and vegetation types (Rustad *et al*. 2001). However, this is dependant on water availability, and will also be affected by N deposition from industrial sources (Kochy & Wilson 2001).

Higher temperatures may also result in a longer growing season. Zhou *et al.* (2001) found that the average period of vegetation greenness (i.e. growing season) increased by 12 days in North America and 18 days in Northern Eurasia between 1981 and 1999. In addition, flowering and fruiting may occur earlier than at present, with unknown consequences for tree regeneration and interaction with pollinators. Similarly, McDonald *et al*. (2004) found that the mean date of spring thaw in the North American boreal forest advanced by 13 days between 1988 and 2001. Goetz *et al*. (2005) reported similar patterns in tundra regions of Canada and Alaska. However, they also found that photosynthesis in unburned boreal forest areas varied by up to ±15% between 1982 and 2003 and showed no systematic pattern in growing season length. Much of the variability in photosynthesis was attributed to the impacts of large forest fires, but could also have been affected by drought, nutrient availability and insect outbreaks (Goetz *et al.* 2005). These authors emphasize the importance of interactions between ecophysiological processes and large-scale disturbance.

Soil Water Availability

Soil available water-holding capacity (AWC) is a critical factor in determining water availability for uptake by the tree's root system. Work in northern Saskatchewan has show that potential biomass production is highly sensitive to climate change, and that differences in AWC strongly affect how productivity will change (Johnston 2001). On sites with low AWC, productivity declines under all future climate scenarios as projected by the Canadian Global Climate Model (CGCM1). On sites with moderate AWC, productivity goes up initially in response to warmer temperatures, but then declines as water availability declines in later decades. On sites with high AWC, productivity continues to increase through this century since available soil water is sufficient to support the increased growth (Johnston 2001). Similarly, Johnston and Williamson (2005) found that simulated future drought reduced productivity of white spruce in Saskatchewan by about 20% on sites with low AWC. Much of the southern boundary of the boreal forest in the prairie provinces is currently vulnerable to drought impacts, and this is expected to increase in the future (Hogg & Bernier 2005). Spittlehouse (2003) found a reduction in summer available water and likely reduction in productivity for a coastal Douglas-fir site.

The net effect of water availability will be determined by its seasonal distribution (spring versus summer) relative to the demand for water from the vegetation. Higher availability may not benefit the trees if uptake is limited, e.g. due to frozen soils in spring with dormant root systems. Lower soil water availability in summer will also cause decreases in growth. Alternatively, if the trees are able to take advantage of the early spring melt, growth could be enhanced (Cohen & Miller 2001).

CO_2

Increased CO_2 concentration affects a number of productivity-related factors. Plants take up CO_2 through stomata in the leaves, but lose water at the same time through transpiration. Under higher levels of atmospheric CO_2, less water is lost for a given unit of CO_2 uptake (known as water-use efficiency or WUE) (Long *et al.* 2004). This increase in WUE could be particularly important on water-limited sites, such that tree growth might continue where it would be severely limited under current CO_2 levels. For example, Johnston and Williamson (2005) used a forest ecosystem model to explore responses of white spruce productivity under a range of future climate conditions in Saskatchewan. They found that even under severe drought conditions, increased WUE due to increased CO_2 concentrations resulted in an increase in productivity relative to current conditions. However, productivity declined by about 20% when the WUE effect was not included in the model.

Experimental evidence has shown that the increased levels of CO_2 expected in the future have the potential to increase tree growth. In a recent review of tree-based Free-Air Carbon dioxide Enrichment (FACE) experiments, Norby *et al.* (2005) found that a doubling of CO_2 (~550 ppm) resulted in a remarkably consistent increase in biomass production among sites in a variety of locations with a variety of species, amounting to about 23%. Long *et al*. (2004) carried out a meta-analysis of FACE experiments and found a similar increase in those experiments that included trees. They suggested that this response was due to higher levels of light absorption and greater light use efficiency. On the other hand, Oren *at al.* (2001), working at the FACE site in North Carolina, found an initial increase in loblolly pine growth, but also that the growth rates returned to that of the control plots after 3-5 years. They attributed this to acclimation to the higher CO_2 levels. In addition, they found that the potential increase in biomass growth was not realized on sites in which moisture or nutrients were limiting. Korner *et al*. (2005) found that mature deciduous species in Switzerland showed no increase in growth after 4 years exposure to 530 ppm CO_2. These data suggest that the ability of trees to realize a growth increase from elevated CO_2 levels will depend on the tree species, the age of the stand, and whether other resources such as moisture and nutrients are limiting.

Diversity is an emergent ecosystem property resulting from the interaction of habitat variability, productivity, disturbance regimes and climate. To the extent that these properties are affected by climate change, diversity is likely to change (Gray 2005). Changes in species-specific growth rates may change competitive interactions, resulting in a change in dominance of tree species. Wildlife species that are dependent on one tree species for food or shelter will then be displaced by species keyed to the newly dominant tree species. Similarly, changes in disturbance rates may favor one species over another based on regeneration mechanisms (Johnston 1996). Again, the favored species will provide new habitat or food resources, resulting in a change on associated wildlife species. While the conceptual basis for these changes in diversity are relatively clear, predicting these changes is particularly difficult.

Our current ability to predict changes in ecosystem function resulting from climate change remains limited. While current models have captured the most important physiological functions, simulating the interaction between complex physiology, diversity among species and complex interactions with the environment remains a difficult task. In addition, for the forested regions of Canada, we lack basic information on soil conditions and climatic regimes, especially in remote northern locations. In addition, complex ecosystem models require extensive parameterization to ensure they represent local conditions of soils and vegetation, and need to be validated against independent data to assess their ability to capture important ecosystem processes. Validation of these models has just begun and will require significant additional work before we can place much faith in the output. The Fluxnet network is an important source of validation data for many ecosystem models currently in use.

While the purpose of this report is not to review the role of forests in carbon sequestration, it is important to note the potential impacts of climate change on carbon storage in Canadian forests. As described in this section, there is a range of potential scenarios regarding growth of forests which could result in either an increase or decrease in carbon in forests. Disturbance will also affect carbon storage, with increases in fire activity and insect outbreaks particularly important to future sequestration (see below). In addition, warming is expected to reduce soil carbon through increases in soil respiration, although this will vary depending on moisture and nutrient availability (Fang *et al.* 2005, Knorr *et al.* 2005). As carbon becomes an increasingly important value of forests and forest management, impacts of climate change on carbon sequestration need to be better understood.

3.2 Disturbance

Future disturbance regimes are also expected to be considerably different from those of today. For the prairie and northern region, forest fires are expected to be more frequent (Bergeron *et al.* 2004), of higher intensity (Parisien *et al.* 2004) and burn over larger areas (Flannigan *et al.* 2005), although the magnitude and timing of these changes is difficult to predict. Insect outbreaks are also expected to be more frequent and severe (Volney and Fleming 2000). Important pests such as spruce budworm, jack pine budworm and forest tent caterpillar are expected to increase due to the direct effects of temperatures on reproduction, and the increased susceptibility of host trees due to other stresses, e.g. drought (Hogg *et al.* 2002, Hogg and Bernier 2005). The long-term effect of insect outbreaks on forest management is difficult to predict, but recent research provides examples of tree mortality resulting from the interaction of insects, drought and fire in the southern margin of the boreal forest in the prairie provinces (Hogg and Bernier 2005, Volney and Hirsch 2005). An interesting example of the interaction between climate, host trees and reproduction is the mountain pine beetle (the following is from Carroll *et al.* 2004). It is currently in a major outbreak phase in central BC, affecting some 8.5 million ha primarily in lodgepole pine stands. The insect's distribution is determined by the position of the -40 ºC isotherm, which currently limits the beetle's eastward spread to the BC-AB border. However, individuals of this species have been found in shelterbelts up to 300 km east of Calgary, so its ability to spread is apparent. If the location of the -40 ºC isotherm shifts eastward and northward due to warming, the beetle will likely spread. Lodgepole pine and jack pine interbreed in north-central Alberta, so if the beetle spreads that far east, it may jump hosts from lodgepole to jack pine. Jack pine is closely related to lodgepole pine and has been shown experimentally to be an acceptable host for the beetle. Since the distribution of jack pine extends nearly unbroken from Alberta to New Brunswick, an emerging scenario is that of mountain pine beetle spreading from the west coast to the east coast in the next few decades. This would have enormous financial impacts.

There is important regional variability in future projections of disturbance in forests. For forests in eastern Ontario and Quebec, Flannigan *et al.* (1998) suggest that rates of fire disturbance will decline due to increased precipitation in summer.

Increased rates of fire disturbance will differentially affect tree species due to differences in flammability and their ability to regenerate following fire (Johnston 1996). Some coniferous species are inherently more flammable than hardwood species (Parisien *et al.* 2004) so increased forest fire activity will likely favor hardwood species (e.g. aspen) over some conifers such as white spruce. However, other conifers such as jack pine are well adapted to reproduce following fire, so a long-term increase in forest fire frequency may lead to an increase in aspen and jack pine at the expense of spruce and other species less resistant to fire. Impacts on forest management will be determined by the relative importance of hardwoods and softwoods to the local forestry economy. For example, oriented strand board mills in Canada generally use 90-100% hardwood (mainly aspen) as feedstock, so an increase in disturbance regime that favors aspen will result in an increase in wood supply for OSB in the long term. In contrast, saw mills that depend on fire-susceptible softwood species such as white spruce for lumber production may experience a decline in wood supply under increased forest fire activity.

Losses from forest diseases in Canada are estimated to be 36 million cubic meters of timber annually, which translates to one-third of the total annual harvest (Hepting *et al.* 2004). Forest diseases in Canada include stem diseases, heart wood rots, stem decay, shoot blights and cankers, foliar and root diseases, mistletoes, viruses and virus-like disorders, vascular wilts, and seed and seedling diseases. The incidence and severity of diseases will change due to anticipated global warming, which will affect the timber sources in the future (Colombo *et al.* 1998). Research indicates that climate has the potential to:

1. alter stages and development of the pathogen,
2. alter the lifecycle of the pathogen, such as increasing the number of generations per year or relax the over-wintering restrictions,
3. modify the host resistance, resulting in changes in the physiology of the host-pathogen interaction,
4. shift the geographic distribution of both the host and the pathogen, resulting in new disease complexes (Coakley 1999).

For foliar fungi, temperature and water availability can affect the ability of the fungus to penetrate the host and sporulation (Harvell *et al.* 2002). Woods *et al*. (2005) found that the local increases in summer precipitation resulted in an outbreak of *Dothistoma* needle blight in northern BC. Approximately 37,664 hectares were infected and 2741 hectares of young lodgepole pine plantations were killed by *Dothistoma* needle blight (Woods *et al.* 2005).

Elevated CO_2 has the potential to increase the canopy size, density and biomass of forests which may potentially result in higher canopy humidity promoting diseases such as powdery mildew, rusts (white pine blister rust), leaf spots and other blights. Drought may trigger increases in plant stress predisposing the plant to disease.

Trees become more susceptible to diseases if they are not physiologically adapted to the site. Armillaria root disease historically has been considered an opportunistic disease of low vigour trees weakened by some cause (s). Plants normally defend themselves against disease attack by producing phenolics and tannins. If the host is sufficiently stressed and weakened it may not have enough reserves to produce chemical defenses (Horsley *et al.* 2002). Pathogens that may become a problem with the onset of drought in Canada include sugar maple decline Armillaria root disease and red spruce dieback (Ayres *et al.* 2000). Drought may also reduce the number and diversity of soil microbes, reducing the availability of plant nutrients required for plant growth (Colombo *et al.* 1998; Ayres *et al.* 2000.)

Changes in climate may result in pathogen expansions and declines in the host habitat range, or the host may be released from disease control by changes in environmental conditions (Harvell *et al.* 2002). Indirect factors of climate change can also enhance the resilience of forest ecosystems. Resistance to disease may take the form of increased thickness of the epicuticular wax layer on leaves resulting in increase resistance to fungi that penetrate the tree or plants leaves. The assessment of elevated CO_2 on the susceptibility of red maple to the disease *Phyllosticta minimal* (leaf spot) showed that disease severity was reduced. Mcelrone *et al.* (2005) proposed that elevated CO_2 altered the leaf chemistry, reduced the stomatal opening, and increased the total phenolics by 15% and tannins by 14%. Increases in atmospheric CO_2 levels may increase the number of soil microbes resulting in increase in nutrient availability to plants in areas where water is available (Colombo *et al.* 1998).

Studies by Venier *et al.* (1998) projected the occurrence and distribution of Sclerodermis disease (canker disease) using historical records on both disease distribution and climate data. These researchers develop a consistent and highly predictive model from the relationship between Sclerodermis occurrence and climate. This type of model could be used as a risk assessment tool for large areas to project the occurrence of this disease. Venier *et al.* 1998 also suggest that a similar model could be applied to forest diseases, such as white pine blister rust, where the infection period is restricted in the distribution by the climate.

3.3 Regeneration

Regeneration is a natural or artificial process of re- establishing the forest land. This process includes production, dispersal, germination of the seed, and the establishment of seedlings including vegetative growth after clearing the land (Price *et al*. 2001). The production of seed is critical for reforestation. The genotype of the seed is essential for the survival and the resistance to biotic and abiotic stresses.

Genetic variation within a geographical location is related to seed population traits that are adapted to climate (such as drought hardiness and growth rates) that are associated with climate gradients in temperature and moisture. Temperature has an effect on number of variables such as seed production and flowering phenology (Price *et al*.2001). Trees and other many plants may be able to "migrate" by spreading seeds into areas better suited to their establishment and survival as climatic conditions change. But if climate changes very rapidly, some tree species may not achieve seed production fast enough to allow seed dispersal to keep up with the changing conditions. The restricted dispersal and gene exchange among small, isolated woodlot populations within the fragmented forests of species may lead to an erosion of the high levels of genetic diversity required to mount an effective adaptive response to adverse or changing environments. Climate change can also affect the establishment of seedlings by the occurrence of drought.

3.4 Preliminary IBIS simulations for Canada

Earlier unpublished simulations using IBIS were based on climate normals data for 1961-1990 and projections of climate change derived from the Canadian CGCM2 forced by the IPCC IS92A (greenhouse gases + aerosols) emissions scenario. The results were not satisfactory, but they have suggested that a warmer climate, with little or no significant change in precipitation patterns, would have some major impacts on Canada's forests. Figure 2 and Figure 3 show simulated distributions of NPP for 2000 and the changes in NPP between 2000 and 2070. It should be emphasized that the estimates of present-day NPP are not very realistic: the lowest values are too low, but in relative terms the spatial distribution appears reasonable. Summarizing these results, for the west coast, where the climate is already mild and wet, small increases in NPP would be limited to those resulting from higher CO_2 concentration (probably leading to little or no significant change in NBP). The central region, lying between the Rockies and Lake Winnipeg, but also including interior BC, is already subject to relatively low rainfall, particularly in Alberta and Saskatchewan, and therefore more prone to wide scale droughts. Here the IBIS results indicate that the main effects of a warmer climate would be to further reduce average productivity, due to increased drought. Figure 4 show maps of simulated vegetation distribution for 2000 and 2070. It should be noted, of course, that these maps do not allow for conversions of natural ecosystems to agricultural and urban uses. Bearing this in mind, the map for 2000 appears as a fairly credible representation of present-day vegetation cover, with some caveats regarding the band of grassland reported between the temperate and boreal forests of Ontario and Québec. For 2070, the central region shows a significant decrease in forest cover, as the simulated forests succumb to increased evaporative demand and are replaced by grassland and shrubland similar to the present-day prairies. When combined with increased die-back, higher decomposition rates, and fires, the central region would likely undergo significant carbon losses, and hence negative NBP. In the east (including much of Manitoba), where present-day productivity is limited primarily by temperature, NPP would be expected to increase due to the combined effects of longer growing seasons, greater nitrogen cycling and higher CO_2 concentration, leading to significant increases in NBP. There are some contradictions to this general story: note for example the slight increases in NPP in southern Saskatchewan seen in Figure 3, which are related to the simulated expansion of temperate deciduous forest into this region (Figure 5).

The changes in NPP lead to some projected changes in vegetation biomass, shown in Figure 6 It should be noted that IBIS generally underestimates forest biomass, particularly in coastal regions where undisturbed forest stands can often achieve 250 tonne C ha^{-1}, compared to the maximum simulated densities of around 10 kg C m^{-2} (or 100 tonne C ha^{-1}). This underestimation problem appears even worse for the prairie provinces which report little or no biomass at all, even where NPP is relatively high. Part of the explanation for this apparent contradiction is that much of the NPP in the central boreal forest region is attributed to understory vegetation (herbs and shrubs), which do not accumulate much biomass over a one year period. With these caveats in mind, however, the broad distribution of simulated biomass density across the country is somewhat consistent, in relative terms, with observations. The simulated changes then show losses of biomass in the west and southern boreal with significant gains in much of the east, and to some extent in the boreal regions of northern Saskatchewan and Manitoba. There is also a band of major biomass decrease extending across Ontario and southern Québec over to Newfoundland. This is explained by the projected change in vegetation where trees give way to grassland and shrubs seen in Figure 5 However, the westward expansion of temperate deciduous forest suggests this decline is really a temporary state, where the boreal forest vegetation is about to be replaced by temperate deciduous forest.

A significant departure from this general rule occurs in a band crossing Ontario and southern Quebec. This is explained by a projected change in vegetation, where IBIS also suggested that in some regions, notably central and northern Alberta and to some extent the central interior of BC, there would be significant loss of forests to be replaced by ecosystems dominated by grasses and shrubs.

Some major caveats concerning these projections using IBIS are:

1. Historical climate data used for baseline (2000) ecosystem states were simply 1961-90 climate normals with no interannual variations.
2. Only a single climate scenario (CGCM2 model forced by IPCC IS92A emissions scenario), was used to project the future
3. Standard IBIS simulation assumes a uniform 4 m soil depth
4. Constraints were imposed on NPP assuming static nitrogen limitations
5. In spite of 4, simulated present-day NPP seems too low (in comparison to other models and to what we know from relatively few field measurements)

These caveats have led to an extensive effort to try to resolve these and other limitations of the model, primarily to improve IBIS' simulation of NPP for boreal ecosystems. This work is in progress in cooperation with modeling groups in the US and the UK.

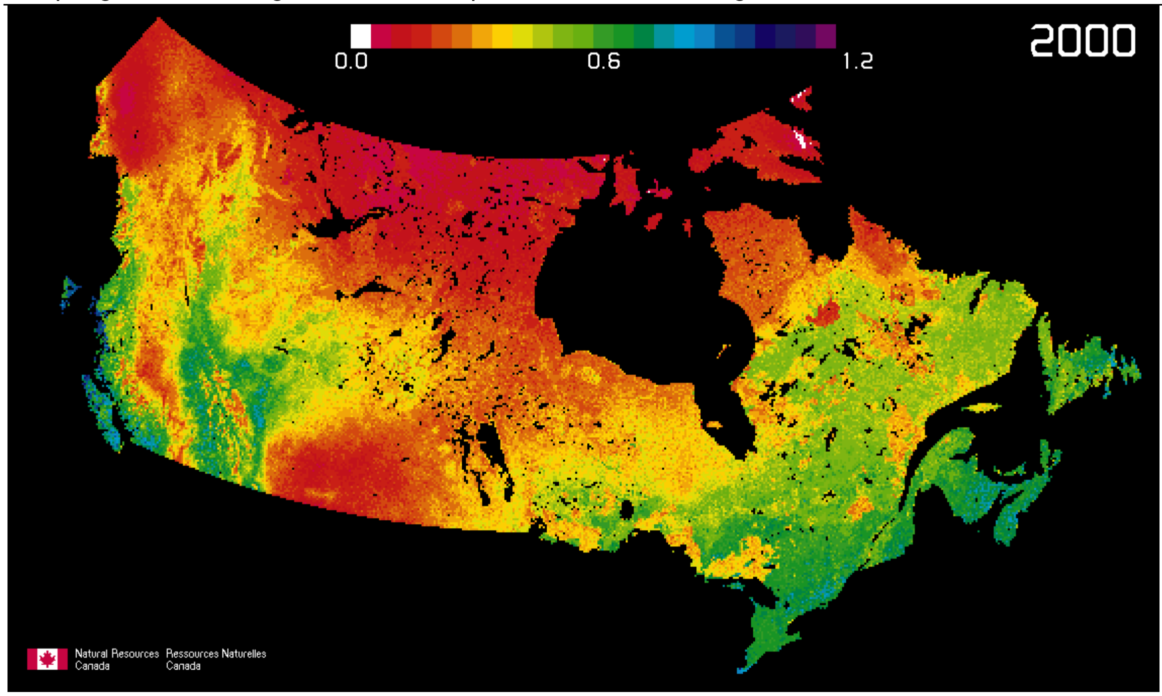

Figure 2. Net Primary Productivity (NPP, kg C m^{-2} yr^{-1}) as simulated by IBIS for 2000. Note the unrealistically low values for much of the grassland and boreal forest regions in the Prairie Provinces and for all ecosystems in interior B.C.

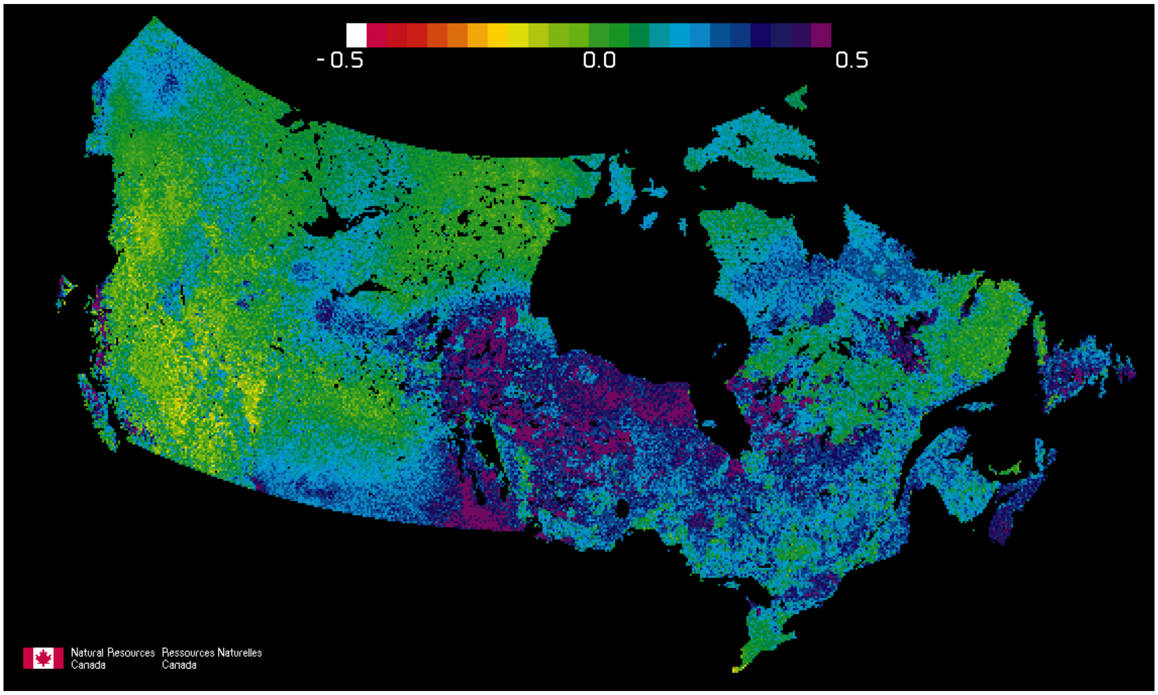

Figure 3. Changes in NPP (kg C m^{-2} yr^{-1}) as simulated by IBIS for the period 2000 to 2070 (a positive value indicates an increase).

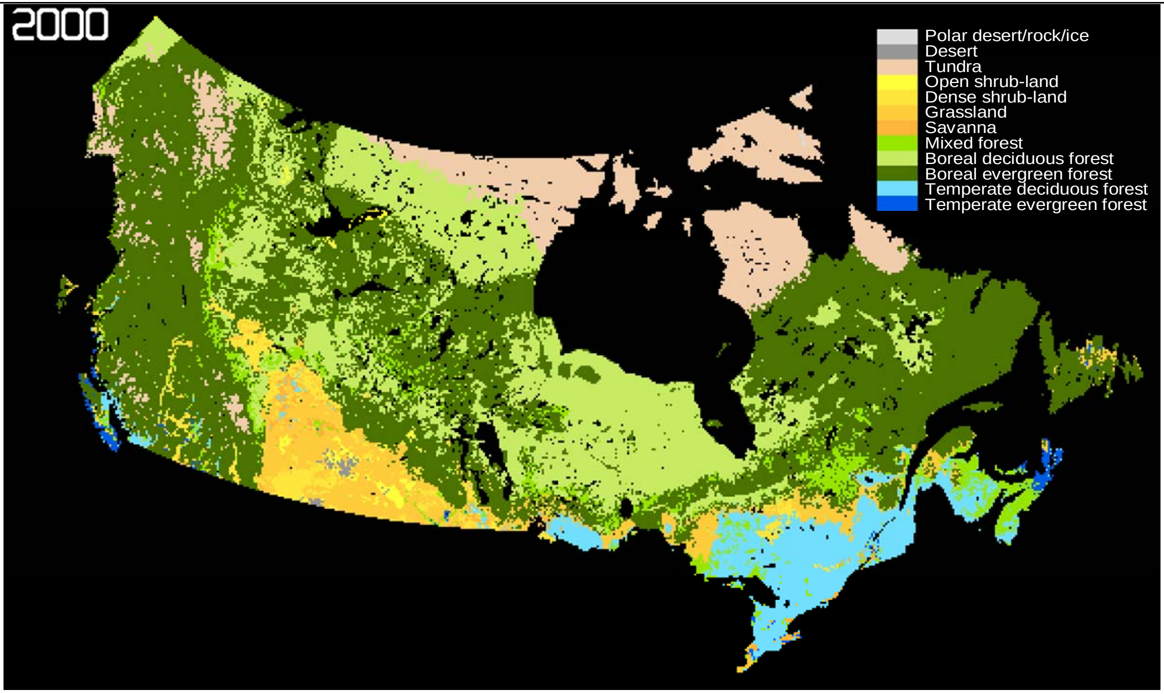

Figure 4. Distribution of major vegetation types as simulated by IBIS for 2000. Note the questionable band of grassland types extending across Ontario and southwestern Quebec and the incorrect simulation of temperate deciduous forest just west of Lake Superior.

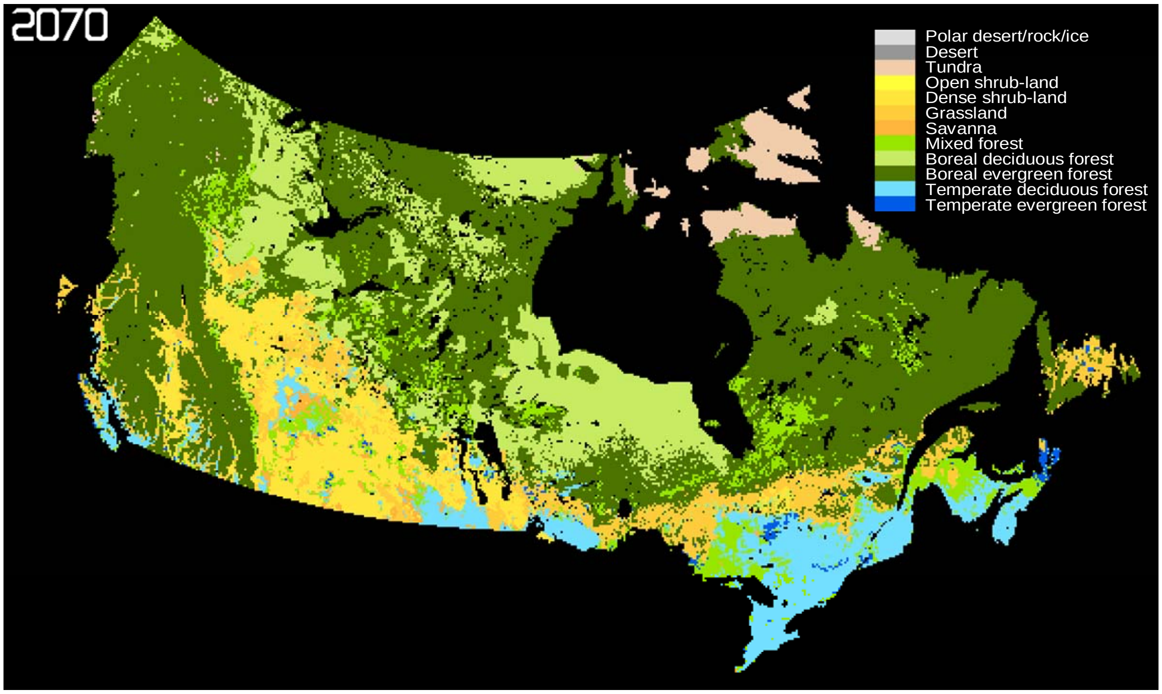

Figure 5. Distribution of major vegetation types as simulated by IBIS for 2070.

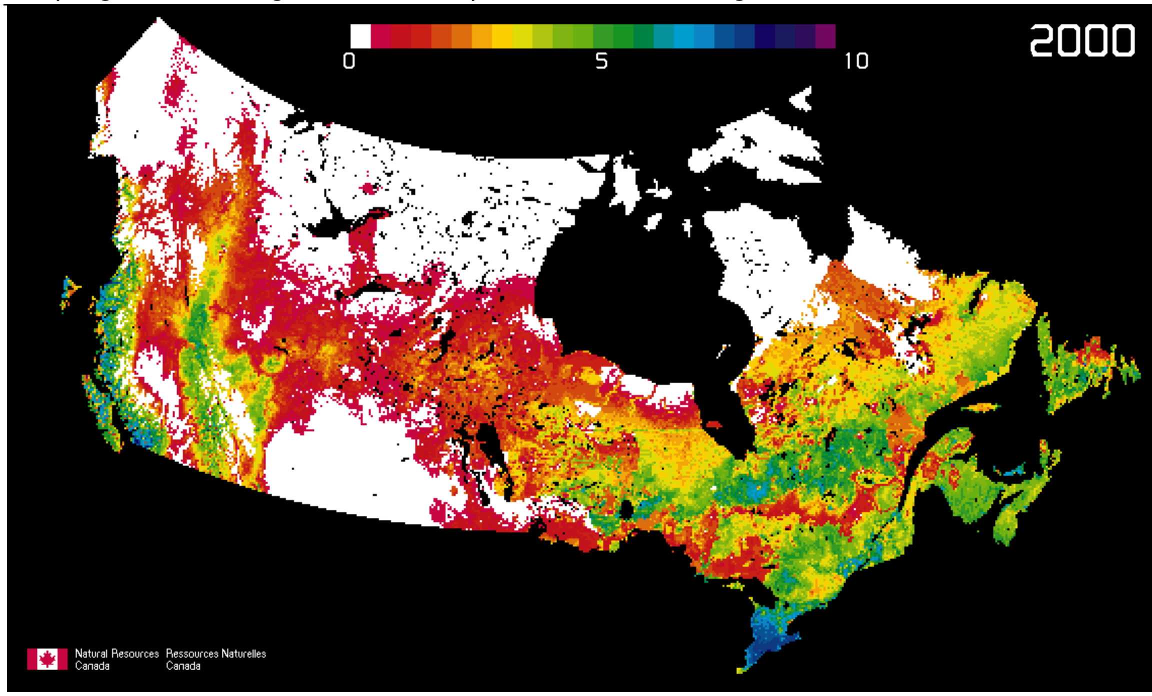

Figure 6. Forest biomass distribution (kg[C] m^{-2}) as simulated by IBIS for 2000. Note the very low values estimated for the prairie Provinces, interior BC and the band across central Ontario and southern Québec.

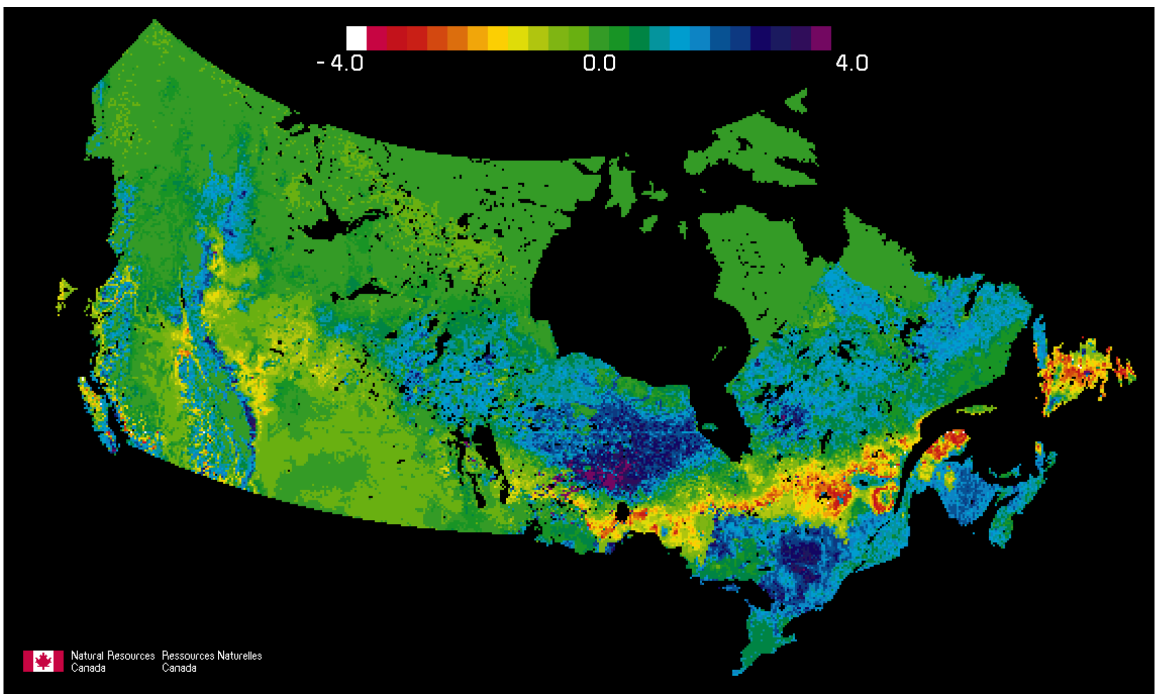

Figure 7. Changes in biomass (kg[C] m^{-2}) as simulated by IBIS for the period 2000 to 2070 (positive value indicates increase). The obvious decreases seen in southern Manitoba and extending across Ontario and southern Québec into the Maritime provinces are evidently related to the replacement of forest by grassland and shrublands seen in Figs. 3 and 4.

Finally, integrated analyses of climatic change, forest management and economics have been carried out. For example, McNulty *et al.* (2000) used an integrated system of forest productivity, forest inventory and economic models to explore climate change impacts to timber supply in the southeastern USA. They found that productivity, and hence levels of harvest, increased under several climate change scenarios. This had several effects, including a shift from pulpwood to saw timber harvest due to higher productivity and shorter rotations, i.e. more valuable saw timber could be grown in what was previously a pulpwood rotation. The higher levels of harvest tended to reduce the price of forest products, resulting in less income for the industry but better prices for the consumers.

3.5 Regional Factors Affecting Vulnerability

The impacts of climate change on forests will vary significantly across Canada. This is due to the wide variety of climatic, topographic and ecosystem types, as well as differences in forest management approaches and land ownership patterns. The objective of this section is not to provide a comprehensive catalogue of all regional differences, but rather to highlight a few critical climate change issues for forestry in each region. With the exception of the Yukon, the following information was taken from each of the regional forestry sections of the second Canadian National Assessment of Climate Change (in press)

Prairies:

- Major drought events (possibly multi-year to decade) especially along the forest fringe Increases in fire
- Increase in relative abundance of fire adapted species
- Increased insect outbreaks: spruce budworm, forest tent caterpillar
- Possible spread of MPB from BC
- Reduction in frozen ground season

Ontario:

- Increased fire
- Increased insect outbreaks: SBW, FTC
- Increased incidence of *Armillaria*
- Shifts in species composition, e.g. to central US hardwoods (very long term)
- Shifts in species due to changes in disturbance regimes

Quebec:

- An increase in Black spruce growth was observed since the 70s at the northern tree line in eastern Canada
- It is quite possible that soil fertility may become a barrier to migration although higher temperature may also affect element cycling within the soils.
- Winter severity is one of the major factors limiting insects and pathogens expansion to the north. In eastern Canada, winter is warming faster than summer.
- In eastern Canada, the potential distribution era of the spruce budworm will greatly increase while intensity of the outbreak may also increase.
- The European gipsy moth which was accidentally introduced in the north-eastern USA (Massachusetts in 1869) may also expand in the forest of south-eastern Canada.
- Forest fires would increase in the north and the west of Quebec and will decrease in the west of the Abitibi region while it would stay constant in the center of the province.

Atlantic:

- Increase in major oceanic storms with associated wind throw
- Increased ice storms
- Invasive species
- Hemlock Woolly Adelgid

British Columbia:

- Coastal forests: There will be an increase risk of fires and water stress Water stress will be important to such species such as redcedar and hemlock.

- Wet cool mid and northern coasts will have an increase in the storms and intensity that will result in windthrow and landslides.
- Lower elevations in southern interior: will have an increase risk of fire.
- Higher elevations in southern interior: warming of wetter areas will promote longer growing seasons. In drier areas, there will be increase risk of fires and drought stress. Regeneration of these sites may benefit initially from a warmer climate.
- Northern interior: Warming with small changes in summer precipitation has the potential to increase tree growth.
- Alpine – The length of the snow pack season, soil conditions and slow regeneration rates will limit the rate of encroachment of the forest.
- Significant response is expected by insect and pathogens to a changing climate. This has already been noted with the mountain pine beetle and needle blight and is anticipated for leader weevil.
- Botanical forest products, such as mushrooms, berries, floral greens, and medicinal plants, may increase in disturbance areas caused by fire.
- Warmer winters will shorten the winter recreational season while summer recreational season will increase in the absence of fire.

Yukon

- Upward movement of treelines.
- Increase of fires in areas of old growth forests especially in southwestern Yukon.
- Increase of infestations by the spruce bark beetle
- Increase in storms and lightning events resulting in fire.
- Drier conditions will stress forest regeneration sites and delay forest renewal
- Warming of permafrost layer may result in increase in the incidences of landslides. Landslides can reduce the slope shear strength.
- Increased moisture stress to trees resulting in a greater mortality from insects, fires and other pathogens.

4 Securing Forest Benefits – Assessing Sectoral Vulnerability

Climate change is expected to lead to changes in forest ecosystems that will in turn impact the various benefits that Canadians associate with and derive from the forests. In Canada, forest values are managed by policies, regulations and practices that have been shaped by the common objective of managing forests to meet the social, economic and environmental needs of present and future generations. However, the development of criteria and indicators used to guide sustainable forest management practices have been driven in large part by our understanding of the maintenance of forest health under current climate conditions. As forest conditions change our assumptions about sustainable forest management may no longer preserve the values that Canadians associated with the forest.

4.1 Forest Policy

Climate change has been notably absent in both the academic forest-based policy literature and within current Canadian forest policies themselves. Howlett's (2001) edited volume, *Canadian Forest Policy*, which attracted some of Canada's top forest political scientists, did not result in climate change issues being addressed in any of the fourteen chapters. Some of the volume's contributors, most notably Cashore, Hoberg, Howlett, and Rayner, have developed policy frameworks in order to understand forest "policy regimes" and policy change. Policy regimes consist of *ideas* effecting policy choice and policy instruments, *institutions* designed to regularize and routinize policy making, and the relationships between state and societal *actors*. Concurrent with the methodological advances made in Canadian forest policy analysis, O'Riordan *et al's* (1998) chapter, *Institutional frameworks for political action* offered similar frameworks for climate change related policy-analysis. However, very few forest-based political scientists have made the link to climate change. Duinker's (1990) article *Climate change and forest management, policy and land use* and (2002) book chapter, *Policies for sustainable forests: Examples from Canada* are the only known attempts to explicitly understand Canada's forest policy regime within a forest-climate change context. From a regional perspective, Wellstead *et al.* (2004) and Stedman *et al.* (2005) empirically describe the interaction between Prairie agriculture, forestry, and water policy actors, their belief structures, and their climate risk perceptions.

In part, the academic unattractiveness of climate change for political scientists can be explained by its absence in the operational policies. Borrowing from Kingdon's (1995) policy streams analogy, adaptation to climate change has failed to be at the forefront of any government's forest policy agenda. Institutional forest policy arrangements, in particular, forest management agreements between provincial governments and the forest industry that define the dominant tenure arrangement in Canada do not contain provisions for climate change impacts and adaptation. Climate change is also absent from provincial forest management *Acts* that determine the relationship between policy actors. In fact, there are often many built-in policy rigidities such as prescribed Annual Allowable Cut (AAC) rules that prevent the necessary operational changes to account for climate change.

Recently, Canada's Standing Senate Committee on Agriculture and Forestry sought to investigate the current levels of knowledge related to climate changes by consulting experts and scientists representing three particularly vulnerable sectors: agriculture, forestry, and water. In its final report, *We are at risk*, the Committee recommended the creation of climate-specific policies for each of the sectors. The key policy-related question is how the issue of climate change can be part of the forest policy agenda and in the process lead to significant policy change. Kingdon (1995) argued that an issue such as climate change becomes part of government's agenda only when three relatively independent streams (problem, policy, and the political) converge and are coupled, promoted by a "policy entrepreneurs," and only then do policy decisions occur when policy windows open (budgets, elections, international agreements, etc). This synthesis report presents much of the literature describing the problem stream—namely the evidence suggesting the scientific extent of climate change impacts and the necessary adaptation measures as public problems. The policy stream consists of those experts and analysts examining problems and proposing solutions to them (Howlett and Ramesh 2003). Spittlehouse and Stewart (2004) attempt to bridge the problem-policy gap by considering the long-term impact of climate change and "determine what the [forest] community might do now and in the future to respond to this threat." These forest management actions which are discussed in detail throughout this report include gene management, changes to forest protection and regeneration, new approaches to silvicultural management and forest operations, and a consideration for enhanced non-timber management. However, a cautionary note must be made when prescribing policy actions and modifying institutional arrangements without understanding their political viability.

Within this policy stream have emerged Federal and Provincial inter-departmental committees that seek to examine climate change issues and problems, and then propose strategic directions. However, many of these committees still remain focused on synthesizing the information pertaining to climate change related problems. Alberta Environment's Alberta Climate Change and Adaptation Team (ACCAT) is an example the recent attempts by governments to move from problem definition to the formulation of strategic directions. Overall very little effort has been made to develop narrower, more focused sector specific policy solutions. The final stream, the political stream reflects such factors as changes in national mood, administrative and legislative turnover, and interest group (pressure). Currently, the potential for policy change to forest policies that reflect the emerging problems associated with climate change is low. However, external events can lead to sudden and dramatic policy changes. These events may simply be the result of media coverage of climate related events (e.g. increased forest fires, the B.C. mountain pine beetle epidemic) that lead to a changing public mood on this issue or more subtle influences such as the role epistemic communities have on international and national policy coordination. For example, at the United Nations Climate Change Conference (COP11) held in December, 2005 in Montreal, the investigation of impacts, vulnerability and adaptation to climate change became a formalized decision. However, absent within the Canadian forest sector are forest *policy entrepreneurs* who are willing to promote climate change related problems and develop successful policy outcomes.

4.2 Forest Management (timber values)

For the purposes of this report, we define forest management as the activities involved in planting, tending and harvesting commercial tree species on crown land. There are two aspects of forest management that make climate change particularly germane to forest sector decision-making. First, forest management is long term, because forests have long growth cycles. In fact, growth rates for Canadian tree species tend to be significantly lower than in many competing countries, and age of maturity is far higher. Thus, the age at which trees get harvested is higher in Canada than in places like the southern US, e.g. southern pines may be harvested at 20-30 years. In Canada, rotations for coniferous species tend to be 80-90 years and 60-70 years for deciduous species. Note that hybrid poplar is a fast growing tree species in which the rotation age can be 20–30 years. However, these species are being considered largely for afforestation on private land which places them outside of forest management as defined in this report.

The second aspect is that climate change has the potential for significant impacts on tree growth, mortality, and patterns of disturbance on the existing forest (i.e. the current stock of forest capital). The combination of long growth cycles and future changes in growing conditions that are likely to occur within the current rotation means that climate change will have important implications for choices we make today (Johnston and Williamson 2005). Unfortunately, with a few exceptions climate change is not considered in decisions and long-term forest management plans (but see below for some recent initiatives).

This section identifies some areas in which climate change has important implications for forest management in Canada, describes some of the possible tools and models that are available for incorporating climate change into decision making and identifies important knowledge gaps and policy barriers.

Growth and Yield

In a sustainably managed forest the amount of wood volume harvested is generally equivalent to the current growth, i.e. the “interest” on the forest capital. The various data and techniques used to determine this harvest level (the Annual Allowable Cut or AAC) are collectively termed forest growth and yield (G&Y). Under current management systems, AAC is determined using empirical models that incorporate forest G&Y data. These data are based on historical data collection, sometimes dating back several decades. The AAC models do not use any inputs related to climate, except to the extent that tree growth reflects past climate. Therefore, current AAC calculations do not and cannot respond to current or future climate scenarios (Battaglia 2004, Johnston and Williamson 2005). Recent research has developed process-based G&Y models that include climate and soils data as inputs, and are suitable for estimating yield functions under future climate. Examples include the models 3PG (Landsberg and Waring 1997), StandLeap (Raulier *et al*. 2003), TRIPLEX (Peng *et al.* 2002) and others. These models are still in the process of being validated and it will be some time before they are routinely used in AAC calculations.

Climate change will have a number of effects on G&Y. Experimental evidence has shown that the increased levels of CO_2 expected in the future have the potential to increase tree growth, although this will depend on the tree species, the age of the stand, and whether other resources such as moisture and nutrients are limiting. Increased rates of forest disturbance (fires, insects) will affect the availability of harvestable trees. Salvage harvesting (harvesting trees after being damaged by disturbance) will provide some ability to make use of dead trees, but wood quality declines in 1-3 years following disturbance and burned trees may not be suitable for use in pulp and paper due to discoloration from charred wood. In addition, damaged trees may be in inaccessible locations or affected over large areas such that salvage is not feasible, e.g. the current mountain beetle outbreak in BC. See Section 2 for a review of climate change impacts on forest ecosystem processes.

Reforestation

Trees are at their most vulnerable following regeneration, whether natural or planted (Spittlehouse and Stewart 2003). Approximately 48% of crown forest land in Canada is planted following harvesting (NFDP 2005). These areas are subject to density control, may sometimes be fertilized, are planted with genetically improved stock that is disease-free and has had 1-2 years growth in greenhouse conditions. Therefore, trees that have been planted are more likely to survive the environmental stresses resulting from climate change than trees that have been naturally regenerated. However, there are additional steps that can be taken to increase the resilience of forests in the regeneration phase (adapted from Spittlehouse and Stewart 2003):

- Identifying and planting drought-tolerant genotypes

- Assisting the migration of commercial tree species from their present to future ranges through artificial regeneration. The northward movement of certain species will, in some instances, be hindered by the lack of suitable soil conditions, such as nutrients, soil depth, and mycorrhizae.

- Planting provenances that grow adequately under a wide range of conditions and (or) planting stock from a range of provenances at a site

- Controlling undesirable plant species, which become more competitive in a changed climate, through vegetation management treatments

Beaulieu and Rainville (2005) provide an approach for determining the optimum seed source for planted stock under future climate conditions.

An important component of regeneration is collection of seed and planting of seedlings after a disturbance of some type in the forest. This activity is governed by provincial government regulations that have fairly strict guidelines restricting where seeds can be collected from and where they can be planted (seed transfer zones) The seed transfer guidelines usually describes the maximum movement from the point of collection in kilometers east and west, north and south as well as meters in elevation. Most provincial seed transfer guides do not consider environmental changes brought about by climate change. With expected change in climate, seed ranges will move northward in latitude and new grouping of species and provenance will occur over space and time. New approaches for seed deployment systems (e.g., climate-based, site-specific, productivity-focused systems) need to be tested for effectiveness and ease of implementation (O Neil and Yanchuk. 2005). Adaptation strategies to climate change for forest regeneration includes:

- The use of climate based seed zones to ensure seedling survival to future climate changes.
- Breeding programs for pest resistance and wider tolerance of climate change stresses
- Maintaining biodiversity by planting mixed provenances and species that have tested for resilient to future climate change for a particular forest site (Spittlehouse and Stewart 2003).

Seed transfer zones should be considered a dynamic, evolving system that will need to modify according to the rate of climate change.

Operational Impacts

Climate scenarios for many locations suggest the future will bring warmer winters with greater precipitation and earlier springs (Flato *et al.* 2000, McDonald *et al.* 2004, Barnett *et al.* 2005). Summers may be somewhat warmer but will be dryer due to increased evapotranspiration (Laprise *et al*. 2003, Wang 2005). In addition, extreme precipitation and drought events may become more frequent (Sauchyn *et al.* 2003). Under these conditions, excess spring moisture from earlier and more rapid snowmelt, earlier and perhaps longer spring road weight restrictions and waterlogged conditions in operating areas can be expected. This could affect both woods operations and the construction and use of forest roads. Sites prone to erosion (e.g. road crossings) could become more vulnerable due to higher and more intense precipitation (Spittlehouse and Stewart 2003). Flooding would be a concern and will require closer attention to proper sizing of culverts and other water control structures (Spittlehouse and Stewart 2003). In areas where winter operations are important, the shorter length of frozen ground conditions will limit woods operations and affect scheduling of harvesting equipment among cutting areas. Harvest access that depends on ice roads would also be vulnerable to warmer winters, with a reduced haul season (Blair 2006).

Planning and Risk Management

The Canadian forest management community is strongly committed to the principle of sustainable forest management. Sustainable forest management in a Canadian forestry context is largely defined by the Canadian Council of Forest Ministers Criteria and Indicator framework. Consistent with Criteria and Indicators is the provincial government requirement that forest companies' carry out long-term forest management plans (e.g. ASRD 1998, OMNR 2005 and many others). These plans provide the biophysical and socio-economic context for company's forest operations and describe generally how their activities will be carried out over the period covered by the plan (often 20 years) and what the implications of these decisions are for 200 year planning horizons. These plans provide the ideal vehicle for incorporating climate change considerations into forest management, given their long-term perspective and general level of detail (Spittlehouse 2005). Climate change is not usually considered in long term forest management plans. However some recent exceptions include Louisianna Pacific in Swan River MB, Miller-Western in Whitecourt AB and Mistik Management in Meadow Lake SK.

As noted, the definition of sustainable forest management in a Canadian forestry context is implied by the Canadian Council of Forest Ministers Criteria and Indicators initiative. These criteria and the associated indicators provide guidance on how to maintain sustainability in the face of changing environmental and socio-economic conditions. However, the CCFM criteria and indicator framework has not been tested specifically for application to climate change adaptation. This should be a high priority for the forest management community.

Another area of increasing importance to forest management in a climate change context is dealing with increased levels of risk and uncertainty. One of the often overlooked consequences of climate change with respect to sustainable forest management (and our desire to sustain environmental benefits for future generations in general) is the heightened levels of risk and uncertainty in the future values of variables of interest to forest management (e.g. future yields, future prices, future costs of management) that will result from future climate change. However, explicit consideration of changes in risk resulting from climate change is not common in forest management. The following excerpt provides further discussion of the implications of climate change for risk management in Canadian forestry.

The following material is extracted from Johnston, M.; and Williamson, T. 2005. Climate change implications for stand yields and soil expectation values: A northern Saskatchewan case study. 81(5): 683-690. – Permission to reprint this material was obtained from the Forestry Chronicle.

A change in risk and uncertainty resulting from climate change has important implications for forest management. Increases in risk and uncertainty suggest the need to change from managing forest resources deterministically to managing resources with uncertainty reduction and risk management as specific objectives. The particular properties, characteristics and features of local forest management systems will influence the capacity of forest managers to manage risk. Three general system properties will be important. First, the forest management system will need to be flexible (Montgomery 1996). Second, the range of technologies used within the system and outputs produced by the system should be as diverse as possible. Third, the forest management system should permit adaptive management (Montgomery 1996).

Two important questions that will have a bearing on the how much adaptive risk management actually occurs in response to climate change are as follows:

1. Is climate risk relevant in a local forest management context?
2. If risk management is relevant, who has the most at stake and therefore is most likely to pursue strategies to manage risk?

To answer the first question it is useful to start with a definition of risk. In general terms, risk is the potential or likelihood of a detrimental impact. The analysis in this paper suggests that there is the potential for a detrimental impact, even though productivity might increase on average. Therefore, risk and risk management are relevant in a local forest management context. However, if the scenarios analyzed here had suggested higher land values over the full range of potential outcomes, the implications for forest management would probably not be considered as risk management. Rather the appropriate management strategy would be to implement adaptations that maximize climate benefits.

The second question pertains to the identification of who has the most to gain by managing risk and who, therefore, is most likely to want to pursue a risk management approach. The two groups that would be expected to be concerned about uncertainty and risk are provincial forest management agencies and forest product companies. However, in general (with some exceptions) they have not, to date, expressed a great deal of concern about climate change and have not expressed significant interest in modifying forest management systems to manage climate risk. There are a number of potential explanations for this general indifference. First, it may be that these two groups have in some way made an assessment of the risks related to climate change and have concluded that there is presently insufficient basis to conclude that risks will be significant. A second potential reason is that there is insufficient (and in some cases conflicting) information about possible future impacts. There simply may be too much uncertainty at this stage about future effects to justify making radical changes in forest policy and management. This seems like a classic catch 22, i.e. there is too much uncertainty to justify modifying forest management but it is the increase in uncertainty that is calling for modification to forest management. The high level of uncertainty, however, should not be an excuse for doing nothing. There are a number of different ways to address uncertainty and manage risk. For example, possibilities include: (a) targeted research and learning, (b) improved data and information sharing, (c) encouraging experimentation and adaptive management in forest management and planning, (d) investigating new kinds of institutional arrangements that are more effective at facilitating autonomous adaptation (e.g. is there a potential larger role for private markets in forest management in Canada?), (e) reducing exposure through hedging, diversification and/or shorter rotations, and (f) risk reduction strategies such as fire-smart landscapes (Hirsch *et al*. 2001). Possibly the most significant change that needs to occur is that forest managers will need to recognize and embrace the increasing levels of uncertainty that are anticipated to occur.

4.3 Market Impacts of Climate Change

Canada's forest industry may be vulnerable to indirect impacts of climate change on its export-based forest economy through long-run structural changes in global forest products markets. Market impacts will be particularly important for provinces like British Columbia and Quebec where forest products exports make a significant contribution to provincial GDP (Figure 8).

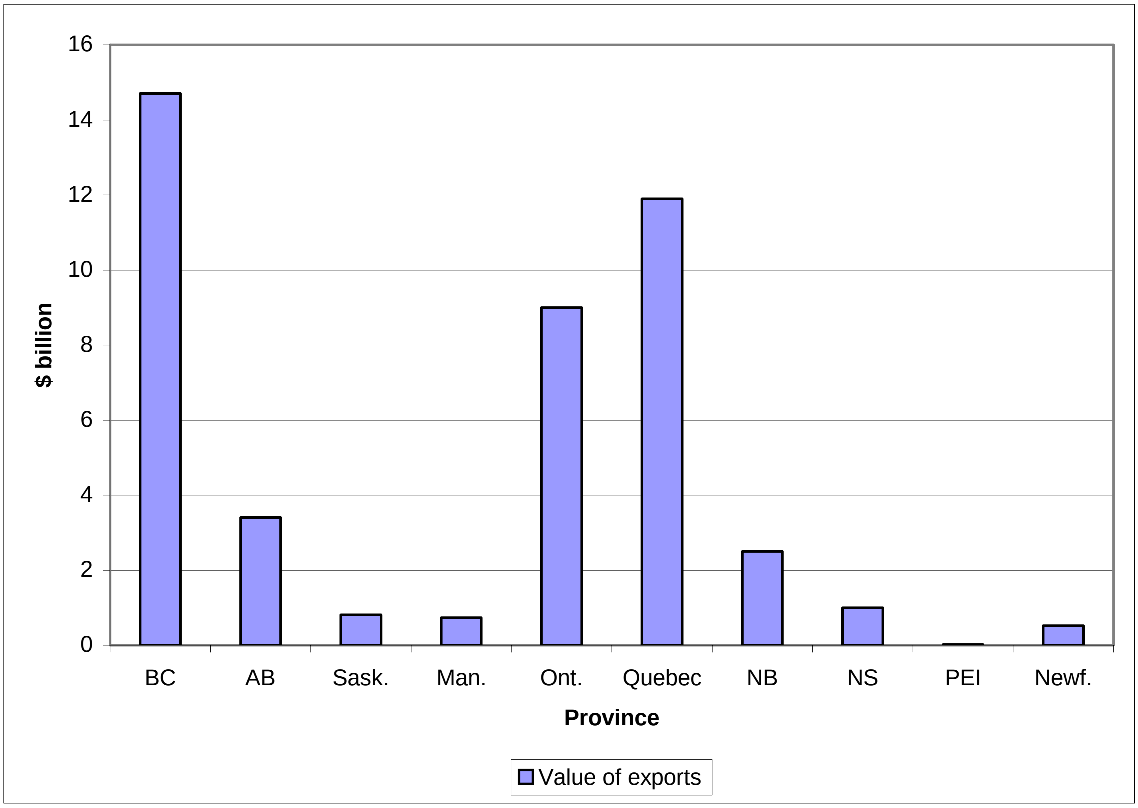

Figure 8 Values of forest products exports by province of origin

Sohngen and Sedjo (2005) analyse the effects of climate change on North American forest products markets by integrating the BIOME model (Haxeltine and Prentice 1996) with a dynamic optimization model of global timber markets. Their analysis suggests that climate change will increase global timber supply (Sohngen and Sedjo 2005). Forests in some regions may decline while forests in other regions increase. The general expected result is that there will be an increase in the supply of forest products and a restructuring in global forest products trade (Sohngen and Sedjo 2005). Sohngen (2004) Figure 9 presents an analysis of climate impacts on the global timber market. Figure 9 shows the distribution of producer effects for various regions of the globe for the period 1995 to 2095. South American producers will benefit from climate change. Moreover, the benefits are continuous over the entire century. The Russian forest industry experiences reductions in benefits in the first part of the century, but benefits increase dramatically in the latter part of the century. Economic benefits for North American producers are reduced by climate change. The decrease is significant in the early part of the century and it is the result of a decline in relative prices and in relative market share by North American producers.

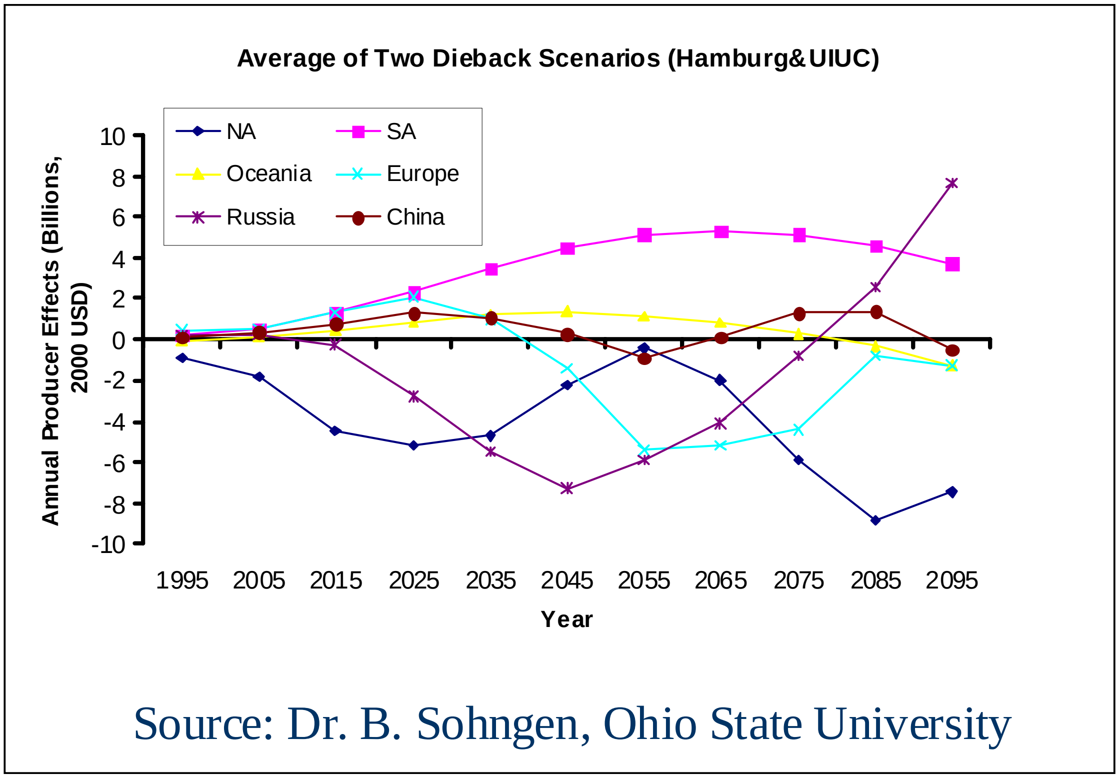

Figure 9. Trends in producer effects from climate change from 1995 to 2095 (source Sohngen)

The analysis summarized in the previous paragraph shows the effects of climate change in terms of global markets and the implications that this structural change may have for North American producers relative to other producing regions. But what are the implications of climate change for Canadian producers? A study by Perez-Garcia *et al*. (2002) provides country specific predictions of the market impacts of climate change (Table 1). The Perez-Garcia *et al.* (2002) study looks at the impacts of climate change up to the year 2040 using transient climate scenarios linked to an ecological model that is in turn linked to the CINTRAFOR Global Trade Model (CGTM). The results show that the market impacts of climate change are particularly significant for Canadian producers. Of the countries included in the analysis, Canada is the only country where producer impacts are negative. Moreover, producer impacts are significant (i.e. a loss of $ U.S.13.4 billion by the year 2040). In fact, the analysis suggests that Canada is in a uniquely vulnerable position relative to other forest products producing countries in the world.

Understanding the possible future market impacts of climate change is useful to know because it gives Canadian producers and policy makers' further insights into the nature and magnitude of competitive pressures that the Canadian industry will face. It may not, however, be possible to adopt specific adaptation measures to climate induced market impacts. Climate change is but one of a number of considerations that will impact the competitiveness of Canadian producers in the future and it may be difficult (and perhaps unnecessary) to try and separate climate effects from other factors (e.g. exchange rates, labour costs, technological change, increased market share from non-traditional suppliers, growth of the China and Indian economies, etc). What might be more reasonable is to recognize that market changes are and will continue to occur and that climate change may magnify or exacerbate some of these effects. Thus, what is needed for the Canadian forest sector is an all-encompassing competitiveness strategy that simultaneously considers all of the factors that will impact the forest industry (including climate change) and comes up with a competitiveness strategy that builds on, and is tailored to Canadian comparative advantages but that also takes climate change into account as well as other ongoing structural changes in global markets. Such a strategy would need to consider tenure, timber supply, technological capacity, product development, market development, access to skilled labour, etc.

Market impacts of climate change in the year 2040 (Million $ 1993 U.S.)

Country	PS: Logging	PS: Products	CS	Total
Canada	- 408	-13,015	2,674	-10,749
Chile	3,879	394	351	4,624
West Europe	-644	120	1,701	1,177
Finland	-353	114	76	164
Japan	-1427	325	2,524	1,422
New Zealand	1,851	334	294	2,478
Sweden	-240	294	103	157
U.S. North	-758	-84	6,474	5,633
U.S. South	-5,149	69	6,937	1,720
U.S. West	1,069	6,354	7	5,292

Source: Perez-Garcia *et al*. 2002

Table 1. Market impacts of climate change in the year 2040

Note: The above results are from Perez-Garcia *et al*. 2002. The paper presents results for six separate scenarios. The results reported above are based on one of the scenarios (i.e. the mid range scenario - RRR-Intensive).
PS: Logging is producer surplus impacts for the logging industry
PS: Products is producer surplus for primary producers (e.g. lumber, pulp and paper)
CS is consumer surplus or consumer benefits.

As suggested, the market impact of climate change on the Canadian forest products sector has the potential to be significant. As such, it is important that Canadian policy makers, industry, and decision makers are informed about these possible impacts and wherever possible, that uncertainties surrounding these impacts are reduced as much as possible. However, current analysis of the market impacts of climate change in Canada originates from non-Canadian researchers and results are highly aggregated. There is limited insight into how impacts might vary across sectors, across regions, and over time. This is a significant knowledge gap.

4.4 Forest Biodiversity - Implications for Protected Area Policy

This section is extracted from Scott, D.; Lemieux, C. 2005. Climate change and protected area policy and planning in Canada. The Forestry Chronicle. 81(5):696-703. – Permission to reprint was obtained from the Forestry Chronicle.

Protected areas are the most common and most important strategy for biodiversity conservation (Woodley and Forbes 1995) and are called for under the United Nations' *Convention on Biological Diversity* (UNCBD 1992: Article 8). However, most protected areas have been designed to represent (and in theory protect for perpetuity) specific natural features, species and communities *in-situ*, and have not taken into account potential shifts in ecosystem distribution and composition that could be induced by global climatic change.

For two decades, climate change has also been identified as an important emerging issue for protected areas. Peters and Darling (1985) anticipated that the role of protected areas would change in an era of global climate change. Since then a number of authors have concluded that protected areas are vulnerable to climate change and will need to be managed differently if they are to meet the conservation challenges of the twenty-first century and beyond (IUCN 1993; Markham 1996; Bartlein *et al.* 1997; Halpin 1997; Hannah *et al.* 2002; Scott *et al.* 2002; World Wildlife Fund 2003; Lovejoy and Hannah 2005; Lemieux and Scott 2005).

Climate change has a number of important policy and planning implications for protected areas in Canada (Table 2), not all of which can be discussed in sufficient detail in this paper. Scott and Suffling (2002), Scott *et al.* (2002), Lemieux *et al.* (2005) and Lemieux and Scott (2005) can be consulted for additional information and specific case studies.

One of the more important policy implications of climate change is for protected area system planning frameworks. Public expectations of how protected areas should be managed and the science behind conservation have changed significantly over time. Sporadic and unsystematic protected area designations in North America from the late 1800s to the mid-1950s gave way to systematic approaches to protect 'representative' samples of ecosystems in the 1960s. All federal and provincial-territorial jurisdictions in Canada have adopted some type of ecoregion or biogeoclimatic land classification system as the main system-planning framework for their terrestrial protected area systems. For example, in the 1970s Parks Canada (1997: 1) delineated 'natural regions' based on geologic and vegetation formations with the goal to "…protect for all time representative natural areas of Canadian significance in a system of national parks, to encourage public understanding, appreciation and enjoyment of this natural heritage so as to leave it unimpaired for future generations." The policy goal of the *System Plan* is to represent each of Canada's natural regions in the national parks system. As of 2005, 25 natural regions (of 39 classified by Parks Canada) are represented by the 41 national parks and national park reserves in the system. Efforts to create new national parks are concentrated on those natural regions that are not yet represented in the system. Similar policy goals exist in each province-territory and on November 25, 1992 the Canadian Parks Ministers Council, Canadian Council of Ministers of the Environment and Wildlife Ministers Council of Canada signed a *Statement of Commitment to Complete Canada's Networks of Protected Areas* (Federal Provincial Parks Council 2000).

The policy implications of projected landscape level vegetation changes from climate change are twofold. First, the policy of completing existing protected area system plans without consideration for the effects of climate change should be reassessed so that limited conservation resources can be better optimized. Second, protected area system planners will be charged with protecting 'a moving target' of ecological representativeness and can only hope to do so with resources to establish additional protected areas in strategic areas.

As striking as ecological change scenarios in the literature are, they may actually present a conservative portrait of the ecosystem impacts that protected area agencies will need to adapt to. None of these studies have explored the implications of climate change scenarios for the latter decades of the twenty-first century or beyond, which ultimately will be the biogeography that protected area agencies must consider. Schmitz *et al.* (2003) contend that climate change may lead to changes in trophic interactions and ecosystem structure that current vegetation models do not contain, which may increase nonlinear and more immediate shifts in ecosystem states. Furthermore, protected areas are already faced with multiple stresses and synergies between existing stresses (e.g., habitat loss, habitat fragmentation, and invasive species) have not been factored into modeling of the potential impacts of climate change. Ecosystems that are under multiple stresses are more apt to behave in unpredictable ways (Hannah *et al.* 2005).

Climate change adaptation in protected areas will occur in two ways. First, protected area managers and Canadian society will have to accept and adjust to the autonomous response of natural systems. Second, protected area managers can use planned adjustments in socio-economic processes, practices and structures to moderate potential risks or to benefit from opportunities associated with climate change (Smit *et al.* 2000). The focus the remainder of this section is the latter.

There are factors that make climate change adaptation more challenging for protected areas professionals than some other natural resource sectors. Unlike other managed resource systems (e.g., water, agriculture, fisheries) there are no past exposures or climate change analogues to learn from at the system planning level. The objectives of protected areas management have very long time horizons (twenty-second century and beyond). Fewer adaptation options exist for protected areas than for lands and waters that are actively and extensively manipulated.

Perhaps as a result of these additional challenges, there have been a limited number of publications that address climate change adaptation options specifically for protected areas. Table 3 provides a portfolio of adaptation options available to conservation professionals and protected area managers. Climate change will challenge protected areas managers and conservation objectives in ways never before. Difficult choices will have to be made regarding which climate change impacts on Canada's protected areas are politically tolerable. As the adaptation portfolio in Table 3 suggests, protected area management may need to become more aggressive and interventionist than in the past. This will need to be communicated clearly to senior levels of government and Canadians.

A major consideration for protected areas policy development is whether adaptation should be a matter of responding to climate change as it manifests, or whether initiatives should be taken in advance to anticipate the potential effects of climate change. The literature (Burton 1996; Smit *et al.* 1996; Smith 1997) suggests that *laissez-faire* approaches to climate change adaptation has several potential drawbacks, including the possibilities that: (i) forced, last-minute, emergency adaptation will be less effective and more costly than anticipatory or precautionary adaptation over the long-term; (ii) climate change may be more rapid or pronounced than current estimates suggest and, consequently, result in increased vulnerability of socio-ecological systems to unexpected events; and, (iii) not adapting now may result in irreversible impacts (e.g., species extinction). Further, some forms of adaptation will require considerable lead-time, especially where major institutional changes or innovations are required (Smit *et al.* 1996). In such cases, institutional changes would need to be devised and implemented in advance in order to offset the effects, or even take advantage of, an abrupt, expected or unexpected climate change event. It is imperative for protected areas to begin to develop climate change adaptation strategies now, considering the length of time required for ecosystems to respond to some management interventions (i.e., changing the wildfire management regime) and planning horizon of their mandate (perpetuity in theory).

Difficult theoretical questions, that have significant policy implications, will need to be confronted over the next two decades. What is considered 'natural vegetation' (or a natural ecosystem)? What is the role of protected areas in an era of climate change and what ecological conditions are protected areas to represent (e.g., pre-European contact, contemporary 'natural region-ecoregion', some projected future state)? An interpretation of existing policy and planning frameworks in Canada suggests that protected area management plans tend to support continued protection of current ecological communities, while the definition of ecological integrity, in contrast, supports protection of the processes that would facilitate ecosystem adaptation to climate change. This ambiguity cannot persist and protected area agencies will need to develop clear climate change policies.

Canadians are likely to place greater demands on their protected area networks and conservation professionals to protect species and ecosystems under stress from climate change. If these agencies are to respond to the demands of Canadians, governments will need to make major new investments in protected area establishment, personnel training, research and monitoring.

Table 2. Selected policy and planning implications of climate change for Canadian protected areas

Protected Areas System Planning	• System planning frameworks (e.g., natural region representation) may not be optimal for the selection of new protected areas • System goals will require interpretation (what to protect – historic-current-future species, processes and not species?) • Because future non-analogue communities are unknown, they are excluded from current steady-state planning frameworks
Park Management Plans	• Established management objectives will no longer be viable in some parks • Park objective statements (e.g., to protect a highly valued species) will force protected areas managers to try to 'hit a moving target' of ecological representativeness
Active Management Plans	• Wildfire management plans (utilize to re-establish or maintain current ecological representation for facilitate adaptation?) • Individual species management plans (commit resources to species re-introduction?, how define invasive species?, exclude southern species from species at risk protection?) • Visitor management plans (how manage for potentially large increases in visitation due to extended and improved warm-tourism season?)

Compiled from: Scott and Suffling 2000, Scott et al. 2002; Suffling and Scott 2002, Scott 2005, Lemieux and Scott 2005, Welch 2005)

Table 3. Climate change adaptation portfolio for protected area agencies

System Planning and Policy	• Expand the protected areas network where possible and enlarge protected areas where appropriate • Improve natural resource planning and management to focus on preserving and restoring ecosystem functionality and processes across regional landscapes • Selection of redundant reserves • Selection of new protected areas on ecotones • Selection of new protected areas in close proximity to existing reserves • Improve connectivity or protected area systems • Continually assess protected areas legislation and regulation in relation to past, anticipated or observed impacts of climate change
Management (including active, adaptive ecosystem management)	• Include adaptation to climate change in the management objectives and strategies of protected areas • Implement adaptive management • Enhance the resiliency of protected areas to allow for the management of ecosystems, their processes and services, in addition to 'valued' species • Minimize external stresses to facilitate autonomous adaptation • Eliminate non-climatic in-situ threats • Create and restore buffer zones around protected areas • Implement ex-situ conservation and translocation strategies if appropriate • Increased management of the landscape matrix for conservation • Mimic natural disturbance regimes where appropriate • Revise protected area objectives to reflect dynamic biogeography

4.5 Outdoor Recreation and Nature-Based Tourism

Outdoor recreation and nature-based tourism are important human-use (social and economic) values that are currently managed for and supported by Canada's forests. Canada's national survey on the Importance of Nature to Canadians found that Canadians took 143 million same day trips and 48 million overnight trips for various outdoor recreation and nature based activities in 1996 (DuWors *et al.* 1999). According to the World Tourism Organization (2004), Canada ranked tenth in terms of international tourism arrivals, and eleventh in terms of international tourism receipts, in 2003. The economic impact of both outdoor recreation and nature-based tourism are significant. International tourism earnings for 2003 in Canada totaled US$10.5 billion. These figures reflect only international tourism and tourists; domestic travel represents a far greater segment. Canadians took approximately 172.2 million domestic travel trips in 2003, with domestic travel spending exceeding CDN$35 billion (Statistics Canada, 2004a, 2004b, Nicholls and Scott in press).

Outdoor recreation and nature-based tourism are inherently vulnerable to climate. Scott and Jones (2005) explain "climate influences tourism and recreation in two main ways:

> Directly — by defining the length (e.g., skiing and golf operating seasons) and quality (i.e., overall comfort and enjoyment of outdoor activities) of tourism and recreation seasons and influencing tourist demand (i.e.natural seasonality);
>
> Indirectly — by impacting the environmental resources(e.g., water levels, snow cover, glacier extent, biodiversity) on which tourism depends.".

Various authors have noted that outdoor recreation is sensitive to climate and therefore that climate change may influence levels and types of outdoor recreation activity in Canada (for example see Wall, 1998). Some empirical analysis of the welfare impacts of climate change on outdoor recreation in the US has been published (Mendelsohn and Markowski, 1999; Loomis and Crespi, 1999). However, empirical analysis of the potential implications of climate change on outdoor recreation in Canada at a national scale has not been presented to date. According to Nicholls and Scott (in press) despite the obvious relationship between outdoor recreation (OR) participation, and weather/climatic conditions, study of the interactions between OR, weather, and climate (change) remains relatively limited, especially in the leisure and recreation literatures. Nicholls and Scott (in press) conducted a review of the existing literature that addresses the likely impacts of climate change on the various outdoor recreation and nature-based tourism activities that are supported by natural systems for the United States and Canada. The reader is directed to the Nicholls and Scott (in press) paper for a more detailed synthesis of knowledge to date and identification of knowledge gaps regarding the expected impacts of climate change on outdoor recreation and nature-based tourism in North America. Below is an overview of the major findings from the studies that have been conducted thus far, and where available supplemented by discussions from the Nicholls and Scott (in press) paper. The activities included in this analysis are not specific to forested ecosystems, furthermore the activities discussed do not represent an inclusive list of all outdoor recreation and nature-based tourism activities that take place in forests.

Camping: Nicholls and Scott identified three studies that looked at the impact of climate change on camping activity. The Wall *et al.* study (1986) concluded that temperature change in terms of extension of the camping season into the shoulder seasons may result in an increase in camping related revenues. Two studies Loomis and Crespi (1999), and Mendelsohn and Markowski (1999) looked at changes in both temperature and precipitation. These studies concluded that increases in temperature (from 1.5ºC to 5ºC) and precipitation (from 0% to 15%) may have a negative impact on the numbers of people participating in, and the welfare value generated by, camping. Nicholls and Scott have identified some key limitations to the last two studies citing the out of date dataset upon which they are based, as well as their failure to consider variations in local and regional climate, activity patterns or climate scenarios.

Hunting: Nicholls and Scott (in press) identified two studies that have empirically examined climate change impacts on hunting in North America. Mendelsohn and Markowski (1999) concluded that climatically induced increases in temperature from 1.5ºC to 5ºC and in precipitation from 0% to 15%, would be unlikely to have any significant impact on the welfare value generated by hunting activity in the US through the year 2060. Again Nicholls and Scott caution that the study was conducted at a national level only. Furthermore, the authors argue "considerable geographic shifts in hunting activity may occur as a result of changes in the geographic distribution and relative abundance of species" (p. 13). Loomis and Crespi (1999) looked at potential climate change impacts on waterfowl hunting in the eastern U.S. and concluded that the number of hunting days would not change. However Nicholls and Scott argue that the study failed to include other important waterfowl habitats in North America that are considered highly vulnerable to future climate change.

Wildlife Viewing and Scenery: Climate affects ecological processes and therefore the types of vegetation and wildlife that will occur in a particular area. The wildlife and vegetative characteristics of an area may influence the quality of recreation sites. A large percentage of wildlife and scenery viewing activity takes place in the national and provincial parks systems within Canada. Because visitation statistics are collected by many of the parks this makes the analysis of climate change impacts on visitor numbers and participation levels a suitable and attractive test subject. As a result a number of studies have been done that look at potential impacts of climate change on park visitation. Richardson and Loomis (2005), Scott and Jones (2005) targeted the five national parks in the Rockies and looked at the current influence of climate on park visitation, as well as projected changes under a number of climate change scenarios. Due to expected changes in seasonality (i.e. longer and improved season) park visitation is expected to increase for all five parks (for warm-weather activities), even more so when coupled with expected increases in population. This could represent significant economic benefits. However Nicholls and Scott (in press) caution that increased visitation will place even greater pressure on these sensitive environments and may further degrade them without intensive visitor management.

Nicholls and Scott (in press) identified two studies that examined the impact of environmental changes induced by alterations in climate on park visitation. Richardson and Loomis (2005), Scott and Konopec (2005) conducted a survey of park visitors to Canada's western mountain parks (Rocky Mountain Park [former] and Glacier-Waterton Lakes International Peace Park [latter]) and asked them how their visitation patterns (number and length of stays) might change under a series of three hypothetical environmental change scenarios (2020s, 2050s, 2080s) that saw changes in variables such as climate, access to scenic roads and trails, crowding, wildlife populations, and vegetation compositions in the park. The majority of respondents in both surveys indicated that they would not change their visitation patterns under all three scenarios. Although under the 2080 scenario (extreme heat) a larger percentage of respondents indicated that they no longer visit the park, and those who would visit would do so less often. Nicholls and Scott note that "although changes in seasonality alone may increase visitation, the environmental changes resulting from alterations in climate may reduce the attractiveness of the mountain landscape to the extent that visitation may actually see an overall decline"(np. in press).

Englin *et al.* (1996), examined the welfare effects of forest fires on canoeists and found that forest fires would result in welfare losses. This is an example of an indirect effect on recreation benefits attributable to a change in vegetation and area aesthetics.

Winter Activities: A large number of winter activities take place in forested environments and are considered vulnerable to the effects of climate change. Skiing and snowmobiling are two such activities where the quality of the experience and participation numbers are highly dependent upon appropriate weather and climate conditions. Nicholls and Scott (in press) identify a number of earlier studies (McBoyle, Wall, Harrison and Quinlan 1986, Lamothe and Periard Consultants 1988, Lipski and McBoyle 1991) that look at the potential impacts of climate change on the North American ski industry.

All studies indicated that under a $2xCO_2$ scenario there would be a negative impact on the ski industry due to a reduction in season and number of skiable days. However Nicholls and Scott (in press) note that there have been major methodological improvements since those studies were conducted including increased availability and quality of GCMs and emissions scenarios, downscaling techniques, and snowmaking as an adaptive strategy. More recently Scott, McBoyle and Mills (2003, in press) integrated snowmaking into an analysis of southern Ontario's ski industry under climate change scenarios. Snowmaking as an adaptation action was shown to alleviate some of the negative impacts of climate change (reduction in the length of the ski season) on the ski industry. Similar results have been show in Scott *et al*. (in press) study that analyzed the vulnerability of six ski areas Ontario, Quebec, Vermon and Michigan.

Winter trail-based activities such as snowmobiling, cross-country skiing, and snowshoeing are highly vulnerable to climate change due to their almost exclusive reliance on adequate levels of natural snowfall. Nicholls and Scott (in press) identified the Scott *et al.* (2002) study that estimated the length of the snowmobile season under two climate change scenarios for the Lakelands region of Ontario. The study concluded that the average length of the snowmobile season in that region is expected to decline progressively under each scenario.

Adaptation Strategies for the Outdoor Recreation and Nature-Based Tourism Sector

Nicholls and Scott (in press) provide a general overview of adaptation strategies for the outdoor recreation and nature-based tourism market on both the supply and demand side. Below are the highlights from that discussion:

Substitution: Replacing one recreation activity for another may be an adaptation response under climate conditions that reduce the quality or suitability of a particular activity. The authors note that the potential for climate change to impact both weather conditions and the natural resource base, substitution by the consumer is likely to occur at least three levels, relating to the timing of the recreation experience, the setting for the experience, and the activity itself.

Diversification: A key adaptation strategy for the supplier of outdoor recreation and nature-based tourism is to diversify the range of activities offered to consumers. By diversify the activities they offer they will reduce their relative vulnerability to climate change. Current examples of adaptation within the sector include downhill ski operations offering activities in their shoulder seasons, such as downhill mountain biking.

Technological Advances: Technological advances through improvements in existing technologies and development of new ones will likely play a role in the industries response to climate change. However the author's note that these solutions tend to be expensive and may not be financially feasible for the small and medium size businesses that tend to dominate the market.

4.6 Adaptation in the Forest Sector

Material for this section is extracted from Spittlehouse, D. 2005. Integrating climate change adaptation into forest management. The Forestry Chronicle. 81(5): 691-695. – Permission to reprint this material was obtained from the Forestry Chronicle.

Adaptation to climate change refers to adjustments in ecological, social, and economic systems in response to the effects of changes in climate (Smit and Pilifosova 2002, Davidson *et al.* 2003). Adaptive actions reduce the risks (decrease vulnerability) by preparing for adverse effects and capitalizing on the benefits. Although forest ecosystems will adapt autonomously, their importance to society means that we will want to influence the direction and timing of this adaptation at some locations. There are numerous challenges to adaptation, not the least of which is the uncertainty in the magnitude and timing of future climate change. This is compounded by the uncertainty in the future markets for our forest resources and global competition (Sohngen and Sedjo 2005). The development of adaptation measures for some time in the future, under an uncertain climate, in an unknown socio-economic context is bound to be highly speculative (Burton *et al.* 2002). Some groups may view responding as a greater risk than doing nothing or that impacts can only be dealt with when they happen. There is a lack of awareness in the forestry community of the risks of climate change (Williamson *et al.* 2005). Consequently, we may have difficulty finding the desire and resources for adaptation.

Another major challenge is our limited knowledge of our vulnerability to climate change. Vulnerability is the degree to which a system (organism, ecosystem, company, or community) is susceptible to or unable to cope with climate change. Different systems are vulnerable to different aspects of change and what may be detrimental to one system could be beneficial to another. Consequently, an important component of adaptation will be balancing different values. The vulnerability of forests and their users depends on a range of factors (Stewart *et al.* 1999, Dale *et al.* 2001, Davidson *et al.* 2003, Gray 2005). Internal factors include sensitivity to climate at an individual and population level, fecundity, life span, habitat requirements, distribution, entrenched societal values, existing forest policy, and the adaptive capacity of the system. External factors include the magnitude and rate of climate change, frequency, timing and size of disturbances (e.g., fire, insects, disease, and harvest), competition by systems better adapted to the new climate and barriers to movement.

The size of the forested land base in most of Canada's provinces and territories means that much of the forest will have to adjust without human intervention. For example, about 62 Mha of the 95 Mha of British Columbia is forested. Of the forested area, there are 38 Mha in the non-timber harvest land base (includes parks, wilderness areas and areas with operational constraints) where forest management is mainly fire protection and conservation. The remaining 24 Mha, the timber harvest land base, is harvested at about 0.2 Mha per year. Consequently, we will be able to assist the adaptation of the forest on only a small part of the land base. Adaptation will focus on the major commercial tree species and perhaps a few animal species, while the majority of forest plants and animals will have to adapt as best they can. Any large-scale disturbances caused by climate change would be particularly difficult to address.

There are institutional and policy barriers to responding to climate change. For example, seed planning zones, reforestation standards and hydrologic and wildlife management guidelines are designed for the current climate regime. There are no requirements for adaptation strategies in forest management plans, nor are there guidelines and sufficient experienced personnel to aid such activities. There are many stakeholders whose different needs are supplied by forests and therefore have different vulnerabilities to climate change. Increased winter precipitation and earlier snowmelt would affect water management by changing the timing and size of peak flows, and increasing the risk of sediment transport to streams, reducing water quality and degrading fish habitat (Mote *et al.* 2003).

How will existing forests respond to the changing climate and what is the risk to the future timber supply? Most of the wood that will be harvested in Canada over the next 50 to 100 years will come from trees that are already growing or will be planted in the next decade with minimal climate change adaptation considerations. In some areas there will be an increase in forest productivity while in other areas there will be a decrease (Spittlehouse 2003, Hogg and Bernier, 2005, Johnston and Williamson 2005). What will this mean for rotation ages, wood quality, wood volume, size of logs and determining the annual allowable cut? Access to timber and harvest scheduling will change because warming winters will limit winter logging and warmer and drier summers will reduce logging due to increased fire risk. Will disturbance by fire and insects become more prevalent leading to a greater amount of the harvest being salvaged wood (Volney and Hirsch 2005)? The magnitude of the impact and the management response to the mountain pine beetle epidemic in British Columbia is an example of what the future might hold. How will these changes affect industry viability particularly as there will be an increase in global wood supply (Sohngen and Sedjo 2005)?

Reforestation is based on the selection of species and provenances that are genetically adapted to the site (climate and soil). A changing climate means that the appropriate provenances or species for a site would change (Spittlehouse and Stewart 2003). Even if we had reasonable knowledge of the climate limits of species and provenances, the unknown spatial and temporal distribution of the future climate severely hampers our ability to respond. It would not be prudent to change the guidelines at present because the climate may not have changed sufficiently to allow acceptable regeneration of the planting stock. Furthermore, because the climate will likely continue to change over the life of the stand, which climate regime should the planting stock be selected to meet?

Although we do not have a clear view of the future climate and forest, or of the vulnerability of species and society, it is critical to begin the process of developing adaptation strategies now. Adaptation requires a planned response well in advance of the impacts of climate change. Adaptation must address biophysical and socio-economic impacts and will require changes in forest policy to allow implementation. Risk analysis tools can be used in planning adaptive actions (Davidson *et al.* 2003, Ohlson *et al.* 2005). Dale *et al.* (2001) and Spittlehouse and Stewart (2003) indicate that adaptation requires that the forest community:

- Increase awareness and education within the community about adaptation to climate change.
- Establish objectives for the future forest under climate change. The debate will be about values, expectations and how society wishes to use its forest resources.
- Determine the vulnerability (sensitivity, adaptive capacity) of forest ecosystems, forest communities, and society.
- Develop present and future cost-effective adaptive actions. Current activities include those that facilitate future responses to reduce vulnerability. Adaptation options must include the ability to incorporate new knowledge about the future climate and forest vulnerability as they are developed.
- Monitor to determine the state of the forest and identify when critical thresholds are reached.
- Manage the forest to reduce vulnerability and speed recovery after disturbance.

Numerous adaptive actions have been proposed for forest management (Spittlehouse and Stewart (2003). They can be grouped into three categories: societal adaptation (e.g., forest policy to encourage adaptation, revision of conservation objectives, changes in expectations), adaptation of the forest (e.g., species selection, tree breeding, stand management, fire smart landscapes), and adaptation to the forest (e.g., change rotation age, use more salvage wood, modify wood processing technology).

Societal adaptation will be a major component of any forest management adaptation strategy. We will have to revise our demands on forest resources. Changes in forest productivity may be positive in some areas and activities such as stand management and forest protection to address climate change impacts will provide benefits to communities (Johnson and Williams 2005, Volney and Hirsch 2005). Changes in wood quality and timber supply will occur globally and market impacts will not be uniformly distributed (Sohngen and Sedjo 2005). Non-timber forest products (NTFPs) such as mushrooms, berries and botanicals are an important part of the rural economy (Forest Practices Board 2004). Availability of some NTFPs may benefit from increase in disturbances such as fire whilst others will be reduced through changes in species distribution and growing conditions. There will also be changes in recreation opportunities. Warmer winters will shorten the winter recreational season while summer recreational season will increase, though increased fire risk may limit this increase.

Adapting the forest to the changing climate will be an appropriate action for reforestation after disturbances such as harvest or fire. The first steps involve determining the limits of transferability of species and provenances by defining their climatic envelopes and developing climate-based seed planning zones (Refeldt *et al.* 1999, Parker *et al.* 2000, Rainville and Beaulieu 2005, Wang *et al.* 2006). Provenance trials show how different species and provenances perform under a range of conditions. We could test Ledig and Kitzmiller (1992) suggestion of mixing a range of provenances at a site. Should we choose species or provenances that can grow adequately over a wide climatic range rather than a provenance that grows better but over a narrower climatic range? There will likely be an increase in reforestation with hardwood species that can grow faster than conifers, reducing the rotation age and aiding adjustment to a continually changing climate. Changes in temperature and precipitation regimes will mean that we will have to revise where and how planting stock and site preparation techniques are used. Species have a wide range of occurrence and it would be prudent to initially target areas near the edge of a species range where the earliest impacts are likely to occur (Hogg and Bernier 2005). In some cases we may have to return to existing second growth stands where the current regeneration is unacceptable as a source for the future forest and replant with other species or genotypes (Woods *et al.* 2005). Reforestation and stand management will allow for the development of FireSmart landscapes that reduce the susceptibility to large fires (Volney and Hirsch 2005). Policies such as seed planning zones and other reforestation standards and guidelines designed for the current climate regime will need to be revised to account for climate change.

Options for adapting to changes in the Canadian timber supply for the next 50 to 100 years are different from those required for reforesting harvested land. They depend on how the existing forest responds to climate change. Options for adapting the forest include disease and insect control, stand management such as controlling undesirable species, partial cutting, sanitation thinning, fire protection and altering forest structure to reduce the extent of disturbance (Parker *et al.* 2000, Dale *et al.* 2001, Volney and Hirsch 2005). We need to develop growth and yield models that explicitly consider climate variability in predicting future yields (Hogg and Bernier 2005, Johnston and Williamson 2005). A shortening of the winter logging period through warming will require a revision of harvesting activities.

The forest industry will have to adapt pulp processing and manufactured wood products technology to changes in wood quality and quantity and increase diversity in processing technology and products. There will be pressure to make greater use of residues and salvage wood for wood products, bio-energy and other bio-products (Hansen and Edwards 2002, McKendry 2002, Lazar 2005). The forest carbon balance will have to be considered in forest management decisions and forests will be used to sequester carbon to offset anthropogenic emissions of carbon dioxide (Pollard 1991, Spittlehouse, 2002). Including adaptation in forest planning is a risk management strategy and may aid in forest certification.

How and when does the forest community begin the process of adapting to climate change? A survey of forestry professionals (Williamson *et al.* 2005) indicated they recognize the need to be proactive on this issue. Asking the questions about how to adapt will help determine:

- Research and educational needs.
- Vulnerability of forest resources.
- Policies to facilitate implementation of adaptation in forest management.
- Monitoring systems to identify problems induced by climate change.

5 FOREST-BASED COMMUNITIES

Levels of concern about threats to forest based communities from hazards that are at least partially climate related are increasing (Davidson *et al.*, 2003). Some examples include wildfire, drought, insect outbreaks, and extreme storm events. These concerns have also led to increased awareness of possible future impacts of climate change on resource dependent communities (IPCC. 2001). For example, climate change may result in increases in severity of wildfire risk, drought and other perturbations and changes in land use. Climate change has implications for the health, productivity, vitality and aesthetic quality of renewable resources surrounding communities – both positive and negative (Natural Resources Canada. 2004). These biological and ecological impacts have potential implications for economic livelihoods; economic, social and cultural values; and social well-being in northern communities.

Community adaptation to climate change implies both reduction of negative impacts and enhancement of benefits. Relevant information on vulnerability at a community level is a key requirement for successful adaptation (IPCC 2001, Kasperson and Kasperson 2001, Smit and Pilifosova 2002). However, community vulnerability to climate change is not well understood. This is due to a combination of factors. First, past efforts to assess vulnerability have tended to ignore multiple social and economic factors that can either exacerbate or alleviate vulnerability. Second, previous research in this area has tended to focus on higher level regional and/or country level vulnerabilities. Third, there exists a general lack of understanding of how individuals *perceive* climate change as a risk issue and/or of how particular social contexts influence perceptions. Perceptions of climate risk will have an important bearing on willingness to adapt. Therefore, developing a better understanding of how features of social systems and characteristics of particular types of risks influence risk perceptions and behavior is an important component of vulnerability assessment. Fourth, there is a lack of understanding of the role of social capital, human capital and community culture in contributing to the inherent resiliency of communities, and their capacity to adapt, and in understanding why communities may differ in terms of their views and responses to climate change. Finally, we lack the kinds of comprehensive, scientifically based, multidisciplinary tools needed for systematic integrated assessments of vulnerability at scales relevant at the community level. Studies are required that address these limitations by (1) developing an interdisciplinary vulnerability approach that links climate scenarios with biophysical models with social and economic research methods and models, (2) focusing on impacts and capacity at community relevant scales, (3) including a survey based method for assessing risk perceptions, (4) conducting surveys to assess social capital and collecting data on other important determinants of adaptive capacity of the community and its local economy, and (5) investigating this issue over a range of communities with different backgrounds and connections to the surrounding landscape.

A common approach for understanding community level social systems and their linkages to surrounding ecosystems is through case study research. The case study approach is well suited to situations where multiple data sources are involved and a “holistic, in-depth investigation is needed” (Tellis 1997). The case studies should be participatory and interdisciplinary in nature. By participatory we mean that a significant component of the vulnerability assessments will involve dialogue with local stakeholders and local leaders to determine values at risk, identify sensitivity, and to obtain information on perceptions of risk and social capital. Information will be exchanged on an ongoing basis with community members and technical results will be presented to the community for discussion, validation, and explanation.

Vulnerability of a community to climate and climate change is considered to be a qualitative function of its *exposure* and *sensitivity* combined with its *adaptive capacity* (i.e., to respond to and overcome negative impacts) (IPCC 2001). Because it is qualitative, however, it is difficult to model vulnerability explicitly. Rather vulnerability assessments generally require determining exposure, sensitivity and adaptive capacity with some subjective weighting applied to provide a general descriptive assessment (e.g. see IPCC 2001). Following this general approach, a combination of technical analyses, consultations within the community, and surveys to determine the extent to which communities are sensitive (and/or exposed) to climate and climate change and the features, characteristics, processes, attitudes, and perceptions that define these communities in terms of their capacity to adapt is called for.

The first step is to obtain "Local Knowledge" about climate impacts. Local knowledge is information obtained from community members in the areas of both exposure (risks and potential impacts) and adaptive capacity. The capture of local knowledge is pursued through instruments such (1) risk perception surveys, (2) social capital surveys, and (3) interviews with community leaders.

Obtaining local knowledge and perceptions of climate change is complementary to biophysical and socioeconomic modeling and analysis. Renewable resource based communities are exposed to climate change because of their connections to the surrounding land base, hence to understand vulnerability at the community level, it is essential to examine how climate change may affect the surrounding area and then communicate these potential impacts back to the community.

The following provides an overview of methods for various components that might be considered as part of a community vulnerability assessment.

5.1 Risk Perceptions

In assessing vulnerability at the community level, a number of authors have identified risk perception as a critical factor and call for a vulnerability assessment framework that incorporates risk perception (Davidson *et al.* 2003; Stedman *et al.* 2004). For the most part, researchers operationalize risk perception at the individual level, reasoning that individuals who perceive a presence of risk or vulnerability are more inclined to act in ways that will mitigate risk. Within this risk perception literature, there are two clear ways in which risk perception contributes to a vulnerability assessment. Researchers attempt to understand:

- Public perception of physical risks to supplement technical risk assessments and gain a more holistic understanding of the 'real risks' associated with GCC.
- Risk awareness as a key component of adaptive capacity in terms of linking knowledge and understanding to actions oriented around risk mitigation.

5.2 Social Capital

Climate change may stress communities that are already being impacted by a host of non-climate related pressures. These pressures are, in some cases, leading to rapid restructuring of rural areas. The ability of communities to deal with stress can vary considerably. Some social scientists have suggested a social indicator approach to evaluate community capacity and well-being (e.g. see Kusel 1996). Although, indicators may have a role relative to taking account of concepts such as human capital, and other community assets (e.g. access to natural resources), social indicators seem to be insufficient in terms of understanding the relationship between external stress and social consequences (Matthews 2003). Rather, it seems that an understanding of features such as (1) the breadth and depth of social networks and interrelationships, and (2) levels of interpersonal trust are important features relative to the success of individuals and communities in coping with and/or adapting to stress. It is important to note that (1) networks and trust are clearly not mutually excusive, and (2) the creation of networks and the generation of trust are the consequence of processes that occur over time and that require social investment. Interpersonal networks and trust are collectively referred to as social capital. In addition, other types of social psychological variables may also be closely related to social capital formation. One example is attachment to place. Matthews (2003) notes "communities are stronger when their residents identify with them and express commitment to them." Social capital may be a vital resource for communities in addressing climate change because social capital provides "resources and supports" to individuals, groups within communities and may be an important collective asset for communities overall (Matthews 2005). Thus, social capital is clearly an important consideration for understanding community vulnerability.

5.3 Ecological Modeling

A defining feature of forest-based communities is that they are often dependent upon local forests as providers of goods (e.g., wood) or services (e.g., recreation and tourism). Hence, there is a need to assess the potential impacts of climate change on forest productivity (as a driver of timber supply) and on species composition and other structural aspects (as drivers of the forest's capacity to support non-timber values). Process-based forest ecosystem models are a primary means of assessing forest responses to plausible climatic change.

5.4 Fire Risk Analysis

Burn probabilities will vary across the landscape that surrounds a community. Due to complex interactions between variables that influence fire spread, some areas will be far more likely to burn than others. Calculated for points on the landscape, burn probability values provide a relative measure that can be evaluate within and between study areas (i.e., landscapes surrounding communities) and between current and future conditions for a given study area.

The Canadian Forest Service is developing models for assessing wildfire burn probability at landscape levels (e.g. BURN-P3 – Parisien *et al*. 2004). Burn probability (BP) mapping can be used to identify areas around communities that are particularly susceptible to fire. The BURN-P3 model combines landscape simulation modeling with a sophisticated fire growth sub-model. The model takes spatial coverage of landscape characteristics (e.g. forest vegetation and topography), and simulates the growth of fires across this landscape using inputs that describe the fire size distribution, fire weather conditions, and ignition patterns. BURN-P3 cannot spread fires into a community, bit it can provide a relative measure of burn probability in interface areas immediately adjacent to the community.

5.5 Landscape Values

One of the key impacts of climate change in terms of communities will be in terms of how climate change affects landscape features and attributes in the area surrounding the community. The typology of landscape values includes human based values such as (1) economic, (2) scientific, (3) recreation, (4) aesthetic, (5) wildlife existence, (6) natural history, etc.(see Brown 2005).

5.6 General Equilibrium Models

General equilibrium (GE) models treat the economy of a region as a single system of interconnected parts and are standard tools for assessing the economic impacts of policy changes, natural disturbance, and other external changes (Berck and Hoffman 2002; Patriquin *et al.* 2003). Quantifying the level of economic activity in a GE database allows the examination of baseline economic conditions (i.e., prior to a natural disturbance or external change) and the construction of a GE model - predicated on the baseline database - for the purpose of simulating the state of the economy post disturbance or shock (Patriquin *et al.* 2005). The outputs of biophysical models of climate change can be linked to regional GE models for the purpose of examining the economic impacts of the alternative scenarios. GE models capture the economic impact on the direct sector, the other sectors of the economy, and household and government institutions. For example, in a timber dependent community, climate change may lead to changes in forest productivity and fire risk that will in turn have consequences on the amount of timber available for harvest and processing in the forestry sector. Under this example, the change in timber supply related to climate change would have implications for the forestry sector (through decreased timber inputs), the other sectors of the economy (through direct transactions with the forest sector and the indirect competition for land, labour and capital), households (through employment and income), and the government (through taxes and royalties). Depending on data availability, it is also possible to capture distributional impacts on households based on low, medium and high household income categories.

5.7 Indicators of Community Capacity

The section on social capital describes the importance of key intrinsic features of communities such as social networks, place attachment, and trust in understanding community resiliency to stress and its capacity to adapt to stress. Social scientists have, however, looked at other types of resources that contribute to community capacities and they have attempted to structure these measures into frameworks of indicators for understanding the sustainability of forest-based communities. These various frameworks are comprised of lists of core indicators that pertain to capacity and capacity outcomes. McKendrick and Parkins (2004) provide a synthesis of the frameworks and their indicators. Some measures pertain to human capital (e.g. education, training, demographic information, health, access to health care). Other measures pertain to current physical plant and infrastructures (e.g. transportation infrastructure, schools, health care facilities, community service infrastructure). Some indicators provide measures of current economic prosperity and the adaptive capacity of the local economy (e.g. income, employment, unemployment rates, investment opportunity, economic diversity).

6 CONCLUSIONS AND RECOMMENDATIONS

The goal of this report is to provide a synthesis of the current state of knowledge, science and assessment capacity as it pertains to understanding climate change impacts on the Canadian forest sector. An additional goal is to identify and discuss considerations that underscore the need for adaptation and factors influencing our capacity to adapt to long-term climate change.

Climate change is underway and the effects will be felt in Canada to a greater extent than in other locations. Forest ecosystems will be affected (in some cases dramatically), by climate change. Changes in growth rates, disturbance regimes and species distributions will all have effects on the forest sector. However, these are currently difficult to predict. Moreover, the effects will vary depending on a) geographic location, b) time scale, and c) the adaptive capacity of the social system that is being impacted. A useful and generally accepted analytical framework for integrated assessment of climate change is the vulnerability approach. The vulnerability approach looks at the exposures of environmental and social systems to climate change and the adaptive capacities of these systems. Large scale integrated assessment approaches have been used to assess forest sector vulnerabilities in Europe and the United States. The vulnerability approach has yet to be implemented in Canada. Given Canada's position as one of the world's major forest nations, this is an area that requires more attention in Canada.

Climate change effects on forests and social systems in Canada will manifest in a number of different ways. Forest disturbance events are expected to increase in frequency and severity. Forest fires are likely to increase in western Canada and the northern part of eastern Canada, but may decrease in the southern (i.e. moister) portions of eastern Canada. Outbreaks by resident insect species will increase, and invasion by exotic species will also occur. For example, forest managers are concerned about the possibility that the mountain pine beetle will spread into jack pine forests in the boreal forest and spread eastward. Increased frequency and intensity of drought events are a significant concern in the aspen parkland forest zone of western Canada. In the maritime region, increased forest damage due to more intense storms will occur. In eastern Canada, increased frequency of ice storms is expected.

Productivity is likely to increase on sites where other resources, especially water and nutrients, are not limiting. Drought will likely play a large role in re-structuring forest ecosystems at the southern boundary of the boreal forest, especially in the prairie provinces and NW Ontario.

Species migration will generally be northward, but modified by availability of suitable soils, competition with other species, and barriers to dispersal. Mixed species stands will not migrate as a unit, with constituent species shifting individualistically.

The biophysical impacts identified above will translate into impacts on society. Forests are a major economic resource in Canada. Climate change will affect timber supply and forest management. The impacts will vary at different locations and over various time periods, however, climate change does have implications for harvesting choices, reforestation choices, and for land use choices. A better understanding of the vulnerability of forest management systems at various locations is required in order to be more proactive in including climate change considerations into forest management planning.

Forests are also highly valued for a range of environmental values including biodiversity, wildlife and pristine wilderness. One policy approach for protecting these types of values is by setting aside land in parks and protected areas. The primary goal of our system of protected areas in Canada is to ensure that representative ranges of unique ecosystems are protected from development. However, environmental features that are currently being protected through parks and protected areas will likely change dramatically under climate change. Consequently the values associated with these features may be "lost" with protected areas policies that are based on fixed boundaries. As outlined in section 3.4, Canadian society faces many difficult challenges and some fundamental philosophical issues with respect to what climate change means in terms of environmental values and what kinds of policy measures need to be adopted in order to protect species and ecosystems that will be under increasing pressure from a changing climate.

Finally, climate change may have implications for human systems that are particularly closely tied to forest environments that are susceptible to climate change. Forest based communities for example, have strong social, economic and cultural associations with surrounding forests and changes in these forests precipitated by climate change has the potential to impact the well-being of residents of these communities. Human communities with strong ties to forests are distributed across Canada – east to west and north to south. These communities are diverse. They vary with respect to the types of associations they have with forests, the degree to which they are already under stress as a result of social change (e.g. urbanization, globalization, etc), and their resilience and fundamental adaptive capacities.

6.1 5 Key Recommendations

The synthesis provided in this document points to five key areas for consideration by the Canadian forest sector in terms of positioning ourselves to better prepare for climate change.

Enhance our capacity to undertake integrated assessments of system vulnerabilities at various scales

There have been a large number of research projects funded by the federal government through the Climate Change Action Fund and related programs. While the scientific quality of individual projects is high, the cumulative value of this research is reduced because of the lack of integration. Integrated Assessments allow the integration of biophysical, social and economic impacts and adaptation options, providing a high-level view of vulnerabilities across society or a sector of the economy (Wilbanks 2004). Recent experience in Europe has shown that integrated assessment is the only approach that provides both high quality scientific information on impacts and policy-relevant data for decision-makers. Examples include the pan-European ATEAM project (Schroter *et al*. 2005), a UK Regional Assessment (Holman *et al*. 2005a,b) and the European forestry sector Silva-Strat project (Kellomäki and Leinonen 2005). In the US, McNulty *et al.* (2000) used an integrated system of forest productivity, forest inventory and economic models to explore climate change impacts to timber supply in the southeast region. They found that productivity, and hence levels of harvest, increased under several climate change scenarios. This had several effects, including a shift from pulpwood to saw timber harvest due to higher productivity and shorter rotations, i.e. more valuable saw timber could be grown in what was previously a pulpwood rotation. The higher levels of harvest tended to reduce the price of forest products, resulting in less income for the industry but better prices for the consumers. The integrated nature of this analysis allowed the economic and ecological impacts of climate change to be brought together in a holistic way. This approach should become the standard way of carrying out vulnerability assessments across or within sectors of the Canadian economy.

One of the most important conclusions reached by these groups was that the choice of future social-economic scenarios is often more important to determining adaptation options than are choices of future climate scenarios. For example, Holman *et al.* (2005b) found that agricultural commodity prices among EU trading partners was more important in determining agricultural vulnerability under climate change than was the choice of climate scenario. Schroter *et al.* (2005) developed region-specific socio-economic scenarios by starting with the global SRES scenarios (Nakicenovic and Swart 2000) and "downscaling" them to the study region. This was done by translating the global patterns of technology development, energy use and fossil fuel emissions to regional equivalents. These were then used in the impacts modeling. We believe it is of critical importance that similar region-specific scenarios of future social and economic conditions be developed for Canada.

Science based integrated assessments of climate change vulnerabilities are required at multiple scales and for various types of values. For example, we require an understanding of system vulnerabilities at national, regional, and local scales. We require methods and approaches that consider vulnerabilities of different types of human systems (i.e. forest management systems, protected areas, forest based communities) to climate change.

Increasing resources for basic climate change impacts and adaptation science

While our ability to model climate change impacts is increasing rapidly, monitoring ecosystems to detect actual climate change impacts and basic science to better understand the relationships that are incorporated into models is essential. Unfortunately, the ability to carry out monitoring at the national level is declining. Examples include the dismantling of the CFS Forest Insect and Disease Survey and the rapid decline in the number of active weather stations maintained by the Meteorological Service of Canada. In order to detect the early impacts of climate change, ecosystem-monitoring programs need to be established and maintained. In addition, species- and ecosystem-specific data are required to parameterize and validate ecosystem models, and these data are often only available from field data collection. Programs such as the Climate Impacts on the Productivity and Health of Aspen monitoring network in western Canada (http://nofc.cfs.nrcan.gc.ca/cipha/en/index_e.html) and the national Fluxnet network are essential for monitoring the early effects on climate change and for validating ecosystem impacts models.

Review forest policies, forest planning, forest management approaches and institutions to assess our ability to achieve social objectives under climate change

The Canadian forest sector has been hesitant to embrace the need for incorporating climate change into policy and planning. This is not unreasonable, given the high levels of uncertainty that are associated with future climate change impacts. Nevertheless, forest companies are already beginning to experience some impacts that may be related to climate change (e.g. a shorter winter harvest season and the expansion of mountain pine beetle range). Moreover, the long growth cycles of trees put forest management in a unique position relative to the need to include climate change considerations into current planning and decision-making. Thus, climate change is not something that should be deferred in the forest sector. It is critical that forest managers gain greater awareness and recognition of climate change as a real issue. The consequences of failing to act could be significant economic costs to present and future stakeholders.

One way to initiate a more systematic discussion of the longer term implications of climate change for forest management is to begin a dialogue about whether sustainable forest management objectives as defined in the Canadian Council of Forest Ministers Criteria and Indicator Framework are achievable under climate change and/or if modifications are required with respect to forestry goals and approaches.

Over and above the general requirement to include climate change into sustainable forest management objectives, there are a number of specific areas that require attention. First, there is a need to have a better understanding of the implications of climate change on growth and yield. Second, there is a need for incorporating climate change into long term timber supply analysis and forest management planning. Third, we need to have a better understanding of what climate change means for reforestation choices. Finally, we need to take account of the implications that climate change has for disturbances in order to better anticipate the implications for protection program requirements and also to possibly begin looking at whether it is possible to reduce vulnerability by managing landscape configurations (e.g. fire smart landscapes, insect proofed landscapes).

Develop an enhanced capacity for risk management

Climate change will increase the degree of risk and uncertainty we face with respect to the values of forest variables of interest to forest managers and to forestry stakeholders. A change in risk may have implications for forest values and for choices we make about how long we are prepared to allow assets to be exposed to higher risks. Moreover, an increase in risk may have implications for the extent to which we need to reconsider how we manage the forest. For example, current forest management is largely prescriptive. Prescriptive approach based on historical experience may be satisfactory when conditions are not changing, but when conditions are expected to change in directions that are somewhat unknown, then there is danger in relying too heavily on prescriptive approaches to management.

Increased risk from climate change and risk have the potential for real economic impacts and also the potential for influencing optimal harvest plans. Thus, ignoring climate change and risk may result in incorrect estimations of forestry benefits and sub-optimal planning decisions. Undertaking research to better understand the impacts of climate change and risk in forestry is a start, but given the long growth cycles that are inherent in forest management it may also be opportune to begin thinking about the kinds of changes in forest policies that might be pursued in order to facilitate the identification and implementation of adaptation in the near term. For example, some possible responses to changes in risk exposure include risk prevention, risk reduction, risk spreading (e.g. insurance schemes), portfolio diversification, and adopting more flexible forest policies (e.g., build the capacity for adaptive management into forest policy).

The financial risk literature suggests that, in most cases, undiversified financial portfolios have higher variance than diversified portfolios. Increasing the range of management options available to forest managers may be an important strategy for reducing uncertainty and risk resulting from climate change and other sources.

One practical example of how this might be implemented is in terms of forest practices and reforestation policies. Current policies and practices often involve clear-cutting areas and reforesting harvested stands with the same species that was harvested from the site. This strategy will likely lead to a managed forest made up of a narrow range of species (some of which may be mal-adapted to future growing conditions) growing in even age stands. But the question that needs to be addressed is what are the risks to future returns from this type of undiversified forest compared to a structurally more diversified forest and if a structurally more diversified forest is deemed desirable - what kind of policy adjustments are needed in order to provide the kinds of incentives that will result in this new type of forest. For example, an alternative strategy could be to (a) encourage the use of a broader range of forest management systems (e.g. mixed wood, agro-forestry systems, etc), and (b) encourage the reforestation of areas with a broader mix of species. Such a strategy could lead to a more diverse portfolio of forestry assets and this should reduce the risk associated with future forestry returns. The potential for reduced risk would, of course, need to be compared with whatever implications there might be relative to expected economic benefits of such a restructured forest.

Our ability to deal with the expected uncertainties inherent in climate change and forest management in general, may require some fundamental changes in our approaches to management. Generally, it is recognized that functional diversity, management systems and institutional structures that recognize and account for uncertainty and unpredictability, and social structures that encourage adaptive management are important system features relative to adaptability Some natural resource economists (Castle *et al*. 1996) argue that maintaining the quantity and quality of the stock of natural capital should not be the goal of sustainable development. Rather, the focus of sustainability should be on maintaining or increasing flexibility and adaptive capacity. These concepts did not emerge in response to uncertainties introduced by climate change. However, climate change does increase the level of uncertainty and unpredictability that we face in forest management. Therefore, the arguments for building flexibility and adaptive management into our current thinking regarding resource management and our current policies for resource management are strengthened.

Maintain or improve our capacity for communications and networking

Groups like the Canadian Climate Impacts and Adaptation Network – Forest Sector – have begun the process of raising awareness about climate change and communicating the need for more attention. Dialogue, communication, networking and cooperation will be essential if we are going to effectively address the many challenges facing us under a changing climate. Social scientists are increasingly pointing to the area of social capital as an asset that differentiates social systems that are successful from social systems that are not successful. Social capital is essentially the degree to which elements of a social system are networked and the degree to which constituents of the social system trust each other. Social systems without networks and without trust are effectively dysfunctional and they are often unable to cope with change and stress. Thus groups like CCIARN – Forest play an essential role relative to the general capacity of the forest sector to cope with and adapt to climate change. It is important that once these networks are established that they continue to be maintained and supported.

Appendix A - Definitions of Commonly Used Vulnerability Terms

Source: Climate Change 2001: Impacts, Adaptation and Vulnerability
Intergovernmental Panel on Climate Change
Third Assessment Report

Adaptation: Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation.

Adaptation Assessment: The practice of identifying options to adapt to climate change and evaluating them in terms of criteria such as availability, benefits, costs, effectiveness, efficiency, and feasibility.

Adaptive Capacity: The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Aggregate Impacts: Total impacts summed up across sectors and/or regions. The aggregation of impacts requires knowledge of (or assumptions about) the relative importance of impacts in different sectors and regions. Measures of aggregate impacts include, for example, the total number of people affected, change in net primary productivity, number of systems undergoing change, or total economic costs.

Climate: Climate in a narrow sense is usually defined as the "average weather," or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands of years. The classical period is 3 decades, as defined by the World Meteorological Organization (WMO). These quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.

Climate Change: Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), which defines "climate change" as: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." See also climate variability.

Climate Variability: Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability). See also climate change.

Coping Range: The variation in climatic stimuli that a system can absorb without producing significant impacts.

Exposure: The nature and degree to which a system is exposed to significant climatic variations.

Exposure Unit: An activity, group, region, or resource that is subjected to climatic stimuli.

(Climate) Impact Assessment: The practice of identifying and evaluating the detrimental and beneficial consequences of climate change on natural and human systems.

(Climate) Impacts: Consequences of climate change on natural and human systems. Depending on the consideration of adaptation, one can distinguish between potential impacts and residual impacts.

- Potential Impacts--All impacts that may occur given a projected change in climate, without considering adaptation.
- Residual Impacts--The impacts of climate change that would occur after adaptation.

Integrated Assessment: A method of analysis that combines results and models from the physical, biological, economic, and social sciences, and the interactions between these components, in a consistent framework to evaluate the status and the consequences of environmental change and the policy responses to it.

Land Use: The total of arrangements, activities, and inputs undertaken in a certain land-cover type (a set of human actions). The social and economic purposes for which land is managed (e.g., grazing, timber extraction, conservation).

Market Impacts: Impacts that are linked to market transactions and directly affect gross domestic product (GDP, a country's national accounts)--for example, changes in the supply and price of agricultural goods.

Non-Linearity: A process is called "non-linear" when there is no simple proportional relation between cause and effect.

Non-Market Impacts: Impacts that affect ecosystems or human welfare, but that are not directly linked to market transactions--for example, an increased risk of premature death. See also market impacts.

No Regrets Policy: One that would generate net social benefits whether or not there is anthropogenic climate change.

Resilience: Amount of change a system can undergo without changing state.
Scenario (Generic): A plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a "narrative storyline." See also climate scenario and emissions scenario.

Sensitivity: Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise).

Stakeholders: Person or entity holding grants, concessions, or any other type of value that would be affected by a particular action or policy.

Uncertainty: An expression of the degree to which a value (e.g., the future state of the climate system) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain projections of human behavior. Uncertainty can therefore be represented by quantitative measures (e.g., a range of values calculated by various models) or by qualitative statements (e.g., reflecting the judgment of a team of experts).

Vulnerability: The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.

Appendix B - A directory of Canadian research capacity

Researchers/Experts	Research/Area of Interest
Sally Aitken Professor; Junior NSERC/Industrial Research Chair in Population Genetics; Director, Centre for Forest Gene Conservation University of British Columbia, Dept. Forest Sciences Vancouver, British Columbia Email: sally.aitken@ubc.ca	Gene conservation and adaptation to climate change in forest trees
Mike Apps Research Scientist Canadian Forest Service, Pacific Forestry Centre Victoria, British Columbia E-mail: mapps@nrcan.gc.ca	Boreal Forest Transect Case Study
Brian Barber Research Scientist British Columbia Ministry of Forests Victoria, British Columbia Email: Brian.Barber@gov.bc.ca	Seed transfer policy aspects of climate change
Jean Beaulieu Research Scientist Canadian Forest Service, Laurentian Forestry Centre Ste-Foy, Québec Email: jeanbeau@nrcan.gc.ca	Determine the reaction of white spruce seedlings to high temperatures, frost, and drought conditions under different emissions scenarios
Yves Bergeron Professor UQAT and UQAM rouyn-noranda, Québec Email: yves.Bergeron@uqat.ca	Effects of disturbance regimes on tree growth (dendroclimatology) and forest dynamics, forest management adaptation, fire regimes and climate change in eastern Canada
Pierre Bernier Research Scientist Canadian Forest Service, Laurentian Forestry Centre Ste-Foy, Québec Email: pbernier@nrcan.gc.ca	Climate Change and Ecosystem Processes in Important Forest Ecosystems of Eastern Canada (ECOLEAP)
Francine Bigras Research Scientist Canadian Forest Service, Laurentian Forestry Centre Email: fbigras@nrcan.gc.ca	Tolerance for abiotic stressors (frost, heat, drought) and effect of environmental conditions in a context of climate change. Effect of an increase in CO_2 concentrations on seedling physiology

Researchers/Experts	Research/Area of Interest
Greg Boland Professor University of Guelph, Environmental Biology Guelph, ON Email: gboland@uoguelph.ca	Impact of climate change on plant health and diseases
Moira Campbell Forest Biology Technologist Canadian Forest Service, Atlantic Forestry Centre Email: mocampbe@nrcan.gc.ca	Work concentrates on genetic diversity, adaptation and climate change
Angus Carr Geo-Spatial Timberline Inc. Email: acarr@saskforestcentre.ca	Silviculture and management options to adapt to potential changes in site suitability in the boreal forest fringe
Allan Carroll Research Scientist Canadian Forest Service Pacific Forestry Centre Victoria, B.C. Email: acarroll@nrcan.gc.ca	Impacts of climate change on natural disturbance, especially outbreaks of forest pests
Hans Chen Assistant Professor Lakehead University Thunder Bay, ON Email: han.chen@lakeheadu.ca	Forest successional dynamics; boreal mixedwood productivity and structural diversity; carbon sequestration, ecosystem respiration
Edward Cloutis Director, Centre for Forest Interdisciplinary Research University of Winnipeg Winnipeg, Manitoba Email: e.cloutis@uwinnipeg.ca	Development of socio-economic models of the impact of climate change on forestry-based communities
Steve Colombo Ontario Ministry of Natural Resources Thunder Bay, Ontario Email: steve.Colombo@mnr.gov.on.ca	Impacts of climate change on Ontario forests
Barry Cooke Research Scientist Canadian Forest Service, Northern Forestry Centre Edmonton, AB Email: bcooke@nrcan-rncan.gc.ca	Spatial Dynamics of Insect Populations

Researchers/Experts	Research/Area of Interest
Roger Cox Research Scientist Canadian Forest Service, Atlantic Forestry Centre Fredericton, NB Email: rcox@NRCan.gc.ca	Impact of winter thaws and late spring frosts on yellow birch.
Debra Davidson Associate Professor University of Alberta Edmonton, AB Email: debra.davidson@ualberta.ca	Social sustainability in forest-based Canadian communities: vulnerability and resilience in the face of dynamic change. Adaptability to climate change: An evaluation of the responsiveness and flexibility of policy communities.
Bill De Groot Research Scientist Canadian Forest Service, Northern Forestry Centre Edmonton, AB Email: Bill.degroot@NRCan.gc.ca	Forest fire management adaptation to climate change in the prairie provinces
Peter Duinker Professor Dalhousie University, School for Resource and Environmental Studies Halifax, NS Email: peter.duinker@dal.ca	Incorporation into forest management plans of realistic interactions between climate and future forest conditions
Pierre DesRochers Research Scientist Canadian Forest Service, Laurentian Forestry Centre Ste Foy, Québec Email: pierre.desrochers@rncan.gc.ca	Interactions between abiotic stressors (air pollutants, climatic extremes) and forest pests (insects and diseases) and their impact on forests
Keith Egger Professor University of Northern BC Prince George, B.C. Email: egger@unbc.ca	Impacts of climate change on microbial communities, including mycorrhizal fungi and associated bacteria
Mike Flannigan Research Scientist Canadian Forest Service, Great Lakes Forestry Centre Sault Ste Marie, Ontario Email: mike.flannigan@nrcan.gc.ca	Forest fires, climate change, future fire regimes, vegetation – weather/climate – fire interactions, lighting fires, landscape fire modelling

Researchers/Experts	Research/Area of Interest
Rich Fleming Research Scientist Canadian Forest Service, Great Lakes Forestry Centre Sault Ste Marie, ON Email: Rich.Fleming@NRCan.gc.ca	Natural Disturbances in Boreal Forests and Climate Change, impacts of climate change on forest pest dynamics
Konrad Gajewski Professor University of Ottawa, Department of Geography Ottawa, ON Email: gajewski@aix1.uottawa.ca	Reconstructing long-term climate change impacts on boreal forests using pollen analysis, sensitivity of terrestrial and aquatic ecosystems to climate changes, reconstruction of climate and fire history
Dr. Sylvie Gauthier Research Scientist Canadian Forest Service, Laurentian Forestry Centre Ste Foy, Québec Email: sgauthie@nrcan-rncan.gc.ca	Forest succession and climate change
Martin Girardin Research Scientist Canadian Forest Service, Laurentian Forestry Centre Ste Foy, Québec Email: Martin.Girardin@rncan.gc.ca	Ecology and global climatology, reconstitution of the Canadian Drought Code index on an ecoregion scale using series of radial tree growth rings and in relation to global climate
Raoul Granger National Water Research Institute Saskatoon, SK Environment Canada Email: Raoul.Granger@ec.gc.ca	Climate Change impacts on forest hydrology
David R. Gray Research Scientist Canadian Forest Service, Atlantic Forestry Centre Email: david.gray@nrcan.gc.ca	Research focuses on landscape modelling of disturbance ecology and the effect of climate change on disturbance regimes in the boreal forest
Paul Gray Ontario Ministry of Natural Resources, Planning and Research Branch Email: paul.gray@mnr.gov.on.ca	Impacts of climate change on wildlife and biodiversity, and on policy change required to adapt to these impacts
Andreas Hamann Assistant Professor University of Alberta, Dept of Renewable Resources Email: andreas.hamann@ualberta.ca	Hardwood genetics

Researchers/Experts	Research/Area of Interest
Brad Hawkes Fire Research Officer Canadian Forest Service, Pacific Forestry Centre Victoria, BC Email: brad.hawkes@nrcan.gc.ca	Climate change and forest fire management
Richard Hebda Curator Botany and Earth History Royal British Columbia Museum Victoria, B.C. Email: rhebda@royalbcmuseum.bc.ca	Using paleoecology to gain insight into forest processes and future forest composition
Ole Hendrickson Scientific Advisor Environment Canada, Canadian Biodiversity Information Network Hull, Québec Email: ole.henderickson@ec.gc.ca	Climate change impacts on forest biodiversity
Grant Hauer Professor University of Alberta, Department of Rural Economy Edmonton, AB Email: grant.hauer@ualberta.ca	Economics of climate change in the forest and agriculture sectors
Paul Hazlett Forest Soils Specialist Canadian Forest Service, Great Lakes Forestry Centre Sault Ste. Marie, Ontario Email: phazlett@NRCan.gc.ca	Impacts of global change and forest practices on hydrological event processes
Norm Henderson Executive Director Prairie Adaptation Research Collaborative (PARC) Regina, Saskatchewan	Climate change and forest management, climate change and nature conservation policy, and general climate change impacts and adaptation policy
Kelvin Hirsch Research Manager Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre Edmonton, AB Email: khirsch@nrcan.gc.ca	Developing proactive adaptation strategies to reduce the impact of forest fires on individuals, communities, forests and the forest industry
Ted Hogg Research Scientist Canadian Forest Service, Northern Forestry Centre Email: thogg@nrcan.gc.ca	Boreal Aspen Forests Under Global Change Drought and climate change in the southern boreal forest

Researchers/Experts	Research/Area of Interest
Anthony Hopkin A/ Director Canadian Forest Service, Great Lakes Forestry Centre Sault Ste Marie, ON Email: ahopkin@NRCan.gc.ca	Diseases and parasites of plants associated with climate change
Daniel Houle OURANOS/Quebec Natural Resources Email: houle.Daniel@ouranos.ca	Forest productivity, soils and climate change
John Innes Professor UBC Faculty of Forestry Vancouver, B.C. Email: john.innes@ubc.ca	Interested in how management practices are changing in different countries in response to international issues such as transboundary air pollution and climate change. As a member of the Sustainable Forestry Board, I am particularly interested in certification and how it is promoting sustainable forest management.
Mark Johnston Senior Research Scientist Saskatchewan Research Council Saskatoon, SK Email: Johnston@src.sk.ca	Modelling climate change impacts on forest productivity and wood supply; identification of adaptation options for the forest sector; determining adaptive capacity of organizations in the forest sector; impacts of climate change on maintenance of carbon sinks
Victor Kafka Parks Canada Québec City, Québec Phone: 418.649.8247	Impact of climate change on landscape flammability and the effectiveness of a forest management adaptation strategy at reducing area burned by wildfires
Sharad Karmacharya Resource Economist International Institute of Field Studies Hinton, AB Email: sharad.iifs@shaw.ca	Climate change impact, enhanced forest management practices, economic analysis of forestry and environmental practices, policy analysis, etc.
Hamish Kimmins Professor of Forest Ecology Director, Forest Ecosystem Management Simulation Lab Canada Research Chair in Forest Ecosystem Modelling UBC, Department of Forest Sciences Vancouver, B.C. Email: kimmins@interchg.ubc.ca	Forest Ecology; Sustainability of Managed Forests; Modelling Forest Ecosystems. Development of a climate change capability in FORECAST/NSERC
Nancy Kingsbury Science Advisor Canadian Forest Service Ottawa, ON Email: nkingsbu@nrcan.gc.ca	Climate change research and policy (linking policy and research)

Researchers/Experts	Research/Area of Interest
Suren Kulshreshtha Professor University of Saskatchewan, Department of Agricultural Economics Saskatoon, SK Email: suren.kulshreshtha@usask.ca	Kyoto protocol, water resources, organic practices, 2001 drought
Werner Kurz Senior Research Scientist Canadian Forest Service, Pacific Forestry Centre Victoria, BC Email: wkurz@nrcan-rncan.gc.ca	Climate change impacts on forest values, specifically carbon as a value at risk
Len Lanteigne Forestry Officer Canadian Forest Service, Atlantic Forestry Centre Email: Len.Lanteigne@nrcan.gc.ca	Relationship of forest practices with climate change and biodiversity
Guy Larocque Research Scientist, Modeling and Ecophysiology Canadian Forest Service, Laurentian Forestry Centre Ste Foy, Quebec Email: larocque@nrcan-rncan.gc.ca	Predicting the effects of climate change on forest productivity using simulation models
Victor Lieffers Professor University of Alberta, Renewable Resources Edmonton, AB Email: vic.lieffers@ualberta.ca	Tree recruitment, competitive relations and ecophysiology of trees, shrubs and herbs, adaptations to cold soils, photosynthesis in low light, light transmission through mixed canopies, root growth, natural reproduction of spruce and aspen, and development of regeneration standards for public lands
Kimberley Logan Fire and Climate Change Analyst Canadian Forest Service, Great Lakes Forestry Centre Sault Ste Marie, ON Email: Kim.Logan@nrcan.gc.ca	Using various climate models to determine potential fire behavior under a changing climate
Pengxin Lu Research Scientist Ontario Forest Research Institute Sault Ste. Marie, ON	Genetics and tree species adaptation

Researchers/Experts	Research/Area of Interest
Joan Luther Biomonitoring Scientist Canadian Forest Service, Atlantic Forestry Centre Corner Brook, NL Email: jluther@nrcan-rncan.gc.ca	Integrated remote sensing and GIS methods for monitoring forest health conditions over space and time. Assessment and mapping forest disturbances, identifying forests at risk to insect infestation
Lorraine MacLauchlan Forest Entomologist BC Ministry of Forests and Range Kamloops, BC Email: Lorraine.MacLauchlan@gov.bc.ca	Dynamics of forest insects in changing ecosystems
John Major Research Scientist Canadian Forest Service, Atlantic Forestry Centre Email: jmajor@nrcan.gc.ca	Potential Effects of Climate Change on Species Dispersal, Migration, and Genetic Adaptation in Eastern Canadian Forests Conservation, and Utilization of Biological Adaptive Traits
Hank Margolis Professor Université Laval Saint-Foy, Québec Email: Hank.Margolis@sbf.ulaval.ca	Eddy co-variance flux, soil respiration, ecological remote sensing, forest ecophysiology, ecosystem ecology
Ralph Matthews Professor The University of British Columbia, Department of Anthropology and Sociology	Research focuses primarily around issues of social capital, community resilience, and sustainable resource development as it relates to climate change
Rob McAlpine Fire Science and technical program Leader Aviation and Forest Fire management Branch Sault Ste. Marie, Ontario Phone: 705-945-5978	Climate change and forest fire activity and is involved in the development of future forest fire danger scenarios
Dan McKenney Chief, Landscape Analysis and Applications Canadian Forest Service, Great Lakes Forestry Centre Sault Ste. Marie, ON Email: dmckenne@nrcan-rncan.gc.ca	Climate change impacts on forest productivity
Jim McLaughlin Research Scientist Ontario Forest Research Institute Sault Ste. Marie, ON Email:	Carbon dynamics in forested peatlands
R. Dan Moore University of British Columbia Vancouver, B.C. Email: rdmoore@geog.ubc.ca	Mountain Pine Beetle outbreaks in western Canada: coupled influences of climate variability and stand development

Researchers/Experts	Research/Area of Interest
Ian Morrison Research Scientist Canadian Forest Service, Great Lakes Forestry Centre Email: imorriso@nrcan.gc.ca	Development of forest condition indicators across a global change gradient in eastern Canada, Interactions between air pollution, climate change, and forest productivity
Alex Mosseler Research Scientist Canadian Forest Service, Atlantic Forestry Centre Email: amossle@nrcan.gc.ca	Potential effects of climate change on species dispersal, migration, and genetic adaptation in eastern Canadian forests
Solange Nadeau Forest Sociologist Canadian Forest Service, Atlantic Forestry Centre Fredericton, NB Email: sonadeau@nrcan-rncan.gc.ca	Research focuses on sustainability of forest-based communities, values and attitudes associated with forest issues by various groups such as woodlot owners, and public participation in forest management and policy.
George Nagle President, Senior Economist Nawitka Renewable Resource Consultants Ltd. Summerland, B.C. Email: Nawitka@aol.com	Economic impacts of climate change on forest practices and industry over time. Pricing amelioration impacts, costs of adaptation to Kyoto or other imperatives, new economics of forest fires
Thomas Noland Ontario Ministry of Natural Resources Email: Tom.Noland@mnr.gov.on.ca	Extreme climatic event on productivity and growth in sugar maple
Aynslie Ogden Forest Science Officer Yukon Department of Energy, Mines and Resources Email: Aynslie.Ogden@gov.yk.ca	Climate change impacts on northern forests Canada
Dan Ohlson Partner Compass Resource Management Ltd. Vancouver, B.C. Email: dohlson@compassrm.com	Integrating ecological risk assessment and adaptive management principles into watershed management plans
Santiago Olmos Ph.D. University of Alberta Edmonton, AB	Climate change vulnerability and adaptive capacity in forest-based communities in Alberta and Saskatchewan
Greg O'Neill Research Scientist BC Ministry of Forests Vernon, B.C. Email: Greg.ONeill@gov.bc.ca	Study of the relationship between patterns of adaptive genetic variation and ecological variation - to provide direction in developing Seed Transfer Guidelines (STGs) that help ensure planted seedlings are adapted to their new environments.

Researchers/Experts	Research/Area of Interest
Rock Ouimet Researcher DRF, MRNFP, Québec Ste-Foy, Québec Email: rock.ouimet@mrn.gouv.qc.ca	Séquestration du carbone par les jeunes plantations, cycle beiogéochimique des ecosystems forestiers, impact des précipitations acides sur les forêts
William Parker Research Scientist Ontario Forest Research Institute Sault Ste. Marie, ON Email: bill.parker@mnr.gov.on.ca	Forest management adaptation to climate change
Kevin Percy Research Scientist Canadian Forest Service, Atlantic Forestry Centre Fredericton, NB Email: kpercy@nrcan.gc.ca	Research is centered on global change (air pollution/climate change) impacts on tree biochemistry and growth. Increasing focus is on global change-forest health state of science reporting, risk analysis, and science input into policy discussions around carbon, climate change and air quality issues
V.S. (Vern) Peters Research Scientist Canadian Forest Service, Northern Forestry Centre Edmonton, AB Email: Vern.Peters@nrcan.gc.ca	Effects of climate change on fire regimes and vegetation dynamics
Caroline Preston Research Scientist Canadian Forest Service, Pacific Forest Centre Email: cpreston@nrcan.gc.ca	Interactions of Forest Soil Carbon Quality and Climate Change
David Price Research Scientist Canadian Forest Service, Northern Forestry Centre Email: dprice@nrcan.gc.ca	Integrative Climate Change Impacts Modeling
Frédéric Raulier Faculty of Forestry University of Laval Email: Frederic.Raulier@sbf.ulaval.ca	Production of correction factors for growth & yield tables that take into account the impact of climate change. Impacts of climate change on the productivity of the boreal forests of Québec.
Maureen Reed Professor University of Saskatchewan, Department of Geography Saskatoon, SK Email: m.reed@usask.ca	Definitions, criteria and indicators of social sustainability related to forestry communities

Researchers/Experts	Research/Area of Interest
Jacques Régnière Research Scientist Canadian Forest Service, Laurentian Forestry Centre Ste Foy, Québec Email: jacques.regniere@rncan.gc.ca	Forest insect population dynamics, integrated pest management, modelling, seasonality (pest control and climate change).
John Richards Regional Director General Canadian Forest Service, Atlantic Forestry Centre Fredericton, NB Email: johnrich@nrcan.gc.ca	Climate change impacts and adaptation in the forest sector
William Richards Researcher Adaptation and Impacts Research Group, Environment Canada Faculty of Forestry and Environmental Management, UNB Fredericton, NB Email: William.Richards@ec.gc.ca	Forest adaptation to climate change, wildlife and climate change, atmospheric hazards
John Richardson Associate Professor University of British Columbia, Dept. of Forest Sciences Vancouver, BC Email: john.richardson@ubc.ca	Effects of discharge, temperature, water quality, etc., on stream and riparian biodiversity and ecosystem processes
Peter Salonius Soil Microbiologist Canadian Forest Service, Atlantic Forestry Centre Email: psaloniu@nrcan.gc.ca	Silvicultural strategies to cope with the anticipated climate change
Dave Sauchyn Professor of Geography and Research Coordinator, Prairie Adaptation Research Collaborative University of Regina Regina, SK Email: sauchyn@uregina.ca	Climate reconstruction using tree rings
Dan Scott Professor, Canada Research Chair University of Waterloo Waterloo, ON Email: dj2scott@fes.uwaterloo.ca	Climate change impacts and adaptation options for biodiversity management, tourism and parks and protected areas

Researchers/Experts	Research/Area of Interest
Stephen Shephard Associate Professor in Landscape Architecture and in Forest Resources Management University of British Columbia Vancouver, B.C. Email: shep@interchange.ubc.ca	Perceptions of climate change, the aesthetics of sustainability, and visualization theory and ethics.
John Sinclair Professor Natural Resources Institute, University of Manitoba Winnipeg, Manitoba Email: jsincla@ms.umanitoba.ca	Incorporating climate change impacts and adaptation issues in environmental assessment decision-making
Dan Smith Lab Director University of Victoria, Tree Ring Laboratory Victoria, B.C. Email: smith@uvic.ca	Forest disturbance dynamics in south central British Columbia
David Spittlehouse Senior Research Climatologist BC Ministry of Forests Research Branch, BC MOF Victoria, BC Email: dave.spittlehouse@gems4.gov.bc.ca	Adaptation in forest management, understanding physiological response of plants to weather and climate, forest carbon balance
Bob Stewart Science Advisor Canadian Forest Service Ottawa, ON Email: Robert.Stewart@nrcan-rncan.gc.ca	
Brian Stocks Research Scientist Canadian Forest Service, Great Lakes Forestry Centre Email: bstocks@nrcan.gc.ca	Climate Change and Boreal Forest Fire Activity Future Forest Fire Danger Scenario Development
Michael Ter-Mikaelian Research Scientist Ontario Forest Research Institute Sault Ste. Marie, ON	Forest modelling, carbon budget modelling
Tony Trofymow Research Scientist Canadian Forest Service, Pacific Forestry Centre Email: ttrofymo@nrcan.gc.ca	Long-term Decomposition Rates in Canadian Forest

Researchers/Experts	Research/Area of Interest
Bart van der Kamp Professor UBC Vancouver, BC Email: vdkamp@interchg.ubc.ca	Host resistance to Armillaria root disease as conditioned by host vigour, stem rusts of pines, particularly the occurrence of 'wave years' of infections, foliage disease of conifers, particularly variation in population resistance as related to provenance
Casey van Kooten	Climate change and forest policy
Jan Volney Research Scientist Canadian Forest Service, Northern Forestry Centre Edmonton, AB Email: jvolney@nrcan.gc.ca	Impacts of climate on insect population outbreaks, estimation of impacts on net primary productivity
Tongli Wang Assistant Director of the Centre of Forest Gene Conservation University of British Columbia, Department of Forest Sciences Vancouver, B.C. Email: tlwang@interchg.ubc.ca	Potential effects of climate change on ecosystem and tree species distribution in British Columbia
Clive Welham Research Associate Forest Ecosystems Management Simulation Group, Department of Forest Sciences, UBC Vancouver, BC Email: welham@interchange.bc.ca	Modelling the impact of climate change upon forest growth and productivity
Adam Wellstead Natural Resource Policy and Social Scientist Canadian Forest Service, Northern Forestry Centre Edmonton, AB Email: awellste@nrcan.gc.ca	Policy research, risk perception, online surveys, policy related beliefs and attitudes
Elaine Wheaton Research Scientist/Climatologist Saskatchewan Research Council Adjunct Professor, University of Saskatchewan Saskatoon, SK Email: wheaton@src.sk.ca	Climate change impacts and adaptation in forestry and agriculture; drought and climate change in the prairie region
Tim Williamson Forest Economist Canadian Forest Service, Northern Forestry Centre Edmonton, AB Email: twilliam@nrcan.gc.ca	Risk and uncertainty, supply function estimation, growth and yield with climate, risk modeling, Bayesian analysis

Researchers/Experts	Research/Area of Interest
Mike Wotton Research Scientist Canadian Forest Service, Great Lakes Forestry Centre Email: mwotton@nrcan.gc.ca	Climate Change and Boreal Forest Fire Activity Future Forest Fire Danger Scenario Development
Alvin Yanchuk British Columbia Ministry of Forests Email: Alvin.Yanchuk@gems4.gov.bc.ca	Seed source selection and deployment to address adaptation to future climates for interior spruce in western Canada

Appendix C - Abbreviations

In the following we list and explain some of the more frequently used abbreviations for the convenience of the reader. Typically these abbreviations have been explained also on first appearance in the text by a footnote.

AAC	Annual Allowable Cut
AB	Alberta
ACCAT	Alberta Environment's Alberta Climate Change and Adaptation Team
ASRD	Alberta Sustainable Resource Development
AWC	Soil available water-holding capacity
BC	British Columbia
Biome-BGC	The Biome-BGC (BioGeochemical Cycles) model is a computer program that estimates fluxes and storage of energy, water, carbon, and nitrogen for the vegetation and soil components of terrestrial ecosystem
BP	Burn probability
BURN-P3	Models that integrates the physical components of fire spread to the probabilistic aspects of the fire regime
CCFM	Canadian Council of Forest Ministers
CCME	Canadian Council of Ministers of the Environment
C-CIARN	Climate Change Impacts and Adaptation Program
CFS	Canadian Forest Service
CGCM1	version 1 of the Canadian Global Coupled Model from the Canadian Centre for Climate Modelling and Analysis. In this report, the results from this model are referred to as the Canadian model scenario. Canadian Global Circulation Models Version 1
CGCM2	version 1 of the Canadian Global Coupled Model from the Canadian Centre for Climate Modelling and Analysis. In this report, the results from this model are referred to as the Canadian model scenario. Canadian Global Circulation Models Version 2
CGTM	CINTRAFOR Global Trade Model
CO_2	Carbon dioxide
COP11	United Nations Climate Change Conference
CDN	Canadian
CRCM	Canadian Regional Climate Model
CS	Consumer Surplus or consumer benefits.
DGVM	Dynamic Global Vegetation Models
FACE	Free-Air Carbon dioxide Enrichment
FireSmart	Preventing and suppressing wildfires by using strategic, operational land and resource management activities
Fluxnet-	Canada has a national research network bringing together university and government scientists to study the influence of climate and disturbance on carbon cycling in Canadian forest and peatland ecosystems (Fluxnet Canada).
FMA	Forest Management Area
G&Y	Growth and Yield
GCC	Global Climate Change
GCM	Global Circulation Models
GDP	Gross Domestic Product
GE	General equilibrium model
IA	integrated assessment
IAM	Integrated Assessment Model
IBIS	Integrated BIosphere Simulator

IPCC	The Intergovernmental Panel on Climate Change
IS92a	Scenario has effective CO_2 concentration increasing at 1% per year after 1990. In the model, the concentrations are specified by linear interpolation between specified values at 2000, 2025, 2050 and 2100 (Environment Canada 2004).
IUCN	World Conservation Union
MB	Manitoba
MC1	New Dynamic Vegetation model created to assess the impacts of global climate change on ecosystem structure and to function at wide variety of spatial scales from landscape to global
NBP	Net Biome Production – summation of the carbon pools in a year (Chen *et al*. 2000)
NFDP	National Forestry Database Program
Mha	Million hectacre
NPP	Net Primary Poduction.
NTFP	Non-timber forest product
NW	North west
OMNR	Ontario Ministry of Natural Resources
	Oriented strand board is a performance-rated structural panel engineered for uniformity, strength, versatility and workability.
PnET	Photosynthesis and Evapotranspiration
PS: Logging	Producer Surplus in logging for the logging industry
PS: Products	Producer Surplus for primary producers (e.g. lumber, pulp and paper)
RCM	Regional Climate Models
SBSTA	Subsidiary Body for Scientific and Technological Advice
SRES	Special Report on Emission Scenarios. There are four scenario families (A1, A2, B1, B2) representing different future worlds with different greenhouse gas emission trajectories. The A1f is a special scenario within the A1 family, representing a world with intensive fossil fuel use.
UNCBD	United Nations Convention on Biological Diversity
UNFCCC	United Nations Framework Convention on Climate Change
VINCERA	Vulnerability and Impacts of North American Forests to Climate Change: Ecosystem Responses and Adaptation
WUE	Water Use Efficiency

Bibliography

Aber, J.D., S.V. Ollinger, C.A. Federer and C. Driscoll. 1997. Modeling nitrogen saturation in forest ecosystems in response to land use and atmospheric deposition. Ecological Modelling 101: 61-78

Aguado, E., J. Burt. 2004. Understanding Weather and Climate. 3rd edition. New Jersey, USA. Pearson Education, Inc.

Amiro, B.D., J.B. Todd, B.M. Wotton, K.A. Logan, M.D. Flannigan, B.J. Stocks, J.A. Mason J.A., D.L. Martell, K.G. Hirsch K.G. 2001. Direct carbon emissions from Canadian forest. Canadian Journal of Forest Research. 31:3, March 2001. 512-525. Direct carbon emissions from Canadian forest.

Alberta Environment. 2002. Albertans and climate change: A strategy for managing environmental and economic risk. Alberta Environment, Government of Alberta.

Alberta Sustainable Resource Development (ASRD). 1998. Interim Forest Management Planning Manual. Available at: http://www3.gov.ab.ca/srd/forests/fmd/manuals.

Amthor, J.S and D.D. Baldocchi. 2001. Terrestrial higher plant respiration and net primary production. Pp. 33-59 in Roy, J., B. Saugier and H. Mooney, editors. Terrestrial Global Productivity. Academic Press, San Diego, USA.

Andalo, C., J. Beaulieu, J. Bousquet. 2005. The impact of climate change on growth of local white spruce populations in Quebec, Canada. Forest Ecology and Management. 205. 169-182

Arctic Climate Impact Assessment Overview report. 2004. Impacts of a Warming Arctic: Arctic Climate Impact Assessment. http://amap.no/acia/

Ayres, M.P, M.J. Lombardero. 2000. Assessing the consequences of global change for forest disturbance from herbivores and pathogens. The science of the total environment. 262: 263-286.

Bachelet, D., J.M. Lenihan, C. Daly, R.P. Neilson, D.S. Ojima,, W.J. Parton. 2001. A Dynamic Vegetation Model for Estimating the Distribution of Vegetation and Associated Ecosystem Fluxes of Carbon, Nutrients, and Water Technical External Service Provider Agreement FIN-FRM-4.0 (April 2005) Page 13 of 26 Documentation, Version 1.0. General Technical Report PNW-GTR-508. USDA Forest Service, Corvallis, OR.

Bachelet D., J. Lenihan, R. Neilson, R. Drapek, T. Kittel. 2005. Simulating the response of natural ecosystems and their fire regimes to climatic variability in Alaska. NCR Research press web site http://cjfr.nrc.ca Article is one of a selection of papers published in the Special Issue on Climate-Disturbance Interactions in Boreal Forest Ecosystems. Canadian Journal of Forest Research 35. 2244-2257.

Baldocchi, D.D. and J.S. Amthor. 2001. Canopy photosynthesis: history, measurements and models. Pp. 9-31 in Roy, J., B. Saugier and H. Mooney, editors. Terrestrial Global Productivity. Academic Press, San Diego, USA.

Barg, S. and D. Swanson. 2005. Exploring the Definition of Adaptive Policies. IISD-TERI-IDRC Adaptive Policies Project, Project Paper #1

Barnett, T. P., J. C. Adam and D. P. Lettenmaier. 2005. Potential impacts of a warming climate on water availability in snow-dominated regions. Nature 483: 303-309.

Bartlein, P. J., C. Whitlock and S. Shafer. 1997. Future climate in the Yellowstone National Park region and its potential impact on vegetation. Conservation Biology 11: 782-792.

Battaglia, M., P. Sands, D. White and D. Mummery 2004. CABALA: a linked carbon, water and nitrogen model of forest growth for silvicultural decision support. Forest Ecology and Management 193: 251-282.

Beaulieu, J. and A. Rainville. 2005. Adaptation to climate change: Genetic variation is both a short- and a long-term solution. The Forestry Chronicle 81: 704-709

Beck, U. 1992. Risk society, towards a new modernity. Sage Publications. London, UK.

Beckley, T., J. Parkins, R. Stedman. 2002. Indicators of forest-dependent community sustainability: The evolution of research. The Forestry Chronicle. 78(5): 626-636.

Berck, P., S. Hoffman. 2002. Assessing the employment impacts of environmental and natural resource policy. Environmental and Resource Economics. 22:133-156.

Bergeron, Y. 2000. Species and Stand Dynamics in the Mixed Woods of Quebec's Southern Boreal Forest. Ecology. 81:6, 1500–1516.

Bergeron, Y. 1991. The Influence of Island and Mainland Lakeshore Landscapes on Boreal Forest Fire Regimes. Ecology. 35:6: 1980-1992.

Bergeron, Y., M. Flannigan, S. Gauthier, A. Leduc and P. Lefort. 2004. Past, current and future fire frequency in the Canadian boreal forest: implications for sustainable forest management. Ambio 33: 356-360.

Bergeron, Y., S. Gauthier, V. Kafka, P. Lefort, D. Lesieur. 2001. Natural fire frequency for the eastern Canadian boreal forest: consequences for sustainable forestry. Can. J. For. Res. 31:384-391.

Bergeron, Y., B. Harvey, A. Leduc, S. Gauthier. 1999. Forest management guidelines based on natural disturbance dynamics: Stand-and forest-level considerations. The Forestry. Chronicle. 15:1. 49-54.

Bergeron, Y., A. Leduc, H. Morin, C. Joyal. 1995. Balsam fir mortality following the last spruce budworm outbreak in northwestern Quebec. Canandian Journal of Forest Research. 91 1375-1384.

Bergeron, Y., P. Richard, C. Carcaillet, S. Gauthier, M. Flannigan, Y. Prairie. 1998. Variability in Fire Frequency and Forest Composition in Canada's Southeastern Boreal Forest: A Challenge for Sustainable Forest Management. Conservation Ecology (online).81:2 www.consecol.org/vol2/iss2/art6/

Bergot, M., E. Cloppet, V. Perarnaud, M. Deque, B. Marcais, Desprez-Loustau. 2004. Simulation of potential range expansion of oak disease caused by Phytophthora cinnamomi under climate change. Global Change Biology 10: 1539-1552.

Bhatti, J.S., R. Lal, J.J. Apps, M.A. Price. 2006. Climate change and managed ecosystems. CRC Press Taylor and Francis Group, Boca Raton, FL.

Binkley, C.S., C. van Kooten. 1994. Integrating climate change and forests: economic and ecological assessments. Climate Change 28:91-110.

Blair, D. in preparation. Climate change Impacts on Transportation in the Prairie Provinces. In: Sauchyn, D and S. Kulshreshtha. Vulnerability to Climate Change in the Prairie Provinces. Chapter XX in the National Climate Change Assessment for Canada. Natural Resources Canada, Ottawa ON.

Bolin, B. 1998. The Kyoto Negotiations on Climate Change: A Science Perspective. Science' Accessed online March 13, 2006 at: http://www.sciencemag.org/cgi/content/short/279/5349/330

Bourque, C.A., R.N. Cox, D.J. Allen, A. Arp, and F.R. Meng. Spatial extent of winter thaw in eastern North America : historical weather records in relation to yellow birch decline. Global Change Biology: 11 1477-1492.

British Columbia Ministry of Forests and Range. 2006. The Future Forest Ecosystems of BC – Exploring the Opportunities. Workshop Overview Summary – Key Opportunities and Messages, University of Northern British Columbia, Prince George, British Columbia, 7 December 2006. Ministry of Forests and Range. Access online at: http://www.for.gov.bc.ca/hts/Future_Forests/ChairWorkshopSummary.pdf. [Accessed on 04.13.06].

Bruce, J, H. Lee, E. Haites. (eds) 1996. Climate change 1995 – economic and social dimensions of climate change. WG III – Second Assessment Report. IPCC.

Burton, I. 1996. The growth of adaptation capacity: practice and policy. *In* Smith, J.B. (ed.). Adapting to Climate Change: An International Perspective. Springer. New York, NY. 475p.

Burton, I. 1997. Vulnerability and adaptive response in the context of climate and climate change. Climatic Change 36:185-196.

Burton, I., S. Huq, B. Lim, O. Pilifosova, and E. L. Schipper. 2002**.** From impact assessment to adaptation priorities: the shaping of adaptation policy. Climate Policy 2:145–159.

Brown, K., R. Hebda. 2002. Origin, development, and dynamics of coastal temperate conifer rainforests of southern Vancouver Island, Canada. Canadian Journal of Forest Research 32: 353–372.

Brown, G. 2005. Mapping spatial attributes in survey research for natural resource management: Methods and applications. Society and Natural Resources. 18:17-39.

Bugmann, H., J.F. Reynolds, and L.F. Pitelka (editors). 2001. How much physiology is needed in forest gap models for simulating long-term vegetation response to global change? Climatic Change 51: 249-557.

Carroll, A., S. Taylor, J. Regniere, and L. Safranyik. 2004. Effects of climate change on range expansion by the mountain pine beetle in British Columbia. In: Proceedings of "Mountain Pine Beetle Symposium: Challenges and Solutions", Oct. 30-31, 2003 Kelowna, BC T.L. Shore and J.E. Stone (eds). NRCAN , Can. For. Serv., Pac. For. Cent. Info Rep. BC-X-399, pp 233-244.

Chen, W.J., J. Chen, D.T. Price, J. Cihlar, 2002. Effects of stand age on net primary productivity of boreal black spruce forests in Canada. Canadian Journal of Forest Research 32: 833-842.

Chen J.M., W. Ju, J. Cihlar, D.T. Price, J. Liu, W. Chen, J. Pan, T.A. Black, A. Barr. 2003. Spatial distribution of carbon sources and sinks in Canada's forests based on remote sensing. Tellus 55B: 622-641.

Chen, McCarl, Adams. 1999. Economic implications of potential climate change induced ENSO frequency and strength shifts. US National Assessment of Climate Change, Agricultural Focus Group. US Global Change Office.

Chen W., Q. Zhang, J. Cihlar, J. Bauhaus, D.T. Price. 2004. Estimating fine-root biomass and production of boreal and cool temperate forests using aboveground measurements: A new approach. Plant and Soil 265: 31-46.

Cherry, M. and W.H. Parker. 2003. Utilization of genetically improved stock to increase carbon sequestration. Applied research and development, Ontario Ministry of Natural Resources, Forest Research Report No. 160. 15 pp.

Churkina, G., S. Running. 2000. Investigating the balance between timber harvest and productivity of global coniferous forests under global change. Climatic Change 47: 167-191. Conference Proceedings: Climate Change in Eastern Canada: A focus on forests. New Brunswick. (Pending).

Climate Change Action Fund. Climate Science in Canada The Arctic. Government of Canada website http://www.climatechange.gc.ca/english/publications/ccaf_200102/index.html

Coakley, S.M. 1999. Climate change and plant disease management. Annual Review of Phytopathology 37: 399-426.

Cogbill, C. 1985. Dynamics of the boreal forests of the Laurentian Highlands. Canadian Journal of Forest Research 61: 252-261.

Cohen, S. 1997. Scientist-stakeholder collaboration in integrated assessment of climate change: Lessons from a case study of Northwest Canada. Environmental Modeling and Assessment 2: 281-293.

Cohen S**.** 1997. The Mackenzie Basin Impact Study. Environment Canada. The Mackenzie Basin Impact Study. Environment Canada. http://www.msc-smc.ec.gc.ca/acsd/publications/RMD_msc_report/policy/policy_6_e.html.

Cohen, S. and K. Miller. 2001. North America. Pp. 735-800 in: McCarthy, J., Canziani, O., Leary, N., Dokken, D., White, K., editors. Climate Change 2001: Impacts, Adaptation and Vulnerability. Cambridge University Press, Cambridge, UK.

Collingham, Y., B. Huntley. 2000. Impacts of habitat fragmentation and patch size upon migration rates. Ecological Applications 10. 131-144.

Colombo, S.J., M.L. Cherry, C. Graham, S. Greifenhagen, R.S. McAlpine, C.S. Papadopol, W.C. Parker, R. Scarr, M.T. Ter-Mikaelian, and Flannigan. The impacts of climate change on Ontario's forests. Ontario Forest Research Institute (OFRI). (Ed) S.J. Columbo and L.J. Buse Forest Research Information Paper No. 143 56pp.

Columbia Mountains Institute of Applied Ecology 2005. Implications of Climate Change in British Columbia's Southern Interior Forests (Workshop). J. Fraser and G. Mckinnon (ed.) April 26-27, 2005.

Comiso, J. 2003. Warming Trends in the Arctic from Clear Sky Satellite Observations. Journal of Climate. 59. 3498-3510.

Cordell, H.C.; McDonald, B.L.; Teasly, R.J.; Bergstrom, J.C.; Martin, J.; Bason, J.; Leeworthy, V.R.; 1999. Outdoor recreation participation trends. in K.H. Cordell (Principal Investigator). Outdoor recreation in American life: A national assessment of demand and supply trends. Sagamore Publishing.

Cummings,S.G. and P.J. Burton. 1996. Phenology-mediated effects of climatic change on some simulated British Columbia forests. Climatic Change 34:213-222.

Dale, V., L. Joyce , S. Mcnulty , R. Neilson , M. Ayres , M. Flannigan , P. Hanson , L. Irland , A. Lugo, C. Peterson, D. Simberloff, F. Swanson, B. Stocks, M. Wotton. 2001. Climate Change and Forest Disturbances. BioScience 51: 723-734.

Davidson, D.J, T. Williamson, J.R. Parkins. 2003. Understanding climate change risk and vulnerability in northern communities. Canadian Journal of Forest Research 33:2252-2261.

Davidson, D.J, Wellstead, A. Stedman, R. 2004. Political Climate Modeling: Predicting socio-political responses to climate change in the Prairie Provinces. Prairie Adaptation Research Collaborative. Summary Document. No 04-01.

Department of Agriculture, Fisheries and Aquiculture. 2005. Forest Net - Study Begins on Island Forests and Climate Change. Guardian Newspaper. Accessed online at: http://www.gov.pe.ca/af/agweb/index.php3?number=1010767&lang=E [Accessed on 03.14.06].

Department of Environment and Conservation. 2005. Climate Change Action Plan. Government of Newfoundland and Labrador.

Dore, M., S. Kulshreshtha, M. Johnston. 2001. An integrated economic – ecological analysis of land use decisions in forest-agriculture fringe region of northern Saskatchewan. Geographical and Environmental Modelling 5:159-175.

Dore, M., M. Johnston. 2001. Value of carbon storage in Canadian forests. Journal of Sustainable Forestry. 12:123-151.

Dowlatabadi, H. 1995. Integrated assessment models of climate change. Energy Policy 23(4/5):289-296.

Draper, D. 2002. Our Environment: A Canadian Perspective. 2nd edition. Nelson Thomson Learning, Scarborough, Ontario.

Duinker P.N. 1990. Climate change and forest management, policy, and land use. Land Use Policy 7:124-137.

Duinker, P.N. 2002. Policies for Sustainable Forests: Examples from Canada. In: Volume 4, Responding to Global Environmental Change (M.K. Tolba, editor), pp. 351-356, of the Encyclopedia of Global Environmental Change (R.E. Munn, chief editor). John Wiley and Sons Ltd., London, UK.

Dullinger, S., T. Dirnbock, G. Grabherr. 2004. Modelling climate change-driven treeline shifts: Relative effects of temperature increase, dispersal and invasibility. Journal of Ecology 92:241-252.

DuWors, E., F. Filion, E. DuWors, P. Boxall, P. Bouchard, R. Reid, P. Gray, A. Bath, A. Jacquemot, G. Legare. 1993. The importance of wildlife to Canadians: highlights of the 1991 survey. Environment Canada, Canadian Wildlife Service., Ottawa, On.

DuWord, E., M. Villeneuve, F. Filion, R. Reid, P. Bouchard, D. Legg, P. Boxall, T. Williamson, A. Bath, S. Meis. 1999. The importance of nature to Canadians: Survey highlights. Environment Canada, Ottawa, Ontario.

Edwards, M., J. Dawe, W. Armbruster. 1991. Pollen size of Betula in northern Alaska and the interpretation of late Quaternary vegetation records. Canadian Journal of Botany. 51:1666-1672.

Edwards., M., L. Brubaker, A. Lozhkin, P. Anderson. 2005. Structurally Novel Biomes: A Response to Past Warming in Beringia. Ecology. 69:7:1696-1703.

El Maayar, M., D.T. Price, C. Delire, J.A. Foley, T.A. Black, P. Bessemoulin. 2001. Validation of the Integrated BIosphere Simulator (IBIS) over Canadian deciduous and coniferous boreal forest stands. Journal of Geophysical Research 106: 339-14,345.

El Maayar, M., D.T. Price, M. Siltanen. 2001. Simulating forest responses to transient changes in climate and atmospheric CO2: A case study for Saskatchewan, central Canada. In: M. Brunet, and D. Lopez, (eds.), Detecting and Modelling Regional Climate Change, Springer-Verlag, Berlin/Heidelberg, pp. 545-554.

El Maayar, M., D.T. Price, T.A. Black, E.R. Humphreys, E-M. Jork, 2002. Sensitivity tests of the Integrated BIosphere Simulator (IBIS) to soil and vegetation characteristics in a Pacific Coastal coniferous forest. Atmosphere–Ocean 40: 313-332.

Englin, J., P. Boxall, K. Chakrabory, D. Watson. 1996. Valuing the impacts of forest fires on backcountry forest recreation. For. Sci. 42:450-455.

Environment Canada. 1997. Canada Country Study: Climate Impacts and Adaptation, The Meteorological Service of Canada-Climate Change: Supporting action through science. http://www.msc-smc.ec.gc.ca/education/scienceofclimatechange/publications/reports_papers/MSC_Brochure/index_e.html

Etterson J. R. and R. C. Shaw. 2001. Constraint to adaptive evolution in response to global warming. Science 5: 294:151-154.

Fang, C., P. Smith, J.B. Moncrieff and J.U. Smith. 2005. Similar response of labile and resistant soil organic matter pools to changes in temperature. Nature 433: 57-59.

Federal Provincial Parks Council. Working together: Parks and Protected Areas in Canada. http://www.cd.gov.ab.ca/preserving/parks/fppc/workingtogether.html

Flannigan, M.D., Y. Bergeron, O. Engelmark, B.M. Wotton. 1998. Future wildfire in circumboreal forests in relation to global warming. Journal of Vegetation Science 9: 469-476.

Flannigan, M.D., K.A. Logan, B.D. Amiro, W.R. Skinner and B.J. Stocks. 2005. Future area burned in Canada. Climatic Change 72: 1-16.

Flato, G.M. and G.J. Boer. 2001. Warming asymmetry in climate change simulations. Geophysical Research Letters 28: 195-198.

Flato, G.M., G. J. Boer, W.G. Lee, N.A. McFarlane, D. Ramsden, M.C. Reader and A.J. Weaver. 2000. The Canadian Centre for Climate Modelling and Analysis Global Coupled Model and its climate. Climate Dynamics 16: 451-467.

Fleming, R.A. and J-N Candau. 1998. Influence of potential climate change on Influences of climate change on some ecological processes of an insect outbreak system in Canada's boreal forests and the implication to biodiversity. Environmental Monitoring and Assessment. 49. 235-249.

Foley, J.A., I.C. Prentice, N. Ramankutty, S. Levis, D. Pollard and co-authors. 1996. An integrated biosphere model of land surface processes, terrestrial carbon balance and vegetation dynamics. Global Biogeochemical Cycles 10: 603-628.

Forest Products Association of Canada. 2006. http://www.fpac.ca/en/economy/trade.php. Accessed January 23, 2006.

Forest Practices Board. 2004. Integrating non-timber forest products into forest planning and practices in British Columbia. Special report FPB/SR/19, Forest Practices Board, Victoria, BC.

Foster, D. 1983. The history and pattern of fire in the boreal forest of southeastern Labrador. Canadian Journal of Forest Research 79. 2459-2470.

FPPC (Federal Provincial Parks Council). 2000. Working Together: Parks and Protected Areas in Canada. Federal Provincial Parks Council. n.p. 64 p.

Francis, D., H. Hengeveld. 1998. Extreme Weather and Climate Change. Minister of Environment, Minister of Supply and Services. Catalogue no. En57-27/1998-01E. 31 pp.

Gamache, I., S. Payette. 2004. Height growth response of tree line black spruce to recent climate warming across the forest-tundra of eastern Canada. Journal of Ecology 92: 835-845.

Gerber, S., F. Joos, I.C. Prentice. 2004. Sensitivity of a dynamic global vegetation model to climate and atmospheric CO2. Global Change Biology 10: 1-17

Gillett, N.P., A. J. Weaver, F.W. Weirs, M.D. Flannigan. 2004. Detecting the effect of climate change on Canadian forest fires. Geophysical Research Letters. No. 31. 4 pg.

Girardin, M., J. Tardif, Y. Bergeron. 2002. Dynamics of eastern larch stands and its relationships with larch sawfly outbreaks in the northern Clay Belt of Quebec. Canadian. Journal of Forest Research 2: 206-216.

Goetz, S.J., A.G. Bunn, G.J. Fiske and R. A. Houghton. 2005. Satellite-observed photosynthetic trends across boreal North America associated with climate and fire disturbance. Proceedings of the National Academy of Sciences 102: 13521-13525.

Government of British Columbia. 2005. British Columbia's Mountain Pine Beetle Action Plan 2005-2010. Government of British Columbia. 24 p.

Filmon, G, D. Leitch, J. Sproul. 2004. 2003 Firestorm Provincial Review. Government of British Columbia. 100 p.

Government of British Columbia, Ministry of Environment, Environmental Protection Division-Indicators of Climate Change. 2002. http://www.env.gov.bc.ca/air/climate/indicat/

Government of Canada publication-Climate Change Action Fund. Taking action on climate change, Together, we can do it. Climate Science in Canada- the arctic. pp 4.

Government of Canada publication-Climate Change Action Fund. Taking action on climate change. Together, we can do it. Climate Science in Canada- climate modelling. 4 pp.

Government of Canada. 2003. Canadian Species at Risk Act. Chpt. 29. Government of Canada. Ottawa. 97 p.

Government of New Brunswick. 2003. Discussion paper: New Brunswick and climate change. Government of New Brunswick.

Government of Quebec. 2000. Quebec Action Plan on climate change 2000-2002. Government of Quebec. Accessed online at: http://www.menv.gouv.qc.ca./changements/plan_action/index-en.htm [Accessed online 03.13.06]

Govindasamy, B., S. Thompson, A. Mirin M., Wickett, K. Caldeira , C. Delire. 2005. Increase of carbon cycle feedback with climate sensitivity: results from a coupled climate and carbon cycle model. Tellus 57B, 153-163

Grace, J., F. Berninger, L. Nagy. 2002. Impacts of Climate Change on the Tree Line. Annals of Botany 90:537-544.

Graham, R. 1988**.** The role of climatic change in the design of biological reserves: the paleoecological perspective for conservation biology. Conservation Biology 2: 391-394.

Gray, P.A. 2004. A climate for life. Re:View, Summer 2004: 1, 4.

Gray, P.A. 2004. Using an ecosystem approach to manage for climate change. Canadian Silviculture, Summer (2004): 14- 15.

Gray, P. 2005. Effects of climate change on diversity in forested ecosystems: Some examples. The Forestry Chronicle. 81: 655-661.

Gray, P.A., P. Boxall, R. Reid, F.L. Filion, E. DuWors, A. Jacquemot, P. Bouchard, A. Bath. 1993. The importance of wildlife to Canadians: Results from three national surveys. XXI International Union of Game Biologists Congress: 151- 157.

Gray, P.A., I. Kirkham, D. Fowle, L. White, R. Stewart, M. McLaren, K. King, J. Baker, A. Roy, D. Ogston, J. Gibb Sr., J. Lounds, R. Calvert, F. Ribordy, T. Morris, B. Davidson, M. Bohl, B.K. MacKay, C. Winter, G. Winterton, and B. Rapley. 1993. A proposed action plan for “Looking Ahead: A Wild Life Strategy for Ontario”. Prepared by the Wild Life Strategy Action Plan Ad Hoc Committee on Behalf of the Wild Life Forums for the Minister of Natural Resources, MNR, Toronto, Ontario. 239pp.

Gray, P.A., L. Demal, D. Hogg, D. Greer, D. Euler, D. DeYoe. 1995. An ecosystem approach to living sustainably: A perspective for the Ministry of Natural Resources. Queen’s Printer for Ontario, Ministry of Natural Resources, Box 7000, Peterborough, Ontario, Canada. 77pp.

Gray, P.A., D. Cameron, I. Kirkham. 1996. Wildlife habitat evaluation in forest ecosystems: Some examples from Canada and the United States. Pages 407-536 in R.M. DeGraaf and R.I. Miller, Editors. Conservation of Faunal Diversity in Forested Landscapes. Chapman and Hall, London.

Gray, P.A., R.J. Davidson. 2000. An ecosystem approach to management: A context for wilderness protection. Pages 59-64 in: D.N. Cole and S.F. McCool, Editors. Proceedings: Wilderness Science in a Time of Change. RMRS-P-15-VOL- 2, Rocky Mountain Research Station, USDA Forest Service, Ogden, Utah. 307pp

Gray, P.A., E. DuWors, M. Villeneuve, S. Boyd, D. Legg. 2003. The socio-economic significance of nature-based recreation in Canada. Journal of Environmental Monitoring and Assessment: 86: 129-147.

Greifenhagen, S., T. L. Noland. 2003. A Synopsis of Known and Potential Diseases and Parasites Associated with climate change. Ontario Forest Research Institute, Forest Research Information paper No.14. 179 pp.

Griss P. 2002. Forest carbon management in Canada. Final Report of the Pollution Probe Forest Carbon Management Workshop Series, July 2002. Toronto, Montreal, Edmonton, Vancouver. http://www.pollutionprobe.org/whatwedo/FCM/finalreport.pdf

Halpin, P.N. 1997. Global change and natural area protection: management responses and research directions. Ecological Applications 7: 828-843.

Hamann, A. and T. Wang. 2005**.** Potential effects of climate change on ecosystem and tree species distribution in British Columbia. Centre for Forest Gene Conservation, Department of Forest Sciences. University of British Columbia. 42 p.

Hamann, A. and T.L. Wang 2006. Potential effects of climate change on ecosystem and tree species distribution in British Columbia. Ecology (accepted).

Hannan L., G.F. Midgley, T. Lovejoy, W.J. Bond, M. Bush, J.C. Lovett, D. Scott, F.I. Woodward. 2001. Diversity; Conservation of Biodiversity in a Changing Climate. Conservation Biology. 16: 264-268.

Hannah, L., G.F. Midgley and D. Millar. 2002**.** Climate change integrated conservation strategies. Global Ecology and Biogeography 11: 485-495.

Hannah, L., T.E. Lovejoy and S. Schneider. 2005**.** Biodiversity and Climate Change in Context. *In* T.E. Lovejoy and L. Hannah (eds.). Climate Change and Biodiversity. pp. 3-14. Yale University Press. New Haven.

Hannah, L. and R. Salm. 2005. Protected Areas Management in a Changing Climate. *In* Lovejoy, T.E. and L. Hannah (eds.). Climate Change and Biodiversity. pp. 363-374. Yale University Press. New Haven.

Hanson, J. and S. Edwards. 2002. Towards a biobased economy: Issues and challenges paper. www.pollutionprobe.org/Reports/Biobased.pdf. Accessed on 15 June 2005.

Harden, J., S. Trumbore, B. Stocks, A. Hirsch, S. Gower, K. O'Neill, E. Kasischke. 2000. The role of fire in the boreal carbon budget. Global Change Biology 6:174-184.

Hepting, G. N, V. J. Nordin, T. S. Buchanan, R. R. Lejeune, G. P. Thomas, C. W. Farstad, H. Pschorn-Walcher, J. E. Kuntz, F. Roll-Hansen and J. S. Murray, with assistance by B. M. McGugan and B. Lekander. 2004. The importance of forest diseases and insects. Food and Agriculture Organization of the United Nations (FAO/IUFRO) Document Respository Unasylva No 78. http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/24847e/24847e08.htm

Harvell, C.D., C.E. Mitchell, J.R. Ward, S. Altizer, A.P. Dobson, R.S. Ostfeld, and M.D. Samuel. Climate warming and disease risks for terrestrial and marine biota. Science 296:2158-2162.

Hauer, G., T. Williamson, M. Renner. 2001. Socioeconomic impacts and adaptive responses to climate change: A Canadian forest sector perspective. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Information Report NOR-X-373.

Haxeltine. A. and I. Prentice. 1996**.** BIOME3: An equilibrium terrestrial biosphere model based on ecophysiological constraints, resources availability, and competition among plant functional types. Global Biogeochemcial Cycles 10: 693-709.

Hebda, R. 1998. Atmospheric change, forests and biodiversity. Environmental Monitoring and Assessment. 49:195-212.

Hebda, R.J. 1997. Impact of climate change on biogeoclimatic zones of British Columbia and Yukon. In Responding to global climate change in British Columbia and Yukon. E. Taylor and B. Taylor (editors). Environment Canada, Vancouver, B.C. pp. 13-1–13-15.

Hedhly, A., J. Hormaza, M. Herrero. 2004. Effect of temperature on pollen tube kinetics and dynamics in Sweet Cherry, Prunus Avium (Rosaceae). American Journal of Botany.75: 558-564.

Henderson, N., E. Hogg, E. Barrow and B. Dolter. 2003**.** Climate change impacts on the island forests of the Great Plains and the implications for nature conservation policy – summary document. Prairie Adaptation Research Collaborative. Regina, Saskatchewan. 116 p.

Hengeveld H.G. 2002. Fall CO2/Climate: Recent unusual weather and related impacts and disasters: natural variability or climate change? Issued by the Science Assessment and Integration Branch, Meteorological Service of Canada. A periodical newsletter devoted to the review of climate change research. 11 pp.

Hengeveld, H.G. 2000. Projections for Canada's Climate Future- A discussion of recent simulations with the Canadian Global Climate Model. Minister of Environment, Minister of Supply and Services. Cataloque no. En57-27/2000-01E. pp 27.

Hengeveld H., P. Edwards. Winter 2000. CO2/Climate. A periodical newsletter devoted to the review of climate change research. http://www.msc-smc.ec.gc.ca/education/scienceofclimatechange/understanding/newsletter/co2_winter_2002/pages/8_e.html

Hengeveld, H.G. 2003. Summer. CO2/Climate: 2001 in review an assessment of new research developments relevant to the science of climate change. Issued by the Science Assessment and Integration Branch, Meteorological Service of Canada. A periodical newsletter devoted to the review of climate change research. 32 pp.

Hengeveld, H., P. Edwards. 2002. Co2/Climate Report. Recent unusual weather and related impacts and disasters: natural variability or climate change? Environment Canada. 8 pp. http://www.msc-smc.ec.gc.ca/education/scienceofclimatechange/understanding/newsletter/co2_winter_2002/pages/8_e.html

Herzog, H., K. Caldeira, J. Reilly. 2003. Temporary carbon storage. Climatic Change Volume 59: 293-310.

Hewitt, G. 2000. The genetic legacy of the Quaternary ice ages. Nature. 411. 907-913.
Higgins, P., Vellinga, M. 2004. Ecosystem Responses to abrupt climate change: Teleconnections, scale and the hydrological cycle. Climatic change 64:127-142.

Hoffman R, B. McInnis. 1988. The Evolution of Socio-Economic Modeling in Canada. Technological Forecasting and Social Change 33: 311-323.

Hogg, E. and P. Hurdle. 1995. The aspen parkland in western Canada: a cry-climate analogue for the future boreal forest? Water, Air and Soil Pollution 82: 391-400.

Hogg, E.H., D.T. Price, T.A. Black. 2000. Postulated feedbacks of deciduous forest phenology on seasonal climate patterns in the western Canadian interior. Journal of Climate 13: 4229–4243.

Hogg, E.H., J.P. Brandt, B. Kochtubajda. 2002. Growth and dieback of aspen forests in northwestern Alberta, Canada, in relation to climate and insects. Canadian Journal Forest Research 32: 823–832.

Hogg, E., P. Bernier. 2005. Climate change impacts on drought-prone forests in western Canada. The Forestry Chronicle 81:675-682.

Holman, I.P. M.D.A. Rounsevell, S. Shackley, P.A. Harrison, R.J. Nicholls, P.M. Berry and E. Audsley. 2005a. A regional, multi-sectoral and integrated assessment of the impacts of climate and socio-economic change in the UK. Part I, Methodology. Climatic Change 71: 9-41.

Holman, I.P., R.J. Nicholls, P.M. Berry, P.A. Harrison, E. Audsley, S. Shackley and M.D.A. Rounsevell. 2005b. A regional, multi-sectoral and integrated assessment of the impacts of climate and socio-economic change in the UK. Part II, Results. Climatic Change 71: 43-73.

Hooper, M., K. Arii, M.J. Lechowicz. 2001. Impact of a major ice storm on an old-growth hardwood forest. Canadian Journal of Botany. 79: 70-75.

Horsley S.B., R.P. Long, S.W. Bailey, R.A. Hallett, P.M. Wargo. 2002. Health of eastern North American sugar maple forests and factors affecting decline. Northern Journal of Applied Forestry, 19. 34-4

Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, and D. Xiaosu. (eds.). 2001. Climate change 2001: the scientific basis. Intergovernmental Panel on Climate Change, Cambridge University Press, New York, NY.

Howlett, M. Introduction: Policy regimes and policy change in the Canadian forest sector. Canadian forest policy. M. Howlett, ed. University of Toronto Press: Toronto. 3-22.

Howlett, M. and M. Ramesh. 2003. Studying public policy: Policy cycles and policy subsystems. 2nd ed. Oxford University Press: Toronto.

Hughes, L. 2000. Biological consequences of global warming: is the signal already apparent? Trends in Ecology and Evolution 15: 56-61.

Humphreys, E.R., T.A. Black, E.-M. Jork, G.B. Drewitt, D.L. Spittlehouse, Z. Nesic , M.A. Arain. 2002. Annual and seasonal variability of latent and sensible heat fluxes above a coastal Douglas-fir forest. Agricultural and Forest Meteorology. 115:109- 125.

Hunter, M.L. 1993. Natural fire regimes as spatial models for managing boreal forests. Biological Conservation 72:115-120.

IPCC (Intergovernmental Panel on Climate Change). 1990**.** Scientific assessment of climate change, IPCC Working Group 1 First Assessment Report. Cambridge University Press, Cambridge, UK.

IPCC (Intergovernmental Panel on Climate Change). 1995**.** Technical Summary - Climate change 1995: The science of climate change, IPCC Working Group 1 Second Assessment Report. Cambridge University Press, Cambridge, UK.

Intergovernmental Panel on Climate Change (IPCC). 2001. Climate Change 2001: The Scientific Basis. J.T. Houghton *et al*. (eds.), Cambridge University Press, 881pp.

IUCN (International Union for Conservation of Nature). 1993. Parks for life – report of the IVth World Congress on National Parks and Protected Areas. *In* McNeely, J. (ed.). IUCN, Gland, Switzerland.

IUCN (International Union for Conservation of Nature). 2003. World Parks Congress 2003: Recommendation 5.05, Climate Change and Protected Areas. Available at: http://www.iucn.org/themes/wcpa/wpc2003/pdfs/outputs/recommendations/approved/english/html/r05.htm

Iverson L. R. and A.M. Prasad. 1998. Predicting abundance of 80 tree species following climate change in the eastern United States. Ecological Monographs 68: 465-485.

Johnston, M.H. 1996. The role of disturbance in boreal mixedwood forests of Ontario. Pages 33-40 in C.R. Smith and G.W. Crook (compilers). Advancing Boreal Mixedwood Management in Ontario: Proceedings of a Workshop. Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, Ontario.

Johnson, E., K. Miyanishi, N. O'Brien. 1999. Long-term reconstruction of the fire season in the mixed wood boreal forest of Western Canada. Canadian Journal of Botany. 50. 1185-1188.

Johnston, M.,P. Uhlig. 2000. Carbon storage in soils and vegetation among forested ecosystem types in northern Ontario. Pp. 63-74 in: Sustainable Forest Management And Global Climate Change: Selected Case Studies from the Americas, Dore, M.H., Guevara, R., Eds. Edward Elgar Publishing, Cheltenham, UK.

Johnston, M. 2001. Sensitivity of Boreal Forest Landscapes to Climate Change. Prepared for the Government of Canada's Climate Change Action Fund. Saskatchewan Research Council, Saskatoon, SK. SRC Publication No. 11341-7E01.

Johnston, M., S. Kulshreshtha, T. Baumgartner. 2001. Agroforestry in the prairie landscape: opportunities for climate change mitigation through carbon sequestration. Prairie Forum 25:195-213.

Kallio, A., A. Moiseyev, Solberg. The global forest sector model EFI-GTM. European Forestry Institute. Internal Report No. 15.

Johnson, M., T. Williamson. 2005. Climate change implications for stand yields and soil expectation valves: A northern Saskatchewan case study. The Forestry Chronicle 81: 683-690.

Kasperson, J.X., R.E. Kasperson. 2001. International workshop on vulnerability and global environmental change. Stockholm Environment Institute.

Kellomäki, S. and S. Leinonen, editors. 2005. Management of European Forests Under Changing Climatic Conditions. Research Report 163, Faculty of Forestry, University of Joensuu. Joensuu, Finland. 21 p.

Kellomäki, S., S. Leinonen, eds. 2005. Management of European Forests Under Changing Climatic Conditions. Final Report of the Project "Silvicultural Response Strategies to Climatic Change in Management of European Forests" (SilviStrat) funded by the European Union under the Contract EVK2-2000-00723. European Forestry Institute, Joensuu, Finland.

Keyser, A., J. Kimball, R. Nemani, and S. Running. 2000. Simulating the effects of climate change on the carbon balance of North American high-latitude forests. Global Change Biology 6:185-195.

Kimmins, H..P. 1990. Modeling the sustainability production and yield for a changing and uncertain times. The Forestry. Chronicle 66: 271-280.

Kimmins, H.P, D. Mailly, B. Seely. 1999. Modelling forest ecosystem net primary production: the hybrid approach simulation approach used in FORCAST. Ecological modelling 122: 195-224.

Kingdon, J. 1995. Agendas, alternates, and public policies. 2nd ed. Boston: Little Brown.

Kirschbaum, M.U.F. 2000. Forest growth and species distribution in a changing climate. Tree Physiology 20:309–322.

Kochy, M. and S.D. Wilson. 2001. Nitrogen deposition and forest expansion in the northern Great Plains. Journal of Ecology 89: 807-817.

Korner, C., R. Asshoff, O. Bignucolo, S. Hattenschwiler, S.G. Keel, S. Pelaez-Riedl, S. Pepin, R.T.W. Siegwolf and G. Zotz. 2005. Carbon flux and growth in mature deciduous forest trees exposed to elevated CO_2. Science 309: 1360-1362.

Kozav R. 2005. Research and resource-dependent communities: A world of possibilities. B.C. Journal of Ecosystems and Management 6:55-62.

Kneeshaw, D., Y. Bergeron. 1998. Canopy Gap characteristics and tree replacement in the southeastern boreal forest. Ecology. 71: 783-794.

Knorr, W., I.C. Prentice, J.I. House and E.A. Holland. 2005. Long-term sensitivity of soil carbon turnover to warming. Nature 433: 298-301.

Kulshreshtha, S., M. Johnston, S. Lac. 2003. Value of stored carbon in protected areas: A case study of Saskatchewan Provincial Parks. Prairie Forum 28:127-144.

Kusel, J. 1996. Well-being in forest-dependent communities. Part I: A new approach. Sierra Nevada Ecosystem Project: Final Report to Congress. No 39. Wildland Resources Center Report. University of California Press, Davis.

Lamothe and Periard Consultants. 1988. Implications of climate change for downhill skiing in Quebec. Climate Change Digest CCD 88-03. Downsview, Ontario: Atmospheric Environment Service, Environment Canada.

Landsberg, J. 2003. Modelling forest ecosystems: state of the art, challenges and future directions. Canadian Forest Research Journal 33: 385-397.

Laprise, R., D. Caya, A. Frigon and D. Paquin. 2003. Current and perturbed climate as simulated by the second-generation Canadian Regional Climate Model (CRCM-II) over northwestern North America. Climate Dynamics 21: 405-421.

Lavender, D.P., R. Parish, C.M Johnson, G. Montgomery, A. Vyse, R.A. Willis and D. Winston (eds.). 1990. Regenerating British Columbia's Forests. Univ. British Columbia Press, Vancouver, BC.

Ledig, F.T and J.H. Kitzmiller. 1992. Genetic strategies for reforestation in the face of global climate change. Forest Ecology and Management 50:153–169.

Le Goff, H., A. Leduc, Y. Bergeron, M. Flannigan. 2005. The adaptive capacity of forest management to changing fire regimes in the boreal forest of Quebec. The Forestry. Chronicle.81: 4.582-592.

Lemieux, C. and D. Scott. 2005. Climate change, biodiversity conservation and protected areas planning in Canada. The Canadian Geographer, 49 (4).

Lemieux, C., D. Scott, R. Davidson, and R. Davis. 2005(in press).Climate Change and Ontario's Provincial Parks: A Scoping Report. Ontario Ministry of Natural Resources: Peterborough, Ontario.

Lemieux, C.J., D.J. Scott and R. Davis. 2005. A preliminary analysis of potential impacts and implications for policy, planning and management. *In* Rehbein, C., J.G. Nelson, T.J. Beechey and R.J. Paine. Parks and Protected Areas Research in Ontario 2005. Proceedings of the Parks Research

Forum of Ontario (PRFO) 2004 Annual General Meeting. pp. 83-104. Parks Research Forum of Ontario. Waterloo, Ontario.

Lemprière T, M. Johnston, A. Willcocks, B. Bogdanski, D. Bisson, M. Apps, Bussler. 2002. Saskatchewan forest carbon sequestration project. The Forestry Chronicle 78: 843-849.

Lenihan, J. and R. Neilson. 1995. Canadian vegetation sensitivity to projected climatic change at three organizational levels. Climatic Change 30: 27-56.

Lescop-Sinclair, K., S. Payette. 1995. Recent advance of the arctic treeline along the eastern coast of Hudson Bay. Journal of Ecology. 83. 929-936.

Li, C., M. Flannigan, I. Corns. 2000. Influence of potential climate change on forest landscape dynamics of west-central Alberta. Canadian Journal of Forest Research 30:1905-1912.

Lipski, S., and G. McBoyle. 1991. The impact of global warming on downhill skiing in Michigan. The East Lakes Geographer, 26, 37-51.

Lin, N. 2001. Building a network theory of social capital. In Social capital, theory and research, eds Lin, Cook, and Burt. Aldine de Gruyter, NY.

Lindner, M., B. Sohngen, L.A. Joyce, D.T. Price, P.Y. Bernier, T. Karjalainen. 2002. Integrated forestry assessments for climate change impacts. Forest Ecology and Management 162: 117-129.

Liu, J., C. Peng, M. Apps, Q. Dang, E. Banfield and W. Kurz. 2003. Historic carbon budgets of Ontario's forest ecosystems. Forest Ecology and Management 169:103-114.

Liu, J., D. T. Price, J. M. Chen, 2005. Nitrogen controls on ecosystem carbon sequestration: a model implementation and application to Saskatchewan, Canada. Ecological Modelling, 186(2): 178-195.

Loomis, J., and J. Crespi. 1999. Estimated effects of climate change on selected outdoor recreation activities in the United States. In R. Mendelsohn and J.E. Neumann (Eds.), *The impact of climate change on the United States economy* (pp. 289-314). Cambridge, UK: Cambridge University Press.

Long, S.P., E.A. Ainsworth, A. Rogers and D.R. Ort. 2004. Rising atmospheric carbon dioxide: Plants FACE the future. Annual Review of Plant Biology 55: 591-628.

Lopoukhine, N. 1990. National parks, ecological integrity, and climate change. In Climatic change: implications for water and ecological resources. G. Wall and M. Sanderson (eds). Department of Geography, University of Waterloo. Waterloo, Ontario. Occasional Paper No. 11: 317–328.

Lovejoy, T.E. and L. Hannah (eds.). 2005. Climate Change and Biodiversity. Yale University Press. New Haven. 418 p.

Lu, P., D.G. Joyce, R.W. Sinclair. 2003. Seed source selection of eastern white pine. Applied research and development, Ontario Ministry of Natural Resources, Forest Research Report Note. 64. 4 pp.

Luckert, M., T. Williamson. 2005. Should sustained yield be part of sustainable forest management? Canadian Journal of Forest Research 35: 356-364.

MacKendrick, N.A., J.R. Parkins. 2004**.** Frameworks for assessing community sustainability: A synthesis of current research in British Columbia. Natural Res. Ca., Can. For. Serv., Inf. Rep. NOR-X-392.

Mäkipää R., T. Karjalainen, A. Pussinen, S. Kellomäki. 1999. Effects of climate change and nitrogen deposition on the carbon sequestration of a forest ecosystem in the boreal zone. Canadian Journal Forest Research: 29:1490-1501.

Malcolm, J., D. Puric-Mladenovic and H. Shi. 2004. A Climate Change Atlas for 134 Forest Tree Species of Ontario, Canada. Accessed online at: http://www.forestry.utoronto.ca/treeatlas/mainpage/main_page.htm [Accessed on 03.13.06].

Manitoba Conservation. 2002. Protecting and managing our future: Next Steps Priorities for Sustaining Manitoba's Forest. Manitoba Conservation, Forestry Branch, Winnipeg, Manitoba. Accessed online at www.gov.mb.ca/natres/forestry/index.html [Accessed on 03.13.06].

Manning W.J., A. von Tiedemann. 1995. Climate change: potential effects of increased atmospheric carbon dioxide, ozone and ultra violet –B radiation on plant diseases. Environ. Pollut. 88: 219-245.

Markham, A. 1996. Potential impacts of climate change on ecosystems: a review of implications for policymakers and conservation biologists. Climate Research 6: 179-191.

Matthews, R. 2003. Using a social capital perspective to understand social and economic development. Horizons. 6(3):25-34.

Matthews, R., R. Cote. 2005. Understanding Aboriginal policing in a social capital context. Unpublished manuscript.

McAndrew, J. 2005. Woodlands hold the Island together. Report to the Minister of Environment, Energy and Forestry. Public Forest Council. March 2005, 37 pp.

McCarty, J. 2001. Ecological consequences of recent climate change. Conservation Biology 15: 320-331.

McBoyle, G., G. Wall, K. Harrison, and C. Quinlan. 1986. Recreation and climate change: A Canadian case study, Ontario Geography, 23, 51-68.

McCurdy D.M. and Stewart, B. 2003. A discussion paper on climate change and forestry in Nova Scotia: Ecological implications and management options Forest Research Report Nova Scotia Department of Natural Resources, Forest Management Planning no. 71 November 2003.

McDaniels, T., L.J. Axelrod, P. Slovic. 1996. Perceived ecological risks of global change: a psychometric comparison of causes and consequences. Global Environmental Change. 6(2):159-171.

McDonald, K.C., J.S. Kimball, E. Njoku, R. Zimmermann and M. Zhao. 2004. Variability in springtime thaw in the terrestrial high latitudes: monitoring a major control on the biospheric assimilation of atmospheric CO_2 with spaceborne microwave remote sensing. Earth Interactions 8, paper no. 20, online at http://EarthInteractions.org.

Mcelrone R., A. Reid, C. Hoye, K. Hart, R. Jackson. 2005 Elevated CO2 reduces disease incidences and severity of a red maple fungal pathogen via change in host physiology and leaf chemistry. Global Change Biology 11: 1828-1836.

McGuire A.D., J.M. Melillo, L.A. Joyce, D.W. Kicklighter, A.L. Grace, B. Moore III, C.J. Vorosmarty. 1992. Interactions between carbon and nitrogen dynamics in estimating net primary productivity for potential vegetation in North America. Global Biogeochemical Cycles 6:101-124.

McGuire A.D., L.A. Joyce, D.W. Kicklighter, J.M. Melillo, G. Esser, C.J. Vorosmarty. 1993. Productivity response of climax temperate forests to elevated temperature and carbon dioxide: A North American comparison between two global models. Climate Change. 24:287-310.

McGuire, A.D., D.W. Kicklighter J.M. Melillo. 1996. Global climate change and carbon cycling in grasslands and conifer forests. In Global Change: Effect on Coniferous Forests and Grasslands (eds Melillo JM, Breymeyer AI), SCOPE volume chapter.

McKendry, P. 2002. Energy production from biomass (part 1): Overview of biomass. Bioresource Technology 83:37-46.

McKenney, D.W., M.F. Hutchinson, P. Papadopol and D.T. Price. 2004. Evaluation of Alternative Spatial Models of Vapour Pressure in Canada. Paper 6.2 in Proceedings, 26th Agricultural and Forest Meteorology Conference, American Meteorology Society, Vancouver, BC, 22-26 August, 2004.

McKinnon, G., S. Kaczanowski. 2003. Climate change and forests: making adaptation a reality: Setting the stage. Proceedings from the workshop Climate Change and Forests: Making Adaptation a Reality, Winnipeg, Manitoba, November 18-19, 2003.

McKinnon, G., S. Webber. 2005. Climate change impacts and adaptation in Canada: Is the forest sector prepared? The Forestry Chronicle. 81:5.653-654.

McKinnon, G., S.L. Webber, N.A. MacKendrick. 2003. Climate Change in Western and Northern Forests of Canada: Impacts and Adaptation. Workshop in Prince George, BC-February 17-19.

McKinnon, G.A., S.R.J. Sheppard. 2005. Facilitating dialogue and action on climate change in British Columbia’s forest sector. An overview of expected impacts and highlights of a discussion at the Faculty of Forestry, University of British Columbia, December 13, 2004.

McLaughlin, J. 2004. Carbon assessment in Boreal wetlands of Ontario. Ontario Forest Research Institute, Forest Research Information paper.158. 79 pp.

McNulty, S.G. and J.D. Aber. 2001. US national climate change assessment on forest ecosystems: an introduction. BioScience 51: 720-722.

McNulty, S., J. Moore, L. Iverson, A. Prasad, R. Abt, B. Smith, G. Sun, M. Gavazzi, J. Bartlett, B. Murray, R. Mickler and J. Aber. 2000. Application of linked regional scale growth, biogeography, and economic models for southeastern United States pine forests. World Resources Review 12: 298-320.

Melillo J.M., A. D. McGuire, D.W. Kicklighter, B. Moore III, C.J. Vorosmarty, A.L. Schloss. 1993. Global climate change and terrestrial net primary production. Nature. 363: 234-240.

Mendelsohn, R., M. Markowski. 1999. The impact of climate change on outdoor recreation. In Mendelsohn, R. and J.E. Newman. The impact of climate change on the United States economy. Cambridge University Press.

Mendelsohn,R., M. Schlesinger and Williams. 2000. Comparing impacts across climate models. Integrated Assessment 1: 37-48.

Morgenstern, K., T.A. Black, E.R. Humphreys, T.J. Griffis, G.B. Drewitt, T. Cai, Z. Nesic, D.L. Spittlehouse and N. J. Livingston. 2004. Sensitivity and uncertainty of the carbon balance of a Pacific Northwest Douglas-fir forest during an El Niño/La Niña cycle. Agricultural and Forest Meteorology. 123:201-219.

Moore, R.D., D. Spittlehouse, A. Story. 2005. Riparian microclimate and stream temperature response to forest harvesting – A review. Journal of American Water Resources Assoc. (in press)

Mote P., E. Parson, A. Hamlet, W. Keeton, D. Lettenmaier, N. Mantua, E. Miles, D. Peterson, D. Peterson, R. Slaughter, A. Snover. 2003. Preparing for climate change: The water, salmon and forests of the Pacific Northwest. Climatic Change 61: 45-88

Mote, P.W. E.A. Parson, A.F. Hamlet, K.N. Ideker, W.S. Keeton, D.P. Lettenmaier, N.J. Mantua, E.L. Miles, D.W. Peterson, D.L. Peterson, R. Slaughter and A.K. Snover. 2003. Preparing for climate change: The water, salmon and forests of the Pacific Northwest. Climatic Change 61:45-88.

Nakicenovic, N. and R. Swart, editors. 2000. Special Report on Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, U.K., 599 pp. Available online at: http://www.grida.no/climate/ipcc/emission/index.htm

Natural Resources Canada. 2001. A change in the wind - Climate change in Quebec. Geological Survey of Canada, Miscellaneous Report 78, 2001. Poster with text.

Natural Resources Canada. 2004. Climate change impacts and adaptation: A Canadian perspective. Climate Change Impacts and Adaptation Directorate, Natural Resources Canada. Ottawa.

Natural Resources Canada. 2005. The state of Canada's forests: 2004-2005: The Boreal Forest. Ottawa.

Neilson, R. 1995. A model for predicting continental-scale vegetation distribution and water balance. Ecological Applications 5: 362-385.

Nicholls, S. and D. Scott. (in press). Implications of Climate Change for Outdoor Recreation in North America. Journal of Leisure Research. 41p.

Nielsen, C. 2003. A review of seedwhere: toward developing a protocol for its application within Southcentral Ontario. Southcentral Science and Information Technical note. 7. 18 pp.

Noble, D., J. Bruce, and M. Egener. An overview of the risk management approach to adaptation to climate change in Canada. Gloval Change Strategies International March 2005. www.gcsi.ca

Norby, R.J., E.H. DeLucia, B. Gielen, C. Calfapietra, C.P. Giardina, J.S. King, J. Ledford, H.R. McCarthy, D.J.P. Moore, R. Ceulemans, P. De Angelis, A.C. Finzi, D.F. Karnosky, M.E. Kubiske, M. Lukac, K.S. Pregitzer, G.E. Scarascia-Mugnozza, W.H. Schlesinger and R. Oren. 2005. Forest response to elevated CO_2 is conserved across a broad range of productivity. Proceedings of the National Academy of Sciences 102: 18052–18056.

Noss, R. 2001. Beyond Kyoto: Forest management in a time of rapid climate change. Conservation Biology 15.3: 578-590

Ohlson, D., G. McKinnon, K. Hirsch. 2005. A structured decision-making approach to climate change adaptation in the forest sector. The Forestry Chronicle. 81: 97-103.

O'Neil, G. and A. Yanchuk. 2005. Seed transfer and climate change. Ministry of Forest and Range, Province of British Columbia. Accessed online March 13, 2006 at: http://www.for.gov.bc.ca/hre/forgen/seedtransfer/seedtransfer.htm

Ontario Ministry of Natural Resources (OMNR). 2004. Forest Management Planning Manual for Ontario's Crown Forests. Queen's Printer for Ontario, Toronto, ON.

Oren, R., D. Ellsworth, K. Johnsen, N. Phillips, B. Ewers, C. Maier, K. Schafer, H. McCarthy, G. Hendrey, S. McNulty and G. Katul. 2001. Soil fertility limits carbon sequestration by forest ecosystems in a CO_2-enriched atmosphere. Nature 411: 469-472.

O'Riordan, T., C. Cooper, A. Jordan, S. Rayner, K. Richards, R. Runci and S. Yoffee. 1998. Institutional frameworks for political action. In Human Choice and Climate Change. Volume 1: The societal framework. S. Rayner and E. Malone, eds. Battelle Press: Columbus, OH. 345-429.

Overpeck, J., J. Cole and P. Bartlein. 2005. A "Paleoperspective" on Climate Variability and Change. *In* Lovejoy, T.E. and L. Hannah (eds.). Climate Change and Biodiversity. pp. 91-108. Yale University Press. New Haven.

Pan Y., J. Melillo, A. McGuire, D. Kicklighter, L. Pitelka, K. Hibbard, L. Pierce, S. Running, D. Ojima, W. Parton, D. Schimel. 2000. 1995. Vegetation/ecosystem modeling and analysis project: Comparing biogeography and biogeochemistry models in a continental-scale study of terrestrial ecosystem responses to climate change and CO2 doubling. Global Biogeochemical Cycles. 4: 407-437.

Parker W., S. Colombo, M. Cherry, M. Flannigan, S. Greifenhagen, R. McAlpine, C. Papadopol, T. Scarr. 2000. Third millennium forestry: what climate change might mean to forests and forest management in Ontario. The Forestry Chronicle 76: 445-463.

Parks Canada Webpage. http://www.pc.gc.ca/docs/v-g/ie-ei/cc/balance_E.asp

Parks Canada. 1997. National Parks System Plan. Minister of Canadian Heritage. Ottawa, Ontario. n.p.

Parks Canada. 2003. State of Protected Heritage Areas. Parks Canada Agency. Ottawa, Ontario. 89 p.

Parisien, M.A., K.G. Hirsch, S.G. Lavoie, J.B. Todd and V.G. Kafka. 2004. Saskatchewan Fire Regime Analysis. Information Report NOR-X-394, Northern Forestry Centre, Canadian Forest Service, Natural Resources Canada. Edmonton, AB. 61 p.

Parisien, M.A., V.G. Kafka, K.G. Hirsch, B.M. Todd, S.G. Lavoie, P.A. Maczek. *In press*. BURN-P3: a tool for mapping wildfire susceptibility. Canadian Forest Service Information Report.

Parmesan, C. and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 421: 37-42.

Parton, J., M. Roddick, M. Woods. 2003. The carbon budget of Ontario's forests: Phase 1: The carbon stocks of Ontario's managed forest lands 1990-The monitoring network. Ministry of Natural Resources, Ontario Forest Research Institute Applied Research and Development-Forest Research note. 63. 4 pp.

Parson, Corell, Barron, Burkett, Janetos, Joyce, Karl, Maccracken, Melillo, Morgan, Schimel, Wilbanks. 2003. Understanding climate impacts, vulnerabilities, and adaptation in the United States: Building a capacity for assessment. Climatic Change 57:9-42

Patriquin, M., J. Alavalapati, A. Wellstead, W. White. 2003**.** A computable general equilibrium model of the Foothills Model Forest economy. Canadian Journal of forest Research. 33:147-155.

Patriquin, M., S. Heckbert, C. Nickerson, M. Spence, W. White. 2005. Regional economic implications of the mountain pine beetle infestation in the Northern Interior Forest Region of British Columbia. Mountain Pine Beetle Initiative Working Paper 2005-3. Natural Resources Canada, Victoria, BC.

Payette, S., M. Fortin. I. GamacheI. 2001. The Subarctic Forest-Tundra: The Structure of a Biome in a Changing Climate. BioScience Vol. 51: 9. 709-718.

Peng, C., J. Liu, M. Apps, Q. Dang and W. Kurz. 2000. Quantifying Ontario's forest carbon budget-carbon stocks and fluxes of Forest Ecosystems in 1990. Ontario Forest Research Institute, Ministry of Natural Resources. 158. 20 pp.

Peng, C., J. Liu, Q. Dang, X. Zhou, M. Apps. 2002. Developing and carbon-based ecological indicators to monitor sustainability of Ontario's forests. Ecological Indicators 1: 235-246.

Peng,C., Q. Dang, J. Liu, X. Zhou, J. Chen. 2003. Developing and testing a dynamic forest carbon budget model for Ontario. Ontario Forest Research Institute, Forest Research Information paper. 65. 4 pp.

Perez-Garcia, J., L.A. Joyce, A.D. McGuire, X. Xiao. 2002. Impacts of climate change on the global forest sector. Climatic Change. 54:439-461.

Peters, R. and J. Darling. 1985. The greenhouse effect and nature reserves. Bioscience 35 (11): 707-716.

Peterson, G., G. Alessandro De Leo, J. Hellmann, M. Janssen, A. Kinzig, J. Malcolm, K. O'Brien, S. Pope, D. Rothman, E. Shevliakova, R. Tinch. 1997. Uncertainty, climate change, and adaptive management. Conservation Ecology. 1:2. http://www.ecologyandsociety.org/vol1/iss2/art4/

Pojar, J., K. Klinka and D.V. Meidinger. 1987. Biogeoclimatic ecosystem classification in British Columbia. Forest Ecology and Management 22:119-154.

Pollard, D.F.W. 1991**.** Forestry in British Columbia: planning for the future climate today. The Forestry Chronicle 67:336–341.

Preston, C., J. Trofymow. 2000. Variability in litter quality and its relationship to litter decay in Canadian Forests. Canadian. Journal of Botany. 78: 1269-1287.

Price, D.T., M.D. Flannigan. 2000. Assessing the impact of climate change on forests and forestry using climate scenarios. In: T. Carter, M. Hulme, W.A. Cramer and R. Doherty (eds.) Climate Scenarios for Agricultural, Ecosystem and Biological Impacts, ECLAT-2 Second Workshop Report, Climate Research Unit, University of East Anglia, Norwich, U.K., pp 32–49.

Price, D., M. Halliwell, J. Apps, W. Kurz, Curry. 1997. Comprehensive assessment of carbon stocks and fluxes in a Boreal Cordilleran forest. Canadian Journal of Forest Research 27. 2005-2016

Price, D.T., D.W. McKenney, I.A. Nalder, M.F. Hutchinson, J.L. Kestevan. 2000. A comparison of statistical and thin-plate spline methods for spatial interpolation of Canadian monthly mean climate data. Agricultural and Forest Meteorology 101: 81–94.

Price, D.T., D.W. McKenney, P. Papadopol, T. Logan and M. F. Hutchinson. 2004. High Resolution Future Scenario Climate Data for North America. Paper 7.7 in Proceedings, 26th Agricultural and Forest Meteorology Conference, American Meteorology Society,Vancouver, BC, 22-26 August, 2004.

Price, D.T., N.E. Zimmermann, P.J. van der Meer, M.J. Lexer, P. Leadley, J. Jorritsma, I.T.M. Schaber, D.F. Clark, P. Lasch, S. McNulty, J. Wu, B. Smith B. 2001. Pattern and process of regeneration in gap models: Priority issues for studying forest responses to climate change. Climatic Change 51: 475-508.

Putnam, R. 2000. Bowling alone: The collapse and revival of American community. Simon and Schuster, New York.

Raulier, F., D. Pothier and P. Bernier. 2003. Predicting the effect of thinning on growth of dense balsam fir stands using a process-based tree growth model. Canadian Journal of Forest Research 33: 509-520.

Rehfeldt, G.E., W.R. Wykoff, C.C. Ying. 2001. Physiological plasticity, evolution, and impacts of a changing climate on *Pinus contorta*. Climatic Change 50: 355-376.

Rehfeldt G., C. Ying, D. Spittlehouse, D. Hamilton Jr. 1999. Genetic responses to climate for *Pinus contorta*: niche breadth, climate change and reforestation. Ecological Monographs 69: 375-407.

Richardson, R.B., and J.B. Loomis. 2005. Effects of climate change on tourism demand and benefits in alpine areas. In C.M. Hall & J. Higham (Eds.), Tourism, recreation and climate change (pp. 164-180). Cleveland, UK: Channel View Publications.

Rizzo, B. and E. Wiken. 1992. Assessing the sensitivity of Canada's ecosystems to climatic change. Climatic Change 21: 37-55.

Root, T., J. Price, K. Hall, S. Schneider, C. Rosenzweig and J.A. Pounds. 2003**.** Fingerprints of global warming on wild animals and plants. Nature 421: 57-60.

Rosenbaum, K.L., D. Schoene and A. Mekouar. 2004 Climate change and the forest sector. Possible national and subnational legislation. Food and Agriculture Organization of the United Nations. Rome, 2004. FAO Forestry Paper 144.

Ruel, J. 1995. Understanding windthrow: Silvicultural implications. The Forestry. Chronicle. 7: 434-445.

Rustad, L., J. Campbell, G. Marion, R.J. Norby, M.J. Mitchell, A.E. Hartley, J.H.C. Cornelissen, and J. Gurevitch. 2001. A meta-analysis of the response of soil respiration, net nitrogen mineralization, and aboveground plant growth to experimental ecosystem warming. Oecologia 126: 543-562.

Sapporta, R., J.R. Malcolm, D.L. Martell. 1998. The impact of climate change on Canadian forests; in Responding to Global Climate Change: National Sectoral Issue. Environment Canada, Canada Country Study: Climate Impacts and Adaptation, (ed.) G. Koshida and W. Avis. Winter 2001. CO2/Climate Report A Periodical Newsletter Devoted to the Review of Climate Change Research (Environment Canada) VII. 319-382. http://dsp-psd.communication.gc.ca/Collection/En56-119-6-1998E

Sauchyn, D.J. J. Stroich and A. Beriault. 2003. A paleoclimatic context for the drought of 1999–2001 in the northern Great Plains of North America. The Geographical Journal 169: 58-167.

Scheraga, J.D., A.E. Grambsch. 1998. Risks, opportunities and adaptation to climate change. Climate Research. 10:85-95.

Schmitz, O.J., E. Post, C.E. Burns and K.M. Johnston. 2003. Ecosystem responses to global climate change: moving beyond color mapping. Bioscience 53(12): 1199-1205.

Schindler, D.W. 1998. Sustaining aquatic ecosystems in boreal regions. Conservation Ecology (online) 2(2): 18. http://www.consecol.org/vol2/iss2/art18/

Schindler, D.W. 2001. The cumulative effects of climate warming and other human stresses on Canadian freshwaters in the new millennium. Can. J. Fish.Aquat. Sci. 58-18-29.

Schnorbus, M., Y. Alila, J., Beckers, D.L., Spittlehouse, R.D. Winkler. 2006. Peak flow regime changes following forest harvesting in a snow-dominated basin: An exploratory analysis using numerical modeling. Water Resources Res. (submitted).

Schroter, D., W. Cramer, R. Leemans, I.C. Prentice, M.B. Araujo, N.W. Arnell, A. Bondeau, H. Bugmann, T.R. Carter, C.A. Gracia, A.C. de la Vega-Leinert, M. Erhard, F. Ewert, M. Glendining, J.I. House, S. Kankaanpaa, R.J.T. Klein, S. Lavorel, M. Lindner, M.J. Metzger, J. Meyer, T.D. Mitchell, I. Reginster, M. Rounsevell, S. Sabate, S. Sitch, B. Smith, J. Smith, P. Smith, M.T. Sykes, K. Thonicke, W. Thuiller, G. Tuck, S. Zaehle, B. Zierl. 2005. Ecosystem service supply and vulnerability to global change in Europe. Science 310: 1333-1337.

Schwartz R., P. Deadman, D. Scott. L. Mortsch. 2004. GIS modeling of climate change impacts on a Great Lakes shoreline community, Journal of the American Water Resources Association, 40 (3), 647-662.

Scott, D. 2005 (in press). Ski Industry Adaptation to Climate Change: Hard, Soft and Policy Strategies. In: Tourism and Global Environmental Change. S. Gossling and M. Hall (eds). London: Routledge.

Scott, D. 2005 (in press). Global environmental change and mountain tourism. In: Tourism and Global Environmental Change. S. Gossling and M. Hall (eds). London: Routledge.

Scott, D. 2005. Integrating climate change into Canada's national parks system. . In: Climate Change and Biodiversity. T. Lovejoy and L. Hannah (eds.). New Haven, CT: Yale University Press. 343-345.

Scott, D.(Contributing Author). 2004. Indicators of Sustainable Development for Tourism Destinations: A Guidebook. Madrid: World Tourism Organization. Author: Case Study 6.15 'Keep Winter Cool': Tourism Sector Greenhouse Gas Mitigation, 400-01. Author: Box 3.28 Snowmaking as an Adaptation to Climate Variability and Change, 160. Contributor to: 3.8.2 Climate Change and Tourism, 155-164.

Scott, D. 2004. Climate change and conservation challenges at the science management interface. Proceedings of the 5th International Conference of Science and Management Protected areas. N. Munroe, T. Herman, P. Dearden (eds.) 11-16 May, Victoria, B.C.

Scott, D and B. Jones. 2005. Climate Change & Banff National Park: Implications for Tourism and Recreation. Report prepared for the Town of Banff. Waterloo, ON: University of Waterloo.
Scott, D. and R. Suffling. 2000**.** Climate Change and Canada's National Parks, Environment Canada. Toronto, Ontario. 183 p.

Scott, D., C. Lemieux. 2005. Climate change and protected area policy and planning in Canada. The Forestry Chronicle.81: 696-703.

Scott, D., C. Lemieux. 2003. Vegetation response to climate change: Implications for Canada's Conservation Lands. Parks Canada. Technical Report in Ecosystem Science. Parks, Ottawa, ON. Canada. 51 pp.

Scott, D.J., J. Malcolm and C.J. Lemieux. 2002. Climate change and modeled biome representation in Canada's national park system: implications for system planning and park mandates. Global Ecology and Biogeography 11(6): 475-485.

Scott, D., G, McBoyle, B. Mills, A. Minogue. (in press – July 2006). Climate change and the sustainability of ski-based tourism in eastern North America. Journal of Sustainable Tourism. Jones, B. and Scott, D. (in press – Dec 2005) Climate Change, Seasonality and Visitation to Canada's National Parks. Journal of Parks and Recreation Administration.

Scott D., G. McBoyle, M. Schwarzentruber. 2004. Climate change and the distribution of climatic resources for tourism in North America. Climate Research, 27, 105-117.

Scott D., G. Wall, G. McBoyle. 2005. The Evolution of the Climate Change Issue in the Tourism Sector. In: Tourism, Recreation and Climate Change. M. Hall and J. Higham (eds). London: Channelview Press. 44-60.

Shugart, H.H. 1998. Terrestrial Ecosystems in Changing Environments. Cambridge University Press, Cambridge. 537 pp.

Sieben, B., D.L. Spittlehouse, J.A. McLean, and R.A. Benton. 1997. White pine weevil hazard under GISS climate change scenarios in the Mackenzie Basin using radiosonde derived lapse rates. In: S. Cohen (ed.), Mackenzie Basin Impact Study (MBIS) - Final Report. Atmospheric Environment Service-Environment Canada, Downsview, Ontario, Canada, pp. 166-175.

Slovic, P. 2000. The perception of risk. Earthscan, London, UK.

Smit, B., D. McNabb and J. Smithers. 1996. Agricultural adaptation to climate change. Climatic Change 33: 7-29.

Smit, B., I. Burton, R.J.T. Klein and J. Wandel. 2000. An anatomy of adaptation to climate change and variability. Climatic Change 45: 223-251.

Smit, B. and O. Pilifosova. 2002. From adaptation to adaptive capacity and vulnerability reduction. In: Enhancing the Capacity of Developing Countries to Adapt to Climate Change. S. Huq, J. Smith, R.T.J. Klein (eds.), Imperial College Press, London, Chapter 2, pp. 1-19.

Smit, B. and O. Pilifosova (ed.). 2001. Adaptation to Climate Change in the Context of Sustainable Development and Equity. Chapter 18 in Climate Change 2001: Impacts, Adaptation, and Vulnerability, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change [McCarthy, J.J., O.F. Canziani, N.A. Leary, D.J. Dokken and K.S. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA.

Smith, J.B. 1997. Setting priorities for adaptation to climate change. Global Environmental Change 7: 251-264.

Smith. V.K. 1982. Economic impact analysis and climate change: a conceptual introduction. Clim Change 4:5-22.

Sohngen, B. 2004. Impacts of climate change on North American forest products markets. Presentation at the joint CIF/SAF Annual General Meetings held at Edmonton, October, 2004.

Sohngen, B. R., R. Mendelsohn. 2001. A global model of climate change impacts on timber markets. Journal of Agriculture and Resource Economics 26: 326-343.

Sohngen, B., R. Sedjo. 2005. Impacts of climate change on forest product markets: Implications for North American producers. The Forestry Chronicle. Vol. 81: 669-674.

Sohngen, B., R. Sedjo, R. Mendelsohn, K. Lyon. 1996. Analyzing the economic impact of climate change on global timber markets. Discussion paper 96-08. Resources for the Future.

Spittlehouse, D.L. 1991. Can we manage resources for climate change? In: Reclamation and Sustainable Development, B.C. Tech. Comm. Res. Recl. & Can. Land Recl. Assoc., B.C. Min. Energy, Mines Nat. Resour., Victoria, B.C., pp. 125-133.

Spittlehouse, D. 1996. Assessing and Responding to the effect of climate change on forest ecosystems. High-Latitude Rain Forests and Associated Ecosystems of the West Coast of the Americas ed. Richard Clawford *et al*. pp. Springer-Verlag, New York, Inc. pp. 306-319.

Spittlehouse, D.1997. Forest Management and Climate Change. Responding to global climate change in British Columbia and Yukon. Contribution to the Canada Country Study: Climate Impacts And Adaptation" Workshop, Feb 27-28, 1997. ISBN 0-660-16869-3. Environment Canada.

Spittlehouse, D.L. 1999. The Kyoto Forest – risks and opportunities in forest carbon credits. In: Proceedings Greenhouse Gas Emissions Trading and Reduction in Alberta's Forest Products Industry, 15 June 1999 Whitecourt, AB, Boreal Woods Centre, Manning AB, tab 5, pp.1-5.

Spittlehouse, D.L. 2001. Evaluating and managing for effects of future climates on forest growth. In: Workshop on Adapting Forest Management to Future Climate, 25-26 Jan. 2001 Prince Albert, SK, PARC and Prince Albert Model.

Spittlehouse, D.L. 2002. Carbon credits. Canadian Silviculture, Fall issue pp. 10-13.

Spittlehouse, D. 2003. Water availability, climate change and growth of Douglas-fir in the Georgia Basin. Canadian Water Resources. 28: 673-688.

Spittlehouse, D.L. 2004. The climate and long-term water balance of Fluxnet Canada's coastal Douglas-fir forest. Proc. 26th Conference on Agricultural and Forest Meteorology, 23-26 August 2004, Vancouver, BC, American Meteorological Society, Boston, MA, P1.42, 6 pp.

Spittlehouse, D.L. 2005. Climate change impacts and adaptation in forestry. In: Climate Change and Forest Genetics, Proc.29th Meeting, Canadian Tree Improvement Assoc., part 2, Symposium, G.A. O'Neill and J.D. Simpson (eds) pp. 43-48.

Spittlehouse, D.L. 2005. Review of Global Climate Change and Human Impacts on Forest Ecosystems, J. Puhe and B. Ulrich, Ecological Studies, Vol. 143, Springer, Berlin, 2001. Agric. For. Meteorol. 128:132-133. doi:10.1016/j.agrformet.2004.08.001

Spittlehouse, D. L. 2005. Integrating climate change adaptation into forest management. The Forestry Chronicle 81: 691-695.

Spittlehouse, D.L. 2005. Adaptation to climate change in forestry management: challenges and responses. Proceeding of Implications of Climate Change in British Columbia's Southern Interior Forests, April 26–27, 2005, Revelstoke, BC, J. Morris (ed.), Columbia Mountain Institute, Revelstoke, BC. pp. 93-99. http://www.cmiae.org/pdf/ImpofCCinforestsfinal.pdf.

Spittlehouse, D.L. 2005. Adaptation to climate change in forestry. Proceedings of the Species at Risk 2004 Pathways to Recovery Conference. March 2–6, 2004, Victoria, BC, T.D. Hooper (ed.), Species at Risk 2004 Pathways to Recovery Conference Organizing Committee, Victoria, B.C. 5 pp. http://www.speciesatrisk2004.ca/html/searchform.html.

Spittlehouse, D. 2006. Climate BC: Your access to interpolated climate data for BC. Streamline Watershed Management Bulletin 9(2) (in press).

Spittlehouse, D.L., R.S. Adams and R.D. Winkler. 2004. Forest, edge, and opening microclimate at Sicamous Creek. BC Ministry of Forests, Victoria, BC, Res. Rep. 24.

Spittlehouse, D.L. and D.W.F. Pollard. (eds.) (1989). Climate change in British Columbia - Implications for the forest sector: Developing a framework for response. FRDA Rep. 075, B.C. Min. Forests, Victoria, B.C

Spittlehouse, D.L. and B. Sieben. 1994. Mapping the effects of climate on spruce weevil infestation hazard. In: Proceedings 21st. Conf. Agricultural and Forest Meteorology and 11th. Conf. Biometeorology and Aerobiology, American Meteorological Society, Boston, pp. 448-450.

Spittlehouse, D.L., B.G. Sieben and S.P. Taylor. 1994. Spruce weevil hazard mapping based on climate and ground surveys. In: The White Pine Weevil: Biology, Damage and Management, R.I. Alfaro, G. Kiss and G.R. Fraser (eds.), FRDA Rep. 226, B.C. Min. Forest, Victoria, pp. 23-32.

Spittlehouse, D.L., R. B. Stewart. 2003. Adapting to climate change in forest management. http://www.forrex.org/jem/2003/vol4/no1/art1.pdf. Printed version, Journal of Ecosystems and Management (2004) 4: 7-17.

Spittlehouse, D.L., R.D. Winkler. 2004. Snowmelt in a forest and clearcut. Proc. 72nd Western Snow Conference, Vancouver, BC. pp. 33-43.

Standing Senate Committee on Agriculture and Forestry. 2003. Climate change: we are at risk. Final Report, Government of Canada, Ottawa, Ont. Available on line at http://www.parl.gc.ca/37/2/parlbus/commbus/senate/com-e/agri-e/repe/repfinnov03-e.pdf

Statistics Canada. 2004a. National tourism indicators. Retrieved May 28, 2005, from http:// www.statcan.ca/Daily/English/040330/d040330a.htm.

Statistics Canada. 2004b. Trips by Canadians in Canada. Retrieved May 28, 2005, from http://www40.statcan.ca/l01/cst01/arts26a.htm.

Stedman, R.C., D. Davidson, and A.M. Wellstead. 2004. Risk and Climate Change: Perceptions of Key Policy Actors in Canada. Risk Analysis 24(5):1393-1404.

Stennes, B., E. Krcmar-Nozic, G.C. van Kooten. 1998. Climate Change and Forestry: What policy for Canada?. Sustainable Forest Management Network. Working Paper 1998-2.

Stewart, R., E. Wheaton, D. Spittlehouse. 1998. Climate Change: Implications for the Boreal Forest. SRC. Saskatchewan Research Council. SRC Publication No. 10442-4D98.

Stocks, B.J., M.A. Fosberg, T.J. Lynham, L. Mearns, B.M. Wotton, Q. Yang, J-Z. Jin, K. Lawrence, G.R. Hartley, J.A. Mason, and D.W. McKenney. 1998. Climate change and forest fire potential in Russian and Canadian boreal forests. Climatic Change 38:1–13.

Stromgren, M. and S. Linder. 2002. Effects of nutrition and soil warming on stemwood production in a boreal Norway spruce stand. Global Change Biology 8: 1195-1204.

Sturm, M., C. Racine, K. Tape. 2001. Increasing shrub abundance in the Arctic. Nature. 86. 546-547.

Suffling R. and D. Scott. 2002. Assessment of climate change effects on Canada's national park system. Environmental Monitoring and Assessment, 74, 117-139.

Tellis, W. 1997. Application of a case study methodology. The Qualitative Report. 3(3) downloaded on May 29 from http://www.nova.edu/ssss/QR/QR3-3/tellis2.html

Thompson I.D, M.D. Flannigan, Wotton and R. Suffling. 1998. The Effects of Climate Change on Landscape Diversity: an example in Ontario forests. Environmental Monitoring and Assessment. 49. 213-233.

Thomas, C.D., A. Cameron, R.E. Green, M. Bakkenes, L.J. Beaumont, Y.C. Collingham, B.F.N. Erasmus, M.F. de Siqueira, A. Grainger, L.Hannah, L. Hughes, B. Huntley, A.S. van Jaarsveld, G.F. Midgley, L. Miles, M.A. Ortega-Huerta, A.T. Peterson, O.L. Phillips and S.E. Williams. 2004. Extinction risk from climate change. Nature 427: 145-148.

Thonick, K. 2001. The fire module of the Lund-Potsdam-Jena Dynamic Global Vegetation Model. http://www.pik-potsdam.de/%7Ekirsten/fire_model.htm#fire_model.

Thormann, M., S. Bayley, R. Currah. 2004. Microcosm tests of the effects of temperature and microbial species number on the decomposition of *Carex aquatilis* and *Sphagnum fuscum* litter from southern boreal peatlands. Canadian Journal of Microbiology. 205: 793-802.

Thyer, M., J. Beckers, D.L. Spittlehouse, Y. Alila and R.D. Winkler. 2004. Diagnosing a distributed hydrologic model for two high elevation forested catchments based on detailed stand- and basin- scale data. Water Resources Res. 40, W01103, doi:10.1029/2003WR002414.

Timmer, V.R. and Y. Teng. 2003. Increasing Carbon Sequestration through Enhanced Stand Establishment Practices: Nursery nutrient loading. Applied research and development, Ontario Ministry of Natural Resources, Forest Research Report No. 161. 15 pp.

Tol, R.S. J. 1996. The damage costs of climate change towards dynamic representation. Ecological Economics 19:67-90.

Timoney, T. Environmentally Significant Areas Inventory of the Rocky Mountain Natural Region of Alberta.
http://www.cd.gov.ab.ca/preserving/parks/anhic/docs/esa_rocky_mountain.pdf

UNCBD (United Nations Convention on Biological Diversity). 1992. Convention on Biological Diversity. 5 June 1992.

UNFCCC (United Nations Framework Convention on Climate Change). 1997. Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC). FCCC/CP/1997/L.7/Add.1. Bonn, Germany.

Van Kooten, G.C., L.M. Arthur. 1989. Assessing economic benefits of climate change on Canada's boreal forest. Canadian Journal of Forest Research. 19:463-470.

Van Kooten C., E. Krcmar-Nozic, B. Stennes B, R. van Gorkom. 1999. Economics of fossil fuel substitution and wood. Canadian Journal of Forest Research. 29. 1669-1678.

Venier, L.A., A.A. Hopkin, D.W. McKenney and Y. Wang. 1998. A spatial, climatic-determined risk rating for Scleroderris disease in Ontario. Canadian Journal of Forestry Research 28:1398-1404.

Volney, W.J.A. and R.A. Fleming. 2000. Climate change and impacts of boreal forest insects. Agriculture, Ecosystems and Environment 82: 283-294.

Volney, W.J.A. and K.G. Hirsch. 2005. Disturbing forest disturbances. Forestry Chronicle 81: 662-668.

Walker, B., W. Steffen. 1997. An overview of the implications of global change for natural and managed ecosystems. Conservation Ecology. 1:2. (online) http://www.ecologyandsociety.org/vol1/iss2/art2/

Walker, D. 2000. Hierarchical subdivision of Arctic tundra based on vegetation response to climate, parent material and topography. Global Change Biology, 6: 19-34.

Wall, G. 1998. Impacts of climate change on recreation and tourism. Pages 591-620 in G. Koshida and W. Avis, eds. The Canada country study: climate impacts and adaptations. Vol. 7. National sectoral volume. Environ. Can., Environ. Adapt. Res. Group, Toronto, ON.

Wall, G. 1998. Implications of global climate change for tourism and recreation in wetland areas. Climatic Change, 40, 371-389.

Wall, G., and C. Badke. 1994. Tourism and climate change: An international perspective. Journal of Sustainable Tourism, *2*(4), 193-203.

Wall, G., R. Harrison, V. Kinnaird, G. McBoyle, and C. Quinlan. 1986. The implications of climatic change for camping in Ontario. Recreation Research Review, 13(1), 50-60.

Wang, G. 2005. Agricultural drought in a future climate: results from 15 global climate models participating in the IPCC 4th assessment. Climate Dynamics 25: 739–75

Wang, T., A. Hamann, D.L. Spittlehouse and S.N. Aitken. 2006. Development of scale-free climate data for western Canada for use in resource management. International Journal of Climatology 26: 383-397.

Warren, F.J. ed. D. S. Lemmon, F.J. Warren. 2004. Natural Resources Canada. 2005. Climate change and adaptations: A Canadian Perspective. Natural Resources Canada and Canadian Climate Impacts and Adaptation Research Network. 173 pp. http://adaptation.nrcan.gc.ca/perspective_e.asp

Weber, M.G., B.J. Stocks. 1998. Forest fires and sustainability in the boreal forests of Canada. Ambio 27: 545-550.

Wein R., J. Hogenbirk, B. McFarlane, A. Schwartz, R. Wright. 1990. Protection strategies for parks under predicted climate change. Parks. 1:17-22.

Welch, D. 2005. What should protected areas managers do in the face of climate change? The George Wright Forum. 22:75-93.

Wellstead, A., D. Davidson, and R. Stedman. 2004. Assessing prairie forest policy networks and policy oriented beliefs. Canadian Forest Centre. Canadian Forest Service Information Report NOR-X-395.

Whitney, R., R. Irwin. 2005. Comparison of Armillaria root disease on burned and unburned, harvested sites in Ontario. The Forest Chronicle. 6: 156-60.

Wilbanks, T. 2005. Issues in developing a capacity for integrated analysis of mitigation and adaptation. Environmental Science & Policy 8: 541-547.

Wilby, R.L., C.W. Dawson and E.M. Barrow. 2002. SDSM - a decision support tool for the assessment of regional climate change impacts. Environmental and Modelling Software 17: 145-157.

Williamson T., Hoscheit, Luttrell. 2002. Participation in outdoor recreation in forested ecoprovinces in Canada in 1996. Information Report NOR-X-385. Can. For. Serv., North. For. Cent., Natural Res. Can., Edmonton.

Williamson, T.B., G. Hauer, M.K. Luckert. 2004. A restricted Leontief profit function model of the Canadian lumber and chip industry: potential impacts of US countervail and Kyoto ratification. Canadian Journal of Forest Research. 34: 1833-1844.

Williamson, T.B., J.R. Parkins and McFarlane 2005. Perceptions of climate risk to forest ecosystems and forest-based communities. The Forestry Chronicle: 81: 710-715.

Winkler, R., D. Spittlehouse, T. Giles, B. Heise, G. Hope, M. Schnorbus. 2004. Upper Penticton Creek: How forest harvesting affects water quantity and quality. Streamline 8:18-20.

Winkler, R.D., D.L. Spittlehouse, D.L. Golding. 2005. Measured differences in snow accumulation and melt among clearcut, juvenile, and mature forests in Southern British Columbia. Hydrolog. Proc. 19:51-62.

Winnett, S.M. 1998. Potential effects of climate change on U.S. forests: a review. Climate Research. 11:39-49.

Woodley, S. J. and G. Forbes. 1995. Ecosystem management: principles, problems, and practicalities. *In* Herman, T., S. Bondrup-Neilsen, J. Willison and N. Munro. (eds.) Ecosystem Monitoring and Protected Areas. pp. 50-58. Science and Management of Protected Areas Association. Nova Scotia.

Woods, A., D. Coats, A. Hamann. 2005. Is an unprecedented Dothostroma needle blight epidemic related to climate change? BioScience. 55:9:761-769.

World Tourism Organization. 2004. *Tourism highlights edition 2004*. Madrid, Spain: World Tourism Organization. Retrieved May 28, 2005, from http://www.world-tourism.org/ facts/highlights/HIGHLIGHTS%20INGLES%2020041.pdf.

Wotton B, L. Martell, K. Logan. 2003. Climate change and people-caused forest fire occurrence in Ontario. Climatic Change 6:275-295.

WWF (World Wildlife Fund). 2003. No Place to Hide: Effects of Climate Change on Protected Areas. WWF Climate Change Program. Washington, D.C. 11 p.

Zhou, L., C. Tucker, R. Kaufmann, D. Slayback, N. Shabanov and R. Myneni. 2001. Variations in northern vegetation activity inferred from satellite data of vegetation index during 1981 to 1999. Journal of Geophysical Research-Atmospheres 106: 20,069-20,083.