# Adapting to climate change in Canadian forest management: Past, present and future

by Tim B Williamson[1*], Mark H. Johnston[2], Harry W. Nelson[3] and Jason E. Edwards[1]

**ABSTRACT**

Canadian forest management agencies have already made significant progress in addressing climate change. Adaptation measures have included undertaking research and completing assessments; implementing organizational changes; beginning to modify policy, practices, and approaches; developing tools; and providing guidance and education. Although progress to date is encouraging, forest managers recognize that adaptation is in its early stages. Suggested next steps include making further progress in adapting wildfire management; adapting forest and pest management; incorporating climate change considerations into seed transfer, tree species selection, and stocking policies; adapting forest industry operations; and adapting forest management decision making by including climate change in assessment, monitoring, analysis, and forest management planning. Potential longer term options are to move toward integrated adaptation and mitigation and to modify forest management to account for the effects of climate change on processes at broader landscape scales. Moving forward with implementation requires consideration of the degree to which organizations and/or key stakeholders are ready, able, and willing to implement the changes and whether there are appropriate partnerships, enabling institutions, required science and actionable knowledge, sufficient adaptation resources (in terms of knowledgeable individuals and funding), and sufficient leadership to meaningfully move forward with change.

**Key words:** climate change, forest management, adaptation history, adaptation futures, factors enabling adaptation

**RÉSUMÉ**

Les agences canadiennes d'aménagement forestier ont déjà réalisé des progrès significatifs relativement aux changements climatiques. Les mesures d'adaptation ont consisté à entreprendre des recherches et à compléter des évaluations ; à entreprendre des changements organisationnels ; à amorcer la modification des politiques, des pratiques et des approches ; à développer des outils et à fournir des conseils et de la formation. Même si les progrès à date sont encourageants, les aménagistes forestiers reconnaissent que l'adaptation n'est qu'à ses tous débuts. Les prochaines étapes suggérées visent à faire progresser l'adaptation aux feux de forêt non contrôlés ; l'adaptation de l'aménagement forestier et du contrôle des ravageurs ; l'inclusion des considérations relatives aux changements climatiques sur le transfert des semences, la sélection des espèces d'arbres et les politiques de production de semis ; l'adaptation des opérations de l'industrie forestière ; et l'adaptation de la prise de décision d'aménagement forestier incluant les changements climatiques lors de l'évaluation, du suivi, de l'analyse et de la planification de l'aménagement forestier. Les options offertes à plus long terme consistent à se diriger vers une adaptation et une atténuation intégrées et de modifier l'aménagement forestier pour tenir compte des effets des changements climatiques sur les processus couvrant des superficies plus étendues du territoire. La poursuite de l'intégration nécessite de considérer quel niveau de changements les organisations ou encore les principaux intervenants sont prêts, capables et désireux d'implanter et s'il existe des partenaires adéquats, des institutions du secteur, des connaissances scientifiques concrètes et exploitables, suffisamment de ressources en matière d'adaptation (sous forme d'individus ayant l'expertise requise et de financement) et un leadership suffisant pour être en mesure de progresser significativement vers le changement.

**Mots clés :** changements climatiques, aménagement forestier, historique de l'adaptation, anticipation de l'adaptation, facteurs permettant l'adaptation



[1]Northern Forestry Centre, Canadian Forest Service, Natural Resources Canada, 5320–122 St. Edmonton, AB T6H 3S5 Canada
*E-mail: tim.williamson@canada.ca
[2]Saskatchewan Research Council, 125- 15 Innovation Blvd., Saskatoon, Saskatchewan S7N 2X8 Canada
[3]Faculty of Forestry, University of British Columbia, Forest Sciences Centre, 2424 Main Mall, UBC, Vancouver, BC V6T 1Z4 Canada

Tim B Williamson

Mark H. Johnston

Harry W. Nelson

Jason E. Edwards



## Introduction

Climate change is already having significant effects on Canada's forests and forest sector. It is projected that these effects will intensify over time (Spittlehouse 2005; Lemprière *et al.* 2008; Johnston *et al.* 2009; Williamson *et al.* 2009; Price *et al.* 2013; Lemmen *et al.* 2014). Moreover, Canadian forests and the forest sector are expected to experience the impacts of climate change to a greater extent than other forest areas globally and other sectors of the Canadian economy. There are five reasons for this. First, climate change simultaneously affects all aspects of natural processes that influence Canada's forests (e.g., growth, renewal, disturbance, mortality) (Price *et al.* 2013). Second, the magnitude of climate change at Canada's northern latitudes is expected to be higher than at more southern latitudes (Price *et al.* 2013). Third, impacts observed to date (e.g., the mountain pine beetle outbreak in central British Columbia and now moving east) illustrate that Canada's forests are sensitive to relatively small changes in climate (Price *et al.* 2013). Fourth, trees in Canada have long growing cycles (i.e., rotation ages of 80 to 100 years), which means that it is more difficult to make correct management decisions that depend on future outcomes, reverse decisions, manage risks, and mitigate impacts than in sectors such as agriculture with shorter crop cycles (Williamson *et al.* 2009; Klenk *et al.* 2011). Finally, many remote forest-based communities in Canada are exposed to climate effects. Also, residents, homeowners, businesses, and workers in these communities tend to have fewer opportunities and/or lower capacity to adapt and adjust to economic and environmental disruptions associated with climate change (Davidson *et al.* 2003; Lemmen *et al.* 2014).

A range of current and potential future impacts on forest conditions resulting from climate change are occurring or, are anticipated (Table 1). Similarly, a number of possible forest sector impacts have been noted (Table 2). Over and above these direct effects, a number of more qualitative effects on forest management decision making are anticipated (Table 3). Among the more important of these qualitative effects is the increased uncertainty that forest managers face as a result of climate change (Klenk *et al.* 2011).

It is generally acknowledged in Canadian forestry that mitigating current and potential future impacts of climate change on Canada's forests and on Canadian society will require adaptation (Spittlehouse 2005; CCFM 2008; Lemprière *et al.* 2008; Johnston *et al.* 2009, 2010; Williamson *et al.* 2009; Gauthier *et al.* 2014). Adaptation involves a combination of: a) modifying existing forest management policies and practices, b) developing and implementing new forest management policies, practices, and approaches, c) investing in and enhancing capacities to respond to climate change and/or mitigate impacts (e.g., incorporating climate change into assumptions and institutions, enhancing science and knowledge, enhancing human resources and funding, enhancing flexibility and resilience), and d) changing social expectations about what forests can supply (Spittlehouse 2005; Lemprière *et al.* 2008; Williamson *et al.* 2009; Johnston *et al.* 2010; Grey 2012; Williamson and Isaac 2013; Gauthier *et al.* 2014).

The response of the Canadian forest sector to climate change over the period 1980 to 2018 can be characterized as a process of continuous change and to some extent variable attention. Given the ubiquitous and interrelated effects of climate change on forestry and the long-term nature of forest management, it is important that progress in adapting to climate change be maintained –through changes in government, periods of fiscal restraint, and periods when mitigating climate change impacts is not necessarily front and centre in the public's mind. In other words, addressing climate change in forest management requires that climate change considerations become "mainstreamed" into forest management. It requires revisiting assumptions that underlie forest management and institutions that guide forest management. It requires a long-term, continuous, and enhanced commitment to action. It requires addressing the call to action set out by the Canadian Council of Forest Ministers (CCFM) in its 2008 vision statement: "Consideration of climate change and future climatic variability is needed in all aspects of sustainable forest management" (CCFM 2008, pg. 9).

We have three objectives in this paper. First, we briefly summarize recent trends and the current state of climate change adaptation in Canadian forestry. Second, we discuss potential next steps in adaptation. Third, we discuss various factors that might influence adaptation processes over the next 10 to 20 years. Our goal is to highlight the importance of adaptation in forestry contexts and the significant progress that has already been made and to support a national discussion on future adaptation requirements, priorities, and pathways and on ways that Canadian forest managers can continue to work together to mitigate the impacts of climate change on forest stakeholders and on Canadian society.

**Table 1. Current and potential future effects of climate change on Canadian forests**

- Changes in the frequency and severity of disturbances (wildfire, drought, severe storms, and damaging insect and disease outbreaks)
- Decreases in moisture availability in some locations increases in othersIncreased growing season
- Forestland losses in some areas and potential gains in other areas
- Changes in the proportion of forestland that is non-regenerated
- Maladaptation and shifts in species composition over time
- Changes in forest yield and inventory
- Introduction of new species into areas where they have not been previously observed
- Changes in forest structure (e.g., percentage of forest in various successional stages) and age-class distribution
- Changes in habitat
- Changes in forest health, mortality, and aesthetics

Note: See Table 4 for sources

**Table 2. Current and potential future impacts of climate change on the forest sector**

- Growing challenges relative to Canada's ability to achieve forest management objectives and possible increases in the cost of regeneration and other forest management practices
- Changes in timber supply (quantity, quality, cost, stability)
- Requirement for increased salvage harvesting
- Reduced winter harvest opportunity and a need for more roads and different types of harvesting equipment
- Impacts on a variety of socially and culturally important non-market goods and services (e.g., cedar bark)
- Negative market impacts on Canada's forest industry resulting from changes in global supply of forest products related to climate change
- Socioeconomics impacts such as changes in production, employment, and taxes that are concentrated in relatively small, sometimes remote, undiversified, resource-based communities
- Increased public safety risk because of increased wildfire, flooding, and extreme weather
- Changes in biodiversity with some species expanding, some species contracting, some species becoming extinct, and new species becoming established

Note: See Table 4 for sources

A point of qualification regarding the content of this article is that for a large country like Canada with many different jurisdictions it is difficult to characterize adaptation futures in a way that applies universally to all. What might be an adaptation future for one jurisdiction might be something that is already being implemented in another. For the purposes of this study we define "adaptation futures" as measures that are in the early stages of implementation in a few jurisdictions, or that are being proposed but have not actually been implemented, or that are long term or transformative in nature.

**Table 3. Qualitative effects of climate change on forestry decision environments**

- Large regional-scale events can occur that are the result of multiple interacting factors, of which climate change is only one factor (e.g., mountain pine beetle outbreak).
- Managers may be required to manage forests within an increasingly complex and dynamic decision environments.
- Climate change may manifest as increased uncertainty in forest management decision environments; uncertainty increases at more refined scales and with time.
- Climate change effects are novel and unprecedented.
- Climate change effects are interrelated and cumulative (e.g., the mountain pine beetle outbreak in BC in the early 2000s significantly increased fire risk).
- Some climate change effects may not be readily apparent until a threshold is reached at which point in time an ecosystem may suddenly start to decline.

## Sources

This report is based on a combination of: a) the state of play report "Forestry Adaptation Initiatives across Canada" (Gatin and Johnston 2016); b) interviews with adaptation experts in Canadian forestry (see Appendix one for a partial list of experts consulted for this study); and, c) recently published literature on climate change impacts and adaptation in Canadian forest management. The information reported here is not necessarily complete, partly because sources were not available for all jurisdictions and organizations. Also, we have attempted to focus on adaptations that have been identified by more than one source, such as those noted in more than one interview or in a combination of expert interviews and published literature.

### State of play report

The report, "State of Play: Forestry Adaptation Initiatives across Canada" (Gatin and Johnston 2016), reviews recent trends in adaptation in forestry across Canada. The report is based on publicly available information from government web sites and information provided by jurisdictions and organizational members of the Forestry Adaptation Working Group (a working group within Natural Resources Canada's Climate Change Adaptation Platform). It focuses on initiatives that have been implemented since 2012 and projects that were implemented before 2012 that are still operational.

### Adaptation interviews

Between 10 January and 3 November 2017, we held 18 one-hour interviews with individuals knowledgeable about climate change adaptation in Canadian forest management. In some cases interviews included two experts, in other cases the interviews were conducted with a single individual. We completed seven interviews with staff of the BC government, and we also conducted interviews with staff of the Alberta (two interviews) and Quebec (one interview) governments. We completed three interviews with individuals who represented a forest industry perspective. We held three interviews with national organizations: the Canadian Parks and Wilderness Society (CPAWS), the Forest Products Association of

Canada (FPAC), and the Sustainable Forests Initiative (SFI). We held one interview with the Association of BC Forest Professionals and another with a postdoctoral fellow at the University of British Columbia working on Indigenous participation in forest management. We also interviewed a doctoral student from the University of Saskatchewan who worked closely with a forest company in northern Saskatchewan, (Mistik Forest Management), in applying the CCFM's methodology and guidebook for assessing vulnerability to climate change (see Edwards *et al.* 2015). Our sample of interviewees is not comprehensive nor does it necessarily represent all regions of Canada. However, we feel that our interviewees do represent the population of Canadian forest managers who are on the leading edge of adaptation planning.

### Published reports

The information obtained from the interviews and from the state of play report was supplemented with information from published literature. Key synthesis documents describing climate change impacts and adaptation in Canadian forest management contexts that have been published in the last 10 years are listed in Table 4.

## The state of climate change adaptation in Canadian forest management

Discussions about the effects of climate change on Canadian forestry date back to the mid–1980s (Pollard 1985). These early discussions were, however, primarily scientific in nature. Climate change started to attain a higher profile in forestry in the early 2000s. As shown by a list of several initiatives that were undertaken between 2000 and 2008 (Table 5), concern about climate change in forest management in Canada was increasing, as were calls for action and investment into research, information gathering, and outreach.

Climate change was elevated to the national policy level when the Canadian Council of Forest Ministers (CCFM) in their 2008 vision statement identified climate change as one of two issues of national concern for forest management (CCFM 2008). Since then, Canadian forest management agencies have made significant progress in addressing climate change, raising public awareness and assessing impacts and adaptation options.

In 2008, the CCFM established a Climate Change Task Force (CCTF). This federal–provincial working group was tasked with investigating how Canada's tree species would be

**Table 4. Canadian forestry impacts and adaptation synthesis reports published since 2005**

1. *The Forestry Chronicle*. 2005. Vol. 8 No. 5. Special issue devoted to climate change impacts and adaptation in Canadian forestry
2. Lempriere *et al.* (2008). The importance of forest sector adaptation to climate change.
3. Williamson *et al.* (2009). Climate change and Canada's forests: from impacts to adaptation.
4. Johnston *et al.* (2009). Vulnerability of Canada's tree species to climate change and management options for adaptation. Canadian Council of Forest Ministers (CCFM), Climate Change Task Force.
5. Johnston *et al.* (2010). Climate change and forest management in Canada: Impacts, adaptive capacity, and adaptation options. A state of knowledge report.
6. Price *et al.* (2013). Anticipating the consequences of climate change for Canada's boreal forest ecosystems.
7. Gauthier *et al.* (2014). Climate change vulnerability and adaptation in the managed Canadian boreal forest.

See reference section for full citations.

**Table 5. Initiatives related to climate change adaptation between 2000 and 2008**

- The Canadian Climate Impacts and Adaptation Research Network – Forest Node organized a number of workshops on climate change and forestry. The network has disbanded.
- The Canadian Model Forest Network supported a number of case studies on climate change and forest-based communities. The Canadian Model Forest Network has disbanded, although a number of individual model forests are still in existence.
- The Network of Centres of Excellence for Sustainable Forest Management supported a range of research initiatives looking at climate change and forest management. It has disbanded.
- The Standing Senate Committee on Agriculture and Forestry noted that climate change will significantly affect agriculture, forests, water, rural communities, and Aboriginal people. They recommended increased research, improved communication, and tailoring of government programs to facilitate adaptation (Standing Senate Committee on Agriculture and Forestry 2003).
- The Forest Products Association of Canada has noted that climate change "poses a significant risk to the health, vitality, and long-run sustainability of the forest and the many communities that depend on them" (Lazar 2005 pg. 631). The Forest Products Association of Canada calls for forest policies that balance the need to adapt to climate change with the need to mitigate factors that contribute to climate change.
- The Government of Quebec announced a $6 million initiative to investigate the vulnerability of Quebec forests to climate change.
- The chief forester of the BC Ministry of Forests and Range suggested that "resource managers have a responsibility to adapt forest management approaches to respond to environmental and ecological change" (Snetsinger 2006). The BC Ministry of Forests and Range announced a number of new initiatives to address and adapt to the impacts of climate change
- The Ontario Ministry of Natural Resources supported new research focused on the impacts of climate change on forest and responsive adaptation strategies.
- At the national level the CCFM identified climate change mitigation and adaptation as one of two priority issues of national importance for Canada's forest sector.
- In 2008 the CCFM established a federal/provincial working group called the Climate Change Task Force. The CCTF completed a comprehensive review of the vulnerability of Canada's commercial tree species to climate change and produced a number of reports designed to support Canadian forest managers in identifying adaptation options.

Note: Source: Williamson *et al.* (2009)

affected by climate change and with developing tools and compiling state-of-the-art information to enable forest managers in Canada to prepare for and adapt to climate change. The CCTF's work has had three phases. In the first phase, it prepared a comprehensive assessment of the vulnerability of commercial tree species in Canada to climate change and a summary of adaptation options (see Johnston *et al.* 2009). In phase two, it developed a suite of tools and information products to support forest managers in identifying adaptation options. These products are available on the CCFM web site at: https://www.ccfm.org/english/coreproducts-cc.asp. The CCTF is currently working on phase three: it is advancing inter-jurisdictional conversations on integrating climate change considerations into definitions of sustainable forest management and other tasks.

In addition to the work of the CCTF, individual jurisdictions and organizations have begun implementing a variety of specific adaptations, including the following:

- Research and assessment
  - Developing practitioner guides for climate change assessment and other tools to support adaptation planning (e.g., Gleeson *et al.* 2011; Edwards *et al.* 2015)
  - Assessing vulnerability and climate impacts and using the results to identify, discuss, and possibly implement adaptation options (BC, Saskatchewan, Ontario, Quebec, Manitoba)
  - Developing regional climate scenarios (e.g., Pacific Climate Impacts Consortium, OURANOS, Environment and Climate Change Canada)
  - Undertaking or promoting applied research into impacts modelling, impacts assessment, and adaptation options (e.g., Natural Resources Canada, BC, Ontario, Quebec, various universities, Saskatchewan Research Council)
  - Completing a major review of changing wildland fire science requirements (Sankey 2018)
- Organizational changes
  - Developing climate change strategies and adaptation action plans (e.g., BC, Alberta)
  - Enhancing capacity by dedicating significant new resources to climate change adaptation (e.g., BC, Ontario, Quebec)
  - Developing performance measures to monitor and evaluate adaptation progress (e.g., BC)
- Policy, practices, and approaches
  - Identifying and implementing new techniques, policies, and approaches to reduce wildfire risk in communities located within or near flammable forests (e.g., Alberta, BC, FireSmart programs in several jurisdictions)
  - Reviewing, researching, and in some cases modifying seed transfer guidelines, regulations, and policies (e.g., BC, Alberta, Quebec)
  - Modifying species deployment (e.g., larch in BC)
  - Conducting assisted migration trials (BC, Alberta, Saskatchewan, Manitoba, Ontario, Quebec)
  - Promoting science, science-policy integration, and science management partnerships (e.g., BC)
- Guidance and extension
  - Undertaking communications, education, and professional development initiatives (e.g., Association of BC Forest Professionals)
  - Organizing workshops with staff within agencies on climate change effects and adaptation initiatives underway within organizations (e.g., BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development)
  - Organizing knowledge exchange workshops about climate change (Canadian Institute of Forestry, Forestry Adaptation Community of Practice)

Attention to issues like climate change adaptation often increases after high-profile events that are in the public eye. The unprecedented mountain pine beetle outbreak in the interior of BC in the early 2000s raised public attention about climate change effects in forestry and it was one of the reasons a number of climate change adaptation initiatives were launched by the BC government. Increases in wildfire and in the number of significant wildfire incidents is another example. Significant wildland fire events in the last 10 years are identified in Table 6. These events have resulted in major independent reviews of policies and practices related to emergency management and wildfire management policies and practices. A number of changes have been, or are in the process of being, implemented. For example, in recent years, fire management priorities have shifted from protecting timber and resource values to protecting communities and infrastructure. Other changes include moving up the official start of the fire season (e.g., from 1 April to 1 March in Alberta), enhancing support to communities for identifying and reducing fire risk, implementing FireSmart measures, and implementing policies that allow more fires to burn to "increase black on the landscape."

**Table 6. Recent significant wildfire events**

- The 2003 Okanagan Mountain Park Fire in BC: 239 buildings destroyed
- The 2011 Slave Lake fire: 433 buildings destroyed, 89 buildings damaged, 7,000 people evacuated, cost $750 million
- The 2015 La Ronge area wildfire: mass evacuation of 13,000 residents around La Ronge, Saskatchewan
- The 2016 Fort McMurray (i.e., Horse River) fire: cost $9.9 billion (direct and indirect), 2,400 buildings destroyed, entire city evacuated
- The 2017 wildfire season in BC: largest total area burnt in recorded history, at least 300 buildings destroyed, release of several evacuation orders, provincial state of emergency declared by the Province of BC
- 2018 was once again a severe fire year in BC. The area burned to date (as of 23 August 2018) ranks among the top five worst years in terms of area burned. A number of structures were burned and evacuation orders were issued for a number of communities. For the second year in a row, the province had to declare a provincial state of emergency. Smoke from BC wildfires created unprecedented air quality issues throughout Alberta.

## Adaptation futures in Canadian forest management

As noted in the previous section, Canadian forest managers are making progress in addressing climate change. However, there is also recognition that forestry adaptation is in the early stages and that climate change adaptation work in forestry needs to continue (Halofsky *et al.* 2018). In this section we discuss potential next steps that have been identified by experts on climate change adaptation in Canadian forestry combined with forestry adaptations suggested in the literature. We note that the next steps we discuss here generally involve activities proposed for the managed forest land base. We are not aware of any adaptation measures being contemplated at this time for forests that are not under active management. This means that a relatively large proportion of Canada's forest land base will be left to adapt to climate change solely through natural processes.

There are six areas that climate change adaptation experts have identified as logical next steps in adapting to climate change in forest management:

- Adapting to increased wildfire risk by incorporating climate change considerations into assessments, strategies, approaches, and policies
- Incorporating climate change considerations into forest and pest management strategies to mitigate biotic risks to forests
- Mitigating maladaptation risk by incorporating climate change considerations into seed transfer, tree species selection, establishment of assisted migration trials, and stocking policies, standards, and guidelines
- Reducing risk of windthrow loss by incorporating climate change considerations into stand management practices
- Mitigating economic costs of climate change by adapting forest industry operations
- Including climate change in assessment, monitoring, analysis, and planning in support of forest management decision making and adaptation planning

### Adapting to increased wildfire risk by incorporating climate change considerations into assessments, strategies, approaches, and policies

Wildfire is a naturally occurring disturbance in Canadian forests. Canada has developed significant capacity and expertise in wildland fire management. Recent research shows that fire regimes have become more active in the last 50 years, particularly in western Canada (Kirchmeier-Young *et al.* 2018; Hanes *et al.* 2019). Research also suggests that climate change will result in further increases in wildfire intensity, frequency, and damage (Flannigan *et al.* 2009; Wotton *et al.* 2010, 2017; Price *et al.* 2013; Boulanger *et al.* 2014). Corroborating anecdotal evidence suggests that wildfire activity is already moving into uncharted territory. The years 2017 and 2018 were both record years for wildfire in BC; provincial states of emergency were declared in both years.

Mitigating fire risk and damage will require new investment in wildland fire management capacity and continued review and adjustment of fire management policies, priorities, resources, practices, and approaches (Wotton *et al.* 2017). As noted in the previous section, actions that are already underway to mitigate fire risk include increasing resources, starting the fire management season earlier in the year, allowing more fires to burn to reduce fuel loads, managing fuels near high-risk forest/community interface areas, and working with communities to reduce the susceptibility of structures to burning (e.g., using fire-resistant roofing, using ember-proof vents, removing dry leaves in gutters, creating defensible spaces around structures (by pruning and removing trees near structures, etc.), and installing sprinklers). There is a need for continued awareness raising, education, and community engagement about wildfire risks and investment in risk mitigation. More attention needs to be paid to assessing and mitigating risk at and near the wildland/urban interface. Fire activity is anticipated to increase in populated forest areas, so continued investment is needed in fire smarting and fuel management in and near communities.

Some have suggested that in a historical context, fire management has been suppression oriented and generally reactive to emergent fire situational contexts. Funding for fire management also tends to be reactive. Fire management agencies are beginning to consider more proactive and more integrative approaches with the goal of mitigating anticipated future increases in wildfire risks (i.e., reducing large uncontrolled and unwanted wildfires), reducing net costs, and returning wildfire as a natural disturbance on the landscape. For example, consideration of wildfire in strategic landscape level planning, land use, and land development approval processes has the potential to, at least in part, mitigate fire risk at a net cost lower than traditional response-oriented fire suppression approaches. Another suggested approach is to integrate forest management decision making with fire management decision making. Hirsch *et al.* (2001) proposed an approach they referred to as "fire-smart forest management" whereby forest management practices such as site preparation, regeneration, stand tending, harvest scheduling, cut block layout and design, and road layout are undertaken partly with the goal of reducing undesirable wildfire, the risks associated with prescribed burning, and the risks associated with decisions to let natural fires burn.

There are barriers to implementing the above approaches because decisions related to these options often fall outside the mandate of wildfire management organizations. Nonetheless, it may be possible to break up high-risk landscapes and reduce risks to human assets, for example, by strategic placement of right of ways (e.g., pipeline corridors, electricity right of ways, roads, and highways), particularly in areas with high values at risk. Another possibility is to include fire considerations in approval processes for infrastructure development on crown land. For example, approval permits for structures on crown land could require measures to reduce fire risk (such as installing sprinklers, using low-flammability materials on structures, and reducing fuels near structures). Timber harvesting could be targeted to break up large contiguous blocks of flammable species such as conifers and intersperse stands of less flammable hardwood species (such as poplar).

A more forward-looking and integrated approach to managing disturbance will require new science and analysis to inform what future fire regimes might look like under different climate scenarios and to assess the effectiveness of alternative approaches. The effects of climate change on fire behaviour need to be projected to support awareness raising and education, identify potential changes in resource requirements (including whether shifts in the relative weights

of prevention, detection, and suppression are warranted), plan and prepare for fires, map fire risk, and manage landscapes to reduce fire risk.

It was suggested that efforts continue at the national level to develop a comprehensive national strategy on wildland fire management under a changing climate. A national strategy currently exists, (the Canadian Wildland Fire Strategy), but some interviewees noted that it needs to be strengthened in a way that recognizes climate change, that creates urgency for action, that clarifies roles for all levels of government, that provides a basis for collaboration and cooperation, and that enhances the capacity for quick national response when fire situations reach emergency conditions.

#### Incorporating climate change considerations into forest and pest management strategies to mitigate biotic risks to forests

The mountain pine beetle outbreak in BC in the early 2000s was attributed, at least in part, to warmer winters from recent climate change (Dymond *et al.* 2014). Previous forest and fire management practices that had created a forest landscape in the central interior of BC that was vulnerable to an outbreak of the pine beetle were also contributing factors (Pedersen 2004). This suggests that it may be possible (and rational) to modify forest and fire management practices in ways that reduce the potential for future outbreaks (Dymond *et al.* 2014).

Climate change may increase losses due to insects and disease in forest regions across Canada (Price *et al.* 2013; CCFM 2019). Climate change has the potential to increase the area, duration, and intensity of infestations of a number of insect species; however, the interactions between hosts, species, and environment are complex so it is difficult to predict impacts or generalize at the national level (Price *et al.* 2013). A possible future adaptation is to examine how climate change might affect the outbreak potential of particular insect species and pathogens on particular landscapes in particular regions under different possible scenarios and to identify and assess options to reduce outbreak potentials. Currently an integrated pest management approach is used to assess and manage insect disturbances. This approach needs to be broadened to include climate change considerations. New software tools such as BioSIM, which predicts the effects of climate change on insect populations, are being developed. Reducing the risk of outbreaks before they occur (if feasible) may cost significantly less than responding after major outbreaks or controlling pests during outbreaks.

Although it is difficult to predict specific impacts of pests, a lesson learned from the mountain pine beetle outbreak in BC is that the presence of large expanses of a single species of trees in a relatively uniform age class can increase the potential for damaging outbreaks. Dymond *et al.* (2014) found that a management strategy designed to enhance the diversity of the managed forest land base resulted in a forest that was more resilient and generated higher harvest rates and more consistent revenues than a forest managed with a business-as-usual strategy.

A recent study by the CCFM (2019, pg. 4) concluded that Canada's "forest health monitoring system was vulnerable to climate-induced changes in that the ability to meet forest health monitoring objectives would be compromised. This means that adaptation is required." The top four adaptation options are as follows:

1. "Incorporate or develop new technologies into monitoring, including remote sensing, molecular diagnostic tools, forest health diagnostic applications and decision support systems"
2. "Adopt proactive forest health monitoring principles by extending current monitoring policies and practices to include all disturbances (not just major pests)"
3. "Identify acceptable monitoring levels and efficiencies"
4. "Promote research needs and maintain existing capacity"

#### Mitigating maladaptation risk by incorporating climate change considerations into seed transfer, tree species selection, establishment of assisted migration trials, and stocking policies, standards, and guidelines

Climate-based seed transfer, (i.e., the movement of seeds to locations other than where they originated), is an important adaptation in advanced jurisdictions. Experts from the BC, Alberta, and Quebec governments noted that their organizations are making changes in forest policies and forest management actions to promote this approach. Climate-based modifications to seed zones require significant internal capacity in terms of both science and policy development. It is anticipated that eventually climate-based seed transfer will be expanded to include climate-based tree species selection and stocking standards. However, at the moment, climate-based tree species selection and new stocking standards are not being operationalized. It bears noting that adaptation initiatives like climate-based seed transfer are often enabled by the presence of strong science capacity and strong science / policy integration.

#### Reducing risk of windthrow loss by incorporating climate change considerations into stand management practices

Some jurisdictions are recognizing that windthrow damage may become more severe if the frequency and intensity of wind events increase with climate change. Forest managers in BC are already implementing measures to reduce windthrow risk. Some forest management jurisdictions are looking into various stand management approaches (e.g., cut block design) to mitigate potential losses from windthrow in vulnerable areas.

#### Mitigating economics costs of climate change by adapting forest industry operations

The forest industry is experiencing climate change impacts in the form of changes in peak stream flows, flood risk, changes in timber supply (due to combinations of increases in insect and disease and fire losses and access disruptions), and shorter winter harvesting season. Climate change has implications for forest industry operations in the form of changes in road and bridge requirements, requirements for new types of equipment for access when ground conditions are not frozen, for increased reliance on salvage wood, and potentially for changes in managing wood supply to increase reliability of supply to mills. Some companies (e.g., Mistik in Saskatchewan) have completed comprehensive analysis of the implications of climate change on their operations (Andrews-Key 2018; Halofsky *et al.* 2018) and are starting to work with the province to identify adaptation options to minimize impacts to their operational requirements.

### Including climate change in assessment, monitoring, analysis, and planning in support of forest management decision making and adaptation planning

Forest management policy and decision making is supported by various analytical processes including assessment, monitoring, inventory, resource analysis (e.g., timber supply analysis), and long-term planning. These analytical processes often involve various combinations of data gathering, analysis, modeling, projection, and mapping. Forestry experts have expressed concern about the lack of climate change considerations in certain aspects of these analytical processes and about the need to adapt them to account for climate change (see for example, Ogden and Innes 2007; Nitschke and Innes 2008; Klenk *et al.* 2011; Nelson *et al.* 2016; CCFM 2019). For example, it was noted in the interviews that there is typically little monitoring of tree and stand health after reforested stands have been designated as "free to grow." However, under a changing climate, stands that are now designated as free to grow could in fact become stressed or unproductive at some future date. Thus, the development and implementation of enhanced monitoring systems of forest condition in all age classes is suggested.

The increased uncertainty that climate change brings is a significant challenge for decision making in forestry (Klenk *et al.* 2011). Adaptation researchers have suggested adaptive management as a way to address this (Klenk *et al.* 2011; Gauthier *et al.* 2014; Keenan 2015; Yousefpour *et al.* 2017). Adaptive management is a continuous social learning process of identifying and implementing adaptations followed by monitoring, assessment, and adjustment. Monitoring is central to adaptive management. If aspects of adaptive management are ultimately implemented in Canadian forestry as a response to climate change, then new systems will be needed to monitor the impacts of climate change and the effectiveness of measures designed to mitigate them.

Climate change is unprecedented in terms of its implications for forest policy and decision making. It affects all aspects of forestry decision making in complex, non-linear ways (see Table 3). Moreover, it changes the context in which decisions are made and policies are created: traditional forest management approaches and the analytical processes that support them have historically assumed a stationary climate (Spittlehouse 2005), but this assumption is no longer valid (Spittlehouse 2005; Cleaves 2014). Responding to climate change requires new information and new analytical tools (Halofsky *et al.* 2018). It requires enhanced capacity to assess future and uncertain impacts that might occur under a dynamically changing climate. It also requires capacity to identify and assess adaptation opportunities that are robust under a range of potential scenarios. A number of approaches for assessing climate change have been suggested, such as incorporating climate change into cumulative effects frameworks and into bio-geoclimatic classification. Another suggested approach is to assess how, when, and where a management system is vulnerable to climate change (Halofsky *et al.* 2018). Vulnerability assessment is an established approach for structured analysis of potential future climate impacts and for identifying robust adaptation options (Spittlehouse 2005; Williamson *et al.* 2012; Edwards *et al.* 2015; Halofsky *et al.* 2018). It is increasingly being applied in the US and Canada (Halofsky *et al.* 2018). Recently the CCFM undertook a comprehensive vulnerability assessment of forest health monitoring policies and practices under a changing climate (CCFM 2019). Views differ, however, about the usefulness of vulnerability assessment in adaptation decision making. Some people think it makes sense, particularly after they have gone through the process. For example, a vulnerability assessment was recently applied in northern Saskatchewan to the Mistik Forest Management Agreement area, and the experience demonstrated the feasibility and value of this type of assessment to the government and company representatives who were involved (Andrews-Key 2018). Others think that vulnerability assessments are too expensive and too complex and that they require too much effort. One of the challenges with vulnerability assessment is that it can initially appear to be overwhelming. The recent application of the CCFM vulnerability assessment framework, (see Edwards *et al.* 2015), with Mistik Forest Management in northern Saskatchewan (see Holofsky *et al.* 2018 and Andrews-Key 2018), demonstrated that having an expert present to guide the assessment with the company significantly increased the company representatives' understanding of the vulnerability assessment approach and their trust in the approach and the information it provided. The approach then became more acceptable to them and it also became possible to integrate company knowledge and expertise with knowledge about the nature and scope of climate effects on the company (Halofsky *et al.* 2018). Also, the USDA Forest Service is using vulnerability assessment with some success (Halofsky *et al.* 2018). Coordination of Canadian assessment work with US assessment work would provide valuable insights into trends in the effects of climate change at a continental scale.

Climate change-related events have already had significant impacts on timber supply. The mountain pine beetle outbreak in the early 2000s killed 80 % of the mature pine forest in the BC interior and timber supply projections had to be significantly modified – initially upward to promote salvage and then downward in the longer term (Pedersen 2004; Corbett *et al.* 2016). Estimates of mid-term timber supply in the BC Caribou region have had to be reduced as a result of the 2017 fire season (BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development 2018). Generally, projections of future timber supply are based – at least in part – on estimates of forestland area, inventory, growth and yield, and expected losses due to disturbance. Each of these inputs is potentially affected by climate change. However, current estimates of future timber supply typically do not consider the effects of future climate change. Growth and yield, for example, are often estimated using a network of sample plots that measure historical yield on the basis of past climate. When climate change factors are included, projections of timber supply can change significantly. Recent estimates of climate effects on timber supply at the national level suggest that under a worst-case climate outlook, timber supply shortages and wood cost increases exceeding 25 % are possible in major producing regions (BC and Quebec) by mid-century (McKenney *et al.* 2018). This analysis is preliminary and its scope is broad. It is not, therefore, a substitute for more refined analysis at regional/local scales. McKenney *et al.* (2018), however, reinforce the need for more forward-looking estimates of long-term wood supply that account for

a variety of possible future climate outlooks in support of adaptation planning and forest management planning and decision making.

There are related suggestions to incorporate climate change into forest management planning (Ogden and Innes 2007). Medium- and long-term planning is central to forest management. Typically, forestry companies operating on large area-based leases must complete forest management plans as part of their licence requirements. Some companies have experimented with incorporating climate change considerations into their planning exercises (see for example Van Damme *et al.* 2008; Andrews-Key 2018). This is considered to be a useful way to incorporate climate change into forest management (Johnston *et al.* 2010).

## Longer term transformational adaptations

The adaptation futures described in the previous section are measures that could potentially be implemented in the context of current governance and forestry institutional contexts. Implementation does not necessarily require large-scale transformation of forest management institutions or regulatory systems, although in some cases it may be necessary to reframe or make marginal adjustments to current standards, rules, and accepted practices. Transformational adaptations are more structural in nature. They typically involve fundamental revision, modification, or replacement of existing norms, standards, principles, and assumptions. Transformation may be called for in cases where the risks and vulnerabilities to a particular management system are considered to be so high that systemic changes are needed (Kates *et al.* 2012).

Transformational adaptation may, or may not, be necessary in Canadian forestry and will probably vary according to the severity of local impacts of climate change: policy makers and the Canadian forest management community at large will have to make this judgement. There is merit, however, in having a conversation about the ability of existing institutions and organizations to deliver expected outcomes and whether broader, longer term, organized, and more systemic changes are needed in forestry to adequately prepare for and respond to climate change. It is through such a conversation that the Canadian forest sector can be begin to develop a vision about what transformation looks like and about how to move forward. However, the challenges associated with transformation should not be underestimated. Lonsdale *et al.* (2015, pg. 6) note:

> "This language and the concepts which underpin it, offer hope that as a society we are capable of big change in a world that increasingly demands reinvention and innovation in response to a myriad of interconnected pressures, thresholds and boundaries. However, these terms may also threaten our sense of stability; a steady change from business as usual may be far more palatable than change which may require us to question what we value and the way we live. It is a challenging, complex concept which lends itself to long-term thinking. In contrast, no regrets and win-win adaptation options are far better suited to current political timescales and appear to offer pragmatism in the face of a limited appetite for significant action to adapt to a changing climate. However, if we only focus on this low hanging fruit, do we risk ignoring the more substantive, systemic changes which may be needed to respond to a changing climate in a rapidly changing world?"

Two potential larger scale transformational adaptations in Canadian forest management are discussed here. They include, 1) movement toward comprehensive and integrated adaptation and mitigation in Canadian forest management and, 2) broadening forest management policy and decision making to consider landscape level effects of climate change and the potential for landscape management in order to mitigate impacts.

### Enhanced and integrated climate change adaptation and mitigation

Adaptation and mitigation, (which in the context presented here refers to the monitoring and management of forest carbon), are closely linked. Some interviewees indicated that the best mitigation strategy for Canadian forest management could be an adaptation strategy that preserves forest capital under a changing climate. There is growing recognition that Canadian forestry needs to acknowledge and address both adaptation and carbon management in a more comprehensive and integrated way (Innes *et al.* 2009; Klenk *et al.* 2011; Kant and Wu 2012). There are significant trade-offs and synergies between adaptation and mitigation and a comprehensive and integrated approach is called for (Millar *et al.* 2007; Keenan 2016; Williamson and Nelson 2017). There are, however, significant harmonization, enabling, and implementation barriers. Important first steps will be to provide the analytical capacity to identify and evaluate comprehensive and integrated adaptation/mitigation strategies that consider trade-offs and synergies between adaptation and mitigation (Williamson and Nelson 2017).

### Modifying forest management to account for the effects of climate change on broader landscape scale processes:

Climate change affects forests at multiple scales: tree level, stand level, and landscape level. To address climate change, forest management may need to be modified to consider responses of forest ecosystems at multiple scales including broader landscape scales (Messier *et al.* 2019). Suggested landscape-oriented adaptations include the following:

- Creating policies and implementing practices to create corridors and increase connectivity within landscapes to facilitate the migration of species and genotypes and to promote resiliency of forest ecosystems to climate change (Millar *et al.* 2007; Nunez *et al.* 2013; Gauthier *et al.* 2014; Messier *et al.* 2019)
- Creating policies and implementing practices to promote species, age-class, and genetic diversity in forest landscapes to promote forest resiliency (Millar *et al.* 2007; Dymond *et al.* 2014; Gauthier *et al.* 2014; Messier *et. al.* 2019)
- Creating policies and rules that enable modifications in harvest profiles to provide for accelerated harvesting of vulnerable stands and to reduce risks at landscapes scales (Gauthier *et al.* 2014)
- Creating policies and implementing practices that enable landscapes to be modified to mitigate wildfire, insect, and disease risk (Hirsch *et al.* 2001; Gauthier *et al.* 2014; Wotton *et al.* 2017; Ronnine et al. 2018; Messier *et al.* 2019)
- Providing guidance in forest management planning regu-

lations and forest certification standards and on vulnerability assessments

To implement these changes, significant changes may be required in current institutions and capacity to assess options may need to be increased (e.g., the development and use of spatially explicit tools for planning and management at landscape levels).

## Enabling future adaptation in Canadian forest management

The adaptation futures described in previous sections are potentially significant. The degree to which organizations and/or key stakeholders are ready, able, and willing to implement the changes will need to be considered. It will also need to be determined whether there are appropriate partnerships, enabling institutions, the required science and actionable knowledge, sufficient adaptation resources (in terms of knowledgeable individuals and funding), and sufficient leadership to meaningfully move forward with change. The remainder of this section addresses these areas in more detail.

### Engagement with Indigenous peoples about forest management adaptation

Climate change is a significant issue for Indigenous communities in forest areas of Canada. Indigenous communities are affected in multiple ways – floods, drought, fires, impacts on local economies, impacts on wildlife, and impacts on materials that are gathered. For example, people in certain Indigenous communities are noting that they are unable to gather cedar bark because trees are stressed and the quality of materials is not good.

There is broad recognition of the need to engage with Indigenous peoples about adaptation – especially those with forest tenure. There is also a need to investigate ways to recognize and consider traditional ecological knowledge. Supreme Court decisions have acknowledged the need for engagement with Indigenous communities on resource development on traditional lands. Enhanced consultation and engagement with Indigenous forest-based communities about adapting forest management to address climate change is needed. There is also a need to incorporate both a western science perspective and an Indigenous knowledge perspective in developing adaptation options. Indigenous resource managers may tend to view such integrated knowledge systems as more useable and valid. In a recent paper, Pinkerton (2018) describes a governance model that enables collaborative forest management decision making between Indigenous and non-Indigenous communities.

### Modifying forest management institutions

In general, forest regulations and policies, tenures, definitions of sustainable forest management SFM (e.g., the current CCFM criteria and indicators), and forest certification standards do not explicitly acknowledge climate change or the degree to which it can affect the ability of forest management agencies to accomplish policy objectives. There are diverse views, however, about the degree to which policies and institutions are a significant barrier to adaptation. In a recent survey, BC forest professionals identified policy and institutional factors as significant barriers to adaptation (e.g., see Nelson *et al.* 2016). Similarly, Johnston and Hesseln (2012) conducted group discussions and interviews with forestry stakeholders and found that institutions were seen as a significant barrier to adaptation. Interviewees "identified tenure reform and a more flexible regulatory environment" (Johnston and Hesseln 2012, pg. 29) as requirements for moving forward with adaptation. On the other hand, a number of respondents in our interviews suggested that there is sufficient flexibility in existing laws and regulations to make adjustments to accommodate climate change considerations without changing legislation. Other respondents noted, however, that current institutions may constrain or limit the scale and intensity of adaptation response that future climate change warrants.

Forestry institutions in Canada have developed and evolved over many years during a period of time when climate change was not an issue. The emergence of climate change as a new reality affecting forest management in Canada leads to a variety of institutional issues and questions. In discussing the implications of climate change on forest policy capacity, Raynor (2012, pg 82) notes that "evidence from both federal and provincial forest policy sub-systems does support the original hypothesis in which mandates are increasing but resources are stable or decreasing, leading to ineffective policy capacity and the adoption of short-term expedients when a longer view is required."

From an industry perspective, an important challenge relates to tenure and tenure obligations (Johnston and Hesseln 2012). The role of industry in forest management adaptation has not yet been defined. One of the risks associated with climate change from an industry perspective is the potential for increased management costs (related to adaptation decisions) that are passed on from the crown. This could be an issue for industry in today's increasingly competitive and protectionist global marketplace. Another concern from an industry perspective is the requirement to comply with current regulatory standards that do not necessarily consider climate change. There is a need, therefore, for governments to have a conversation with industry about expectations relative to tenure-related objectives, climate change adaptation measures, and the role of industry in implementing these measures. From an industry perspective there is a need to clarify what climate change adaptation means in terms of security of wood supply, costs, and liabilities. There is also a need for a discussion about how best to incentivise industry to support government adaptation goals at a time when industry is under significant strain from a combination of regulatory requirements and market pressures.

Table 3 lists various qualitative factors that can be expected to affect forestry decision making. In addition to implementing specific adaptation measures it will be important to create and maintain an environment in forest management that supports decision making about climate change adaptation. In a widely cited manuscript, Millar *et al.* (2007, pg. 2145) note: "We encourage flexible approaches that promote reversible and incremental steps, and that favor ongoing learning and capacity to modify direction as situations change. We suggest that no single solution fits all future challenges especially in the context of changing climate, and that the best strategy is to mix different approaches for different situations." A number of studies have suggested adaptive

management and resiliency as an approach that promotes flexible, reversible, incremental, and local actions in the face of increasing uncertainty (Klenk *et al.* 2011; Gray 2012; Keenan 2015; Messier *et al.* 2019). There are, however, institutional, policy, and governance barriers to such an approach (Johnston and Hesseln 2012; Rayner 2012; Nelson *et al.* 2016). To implement an adaptive management approach, explicit attention will have to be paid to overcoming these barriers or at least opening up a conversation within forestry about the institutional contexts for forestry in Canada and determining whether these contexts need to be reformed or modified to respond appropriately to climate change.

**Science and knowledge exchange:**

There are diverse views about the requirements for climate change science in forest management. A number of respondents noted that the current state of the science about climate change impacts and adaptation in Canadian forestry is relatively good. Other respondents indicated that new knowledge must continue to be developed and disseminated, and understanding of the current and future impacts of climate change on forestry and of adaptation options must be enhanced. Other sources used for this report suggest that the need for science related to climate change continues to expand. In fact, many of the adaptation next steps identified by respondents will require both new science and explicit mechanisms for science/policy integration. There is also growing recognition of the need for more forward-looking approaches in forest management that recognize that the climate of the future will be different than the climate of the past. A forward-looking approach to management will probably increase demand for information about potential future climate scenarios, forest impacts, forest thresholds, and adaptation options. As adaptation progresses or becomes mainstreamed into forest management decision making, new science questions are likely to emerge. Continued attention will need to be paid to identifying, prioritizing, and addressing science requirements and priorities.

An example of how climate change is affecting demands for new science is illustrated by a recent initiative to develop a blueprint for wildland fire science in Canada for the next 10 years (Sankey 2018). This document was the result of a major review of the current capacity of wildland fire science relative to emerging demands. It involved significant consultations with fire managers, fire researchers, and forest managers across Canada. The document states: "The capacity of wildland fire science and technology in Canada is not keeping pace with the growing complexity of wildland fire. Fire seasons are becoming longer, fire events are becoming more severe, and experts predict that the area burned on an annual basis could double by the end of this century. However, wildfire research programs have declined, existing academic wildland fire science programs are limited, and a large cohort of experts has begun to retire. This research gap puts future public safety and security at risk. National wildland fire research capacity, which includes human resources, financial investments, and other supports for science, must be increased to inform the ways fire events are managed, communities are built, and preparations for emergencies are made." In many respects, the compelling case for increased attention to fire science to address climate change applies to all aspects of forest management. However, as discussed in the following paragraphs, there is also a need to adapt how climate change science is undertaken and mobilized.

Hagerman and Pelai (2018) reviewed climate change science and analysis in forest management over the past 20 years. They conclude that recommendations within scholarly literature are often general and non-actionable. They suggest that there is a need for scholarly research that is more actionable, for a greater emphasis on mixed social-ecological inquiry, and for the development of governance processes that promote discourse and enhance the ability to anticipate and prepare for changed circumstances in forest management contexts.

In addition to expanding our knowledge base about climate change and forest management, our respondents indicated that there needs to be a stronger emphasis on mobilizing science and getting new scientific knowledge into the hands of policy and decision makers. There are barriers that can make it difficult for policy makers and practitioners to access new knowledge and in some cases for forest management agencies and forestry companies to access and use available knowledge and tools.

Adaptation is best served when multiple sources of information can be integrated (Van Damme *et al.* 2008; Littell *et al.* 2012; Peterson *et al.* 2014; Keenan 2015, 2016). A number of interviewees identified the importance of integrating scientific knowledge with the knowledge of forest managers and policy makers for the purposes of adaptation. Respondents identified new and innovative processes recently developed for this purpose. The USDA Forest Service is working with a science/management partnership model to integrate scientific knowledge about climate change impacts and scenarios with manager knowledge about adaptation options and requirements (Littell *et al.* 2012). The BC Future Forest Ecosystems Science Council is an example of a science/policy integration process that has laid the foundation for much of the adaptation work related to climate-based seed transfer that is currently underway in BC (Prescott and Weese 2014). Science/policy integration continues to be fundamental in implementing a new approach to seed transfer in BC. Further science/policy integration efforts are foreseen for the development of climate-based species selection guidelines, stocking standards, and climate-based harvesting guidelines.

Some jurisdictions have developed internal science capacity to support new approaches that consider climate change (e.g., climate-based seed transfer in BC). Some forest companies have had success in addressing complex issues like climate change by embedding scientific/technical experts in their organizations and incorporating climate change considerations into forest management plans (i.e., embedded science; see Van Damme *et al.* 2008). A recent application of the CCFM vulnerability assessment framework was possible because a technical expert who was knowledgeable about the CCFM assessment framework worked closely with the company's forest managers to identify vulnerabilities and adaptation options (Andrews-Key 2018; Halofsky *et al.* 2018). A number of our interviewees pointed out that there is a need for stronger levels of engagement and bridging with policy makers, practitioners, and decision makers in terms of identifying and implementing science-based adaptation options.

#### Awareness and education:

Awareness of climate change impacts and recognition of the need for adaptation in Canadian forestry has increased in the last 10 years. Awareness has been enhanced by various means, including the production of synthesis reports, the establishment of working groups that facilitate information exchange (e.g., the Forestry Adaptation Working Group), and the support of various groups for workshops and seminars (e.g., the Canadian Institute of Forestry, the Association of BC Forest Professionals, the Forestry Adaptation Community of Practice). Jurisdictions have also made significant investments by producing provincial-level synthesis reports, undertaking internal knowledge exchange activities, and conducting vulnerability assessments. Lack of awareness about climate change impacts and adaptation requirements is less of a barrier now. There are, however, other barriers to awareness and knowledge access. For example, although individuals working in forestry generally recognize the seriousness of climate change and the need for some kind of action, forest managers are often not sure what to do locally. They are uncertain how to assess the effects of climate change on their forest management systems, what kinds of practical and pragmatic adaptation options might be available to them, and what science products are available to support their choices. More work is needed to raise awareness and educate practitioners at local scales about the knowledge and tools that are available to them to support adaptation planning (e.g., the recent Mistik example). Respondents suggested that if climate change experts were established at regional levels to support local analysis and education, the capacity for local adaptation efforts would be enhanced.

As climate change impacts continue and as the implementation of adaptation measures progresses, there will be a need for ongoing awareness and education efforts. A number of jurisdictions are undertaking initiatives to raise awareness, and other groups are supporting awareness raising and education. These include the Canadian Institute of Forestry, the Forestry Adaptation Community of Practice, forestry professional organizations (e.g., the Association of BC Forest Professionals), and the forestry adaptation platform supported by Natural Resources Canada, Canadian Forest Service knowledge exchange activities, and certification body initiatives.

#### Adaptation resources

A number of interviewees mentioned funding, insufficient human resources, and lack of time as significant barriers to adaptation. Other studies based on interviews with forest management experts reported similar issues (Johnston *et al.* 2010; Johnston and Hesseln 2012). Some respondents noted that there is a need to undertake economic analysis of the costs and benefits of adaptation to evaluate whether there is an economic rationale for increasing resources for adaptation. Although awareness of climate change is relatively high among forestland managers, it is not necessarily a front-and-centre issue with CEOs, senior executives, or government ministers. CEOs tend to focus on competitiveness and economic issues. In many cases a business case has not been made for adaptation or there is a lack of understanding of how climate change affects forestry companies in terms of their business operations. CEOs are more likely to respond to economic analyses of climate change and analyses of things that may affect the company's business and profitability over the long run. Thus, more work is also needed in terms of understanding the costs and benefits of adaptation and ensuring a balanced and economically efficient distribution of costs and benefits between industry and provinces.

#### Leadership

Some of the possible future adaptations that we have discussed are incremental in nature and others are more transformative. In terms of Canada's forest sector as a whole, adaptation is a social process that occurs simultaneously at multiple levels: local, mid-level management, executive, and political. A number of studies have noted the importance of leadership in continuing to move Canada's forest sector forward in addressing climate change (Van Damme *et al.* 2008; Gray 2012; Johnston and Edwards 2013; Williamson and Nelson 2017). There are, however, a variety of different kinds and levels of leadership. For example, political leadership and political will are required to change legislation, set priorities, allocate funding, and establish inter-jurisdictional collaborations. Organizational leadership is required to promote innovation and change within the context of existing policies and laws and to reframe policies to suit changed circumstances. Local leadership supports local innovation and experimentation (e.g., see Van Damme *et al.* 2008). Collaborative leaders have the ability to bring people together to address issues of common interest.

Leadership is important at each level. It is also needed at all levels simultaneously. Researchers characterize adaptation as a multi-tiered interactive process of social learning. An absence of leadership at any particular level can disrupt adaptation at other levels (Pahl-Wostl 2009). For example, an absence of political will for adaptation will be a barrier to adaptation at lower levels. Similarly, an absence of leadership at local levels may prevent experimentation and innovation, resulting in lost opportunities for obtaining new information that can inform higher level decision making.

## Summary and conclusions

Adaptation in Canadian forest management has begun in a significant way, as illustrated by the measures described in the section "The state of climate change adaptation in Canadian forest management". Forest managers and forest management organizations are mobilizing to address climate change. They are taking concrete measures to manage risks and mitigate potential impacts. However, our interviewees and our review of the published literature indicate that adaptation in Canadian forestry is in the early stages and that further investment in adaptation planning and in the implementation of adaptation measures is needed. A number of the adaptation proposals identified in previous sections could be implemented in the context of existing policies and practices. Others are more transformational and may require investment in new capacity and fundamental rethinking of how forestry is practiced in Canada.

## Acknowledgements

We are grateful to the Natural Resources Canada / Canadian Forest Service Forest Change Program, in particular Catherine Lafleur, for supporting this project. We are particularly grateful to all the individuals and organizations who provided our team with time and their insights about climate

change adaptation in Canadian forest management. They include Sheri Andrews-Key, Guy Burdikin, Kerri Brownie, Florence Daviet, Andrew Devries, Eric Domaine, Christine Fletcher, Megan Hanacek, Kathy Hopkins, Pam Kertland, Don Lemmen, Kate Lindsay, Archie MacDonald, Leslie McAuley, Denis Paradine, Deogratias Rweyongeza, Teresa Ryan, Erica Samis, Brian Simpson, Margot Spence, Cordy Teemstra, and Thomas White. We are grateful to Teresa Ryan of the University of British Columbia for the insights in the section on engagement with Indigenous peoples about forest management adaptation.

## References

**Andrews-Key, S. 2018.** Vulnerability and adaptation to climate change in sustainable forest management and the forest industry in Saskatchewan. PhD dissertation, School of Environment and Sustainability, University of Saskatchewan, Saskatoon, SK. 147 p.

**BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development. 2018.** Impacts of 2017 fires on timber supply in the Cariboo Region. Forest Analysis and Inventory Branch, Office of the Chief Forester, Victoria, BC.

**Boulanger, Y., S. Gauthier and P.J. Burton. 2014.** A refinement of models projecting future Canadian fire regimes using homogeneous fire regime zones. Can. J. For. Res. 44: 365–376.

**Canadian Council of Forest Ministers (CCFM). 2008.** A vision for Canada's forests: 2008 and beyond. Natural Resources Canada, Ottawa.

**Canadian Council of Forest Ministers (CCFM). 2019.** Vulnerability assessment of forest health monitoring policies and practices under a changing climate: Adaptation, implementation and evaluation. Natural Resources Canada, Ottawa. Available at http://cfs.nrcan.gc.ca/publications?id=39570.

**Cleaves, D. 2014.** Forward. *In*: D.L. Peterson, J.M. Vose and T. Patel-Weynand (eds). Climate change and United States forests. Springer, Netherlands.

**Corbett, L.J., P. Withey, V.A. Lants and T.O. Ochuodho. 2016.** The economic impact of the mountain pine beetle infestation in British Columbia: Provincial estimates from a CGE analysis. Forestry 89: 100–105.

**Davidson, D., T. Williamson and J.R. Parkins. 2003.** Understanding climate change risk and vulnerability in northern forest-based communities. Can. J. For. Res. 33: 2252–2261.

**Dymond, C.C., S. Tedder, D.L. Spittlehouse, B. Raymer, K. Hopkins, K. McCallion and J. Sandland. 2014.** Diversifying managed forests to increase resilience. Can. J. For. Res. 44: 1196–1205.

**Edwards, J.E., C. Pearce, A. Ogden and T.B. Williamson. 2015.** Adapting sustainable forest management to climate change: A practitioner's guide for assessing sustainable forest management vulnerability and mainstreaming adaptation into decision making. Canadian Council of Forest Ministers, Ottawa, ON. Available at: http://www.ccmf.org/english/coreproducts-cc.asp.

**Flannigan, M., M.A. Krawchuk, W.J. de Groot, B.M. Wotton and L.M. Gowman. 2009.** Implications of changing climate for global wildland fire. Int. J. Wildland Fire 18: 483–507.

**Gatin, J. and M. Johnston. 2016.** State of play report: Forestry adaptation initiatives across Canada. Environment Division, Saskatchewan Research Council, Saskatoon, SK.

**Gauthier, S., P. Bernier, P. Burton, J. Edwards, K. Isaac, N. Isabel, K. Jayen, H. Le Goff and E.A. Nelson. 2014.** Climate change vulnerability and adaptation in the managed Canadian boreal forest. Environ. Rev. 22: 256–285. doi:10.1139/er-2013-0064.

**Gleeson, J., P. Gray, A. Douglas, C.J. Lemieux and G. Nielsen. 2011.** A practitioner's guide to climate change adaptation in Ontario's ecosystems. Ontario Centre for Climate Impacts and Adaptation Resources, Sudbury, ON. 74 p.

**Gray, P.A. 2012.** Adapting sustainable forest management to climate change: a systematic approach for exploring organizational readiness. Canadian Council of Forest Ministers (CCFM), Climate Change Task Force, Ottawa, ON. Available at http://www.ccfm.org/english/coreproducts-cc.asp [Accessed 22 June 2017].

**Hagerman, S.M. and R. Pelai. 2018.** Responding to climate change in forest management: Two decades of recommendations. Front. Ecol. Environ. 2018:16 (10). doi:10.1002/fee.1974.

**Halofsky, J.E., S.A. Andrews-Key, J.E. Edwards, M.H. Johnston, H.W. Nelson, D.L. Peterson, K.M. Schmitt, C.W. Swanston and T.B. Williamson. 2018.** Adapting forest management to climate change: The state of science and applications in Canada and the United States. For. Ecol. Manage. 421: 84–97.

**Hanes, C.C., X. Wang, P. Jain, M-A. Pariesien, J.M. Little and M.D. Flannigan. 2019.** Fire-regime changes in Canada over the last half century. Can. J. For. Res. 49: 256–269.

**Hirsch, K., V. Kafka, C. Tymstra, R. McAlpine, B. Hawkes, H. Stegehuis, S. Quintilio, S. Gauthier and K. Peck. 2001.** Fire-smart forest management: A pragmatic approach to sustainable forest management in fire-dominated ecosystems. For. Chron. 77: 357–363.

**Innes, J., L. Joyce, S. Kellomaki, B. Louman, A. Ogden, J. Parrotta and I. Thompson. 2009.** Management for adaptation. *In*: R. Seppälä, A. Buck and P. Katila (eds.). Adaptation of forests and people to climate change. A global assessment report. International Union of Forest Research Organizations (IUFRO), Helsinki, Finland. IUFRO World Ser. 22: 135–186.

**Johnston, M. and H. Hesseln. 2012.** Climate change adaptive capacity of the Canadian forest sector. For. Ecol. Manage. 24: 29–34.

**Johnston, M.J., and J.E. Edwards. 2013.** Adapting sustainable forest management to climate change: An analysis of Canadian case studies. Canadian Council of Forest Ministers (CCFM), Climate Change Task Force, Ottawa, ON. Available from http://www.ccfm.org/english/coreproducts-cc.asp.

**Johnston, M., T. Williamson, A. Munson, A. Ogden, M. Moroni, R. Parson, D. Price and J. Stadt. 2010.** Climate change and forest management in Canada: Impacts, adaptive capacity, and adaptation options. A state of knowledge report. University of Alberta, Sustainable Forest Management Network, Edmonton, AB.

**Johnston, M., M. Campagna, P. Gray, H. Kope, J. Loo, A. Ogden, G.A. O'Neil, D. Price and T. Williamson. 2009.** Vulnerability of Canada's tree species to climate change and management options for adaptation. Canadian Council of Forest Ministers (CCFM), Climate Change Task Force, Ottawa, ON. Available from http://www.ccfm.org/english/coreproducts-cc.asp [Accessed 22 June 2017].

**Kant, P. and S. Wu. 2012.** Should adaptation to climate change be given priority over mitigation in tropical forests? Carbon Manage. 3: 303–311. doi:10.4155/cmt.12.29.

**Kates, R.W., W.R. Travis and T. J. Wilbanks. 2012.** Transformational adaptation when incremental adaptations to climate change are insufficient. Proc. Natl. Acad. Sci. U.S.A. 109 (19): 7156–7161. doi:10.1073/pnas.1115521109. PMID: 22509036.

**Keenan, R.J. 2015.** Climate change impacts and adaptation in forest management: A review. Ann. For. Sci. 72: 145–167. doi:10.1007/s13595-014-0446-5.

**Keenan, R.J. 2016.** Forests and climate change: Introduction to a special section. For. Ecol. Manage. 360: 353–356. doi:10.1016/j.foreco.2015.11.039.

**Kirchmeier-Young, M.C., F.W. Zwiers, N.P. Gillett and A.J. Cannon. 2018.** Attributing extreme fire risk in Western Canada to human emissions. Climatic Change. 144: 365–379.

**Klenk, N.L., B.W. Adams, G. Q. Bull, J.L. Innes, S.J. Cohen and B.C. Larson. 2011.** Climate change adaptation and sustainable forest management: A proposed reflexive research agenda. For. Chron. 87: 351–357. doi:10.5558/tfc2011-025.

**Lazar, A. 2005.** A proud record of leadership in addressing and adapting to climate change. For. Chron. 81(5): 631–632.

**Lemmen, D.S., M. Johnston, C. Ste-Marie and T. Pearce. 2014.** Natural resources. *In*: F.J. Warren and D.S. Lemmen (eds.). Canada in a changing climate: Sector perspectives on impacts and adaptation. pp. 67–98. Government of Canada, Ottawa, ON.

**Lemprière, T.C., P.Y. Bernier, A.L. Carroll, M.C. Flannigan, R.P. Gilsenan, D.W. McKenney E.H. Hogg and J.H. Pedlar. 2008.** The importance of forest sector adaptation to climate change. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, AB. Inf. Rep. NOR-X-416E.

**Littell, J.S., D.L. Peterson, C.I. Millar and K.A.O. O'Halloran. 2012.** U.S. national forests adapt to climate change through science-management partnerships. Climatic Change 110: 269–296. doi:10.1007/s10584-011-0066-0.

**Lonsdale, K., P.S. Pringle and B. Turner. 2015.** Transformative adaptation: What it is, why it matters, and what is needed. UK Climate Impacts Programme, University of Oxford, Oxford, UK.

**McKenney, D.W., D. Yemshanov, J. Pedlar, D. Allen, K. Lawrence, E. Hope, B. Lu and B. Eddy. 2018.** Canada's timber supply: Current status and future prospects under a changing climate. Natural Resources Canada, Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON. Inf. Rep. GLC-X-15.

**Messier, C., J. Bauhus, F. Doyon, F. Maure, R. Sousa-Silva, P. Nolet, M. Mina, N. Aguilue, M.-J. Fortin and K. Puettmann. 2019.** The functional complex network approach to foster forest resilience to global changes. Forest Ecosystems 6:21.

**Millar, C.I., N.L. Stephenson and S.L. Stephens. 2007.** Climate change and forests of the future: Managing in the face of uncertainty. Ecol. Appl. 17: 2145–2151.

**Nelson, H., T. Williamson, C. Macaulay and C. Mahony. 2016.** Assessing the potential for forest management practitioner participation in climate change adaptation. For. Ecol. Manage. 360: 388–399. doi:10.1016/j.foreco.2015.09.038.

**Nitschke, C.R. and J.L. Innes. 2008.** Integrating climate change into forest management in South-Central British Columbia: An assessment of landscape vulnerability and development of a climate-smart framework. For. Ecol. Manag. 256: 313–327.

**Nunez, T.A., J.J. Lawler, B.H. Mcrae, D.J. Pierce, M.B. Krosby, D.M. Kavanagh, P.H. Singleton and J.J. Tewksbury. 2013.** Connectivity planning to address climate change. Conserv. Biol. 27(2): 407–416.

**Ogden, A.E. and J. Innes. 2007.** Incorporating climate change adaptation considerations into forest management planning in the boreal forest. Int. For. Rev. 9: 713–733.

**Pahl-Wostl, C.L. 2009.** A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. Glob. Environ. Change. 19: 354–365.

**Pedersen, L. 2004.** How serious is the mountain pine beetle problem? From a timber supply perspective. *In*: T.L. Shore, J.E. Brooks and J.E. Stone (eds.). Mountain pine beetle symposium: Challenges and solutions. pp. 10–18. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Inf. Rep. BC-X-399.

**Peterson, D.L., J.M. Vose and T. Patel-Weynand, T. (eds.). 2014.** Climate change and United States forests. Springer, New York.

**Pinkerton, E. 2018.** Benefits of collaboration between Indigenous and non-Indigenous communities through community forests in British Columbia. Can. J. For. Res. 49:387–394.

**Pollard. D.F.W. 1985.** A forestry perspective on the carbon dioxide issue. For. Chron. 61(4): 312–318.

**Prescott, C.E., and K. Weese. 2014.** Crossing the divide: Engaging scientists and policy-makers in adapting forest management to climate change in British Columbia. For. Chron. 90: 89–95. doi:10.5558/tfc2014-014.

**Price, D.T. *et al.* 2013.** Anticipating the consequences of climate change for Canada's boreal forest ecosystems. Environ. Rev. 21: 322–365. doi:10.1139/er-2013-0042.

**Raynor, J. 2012.** Shifting mandates and climate change policy capacity: The forestry case. Can. Pol. Sci. Rev. 1: 75–85.

**Roninne, F.N., J. Burns, P. Kant, B. de Groot, M.D. Flannigan, M. Kleine and D.M. Wotton (eds). 2018.** Global fire challenges in a warming world. International Union of Forest Research Organizations, Vienna, Austria. Occasional Paper No. 32.

**Sankey, S. 2018.** Blueprint for wildland fire science in Canada (2019–2029). Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, AB.

**Snetsinger, J. 2006.** Government initiatives address climate change. BC For. Prof. 13(5):14–15.

**Spittlehouse, D. 2005.** Integrating climate change adaptation into forest management. For. Chron. 81(5): 691–695.

**Standing Senate Committee on Agriculture and Forestry. 2003.** Climate change: We are at risk. Final Report. The Honourable Donald Oliver, Q.C. Chair, Ottawa, ON.

**Van Damme, L., P.N. Duinker and D. Quintilio. 2008.** Embedding science and innovation in forest management: Recent experiences at Millar Western in west-central Alberta. For. Chron. 84: 301–306.

**Williamson, T.B. and K. Isaac. 2013.** Adapting sustainable forest management to climate change: an overview of approaches for assessing human adaptive capacity. Canadian Council of Forest Ministers, Ottawa, ON. Available from http://www.ccmf.org/english/coreproducts-cc.asp.

**Williamson, T.B. and H.W. Nelson. 2017.** Barriers to enhanced and integrated climate change adaptation and mitigation in Canadian forest management. Can. J. For. Res. 47: 1567–1576.

**Williamson, T.B., M.A. Campagna and A.E. Ogden. 2012.** Adapting sustainable forest management to climate change: A framework for assessing vulnerability and mainstreaming adaptation into decision making. Canadian Council of Forest Ministers, Ottawa, ON. Available from http://www.ccmf.org/english/coreproducts-cc.asp.

**Williamson, T.B., S.J. Colombo, P.N. Duinker, P.A. Gray, R.J. Hennessey, D. Houle, M.H. Johnston, A.E. Ogden and D.L. Spittlehouse. 2009.** Climate change and Canada's forests: From impacts to adaptation. Sustainable Forest Management Network, University of Alberta, and Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, AB. 104 p.

**Wotton, B.M., C.A. Nock and M.D. Flannigan. 2010.** Forest fire occurrence and climate change in Canada. Int. J. Wildland Fire 19: 253–271.

**Wotton, B.M., M.D. Flannigan and G.A. Marshall. 2017.** Potential climate change impacts on fire intensity and key wildfire suppression thresholds in Canada. Environ. Res. Lett. 12: 095003. Available from https://doi.org/10.1088/1748-9326/aa7e6e.

**Yousefpour, R. *et al.*** A framework for modeling adaptive forest management and decision making under climate change. Ecol. Soc. 22: 40. Available from https://doi.org/10.5751/ES-09614-220440.

**Appendix: Some key contacts in various aspects of adaptation in Canadian forest management**

1. Kathy Hopkins: BC Ministry of Forests, Lands, and Natural Resource Operations and Rural Development. Climate change specialist. Kathy.Hopkins@gov.bc.ca
2. Margot Spence: BC Ministry of Forests, Lands, and Natural Resource Operations and Rural Development. Tree seed policy officer: climate based seed transfer and species selection. Margot.Spence@gov.bc.ca
3. Leslie McAuley: BC Ministry of Forests, Lands, and Natural Resource Operations and Rural Development. tree Seed policy officer. Leslie.McAuley@gov.bc.ca
4. Denis Paradine: BC Ministry of Forests, Lands, and Natural Resource Operations and Rural Development. Climate change policy. Dennis.Paradine@gov.bc.ca
5. Christine Fletcher: BC Ministry of Forests, Lands, and Natural Resource Operations and Rural Development. Forest analysis and inventory. Christine.Fletcher@gov.bc.ca
6. Kerri Brownie: BC Timber Sales, BC Ministry of Forests, Lands, and Natural Resource Operations and Rural Development. Forestry operations. Kerri.Brownie@gov.bc.ca
7. Megan Hanacek: Private Forest Landowners Association. meghanacek@outlook.com
8. Eric Domaine: Quebec Ministère des Forêts, de la Faune et des Parcs. Professionnel en adaptation aux changements climatiques. Eric.Domaine@mffp.gouv.qc.ca
9. Cordy Teemstra: Alberta Agriculture and Forestry. Wildfire science coordinator. Cordy.Tymstra@gov.ab.ca
10. Erica Samis: Alberta Agriculture and Forestry. Director, Forest Health and Adaptation. Erica.Samis@gov.ab.ca
11. Brian Simpson: Retired director of the BC Wildfire Management, currently a private consultant, Brian Simpson Wildfire Management Services. Wildfire.simpson@outlook.com
12. Sheri Andrews-Key: Saskatchewan Research Council. Climate change researcher. Sheri.Andrews-Key@src.sk.ca