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**Barriers to enhanced and integrated climate change adaptation and
mitigation in Canadian forest management**

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Abstract:

Forests are sensitive to the effects of climate change and they play a significant role in carbon cycles. This duality has important implications for forest management in terms of requirements for enhanced and integrated adaptation and mitigation interventions. Two ideal conceptual level changes could provide the means for implementation. First, the incorporation of climate change considerations into definitions of sustainable forest management (SFM) would provide mandates for enhanced approaches. Second, the mainstreaming of enhanced SFM would facilitate implementation. There are, however, factors that may impede implementation. Identifying and evaluating these factors informs our understanding of requirements for adaptation/mitigation mainstreaming. This study reviews, organizes, and interprets the literature for the purposes of identifying and evaluating potential impediments. Harmonization barriers pertain to differences between adaptation and mitigation in pre-existing frames and beliefs. Enabling barriers are psychological and institutional in nature. Implementation barriers include capacity deficits (e.g., funding limits, science and knowledge deficits regarding benefits, trade-offs, and synergies between adaptation and mitigation) and governance issues. Barriers are interrelated, dynamic, and subjective. Addressing barriers requires a holistic approach that recognizes the complex and dynamic nature of forest management policy change processes.

Keywords: Climate change, sustainable forest management, adaptation / mitigation integration, mainstreaming barriers

54 Introduction

55 The purpose of this review manuscript is to identify barriers to comprehensive and
56 integrated climate change adaptation and mitigation in Canadian forest management. In its
57 strategy document *A vision for Canada's forests: 2008 and beyond* the Canadian Council of
58 Forest Ministers (CCFM) stated: "consideration of climate change and climate variability is
59 needed in all aspects of sustainable forest management." (CCFM 2008). We begin, therefore,
60 with the normative view that in the context of climate change, one of the long-term goals of
61 forest policy in Canada is to develop and implement a comprehensive and integrated response
62 that incorporates, enhances, and integrates both adaptation and mitigation. However, climate
63 change is a relatively new, unprecedented, and complex issue in forest management. Progress in
64 developing and implementing adaptation and mitigation measures are in their early stages
65 (Johnston et al. 2010; Gray 2012; Hoberg et al. 2016). Moreover, these measures are typically
66 considered separately (Johnston et al. 2010; Keenan 2016). A logical first step in moving
67 forward is to identify, evaluate, plan for, and where possible address barriers that may impede
68 the development and implementation of comprehensive and integrated adaptation and mitigation
69 (Moser and Ekstrom 2010).

70 To date, the literature on adaptation and mitigation process has identified a number of
71 capacity requirements and barriers to either adaptation or mitigation in the contexts of human
72 management systems in general (Moser and Ekstrom 2010; Biesbroek et al. 2013; Eisenack et al.
73 2014) and in forest management systems in particular (Jantarasami et al. 2010; Nelson et al.
74 2016; Johnston and Hesseln 2012; Hoberg et al. 2016). To our knowledge, however, there are no
75 studies that have explicitly considered potential barriers to the development and implementation
76 of comprehensive and integrated adaptation and mitigation in Canadian forest management

contexts. The goal of this paper, therefore, is to address this knowledge gap by reviewing, interpreting, and structuring the current literature in order to provide a holistic overview of potential barriers to comprehensive and integrated adaptation/mitigation in Canadian forest management.

Concepts and definitions

There is growing evidence and analysis regarding the current and potential future effects of climate change on forest ecosystems and of requirements to adapt forest management to maximize benefits and reduce negative impacts (Spittlehouse 2005; Lempriere et al. 2008; Johnston et al. 2009; Seppälä et al. 2009; Williamson et al. 2009; Edwards and Hirsch 2012; Price et al. 2013; Peterson et al. 2014; Keenan 2015). *Adaptation* is defined as: “adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities” (Edwards et al. 2015). The benefits of adaptation in forest management include the potential to reduce impacts to both traditional forest management values and objectives as well as to a host of new societal and community-related impacts including water regulation and quality, soil erosion, public safety issues (e.g., reducing wildfire risk), and impacts on aquatic and terrestrial habitats. A variety of adaptations in forest management have been suggested (Spittlehouse 2005; Millar et al. 2007; Ogden and Innes 2007a; Seppälä et al. 2009; Williamson et al. 2009; Johnston et al. 2009; Johnston et al. 2010; Peterson et al. 2011; Gauthier et al. 2014; Le Goff and Bergeron 2014; Peterson et al. 2014). In general these findings suggest a requirement for a comprehensive and multifaceted approach to adaptation in forest management.

There is also broad recognition of the role of forest management in supporting climate change mitigation (Nabuurs et al. 2007; CCFM 2009; Carlson et al. 2010; Golden et al. 2011;

100 Lemprière et al. 2013; Smyth et al. 2014; FAO 2016; Hoberg et al. 2016; Lempriere et al. 2017).
101 In the context of forest management, *mitigation* refers to measures or actions that reduce the
102 release of carbon from forest carbon stocks (e.g., reducing deforestation), that increase the
103 carbon capture and sink potential of forests (i.e., increasing carbon sequestration and forest
104 carbon stocks through afforestation or other forest management actions), and that promote the
105 substitution of wood products (including bioenergy) for products that are more emissions-
106 intensive on a life-cycle basis (Lemprière et al. 2013; Smyth et al. 2014; FAO 2016). A number
107 of forest based mitigation actions and strategies have been proposed for Canadian forest
108 management (Carlson et al. 2010; Golden et al. 2011; Metsaranta et al. 2011; Colombo et al.
109 2012; Lempriere et al. 2013; Smyth et al. 2014; Xu et al. 2017; Lempriere et al. 2017). A number
110 of studies have also looked at the economics of forest carbon strategies in Canada (McKenney et
111 al. 2004; Man et al. 2015; Kennedy et al. 2007).

112 In the broader arena of climate change policy, adaptation and mitigation are often
113 considered and addressed independently (Tol 2005; Biesbroek et al. 2009; Berry et al. 2015).
114 The same independence of approach has occurred in Canadian forest management (Johnston et
115 al. 2010). Adaptation and mitigation in forest management, however, are not mutually exclusive
116 (Innes et al. 2009; Keenan 2015; Keenan 2016). There are trade-offs, synergies, and interactions
117 between adaptation and mitigation in forest management (D'Amato et al. 2011; Metsaranta et al.
118 2011). For example, climate change could increase risks to forest carbon and reduce the benefits
119 of forest carbon mitigation over time (Metsaranta et al. 2011). Adaptation measures within forest
120 management may reduce the risks to mitigation and enhance the permanence of mitigation
121 investments (Locatelli et al. 2011).

Various studies have suggested that integration and coordination of adaptation and mitigation in forest management is logical if not necessary for ensuring appropriate climate responses (Millar et al. 2007; Ravindranath 2007; Collaborative Partnership on Forests 2008; Guariguata et al. 2008; Buck et al. 2009; Innes et al. 2009; Klenk et al. 2011; Locatelli et al. 2011; D'Amato et al. 2011; Kant and Wu 2012; FAO 2013; Wang and McCarl 2013; Millar et al. 2014; Smith et al. 2014; Berry et al. 2015; Keenan 2015; Locatelli et al. 2015; Keenan 2016). There are a variety of motivations and reasons for integration. Integration results in more efficient and more cost-effective climate change interventions (Duguma et al. 2014). Locatelli et al. (2015) noted that, depending on how they are implemented, mitigation projects can either facilitate or hinder adaptation. For example, investments in mitigation (that ignore adaptation) can potentially crowd out investments in adaptation. Similarly, adaptation projects, if evaluated or implemented without consideration of mitigation, can restrict mitigation opportunities or may reduce the carbon benefits of previously implemented mitigation projects. From an economics perspective, the underlying costs and benefits associated with modifying regeneration, timber harvest, or timber rotation in anticipation of climate effects on productivity or disturbance risk may be quite different depending on whether carbon costs and benefits are included or excluded (Wang and McCarl 2013).

As noted the goal of this study is to provide an overview of potential barriers to the development and implementation of comprehensive and integrated adaptation/mitigation in Canadian forest management. Following Moser and Ekstrom (2010), *barriers* are considered to be impediments and capacity deficits that can “stop, delay, or divert” the development and implementation of comprehensive and integrated adaptation/mitigation. *Comprehensive and integrated adaptation/mitigation* is considered to be an ideal state of being where Canadian

forest management policies, practices, and investments support the identification and implementation of economically rational, and technically feasible adaptation and mitigation measures where interactions, synergies, trade-offs, and interrelationships between adaptation and mitigation have been fully considered.

Approach

This review follows what Eisenack et al. (2014) describe as a positive (i.e., descriptive or explanatory) approach for barriers analysis. Following this approach an ultimate outcome is specified precisely, the means necessary for implementation are identified, and the reasons why the means are not being implemented (i.e., barriers) are identified and evaluated. The following section provides a more detailed description of the ideal outcome and the means of implementation.

The second part of this manuscript reviews, synthesizes, and structures the literature on adaptation and mitigation barriers in Canadian forest management systems in order to identify and evaluate potential barriers to developing and implementing the conceptual ideal described in the next section. Barriers are grouped into three broad categories: harmonization, enabling, and implementation barriers. We consider this categorization as a way of organizing barriers to developing and implementing the ideal outcome described in the next section.

An ideal outcome and means of implementation

The general context for this review is Canadian forest management. The majority of forestland in Canada is retained in public ownership. Forestry related policies and regulations are established and enforced by provincial governments. In general the goals of forest management on crown lands are consistent with sustainable forest management principles. Canada's forest industry obtains access rights to timber on public lands through various kinds of tenure

arrangements that require them to fulfill certain management obligations that ensure that forests are managed in a manner consistent with public forest policies and regulations.

Sustainable forest management (SFM) is the basis for many forest policies in Canada (CCFM 2008). It is a holistic approach to forest management that considers the economic, social, and environmental benefits of forests and the importance of maintaining natural capital and ecological processes for the purpose of preserving forest goods and services in perpetuity. Sustainable forest management as a concept provides a possible frame for comprehensive and integrated adaptation/mitigation (Spittlehouse 2005; Collaborative Partnership on Forests 2008; Seppälä et al. 2009; Edwards and Hirsch 2012; Gray 2012; Steenberg et al. 2013; Klenk et al. 2015). In some cases, current SFM standards may already support aspects of both adaptation and mitigation (e.g., maintaining biodiversity, recognizing the role of forests in global ecological cycles) (FAO 2013; Klenk et al. 2015).

Although SFM potentially provides the necessary enabling frame for comprehensive and integrated adaptation/mitigation, modifications to current SFM standards are needed because current versions of SFM tend not to be sufficiently explicit in terms of recognizing climate change and the linkages between adaptation and mitigation (Steenberg et al. 2013; Williamson and Edwards 2014; Keenan 2015). Therefore, modified forms of SFM that recognize opportunities and requirements for both adaptation and mitigation and their interrelationships are needed (Williamson and Edwards 2014; Klenk et al. 2015).

Presuming the existence of SFM standards that account for climate change and that enable comprehensive and integrated adaptation/mitigation, the question then becomes one of determining how to implement such a standard. Various papers have proposed structured

decision-making or mainstreaming approaches for incorporating adaptation considerations into decision making in general and forest management in particular (Ohlson et al. 2005; Nitschke and Innes 2008; Ogden and Innes 2009; Johnston et al. 2010; Peterson et al. 2011; FAO 2013; Edwards et al. 2015; Wamsler 2015; Pasquini et al. 2015). Guariguata et al. (2008) and Locatelli et al. (2015) identified mainstreaming as a potential way of incorporating both adaptation and mitigation into forest management (however these authors also suggested that there are a number of reasons for mainstreaming adaptation and mitigation separately).

Mainstreaming is the incorporation of climate change considerations into all aspects of forest management policies, programs, plans, and practices on a regular and ongoing basis (Cowling et al. 2008; Williamson et al. 2012). A mainstreaming approach to climate change adaptation based on a third-generation vulnerability assessment methodology was first described by Fussler and Klein (2006). The Canadian Council of Forest Ministers (CCFM) modified this approach for application to Canadian forest management (Williamson et al. 2012; Edwards et al. 2015). Mainstreaming, as described in recent CCFM work, is a process that combines structured decision-making and adaptive management approaches (Williamson et al. 2012; Edwards et al. 2015). The CCFM mainstreaming approach does not specifically include mitigation but it could be expanded to do so. Mainstreaming would support the ability to account for trade-offs, to address uncertainty, and to manage adaptively by promoting a continuous process of selecting and implementing options, evaluating, and modifying where justified.

Types of barriers

As noted, the goal of this review is to identify potential barriers to developing and implementing the ideal outcome described in the previous section. We group barriers into three categories based on their similarities, differences, and resemblances and based on how they

pertain to particular aspects of adaptation/mitigation mainstreaming (Table 1). The barrier types (harmonization, enabling, and implementation) are defined as follows.

Harmonization barriers are defined as pre-existing frames and beliefs about adaptation and mitigation that promote the continued consideration of adaptation and mitigation as independent responses to climate change. Harmonization barriers result from biases to, and or preferences for, either mitigation or adaptation on the part of agents or to a tendency to view these as independent and unrelated climate responses. The effect of harmonization barriers is an inability or significant challenges in agreeing on integrated adaptation and mitigation as a forest management goal. Thus, in the presence of significant harmonization barriers, the ability to address enabling and implementation barriers may be constrained. Harmonization barriers are, in some respects, unique to integration aspects of adaptation and mitigation. Enabling and implementation barriers can exist for adaptation or mitigation independently or to joint adaptation/mitigation.

Enabling factors are those that empower, motivate, or provide incentive for the pursuit of comprehensive and integrated mainstreaming. **Enabling barriers**, therefore, are defined as the absence of factors that are required to empower, motivate, or incentivize comprehensive and integrated mainstreaming approaches. The effect of enabling barriers is that there is no motivation or incentive for adopting integrated mainstreaming. There may, in fact, be penalties or sanctions associated with proceeding with this approach.

Implementation barriers are factors that are to some degree incremental to harmonization or enabling barriers. **Implementation barriers** are defined as absence (or insufficiency) of resources, required knowledge, and or the means and mechanisms for implementation. The effect

of implementation barriers is limited capacity for implementation, which is in addition to the effects of harmonization and enabling barriers.

The following three sections describe and assess various harmonization, enabling, and implementation barriers in more detail and provide strategies and options for addressing them. There are, however, some overarching considerations about barriers in the literature that merit noting. The first is that barriers are interrelated and that actions to address barriers individually will not necessarily be effective (Eisenack et al. 2014). Eisenack et al. (2014) refer to “dynamic webs of barriers” suggesting the need for comprehensive assessment approaches and comprehensive strategies for addressing barriers. The barriers discussed in the following sections are to varying degrees structural, interrelated, dynamic, and ubiquitous. Some barriers are “actor centered” and others are embedded in the “system of interest” (Eisenack et al. 2014). These features have implications for how and why barriers emerge and for how they may be addressed. The degree to which specific barriers or clusters of barriers are mutable varies. In some cases reducing barriers requires system transformations, which often are the result of longer term, multi-scale processes of social learning and policy reform.

Harmonization barriers

Although there are rational arguments for an integrated approach to adaptation and mitigation in forestry, significant challenges may arise because of ambivalence, resistance, or opposition to proceeding with such an approach on the part of key forestry decision-makers and agents. This may, to some extent, be attributable to differences between adaptation and mitigation among forest management agents in beliefs, framing, knowledge, and awareness (Locatelli et al. 2015; Keenan 2016). Moser (2012) refers to these differences as “disharmonious discontents.”

Adaptation is a recent addition to the discourse on climate change in forestry, and it has received less attention than mitigation (Johnston et al. 2010; Keskitalo 2011; Keenan 2016). Mitigation in forestry has a longer history (at least in terms of discussion and analysis of deforestation issues and mitigation opportunities; see, for example, Sedjo and Solomon (1989)). Independence of analysis and discourse on adaptation and mitigation can result in differences in beliefs, as well as greater awareness and understanding of, and stronger support for, one area over another, on the part of influential forestry decision-makers.

Keenan (2016) suggests that adaptation and mitigation in forest management are not on an equal footing. The question then arises: how can attitudinal differences within a particular forest management community be mediated. Under the right conditions, and despite significant challenges, forest management is a sector with some potential to address the various barriers that stand in the way of harmonizing adaptation and mitigation (Buck et al. 2009; Innes et al. 2009; Roberts et al. 2009). Forest management activities can address both adaptation and mitigation and their integration may be more feasible in cases involving a homogeneous group of agents within similar institutional contexts operating under similar norms and principles of management (Thuy et al. 2014).

As noted, factors contributing to differences in attitudes, frames, beliefs and support for adaptation and mitigation generally manifest as ambivalence, resistance, or opposition to integration. These tend to be, therefore, barriers to even initial consideration of comprehensive and integrated adaptation and mitigation in forest management. These barriers may diminish over time as social learning about the merits of integration occurs. However, the completion of integrated research and analysis about adaptation/mitigation strategies and information sharing and dialogue about what a comprehensive and integrated approach to climate change in forest

management might look like and how it would be implemented would help to mediate differences in support for adaptation and mitigation. Locatelli et al. (2011) suggested that processes allowing individuals engaged in forest mitigation activities to become informed about adaptation and vice versa improve the prospects of integration (note this also pertains to the presence of harmonization barriers noted earlier). Participants from both groups could be educated about the rationales for each activity and trained in the other group's tools and methods.

Enabling barriers

Enabling barriers exist where agents are not empowered, they are not motivated, there is a lack of incentives, or there are penalties associated with adaptation/mitigation mainstreaming. Enabling barriers for comprehensive and integrated adaptation/mitigation can result from enabling barriers to adaptation or mitigation or enabling barriers to joint implementation.

Psychological factors

Psychological factors such as cognitive bias and perception bias have the potential to affect judgements related to the salience of issues, and the need for comprehensive and integrated responses to climate change in forest management. Cognitive biases result in departures from rational or justifiable choices. One example of a cognitive bias is "status quo bias" (Kahneman et al. 1991). In their behavioral experiments, Samuelson and Zeckhauser (1988) found a strong preference for the status quo (i.e., maintain current status by sticking with previous choices or doing nothing). Various explanations for this behavior are possible, including loss aversion, sunk cost thinking, and the need to feel in control. Kahneman and Tversky (1982) suggested that preference for the status quo may be attributable to feelings of regret associated with potential bad outcomes from change outweighing feelings of regret associated with bad outcomes from inaction. The connections to mainstreaming of adaptation/mitigation

mainstreaming are clear. Status quo bias has the potential to reduce the motivation of forestry agents for adaptation/mitigation mainstreaming. Overcoming status quo bias may require evidence that the potential bad outcomes (or potential net benefits) of the status quo are disproportionately worse than the potential bad outcomes (or potential net benefits) associated with new approaches.

In the context of forest management, perceptions about climate change risks to forests and forest values directly influences the willingness of forest management agents to consider adaptation (Davidson et al. 2003). Several studies have evaluated the degree to which Canadian forest managers are concerned about climate change and whether they are prepared to consider adaptation. Many studies have found that generally individual forest managers, professionals, and forest experts in Canada are concerned about climate change and generally support adaptation (Williamson et al. 2005; Colombo 2006; Johnston et al. 2010; Johnston and Hesseln 2012; Morin 2015; Nelson et al. 2016).

The studies noted above suggest that general perceptions about climate change risks are not a significant barrier to adaptation. The level of support on the part of forest managers for adaptation may be attributable to significant education efforts in Canadian forestry about climate change impacts and adaptation requirements over the last number of years (Table 2).

As opposed to mitigation and adaptation, comprehensive and integrated adaptation/mitigation is currently not at the forefront of conversations about climate change in Canadian forest management. One can speculate that in addition to cognitive bias, there may currently be a relatively low degree of concern about the lack of consideration of this approach in Canadian forest management. This may translate into passive (or lack of) support for adaptation/mitigation mainstreaming. As was the case for adaptation, developing support for

comprehensive and integrated adaptation/mitigation may require new information regarding the relative merits, costs, and risks of this approach and significant effort to raise awareness and engage in conversations with forest management stakeholders about how to develop and implement the approach.

Institutions

Forest management institutions include laws, policies, tenure arrangements, codes of conduct, behavioral norms, rules, penalties, and forest management standards. They provide incentives for, and enable actions, and they penalize unacceptable behaviours and decisions. Institutions are therefore central to the capacity and effectiveness of forest management systems in adapting to and mitigating climate change (Williamson and Isaac 2013). Forest management institutions that have not incorporated climate change are a barrier to adaptation and to mitigation in Canadian forest management (Klenk et al. 2011; Johnston and Hesseln 2012; Hoberg et al. 2016) and, therefore, by extension to comprehensive and integrated adaptation and mitigation.

Currently forest management institutions in Canada do not consider climate change to the degree necessary for enabling effective climate response (Spittlehouse 2005; Johnston et al. 2010; Klenk et al. 2011; Greig and Bull 2011; Johnston and Hesseln 2012; Rayner 2012; Steenberg et al. 2013; Nelson et al. 2016; Hoberg et al. 2016). This situation creates a dilemma for the mainstreaming of adaptation and mitigation, because institutions that do not consider climate change or that do not link adaptation and mitigation in policy contexts pose direct barriers to integrated adaptation and mitigation action (Locatelli et al. 2011).

Institutional barriers to comprehensive and integrated adaptation/mitigation can be grouped into two broad types. The first type of barrier is absence of policy regimes that recognize climate

change, that support and enable adaptation and mitigation, and that link adaptation and mitigation (Spittlehouse 2005; Collaborative Partnership on Forests 2008; Johnston et al. 2010; Locatelli et al. 2011; Golden et al. 2011; Greig and Bull 2011; Steenberg et al. 2014; Keenan 2015; Keenan 2016; Hoberg et al. 2016). The second type of barrier pertains to institutions that are ill equipped to address the increasingly complex, dynamic, and uncertain decision environments associated with climate change (Ogden and Innes 2007a; Millar et al. 2007; Joyce et al. 2009; Seppälä et al. 2009; Innes et al. 2009; Williamson et al. 2009; Klenk et al. 2011; Johnston and Hesseln 2012; Gray 2012). Institutions that are forward looking, that enable collaborative adaptive management, that promote flexible approaches that are reversible as new information becomes available, that promote learning, and that allow for diversity of approaches that can be tailored to different local circumstances and modified over time are called for (Millar et al. 2007; Ogden and Innes 2009; Klenk 2011; Gray 2012).

A particular aspect of the Canadian forest management institutional context is the potential for differences in incentives and costs of adaptation between private agents operating on crown forest lands and provincial governments. In Canada, various kinds of tenure arrangements provide the basis for transferring rights to harvest timber on crown land. Forest industry tenures “specify the rights, obligations, and duration of the tenure agreement as well as how the tenure will be administered (Hoberg et al. 2016, pg 77). Hotte et al. (2016) notes that differences in the distribution of costs and benefits of some adaptation measures between private agents and public management agencies can be a barrier to action (the “principal-agent problem”). They note that explicit analysis of the incentives and disincentives facing private sector interests on crown land and public forestland managers may be required in order to identify and address barriers to adaptation. The principal-agent problem also pertains to forest carbon mitigation. Hoberg et al.

(2016) note that in British Columbia, including carbon in tenure, and expanding the duration of tenures would provide a stronger incentive for tenure holders to manage for carbon as well as timber values.

Overcoming institutional barriers will be challenging. It may require overcoming “longstanding and sometimes hard-won standardized practices and deeply ingrained rules of thumb.” Kates et al (2012, pg 7159) and it may require different policy learning types (e.g., government, social) for different learning outcomes (e.g., organization change, paradigm change) (Bennett and Howlett 1992). An important initial step is to undertake assessments and analysis that illustrate the costs and risks of inaction, that demonstrate the benefits of change, and that identify options for moving forward (Edwards et al. 2015). In terms of comprehensive and integrated adaptation/mitigation, this type of analysis is not currently available. Beyond the development of basic new knowledge, it should be also be acknowledged that there are significant knowledge gaps about the organic nature of policy and institutional change processes in forestry. There is, therefore, also a need for research into governance and policy change processes. This is required in order to provide a realistic understanding of factors that affect policy change processes and about how to mobilize policy change processes in order to support comprehensive and integrated adaptation/mitigation (Klenk et al. 2011).

Leadership

Experimentation, innovation, and change can occur at many different levels. Leadership usually plays a significant role in supporting experimentation, innovation, and change at these various levels. Cumulative learnings obtained through experimentation, innovation, and change at multiple levels leads to higher-level system wide changes (Pahl Wostl 2009). There are many different kinds of leadership. Political leadership and political will is required for higher-level

policy change at legislative levels and for the establishment of inter-jurisdictional collaborations. Organizational leadership (e.g. senior managers in organizations) is required for enabling mid-level adaptations and for promoting innovative approaches to management within the context of existing laws and policies. Collaborative leaders are individuals who have the ability to bring together people from diverse backgrounds to address issues and challenges of common interest.

Various studies in Canada have noted the importance of leadership in addressing climate change in Canadian forestry. Gray (2012, pg 12) notes: “The ability of an organization to manage for climate change depends not only on how its staff and partners are marshalled and organized to work together, but also on its leadership.” Leadership can be important for the adoption of innovative approaches at local scales. In a review of forest sector based vulnerability case studies across Canada, Johnston and Edwards (2013) noted that a significant factor in the successful completion of the studies was the presence of local champion who provided an essential bridge between local stakeholders and outside experts involved in the technical analysis. Van Damme et al. (2008) identified the significant contribution of corporate leadership at Millar Western (a forest company in west-central Alberta) in promoting a culture that values and promotes “family, productivity, innovation, integrity, and social responsibility,” Millar Western was one of the first companies in Canada to incorporate climate change considerations into their long run forest management planning process.

Leadership is also important at provincial and national scales. Canada’s forest ministers provided significant leadership in identifying climate change as one of two issues of national importance in its strategic document “Vision for Canada’s forests:2008 and beyond.” In 2010, Canada’s provincial and territorial premiers asked their forestry ministers to collaborate with the federal government to assess the vulnerability of Canada’s tree species to climate, to identify

adaptation options, and to develop tools to support forest managers in incorporating climate change into forest management (Edwards and Hirsch 2012).

A lack of leadership support or a lack of political will can be an important barrier to responding to climate change (Norman 2008; Ford et al. 2011; Ford and King 2015). Moser and Ekstrom (2010) noted that leadership is important at all stages of adaptation mainstreaming, particularly in the early stages, when there are no laws, mandates, or public demands, but also over the longer term, for sustaining attention and focus. A potential absence of leadership support for mainstreaming of integrated adaptation and mitigation or lags in supporting changes in approach is an impediment. For example, Klenk et al. (2011, pg 353) note that “without political will and a social licence to legitimize proactive, experimental, adaptive collaborative management, prospects of implementing flexible policies to mitigate and adapt to climate change within sustainable forest management are low.” As previously noted, differences in perceptions, differences in how policy makers frame adaptation and mitigation, or simply their tendency to prefer the status quo over significant change (as discussed previously) could affect the willingness of leaders to support comprehensive and integrated adaptation/mitigation. In the specific context of Canadian forestry policy, forestry leaders are currently facing an array of competing issues, including increasing competitive pressures on Canada’s forest industry, diminishing resources for many aspects of forest management, urbanization, changes in societies expectations about forest values (Johnston and Hesseln 2012; Rayner 2012). These issues influence their willingness to introduce and champion novel, complex, untested modifications that have long-term time horizons and uncertain outcomes.

Processes designed to integrate science and policy can make a significant difference relative to ensuring policy relevant research and influencing policy leaders. Prescott and Weese (2014)

describe an eight-step process developed in British Columbia, Canada, for science policy integration on climate change adaptation in BC forest management. This process was used to identify and prioritize policy relevant research in support of adapting BC's forest management framework to address climate change.

Implementation barriers

For the purpose of this review, implementation barriers refer to deficits or inadequacies in funding, knowledge, governance, and in assessment and monitoring capacity. Overcoming implementation barriers requires enhancements in the capacity of forest management systems to develop and implement comprehensive and integrated mainstreaming approaches. Similar to enabling barriers, implementation barriers to comprehensive and integrated adaptation/mitigation may be a result of adaptation or mitigation barriers, or joint barriers.

Governance

Current forest management governance regimes are ill-equipped to handle the enhanced policy requirements associated with adaptation and mitigation (Rayner 2012; Lindahl et al. 2017; Timberlake and Schultz 2017)). Governance issues pertain to both policy capacity (Rayner 2012) and structural features (Gray 2012; Hoberg et al. 2016). Pettersson and Keskitalo (2013) argued that forest policy systems tend to be reactive and that modifying these systems in anticipation of uncertain futures is difficult. Rayner (2012) examined forest management adaptation in the context of a Canadian forest policy system and found disconnects between increasing policy mandates associated with climate change and decreasing governance capacity. Reducing these disconnects would contribute to the efficiency and effectiveness of responses to climate change in Canadian forest policy.

In terms of the structural aspects of governance, several authors have found that traditional modes of forest management governance (e.g., top-down, monocentric structures) may not have the necessary flexibility or responsiveness to deal with the complex, dynamic, spatially diverse, and uncertain features of climate change (Seppälä et al. 2009; Gray 2012; Timberlake and Schultz 2017). Effective implementation of mainstreaming for adaptation and mitigation requires the development of new hybrid forms of governance combining the advantages of centralized governance (coordination, stability, compliance) with those of more horizontal structures (flexibility, autonomy for local decision-making, multi-stakeholder engagement, co-management) (Gray 2012). In many respects climate change impacts will be noticed first at local scales. Adaptation at local scales is dependent on local forest managers having the authority, mandate, knowledge, and autonomy to implement adaptations locally (Keenan 2015; Johnston et al. 2010). Nelson et al. (2016), however, note that forest management practitioners in BC feel they do not have sufficient authority to develop and implement local adaptation measures.

Science and knowledge factors

Climate change is unprecedented in forest management and it creates demands for new knowledge and scientific research (Millar et al. 2007; Lemprière et al. 2008; Klenk et al. 2011; Williamson et al. 2012; Lemprière et al. 2013; Keenan 2016; Nelson et al. 2016; Lawrence 2017). Uncertainty is greatest at local scales (i.e. scales most relevant to forest management decision-making) (Williamson et al. 2009; Johnston et al. 2010). Arguably, climate change makes obsolete that portion of scientific knowledge in forest management that has assumed a stationary climate. The combination of potential obsolete knowledge and new knowledge requirements results in knowledge gaps that act as barriers. There are four subcomponents to the science deficit problem as it relates to mainstreaming of adaptation and mitigation. First, there

are knowledge gaps in assessing the impacts of climate change (including impacts on forest carbon) and identifying suitable adaptation measures (Lemprière et al. 2008; Williamson et al. 2009; Johnston et al. 2009; Johnston et al. 2010). Second, there are knowledge gaps in assessing forest carbon and identifying mitigation options under different biophysical, institutional, and governance contexts (Greig and Bull 2011; Lemprière et al. 2013; Smyth et al. 2014). Specific knowledge gaps pertain to permanence, leakage, monitoring of forest carbon over time, and estimation of changes in forest carbon stocks (Nabuurs et al. 2007). Third, there are knowledge gaps in terms of assessing synergies and trade-offs between adaptation and mitigation (Klein et al. 2005; Ravindranath 2007; Golden et al. 2011; Lemprière et al. 2013; Lemprière et al. 2017). Fourth, there are knowledge gaps about social transformation processes and about how to overcome barriers to developing and implementing comprehensive and integrated adaptation / mitigation (including institutional and governance barriers) given the reality of political/policy change processes (Klenk et al. 2011).

Knowledge gaps are partly a result of the current funding of adaptation and mitigation science. However, adaptation researchers have also noted that addressing knowledge gaps requires more than simply spending more money on traditional science. Reducing knowledge gaps also requires transforming the ways in which knowledge is created, accessed, and information disseminated (Klenk et al. 2011; Gray 2012; Blades et al. 2016). Proposed options for changing the way knowledge is produced and utilized include (1) establishing science partnerships for joint knowledge production (Van Damme et al. 2008; Joyce et al. 2009; West et al. 2009; Klenk et al. 2011; Peterson et al. 2011; Littell et al. 2012; Guariguata et al. 2012; Prescott and Weese 2014; Keenan 2015; Keenan 2016); and (2) nurturing learning cultures (e.g., adaptive comanagement) within forest management systems to promote adaptability and

perpetual learning (Millar et al. 2007; Innes et al. 2009; Pahl Wostl 2009; Klenk et al. 2011; Keenan 2015).

Knowledge exchange, information, education, and training

Although education efforts (Table 2) have been effective in increasing awareness and understanding of climate change risks, there remains an issue related to levels of technical knowledge and expertise required to support the development of practical adaptation and mitigation strategies. A barrier that is often identified by forest managers is their own general lack of specific understanding of climate modelling (including downscaling) and assessment tools and techniques (e.g., vulnerability assessment, carbon budget models) (Williamson et al. 2005; Colombo 2006; Ogden and Innes 2007b; Nelson et al. 2016). These knowledge gaps make it difficult for forest management practitioners to make decisions about climate change adaptation and mitigation (Klenk et al. 2011).

A number of strategies have been proposed to address practitioner knowledge gaps. Continued attention to traditional approaches to knowledge exchange such as workshops, newsletters, and the development of communities of practice is necessary but not sufficient. The development of user-friendly decision support tools and training in their use are needed to assist managers in identifying options (Greig and Bull 2011; Edwards et al. 2015). There is also a need to provide access to, or build technical capacity at local scales in the areas of climate modelling and assessment (Klenk et al. 2011). Van Damme (2008) discusses an innovative approach where the embedding of scientists in forest industry planning processes provides an effective model for addressing complex science oriented issues in long term forest management plans.

Funding for adaptation and mitigation

Climate change creates a new context and a new mandate for forest management (Edwards and Hirsch 2012; Keenan 2015). Managing forests with new mandates and objectives, new methods, and possibly more intensive management approaches will require increased financial and human resources. Numerous authors have noted that limits on the financial resources available for adaptation and mitigation represent a significant barrier (Innes et al. 2009; Roberts et al. 2009; Seppälä et al. 2009; Johnston et al. 2010; Johnston and Hesseln 2012; Littell et al. 2012; Rayner 2012; Guariguata et al. 2012; Hoberg et al. 2016; Lawrence 2017). Nelson et al. (2016) similarly reported that, according to BC forest professionals, a general lack of capacity and multiple competing demands on existing resources were significant barriers to climate change adaptation. Johnston and Hesseln (2012) noted that managers in the Canadian forest industry are concerned about economic issues and often they do not have sufficient time to address longer-term issues such as climate change, even though they recognize its importance.

Although effective implementation of a comprehensive and integrated approach to climate change in forest management is contingent on increased funding, recent evidence suggests an opposing trend, with some forest management organizations and forestry companies undergoing decreases in staff and budget (Johnston et al. 2010; Morgan and Daust 2013; Lawrence 2017).

Assessment

An often-mentioned barrier to climate change adaptation in forestry is a lack of investment in comprehensive science-based assessments (Johnston and Williamson 2007; Williamson et al. 2012; Lemprière et al. 2013; Nelson et al. 2016). Assessments of the current and potential future impacts of climate change are a required step in the adaptation process (Johnston and Williamson 2007; Williamson et al. 2012; Le Goff and Bergeron 2014; Janowiak

et al. 2014). However, Johnston and Edwards (2013) found that in Canada, climate change vulnerability assessments are not mainstreamed into forest management decision-making. Assessments of forest carbon, of the potential impacts of climate change on forest carbon, and of the amounts of carbon within harvested wood products (along with product substitution effects) are required for identification and implementation of mitigation measures (Nabuurs et al. 2007; Lemprière et al. 2013; Smyth et al. 2014). However, there are currently limits on the ability to model the impacts of climate change on forests (and therefore forest carbon) (Lemprière et al. 2008; Lempriere et al. 2017). Mainstreaming of adaptation and mitigation requires integrated assessment approaches that evaluate climate change impacts (including impacts on forest carbon); the effects of joint adaptation and mitigation strategies; and the relation of these strategies to other forest management objectives. The knowledge, tools, methods, and data to support these goals do not currently exist (Locatelli et al. 2011; Lempriere et al. 2017).

Monitoring

The incorporation of aspects of adaptive management and adaptive governance into decision-making has been suggested as a way of responding to the increased uncertainty and variability of impacts associated with climate change (Seppälä et al. 2009; West et al. 2009; Klenk et al. 2011; FAO 2013; Millar et al. 2014; Keenan 2015; Lawrence 2017). Mainstreaming is often described as a continuous process that incorporates adaptive management principles (Williamson et al. 2012). Adaptive management requires effective monitoring for early identification of impacts (Spittlehouse 2005; Williamson et al. 2012; Janowiak et al. 2014). It also requires effective monitoring to generate the knowledge and information necessary to evaluate previously implemented adaptation and mitigation measures and to determine whether changes in direction are required (Williamson et al. 2012). Some authors have suggested that current monitoring

capacity is insufficient to support forest management under a changing climate (Spittlehouse 2005; Williamson et al. 2009; Metsaranta et al. 2011). BC forest professionals, for example, perceived the current state of monitoring as a barrier to adaptation (Nelson et al. 2016).

Conclusions

The ability of Canadian forest managers to “incorporate climate change considerations into all aspects of sustainable forest management” is an open question. We suggest, however, that recent progress on adaptation and mitigation in Canadian forestry indicates that there is an intrinsic capacity for modifying and improving forest management systems in response to new drivers of change including climate change.

This study identifies and evaluates barriers to enhanced and integrated climate change adaptation and mitigation in Canadian forest management. A number of harmonization, enabling, and implementation related barriers are identified. Barriers are structural, interrelated, and dynamic. Overcoming barriers will involve continuation of the complex and incremental process of learning, policy development, and transformation that is already underway in Canadian forestry relative to climate change. An important question is: What is a logical next step relative to dealing with barriers to comprehensive and integrated adaptation/mitigation? We propose that a significant early requirement is to address harmonization barriers because as long as there are substantive differences in frames and beliefs about adaptation and mitigation there will be ambivalence or opposition to even initial consideration of integrated approaches. As noted in this manuscript one strategy for addressing harmonization barriers would be to advance research and analysis of joint adaptation/mitigation strategies. Also as Locatelli et al. (2011) suggest processes that allow mitigation experts to become better informed about adaptation and vice versa would improve prospects for integration.

A number of potential research questions emerge from this review. The barriers identified in this manuscript are considerable. Institutional and governance related barriers are particularly challenging to overcome. Our understanding of policy and decision-making processes in forest management and how these processes affect the capacity to implement comprehensive and integrated approaches to climate change in forest management is a knowledge gap (Klenk et al. 2011). Another research opportunity is to undertake more in-depth research into the interrelationships and dynamic nature of the barriers identified in this study (Eisenack et al. 2014) and to investigate how and why barriers emerge and persist (Biesbroek et al. 2013). This knowledge would inform political/policy change and would help in developing intervention strategies. Empirical studies identifying and assessing barriers and interventions to overcome barriers in specific contexts would contribute to a better understanding of change processes in forest management.

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Table 1. Barriers to integrated consideration of adaptation and mitigation in forest management

Category	Barriers
Harmonization	Differences between A and M in knowledge and understanding of each domain by agents Differences in beliefs and framing about A and M
Enabling	Psychological factors: e.g., cognitive bias, perception bias Lack of leadership and political will to proceed with enhanced and integrated A and M Institutions that do not enable enhanced and integrated A and M
Implementation	Governance systems that do not support enhanced and integrated A and M Insufficient or ineffective investment in science and knowledge relative to A and M mainstreaming requirements Underinvestment in knowledge exchange, education, and training Insufficient funding for enhanced and integrated A and M mainstreaming Insufficient assessment capacity to support mainstreaming Insufficient monitoring capacity

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Table 2. Initiatives in Canadian forest management to raise awareness about climate change

impacts and adaptation

- Efforts by various Canadian Model Forests,
- Collaborative work by provinces and the federal government through the Canadian Council of Forest Ministers,
- Outreach and knowledge exchange activities by provincial management agencies,
- Work by the Canadian Federal Government through the now disbanded Canadian Climate Impacts and Adaptation Research Network (CCIARN) and more recently through various adaptation platforms,
- National and regional assessments,
- Knowledge exchange activities conducted by professional forester organizations (e.g., The Association of British Columbia Forest Professionals), work conducted by the Canadian Forestry Community of Practice (FACOP), and the Canadian Institute of Forestry
- Work conducted by industry associations such as the Forest Products Association of Canada
- Work completed by the now disbanded Network Centre of Excellence on Sustainable Forest Management.