Canadian Council of Forest Ministers
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Adapting Sustainable Forest Management to Climate Change:

A Framework for Assessing Vulnerability and Mainstreaming Adaptation into Decision Making

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Adapting Sustainable Forest Management to Climate Change:
A Framework for Assessing Vulnerability and Mainstreaming Adaptation into Decision Making

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"Consideration of climate change and future climatic variability is needed in all aspects of sustainable forest management"

A vision for Canada's forests: 2008 and beyond

(CCFM 2008)

Photo: Natural Resources Canada

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Photo: Kelvin Hirsch

FOREWORD

Canada has 397 million hectares of forests and other woodlands, representing 10% of the world's forest cover. Our forests constitute a world-class natural treasure providing ecological, economic, social, and cultural benefits to all Canadians, regardless of whether they live in small northern communities or large urban centres. Canada is committed to sustainable forest management, which aims to maintain and enhance the long-term health of forested ecosystems while providing ecological, economic, cultural, and social opportunities for present and future generations.

One of several factors that pose both opportunities and challenges in terms of effectively and efficiently meeting our sustainable forest management goals is climate change and its inherent uncertainties. The Canadian Council of Forest Ministers (CCFM) identified climate change as one of two priority issues for Canada's forest sector. In its *Vision for Canada's Forests: 2008 and Beyond*, the CCFM stated, "Consideration of climate change and future climatic variability is needed in all aspects of sustainable forest management." In addition, to minimize the risks and maximize the benefits associated with a changing climate, Canada's provincial and territorial premiers asked their Ministers responsible for forest management to collaborate with the federal government on adaptation in forestry through the CCFM's Climate Change Task Force. Phase 1 of this work, completed in 2010, involved a comprehensive assessment of the vulnerability of various tree species and identified management options for adaptation. Phase 2 has gone beyond the level of trees to look at climate change adaptation within forest ecosystems and the broader forest sector. The goal of phase 2 was to equip members of the forest sector with a suite of tools and state-of-the-art information to enable them to make better decisions about the need for adaptation and the types of measures that may be most beneficial.

Over a period of two years, nearly one hundred individuals from a wide range of organizations have contributed to achieving this goal. The fruits of their labour have been captured in the CCFM's Climate Change Adaptation series, which comprises several technical reports and review papers. It is our sincere hope that these documents, which will be used in conjunction with workshops, seminars, and presentations, will benefit forest practitioners from coast to coast to coast as they seek innovative ways to adapt sustainable forest management policies and practices for a changing climate.

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ABSTRACT

One of the consequences of climate change is that new kinds of information will be needed to support policy- and decision making. The vulnerability approach is an established methodology for providing information in a form that supports policy- and decision making in the context of adapting to climate change. For example, climate change is ubiquitous, so approaches to assessment are needed that simultaneously consider the breadth of impacts both on forests and on sustainable forest management objectives. In addition, the long growth cycles of trees mean that forest management is inherently a long-term undertaking. This, combined with the fact that Canada's climate could change significantly in the next 100 years, means that a long-term view of climate change impacts is needed in order to make correct forest management decisions today. There is, however, uncertainty about future climate change impacts. Vulnerability assessments acknowledge and address uncertainty through a process of scenario construction. Typically, such a process results in multiple stories of the future, which are informed by a combination of science, modeling, and expert judgment. Climate change will have implications for the capacity of forest managers, forest management organizations, and forest management systems to adapt. Vulnerability approaches incorporate assessments of adaptive capacity. This document presents a framework for assessing the vulnerability of sustainable forest management in Canada to climate change and linking the results of vulnerability assessment to an adaptation process that is integrated into forest management decision making. The framework will enable Canadian forest managers to better understand the location, timing, and magnitude of potential climate change impacts on sustainable forest management objectives and their capacity to adapt to current and future impacts. The framework also describes a process for structured, adaptive management decision making in which information about sources of vulnerability is used to implement adaptation actions, the state of the system after adaptation is monitored, and vulnerabilities and adaptation requirements are regularly and systematically re-examined.

Key words: climate change, sustainable forest management, vulnerability, assessment, exposure, sensitivity, impacts, adaptive capacity, scenarios, adaptation, adaptive management, mainstreaming adaptation, structured decision making

RÉSUMÉ

Les changements climatiques auront, entre autres, des répercussions sur les processus décisionnels et l'élaboration des politiques en conséquence de quoi l'apport d'information nouvelle sera requise pour les guider. Une méthodologie reconnue, l'évaluation de la vulnérabilité, fournit une part de cette nouvelle information qui guidera les décideurs chargés de l'adaptation aux changements climatiques. Considérant le caractère global des changements climatiques, il est nécessaire que les évaluations considèrent simultanément l'étendue des impacts des changements climatiques sur les forêts et les objectifs d'aménagement durable. Par ailleurs, la lenteur de croissance des arbres dicte la perspective à laquelle l'aménagement forestier est envisagé. Cette réalité jumelée aux changements prévus du climat canadien dans les 100 prochaines années implique l'adoption d'une perspective à long terme des impacts des changements climatiques si l'on veut guider dès maintenant les décisions en aménagement forestier. Une part d'incertitude demeure cependant sur les impacts attendus des changements climatiques. Dans l'évaluation de la vulnérabilité, on reconnaît cette incertitude ; elle est d'ailleurs intégrée dans l'élaboration des scénarios soient des descriptions du futur établies à partir de documentation scientifique, de modélisation et d'avis d'experts. L'évolution continuelle du climat va exiger une évaluation et une amélioration continue de la capacité d'adaptation des systèmes d'aménagement forestier, des aménagistes forestiers et des organisations concernées par l'aménagement, exigences que les évaluations de la vulnérabilité sont en mesure de satisfaire. Ce document présente un cadre d'évaluation de la vulnérabilité de l'aménagement forestier durable aux changements climatiques au Canada et montre comment lier les résultats de ces évaluations à un processus d'adaptation qui s'intègre dans le processus décisionnel d'aménagement forestier. Avec l'aide de ce cadre, les aménagistes forestiers canadiens comprendront mieux où, quand et comment les impacts potentiels des changements climatiques affecteront les objectifs d'aménagement forestier durable et leur capacité de s'adapter aux impacts actuels et à venir. Le cadre décrit aussi un processus décisionnel de gestion adaptative dans lequel 1) l'information disponible sur les sources de vulnérabilité sert de point de départ à la mise en œuvre des mesures d'adaptation, 2) l'état du système est suivi après la mise en œuvre des mesures d'adaptation et 3) les vulnérabilités et les besoins en matière d'adaptation font l'objet d'examens réguliers et systématiques.

Mots clés : changements climatiques, aménagement forestier durable, vulnérabilité, évaluation, exposition au risque, impacts, sensibilité, capacité d'adaptation, scénarios, adaptation, gestion adaptative, intégration de l'adaptation, processus structuré de prise de décision

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EXECUTIVE SUMMARY

Climate change is a relatively new issue for Canadian forest management, one that may require new policies and management approaches. Concurrently, new types of analysis and knowledge will be required to support policy making and management decision making (Edwards and Hirsch 2012). The first step for any organization preparing to deal with climate change is to understand its readiness to adapt. A framework and approach for assessing organizational readiness to deal with climate change is described by Gray (2012).

The second fundamental step in preparing for climate change is to assess vulnerability and to use this information to support adaptation. Vulnerability assessment is an internationally established methodology for evaluating potential climate change impacts and linking this knowledge to adaptation policy. On a more local scale, the vulnerability approach is currently being used in one form or another in a number of forest and forest management–oriented climate change assessments in Canada (Johnston and Edwards n.d.).

This document describes a framework for identifying sources of vulnerability to climate change that are important to sustainable forest management (SFM) in Canada and presents an approach for mainstreaming adaptation into SFM policy- and decision making (for the purposes of this report, the term "vulnerability" encompasses the concept of adaptation). The broad objective of the assessment framework presented here is to assist forest managers in identifying how SFM is vulnerable to climate change and in using this information to identify and implement appropriate adaptations on a continual basis. In this report, the term "vulnerability" refers to the identification of both the positive effects of climate change on SFM (which might be enhanced by adaptation) and the negative effects (which might be reduced by adaptation). The consideration of positive effects within a vulnerability assessment may, on the surface, appear counterintuitive. Furthermore, it is not necessarily consistent with the way in which vulnerability assessments are typically performed. Nonetheless, it is important to consider both positive and negative effects when developing an adaptation strategy.

The assessment framework presented in this document comprises the following six integrated components:

- Provide context (C1)
- Describe current climate and forest conditions (C2)
- Develop scenarios of future climate and forest conditions (C3)
- Assess the vulnerability of SFM to current and future climate (C4)

- Develop and refine options for adaptation (C5)
- Implement and mainstream options for adaptation (C6)

Providing context for a vulnerability assessment (C1) includes determining the need for an assessment, identifying how the results of the assessment will be used, and determining the capacity of the agency or organization to undertake the assessment. It also includes describing the particular management system of interest. Overviews of nonclimatic factors that have or will have implications for the SFM system of interest also contribute to the context.

The second component (C2) involves describing current climate and forest conditions. Climate change is a multifaceted and complex issue, and it may be difficult to understand future vulnerability when the future climate is itself uncertain. Determining and describing how forests are being affected by, and how forest managers have adapted to, current climate, clarifies relationships among climate, forests, and current management.

Forest management is inherently a long-term undertaking, and assessing SFM vulnerability therefore requires estimation of the potential future positive and negative impacts of climate change on forests. However, the potential impacts of future climate change on forests are uncertain. The third component of the vulnerability assessment framework (C3) therefore involves the development of scenarios of future climate and forest conditions (see Price and Isaac 2012).

The fourth component (C4) builds on the analysis of current climate and forests (C2) and the scenarios of future climate and forest conditions (C3) to assess the impacts of current and future climate and forest conditions on SFM. The sustainable management of forests in Canada is defined by the Canadian Council of Forest Ministers (CCFM) criteria of SFM (i.e., biological diversity, ecosystem condition and productivity, soil and water, role in global ecological cycles, economic and social benefits, and society's responsibility) (see CCFM 2006). Assessment should consider the potential for differences in impacts on SFM across various climate scenarios (including current climate) and across spatial units, as well as the potential for changes in impacts over time.

The fourth component also includes assessments of the capacity of SFM systems to adapt. Adaptive capacity is the inherent ability of individuals, organizations, or systems (such as SFM systems) to adapt to changes in operating environments. For the purposes of the framework being proposed here, adaptive capacity refers to the human (as opposed to biological) components of the SFM system. Williamson and Isaac (n.d.) provide guidelines for assessing the adaptive capacity of individuals, groups, and organizations involved in SFM and of SFM systems overall. The adaptive capacity of the biological components of SFM systems is not explicitly considered in the adaptive capacity assessment portion of the framework presented here. However, biological adaptive capacity is accounted for by the biological diversity criterion of the CCFM Criteria and Indicators (CCFM 2006). A forest system with high biological adaptive capacity is one with a high level of diversity at the genetic, species, and landscape scales.

The fifth component of the framework (C5) involves using the results of the SFM vulnerability assessment conducted in the fourth component (C4) to identify and refine options for adaptation.

The sixth component of the framework (C6) describes an ongoing process for mainstreaming adaptation into decision making. The process of mainstreaming adaptation incorporates the following activities:

- Adaptation options are assessed in terms of whether they are beneficial.
- Technical, institutional, and organizational feasibility and costs and benefits are evaluated.
- Feasible and economically viable adaptations are implemented.
- Adaptation performance is evaluated and monitored over time.
- If necessary, the adaptation program or management objectives are modified.
- Vulnerability is periodically reassessed as new knowledge, learning, and insights become known.

Forest managers may consider applying vulnerability assessments such as the one described in this document for a variety of reasons. In particular, such assessments offer managers the ability to perform numerous critical planning and adaptation activities, such as the following:

- to better prepare and plan for future climate change by organizing information so that it is relevant to decision making about adaptation and by mainstreaming adaptation into the decision making process
- to identify critical knowledge gaps
- to explicitly take account of uncertainty
- to assess adaptive capacity and include adaptive capacity in adaptation decisions
- to undertake adaptation in a planned and proactive way
- to monitor adaptations, assess their effectiveness, and modify them if necessary
- to subdivide the complex climate change problem into manageable parts
- to link science, research, policy, and practitioner knowledge in support of planning and decision making related to adaptation
- to develop a common language for analysis, consultation, and discussion

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INTRODUCTION

Johnston et al. (2009) identified several current and potential future impacts of climate change on Canada's tree species and forest landscapes. Climate change will (or could) result in productivity changes, maladaptation of trees, changes in the forest land cover, changes in species composition, increases in the frequency and intensity of biotic and abiotic disturbances, and a host of other biological responses (Lemprière et al. 2008; Williamson et al. 2009). Although in some cases, climate change impacts may be positive, it is expected that the overall net effect of climate change on Canada's forest will be negative, especially in the absence of early adaptation by forest managers (Johnston et al. 2009). For example, the National Round Table on the Environment and the Economy recently suggested that, by 2050, the annual reduction in Canadian gross domestic product resulting from the effects of climate change on the Canadian timber supply could range from $2.4 billion to $17.4 billion (NRTEE 2011).

The effects of climate change on forests and the interactions among these effects will have important implications for Canada's ability to achieve its sustainable forest management (SFM) objectives (Johnston et al. 2010; Edwards and Hirsch 2012). Currently, SFM policies and practices are based on the assumption that future environmental processes and conditions shaping forests will be similar to those that shaped existing forests. Under a changing climate, however, this assumption is no longer valid. Recognition that future climate and hence growing conditions will differ from those of the present calls for a fundamental rethinking of the approaches and assumptions used in forest management. The CCFM recognized this in its report "A vision for Canada's forests: 2008 and beyond" (CCFM 2008), identifying climate change as one of two strategic issues of national importance for Canadian forest management. In particular, the report stated, "Consideration of climate change and future climatic variability is needed in all aspects of sustainable forest management."

The current report introduces and describes a framework that Canadian forest managers can use to enhance their capacity to achieve SFM under a changing climate. The framework will enable forest managers to accomplish the following broad goals:

- identify where SFM is vulnerable to climate change and therefore where adaptation is needed
- identify and prioritize adaptation measures
- mainstream adaptation into decision making

The framework described in this report is comprehensive and scalable, and can be used in a variety of ecosystems and under different policy and management planning systems. Individual applications of frameworks such as this one will allow Canadian forest managers to reduce the risks to and impacts on SFM and to capitalize on the opportunities afforded by climate change. The cumulative results of widespread application of the framework will contribute to a national dialogue about incorporating climate change considerations into SFM in Canada. National and provincial "state of the forest" reports would be useful vehicles for monitoring the impacts, risks, and vulnerabilities of climate change and for reporting on progress toward the inclusion of climate change considerations into SFM.

Photo: Kelvin Hirsch

FUNDAMENTAL CONCEPTS

What is Sustainable Forest Management?

By the mid-1990s, SFM was entrenched within Canadian forest policy, and it is now the primary guiding principle for forest management in Canada. The goal of SFM is to ensure the conservation and health of the forests for current and future generations, while allowing for a balanced, equitable, and efficient flow of environmental, social, and economic benefits. A national framework of criteria and indicators was created through the Canadian Council of Forest Ministers (CCFM 2006) to define and provide a basis for monitoring SFM. This framework contains six criteria to assist forest managers in assessing progress toward SFM objectives: biological diversity, ecosystem condition and productivity, soil and water, role in global ecological cycles, economic and social benefits, and society's responsibility (CCFM 2006).

These six criteria provide a particular national definition of SFM in Canada. Other definitions of SFM used in Canada may vary, however, depending on location and management context. The vulnerability assessment framework presented here can be applied to any SFM system, so long as the criteria and indicators used to define SFM for that system are clearly defined.

What is a Vulnerability Assessment?

Vulnerability is the degree to which a system is susceptible to and unable to cope with adverse effects of climate change, including climate variability and extremes. It "is a function of the character, magnitude, and rate of climate change and variation to which that system is exposed, its sensitivity, and its adaptive capacity" (Schneider et al. 2007). The Intergovernmental Panel on Climate Change applied a vulnerability assessment approach in its Fourth Assessment report (Parry et al. 2007), and this approach was also applied for Canada's national assessment of climate change impacts (Lemmen et al. 2008). Vulnerability assessment has been undertaken in a broad range of other climate change contexts (e.g., Fussel and Klein 2006) and has been used in several forestry and nonforestry applications (O'Brien et al. 2004; Ford et al. 2006; Reid et al. 2007; Lindner et al. 2010). The vulnerability approach is currently providing the basis for several forest and forest management–oriented climate change assessments in Canada (see Johnston and Edwards n.d.).

The foundation for the vulnerability assessment framework presented here is referred to as an "adaptation policy assessment" (Fussel and Klein 2006). It represents the fourth generation of vulnerability assessment methodologies. Figure 1 is a simplified schematic of the adaptation policy assessment approach, showing the relationships among exposure, sensitivity, impacts, adaptive capacity, vulnerability, and adaptation. The Appendix provides more detailed technical descriptions of the vulnerability approach in general and the adaptation policy assessment approach in particular.

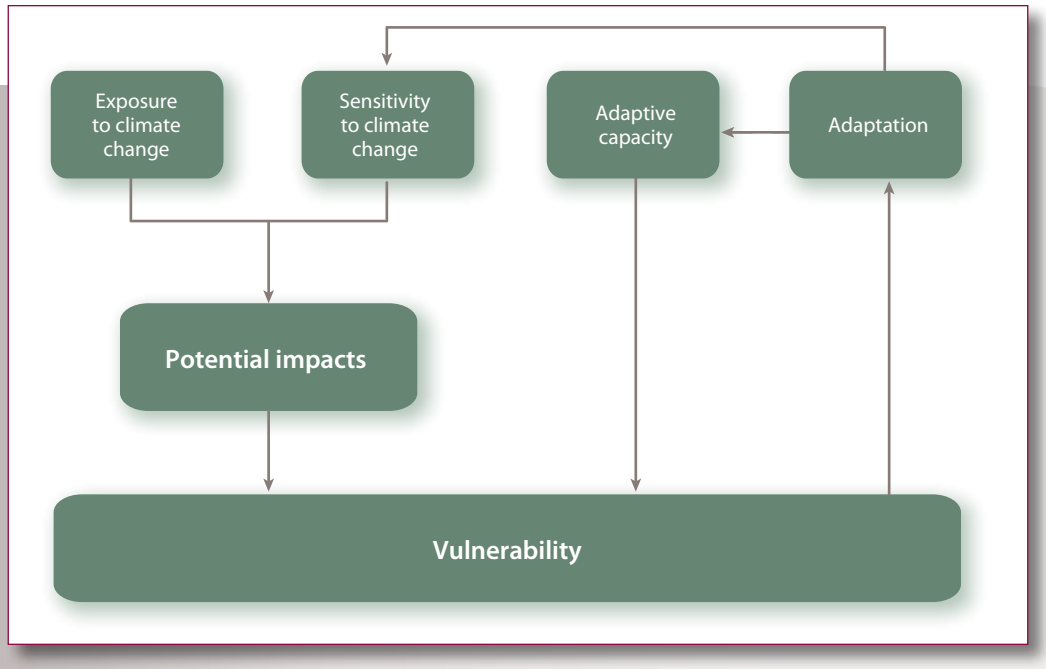

FIGURE 1. Simplified version of the adaptation policy assessment approach. This general approach applies to coupled human–ecological systems that are potentially vulnerable to climate change. Therefore, reference to exposure, sensitivity, and adaptive capacity embodies aspects of both biophysical and human impacts. In the case of sustainable forest management, biological adaptive capacity is a component of biodiversity. Therefore, in the framework proposed here, adaptive capacity refers only to the adaptive capacity of the human system.

In this report, the term "vulnerability assessment" refers to the identification of both the positive effects of climate change on SFM (which might be enhanced by adaptation) and the negative effects (which might be reduced by adaptation). The consideration of positive effects within a vulnerability assessment may, on the surface, appear counterintuitive. Furthermore, it is not necessarily consistent with the way in which vulnerability assessments are typically performed. Nonetheless, it is important to simultaneously consider both positive and negative effects when developing an adaptation strategy, to avoid eliminating or excluding adaptation options that could enhance positive effects.

NEED FOR SFM VULNERABILITY ASSESSMENTS

Given the long lifespan of trees, the process of forest management requires assumptions about future conditions when deciding how to manage forests today. As noted, current SFM policies and practices are based on the assumption that future environmental processes and conditions will be similar to those that shaped existing forests. Under a changing climate, this assumption is no longer valid. Therefore, policies, standards, approaches, and various other assumptions may need to be adjusted to reflect the reality that future climate and growing conditions in the forest will be different from those currently in effect.

Climate change is a relatively new issue for Canadian forest management, one that may require new policies and management approaches (Edwards and Hirsch 2012). Concurrently, new types of analysis and knowledge will be required to support policy making and management decision making. The first step for any organization preparing to deal with climate change is to understand its readiness to adapt (stage 1 in Figure 2). A framework and approach for assessing organizational readiness in the context of climate change is described by Gray (2012).

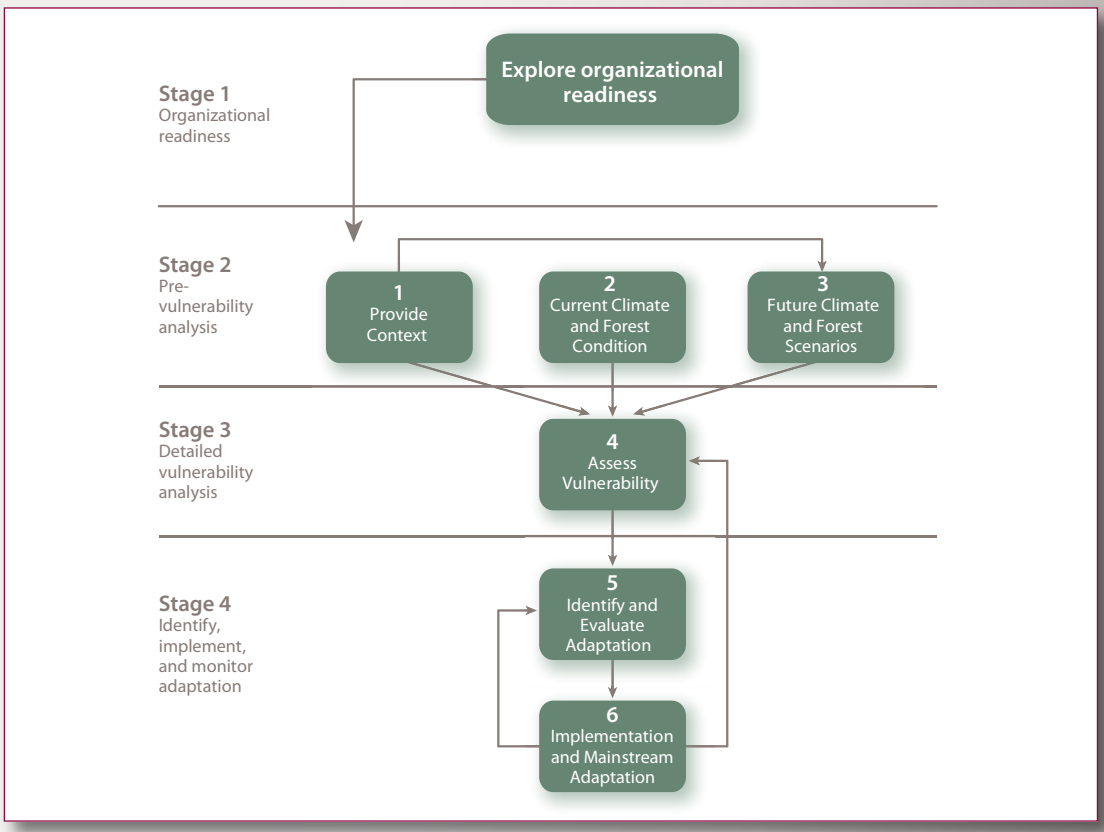

FIGURE 2. **Four stages of adaptation to climate change in the context of sustainable forest management.**

The second step in preparing for climate change is to assess the organization's vulnerability and to use this information to support adaptation efforts (stages 2, 3, and 4 in Figure 2). Vulnerability assessment is an established methodology for evaluating potential climate change impacts and linking this knowledge to adaptation policy. This document describes a framework for identifying sources of vulnerability to climate change that are important to SFM in Canada and presents an approach for mainstreaming adaptation into SFM policy- and decision making.

The approach presented in this report is designed to address the specific information requirements of forest managers who are interested in adapting to climate change. This approach has the following key features:

- It establishes a direct linkage between assessments and adaptation decision making.
- It promotes and requires input from a wide range of experts, including scientists, forest managers, policy makers, and local stakeholders.
- It facilitates learning and the exchange of information and knowledge.
- It is applicable at different temporal and spatial scales and in different organizational contexts.
- It adopts a forward-looking approach, while acknowledging and accounting for uncertainty and the need to develop and implement adaptation measures that will be robust in the uncertain future.
- It embraces a systems-based approach that is applicable to complex, cross-cutting, dynamic, and interactive issues related to SFM and climate change.

Photo: Natural Resources Canada

ASSESSMENT FRAMEWORK

The framework for vulnerability assessment presented in this report (stages 2, 3, and 4 in Figure 2) is based on a fourth-generation vulnerability assessment methodology (Fussel and Klein 2006). Applying this framework will enable forest managers to determine how SFM is vulnerable to climate change in Canada and how this information can be used to support ongoing adaptation of SFM to climate change. The vulnerability assessment framework for SFM has 6 components (Figure 2):

- Provide context (C1)
- Describe current climate and forest conditions (C2)
- Develop scenarios of future climate and forest conditions (C3)
- Assess the vulnerability of SFM to current and future climate (C4)
- Develop and refine options for adaptation (C5)
- Implement and mainstream options for adaptation (C6)

Components 1, 2, and 3 form a pre-vulnerability assessment (Figure 2), setting the stage and preparing the agency or organization for the detailed assessment (component 4). Components 5 and 6 constitute a follow-up stage, in which options for adaptation are identified, assessed, and implemented (if feasible and justified). Over time, new information or changes in forest management objectives may require modification of previous adaptations, implementation of new adaptations, or reassessment of SFM vulnerability. Thus, the process of assessing vulnerability and adapting to climate change is continual.

Component 1: Provide Context

Component 1 of the vulnerability assessment framework provides the analytical and decision making context. A description of the context is needed for three reasons. First, it ensures that the goals and design of the assessment are consistent with the management system and the management context for which it will be used. Second, it ensures a clear and direct link between the vulnerability and adaptation segments of the assessment. Third, it confirms that the organization has the necessary capacity to complete the assessment.

Defining the analytical context

Providing the analytical context ("scoping the problem") requires a description of the need for assessment, a description of how the assessment will be used, and definition of the resources needed and available. The agency or organization might ask the following questions, among others:

- Is there a significant concern about the effects of climate change on SFM in the region of interest, and if so, why?
- What might be the consequences of not undertaking a vulnerability assessment and not adapting proactively to climate change?
- If the assessment proceeds, how will its results be used?
- What level of detail is needed, and what resources are available for the assessment?
- Is the agency or organization equipped to complete the vulnerability assessment?
- Is the agency or organization equipped to apply the results of an assessment and implement adaptations?

Describing the management system of interest

The second step in providing context is to describe the management system of interest. The system of concern is typically a coupled human–forest system that has certain SFM objectives in place and that is sensitive to climate change. The system may be of any scale, for example, a provincial forest, community forest, protected area, industrial lease area, or small private woodlot. The following types of information, among others, are needed to describe the SFM management system:

- spatial and structural description of the managed forest system (e.g., types of ecosystems, distribution of ecosystems, species, age classes, volume)
- benefits and values derived from the forest, including industrial production values (e.g., wood values) and nontimber values (e.g., recreational use, wildlife-related benefits, intrinsic forest values)
- overview of the organization or agency that is proposing to undertake the assessment, including information about its responsibility and mandate for SFM
- description of how SFM is defined and implemented relative to the system of interest

Describing nonclimatic factors affecting the system

Climate change is not the only factor affecting SFM. Factors such as globalization, urbanization, technological change, market restructuring, demographic shifts, changes in societal values related to the use and management of public forests, air pollution, and development of nonforest natural resources may also have important implications for SFM. Therefore, an important aspect of vulnerability assessment in relation to climate change is to consider the results in the context of the many other nonclimatic factors that may be concurrently affecting the system. As such, the third step in defining the context for the vulnerability assessment is to review the nonclimatic factors that are having and will have implications for the SFM system of interest.

Component 2: Describe Current Climate and Forest Conditions

Component 2 is a description of current climate, recent climatic changes, the ways in which current climate affects forests and forest processes, and the ways in which forest managers have adapted to current climate and related forest conditions. Planned adaptation (i.e., adaptation in anticipation of future climate change impacts) requires that forest managers adequately comprehend the implications of future climate change. However, climate change is a multifaceted and complex issue, and it may be difficult to understand future vulnerability and impacts when the climatic future is itself uncertain. Initiating a vulnerability assessment by documenting and understanding how an individual or organization is affected by and has adapted to (or functions under) current climate allows a better understanding of relationships (biophysical and human) with climate (Ford et al. 2006). For example, year-to-year variations in area burned by wildfire are generally attributed to intra- and inter-annual variations in temperature and precipitation. Managers will know when the most recent severe fire years occurred, and they will understand what combination of high-temperature days and/or periods without rainfall contributed to them. Identifying these relationships makes it easier to answer questions like "What would happen if conditions in the future change significantly from those in effect today (e.g., hotter and drier on average or more frequent and more severe storms)?" and "How would individuals, organizations, or the sustainable forest management system in general be affected?"

Assessing current climate and forest conditions is an important step in the vulnerability assessment framework because it allows managers to describe what they know with some certainty. In fact, their understanding of current relationships among climate, forests, and forest management may be the only thing about which managers are reasonably certain.

Component 3: Develop Scenarios of Future Climate and Forest Conditions

Climate has a direct influence on species habitats, tree growth, regeneration, mortality, and disturbance processes. Climatic change will therefore modify the location and structure of forests, the distribution of species, and forest productivity. It will also affect the physical attributes of the landscape, such as permafrost, soil stability, and water regimes, as well as human-made infrastructure, such as winter roads. These effects have important implications for the long-term achievement of SFM objectives and for decision making today. Assessing the vulnerability of SFM to climate change therefore

requires some understanding or estimation of the potential future impacts (or range of potential impacts) of climate change on forests.

An important consideration, however, is that future climates are uncertain, and future forest responses to any given climate are also uncertain. One option is to predict or forecast future impacts using models or scientific knowledge and inference. A limitation of this approach is that predictions and forecasts based on modeling are not by themselves reliable, especially over the time scales that are inherent to analysis of climate change. A second approach is to develop scenarios. The use of scenarios is a well-established technique in futures planning for compiling relevant information in uncertain planning environments.

What are scenarios?

According to Berkhout et al. (2002), scenario analysis is based on four underlying principles: (1) recognition that past trends do not provide a basis for projecting the future, (2) acceptance that the future cannot be predicted with certainty but that "exploring" possible futures can inform local decision making, (3) acceptance of uncertainty and recognition that any number of different futures could occur, and (4) acknowledgment that local knowledge is fundamentally important for successful development of scenarios. A recent example of an integrated scenario development exercise in forestry is the Forest Futures project, completed by the Sustainable Forest Management Network (SFMN 2002–2011).

Scenarios are not predictions or forecasts. Rather, they are constructed stories about conditions that could occur in the future. The product of scenario development is a range of plausible stories about future conditions, each of which has equal likelihood of occurring. In the context of SFM and climate change, scenarios provide the basis for developing insights about possible future impacts on SFM objectives and outcomes. They are an aid to understanding potential sources of vulnerability and to identifying adaptation options. A scenario does not specify what will happen and what should be done as a consequence. Rather, it presents a number of equally likely stories about what might happen and asks, "What could be done now to minimize or reduce the effects or risks associated with particular stories and with the group of stories collectively?"

Scenarios may be based on combinations of expert judgment, technical information, modeling, and intuition. A scenario development process will usually result in the development of multiple storylines, each with different assumptions about the underlying drivers and each describing a unique set of potential climate change impacts. Each storyline within a scenario process is as likely to occur as any other. The development of scenario storylines requires large groups of participants. Scenarios are developed through consultation and dialogue with experts, modelers, and stakeholders, as well as the involvement of those who will use the information (i.e., decision makers, policy makers, and practitioners). It is important that the organization, agency, or individual who will be using the scenarios is comfortable with, and willing to take ownership of, the scenarios.

References describing the rationale, formal methods, and approaches for developing scenarios include Wilson (1978), Godet (1987), Schoemaker (1993), Bell (1997), and Peterson et al. (1997). Berkhout et al. (2002) described approaches to scenario development in the context of climate change assessment.

How are forest impact scenarios developed?

Price and Isaac (2012, n.d.) discuss in detail the development of scenarios of climate change impacts on forests. The first step in developing these forest impact scenarios (Figure 3, left side) is to select climate scenarios representing a range of plausible climate futures for the region of interest. Each climate scenario necessarily includes projections of selected climatic variables that affect forest ecosystems. The second step is to evaluate the response of forests and forest ecosystems to each climate scenario (i.e., the climate change impacts). This response (i.e., the effects on the forest) will be a function of the magnitude of the change in climate under a particular scenario (i.e., exposure) combined with the degree to which the forests are able to tolerate or adapt to the degree of change in climate under a particular scenario (i.e., sensitivity).

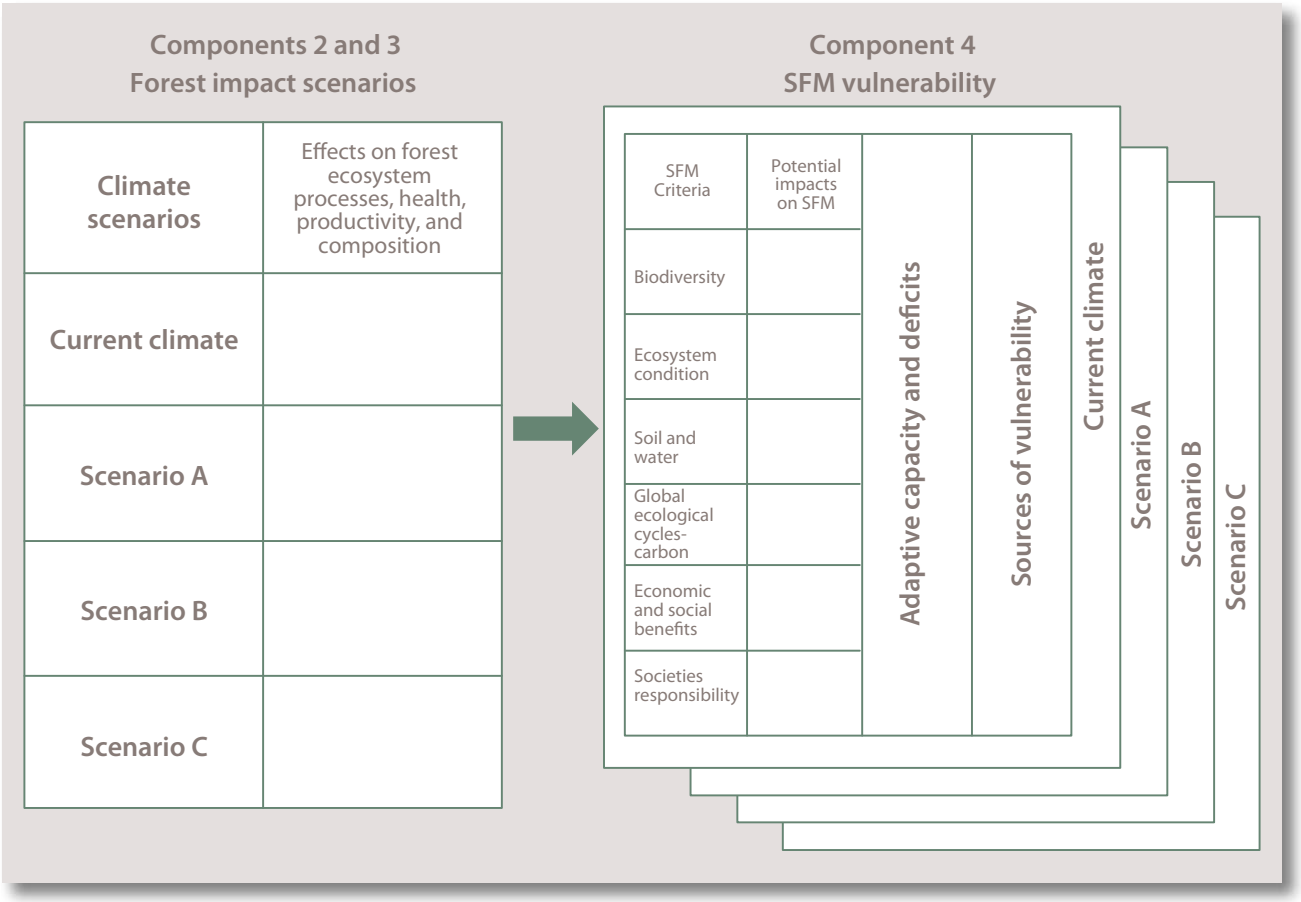

FIGURE 3. Detailed assessment of vulnerability of sustainable forest management.

A range of forest impact scenarios (one for each climate scenario) should be generated. The forest impact scenarios could include descriptions of changes in a variety of factors:

- processes such as physiology, phenology, and regeneration
- frequency and intensity of biotic disturbances (such as insect outbreaks and diseases) and abiotic disturbances (such as severe weather, drought, and wildfire)
- ecosystem health and productivity
- forest inventory
- forest composition and age class over the landscape

The assessment of climate change impacts on forests will be specific to particular time scales and spatial contexts. Typical time scales for climate analysis are 30-year periods, such as 2010 to 2039 (referred to as the 2020s), 2040 to 2069 (referred to as the 2050s), and 2070 to 2099 (referred to as the 2080s). The impacts of climate change on forests can be evaluated through combinations of modeling (including stand-level simulators, climatic envelope models, and dynamic vegetation models), scientific investigations (for example, of forest responses to climate variables), and consultations with experts, practitioners, and decision makers.

Component 4: Assess the Vulnerability of SFM to Current and Future Climate

The right side of Figure 3 shows the various elements of a detailed SFM vulnerability assessment. As previously described, SFM vulnerability to current and future climate is a function of existing and potential future impacts on SFM (i.e., exposure and sensitivity) and the current adaptive capacity of the SFM system. The first part of assessing the vulnerability of SFM to current and future climate is to consider how the analysis of current climate and forest conditions (performed in C2) and the forest

impact scenarios generated in C3 (left side of Figure 3) might affect each of the SFM criteria. The impacts on SFM criteria should be assessed for current climate and for each of the future climate and forest impact scenarios. The analysis should also account for differences in responses across spatial units (e.g., forested ecozones) and for changes over time (e.g., current, 2020s, 2050s, 2080s).

The second part of assessing SFM vulnerability is to determine the current adaptive capacity of the forest management organizations of interest or the SFM management system. Williamson and Isaac (n.d.) discuss the concept of adaptive capacity and present guidance for its assessment. There are a number of different approaches to describing or characterizing adaptive capacity. For example, general adaptive capacity can be represented as a function of specific determinants such as the effectiveness of institutions, the availability of technological options, the availability of human and social capital (e.g., skills, education, experience, and networks), information and information management, financial resources and natural capital, and the capacity for risk management (McCarthy et al. 2001; Johnston et al. 2010; Johnston et al. 2011). A related concept is that of adaptive capacity deficits (Williamson et al. 2012), which are the results of factors causing under- or over-investment in adaptive capacity assets. Such factors arise from market, governance, institutional, and social system failures. Irrational choices may also result in adaptive capacity deficits.

One approach to assessing SFM adaptive capacity is to determine the adaptive capacity of the organizations with a mandate to implement SFM. Gray (2012) identifies various organizational factors, such as leadership, management philosophy, corporate structure and function, and partnerships, as well as availability of suitable tools (i.e., strategic or long-term planning, policy making capacity, knowledge-gathering capacity, knowledge dissemination, and authority and capacity for on-site management), as key determinants of adaptive capacity. Authority and capacity for on-site management can be further subdivided into the adaptive capacity of specific forest management functions that support SFM (e.g., forest management planning, forest renewal, research, and forest protection).

Component 5: Develop and Refine Options for Adaptation

Early adaptation to climate change in forestry has the potential to substantially reduce impacts occurring in the future (Ogden and Innes 2007; Lemprière et al. 2008; Spittlehouse 2008; Bernier and Schoene 2009; Seppala et al. 2009; Williamson et al. 2009; Johnston et al. 2010; Edwards and Hirsch 2012). Adapting SFM to account for climate change may involve a variety of activities. Beneficial outcomes of adaptation include the following:

- reduced negative effects through specific adaptation actions
- increased positive effects
- enhanced adaptive capacity assets
- more adaptive management systems
- modified SFM objectives that incorporate or consider the effects of climate change on forests

Component 5 of the vulnerability assessment framework pertains to developing and refining options for adaptation. This goes beyond the direct assessment of current and future SFM impacts and adaptive capacity. Component 5 incorporates a process whereby the organization or agency uses the results of the impacts and adaptive capacity assessments to inform, develop, and refine options for adaptation.

Figure 4 presents a systematic and structured framework for continual development and implementation of adaptation recommendations in response to identified SFM vulnerabilities, a process known as "mainstreaming adaptation." A fundamental premise of this system is that adaptation is informed by the results of the vulnerability assessment performed in component 4 of the framework.

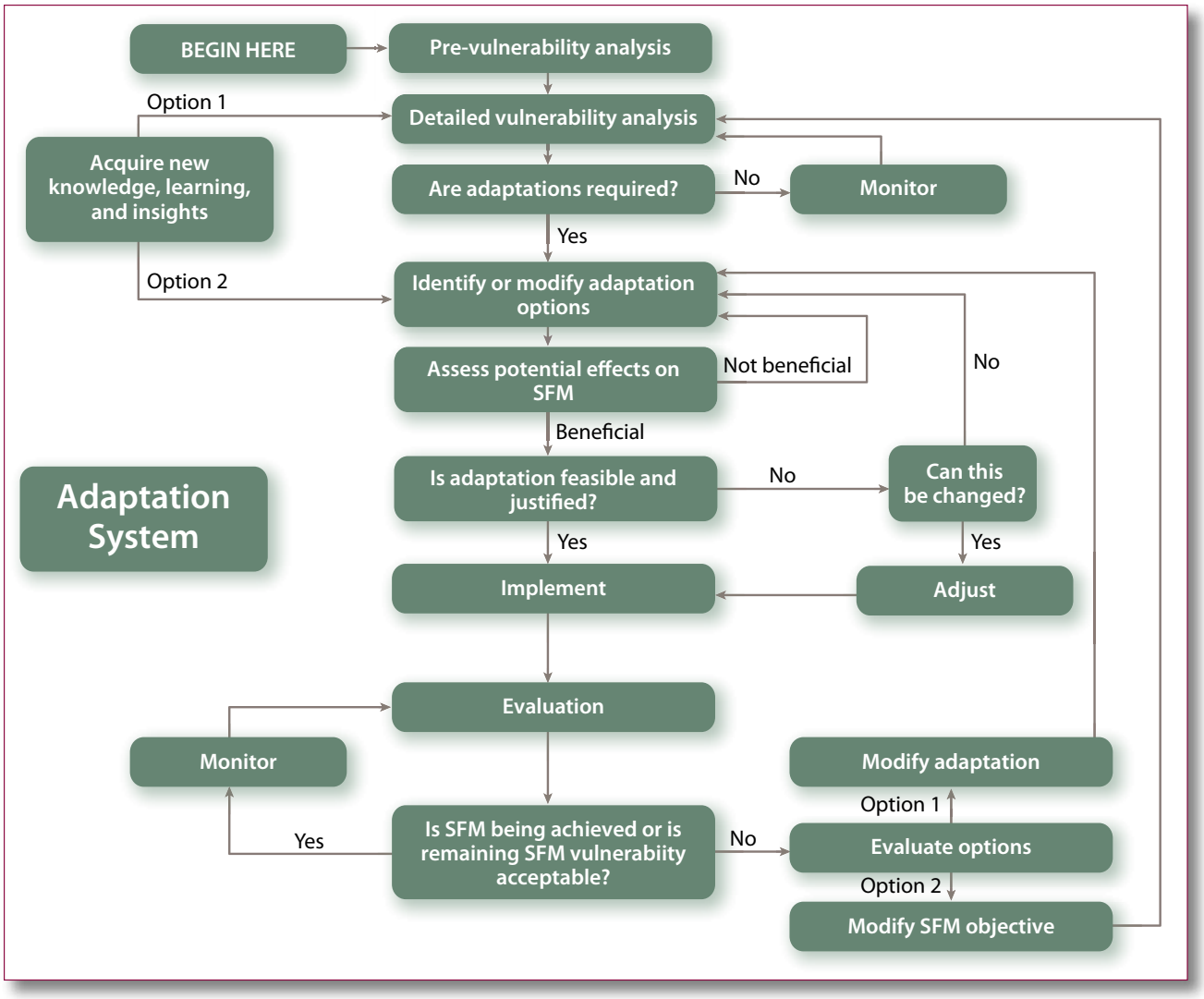

FIGURE 4. Decision-analysis framework for adaptation to climate change.

The adaptation system shown in Figure 4 has no end point. The process of adaptation begins with the assessment of vulnerability. On the basis of the vulnerability assessment results, adaptation measures are identified, implemented, monitored, and modified. Periodically, the adaptations may have to be revisited and vulnerabilities reassessed. Thus, the process of assessing SFM vulnerability is ongoing and iterative. In others words, adaptation to climate change becomes mainstreamed into policy development and day-to-day decision making. The remainder of this section and the whole of the next section in this report describe the various elements of the adaptation system presented in Figure 4.

Component 5 has two main elements: determining whether adaptations are required and identifying or modifying adaptation options (Figure 4).

Determining whether adaptations are required

The analysis completed in component 4 of the framework (assessment of SFM impacts and adaptive capacity) identifies sources of current and future SFM vulnerability. Understanding these sources helps in determining if adaptations are required. If it is decided that no adaptation is required at the present time, then the SFM system should be monitored, and there should periodically be a reassessment of vulnerability and the potential need for adaptation.

Identifying or modifying adaptation options

If it is determined that adaptation is required, it is then necessary to identify options. The identification of these options or their subsequent modification will depend on the types and magnitudes of SFM vulnerability identified in component 4. Some adaptation options will reduce the potential negative impacts or increase the potential positive impacts, whereas others will enhance adaptive capacity or reduce adaptive capacity deficits.

Component 6: Implement and Mainstream Options for Adaptation

Mainstreaming adaptation into decision making is a continual process whereby (1) adaptations are assessed in terms of the degree to which they are effective; (2) technical feasibility and costs and benefits are evaluated; (3) adaptations that are feasible and economically justified are implemented; (4) the performance of the adaptations is monitored and evaluated; (5) the adaptation program and/or management objectives are modified, if necessary; and (6) vulnerability is periodically reassessed as new knowledge, learning, and insights become known (Figure 4).

Assess effectiveness of potential adaptations

Once a suite of potential adaptations has been identified, the next step is to assess them and select those that have the greatest potential benefit for SFM or that offer the greatest promise in terms of achieving SFM (however it is defined for the management system of interest), given the realities of climate change.

If the projected benefits of the selected options relative to SFM goals seem acceptable, then their technical feasibility is assessed (see next subsection). Otherwise, another round of identifying and assessing alternative possibilities for adaptation is undertaken.

Determine feasibility, costs, and benefits of adaptation options

The next step is to evaluate the feasibility of implementing the proposed adaptations. This step might include considerations of economic feasibility (e.g., affordability, cost, effectiveness, presence of net benefits), technical feasibility, social acceptability, and institutional feasibility. In some cases, feasibility may be limited by specific barriers or constraints. For example, the uncertainty of success may be too high to justify implementation of the adaptation without further research. Such constraints should be noted and described.

If a particular adaptation option is deemed unfeasible, then it may be worth determining whether the option can be changed so as to make it feasible. If so, then the adaptation option can be adjusted; otherwise, it is rejected, and alternatives must be sought.

Once it has been determined that a particular suite of adaptation options will benefit SFM objectives and that the options will be acceptable and feasible, then the options can be upgraded from "options" to "recommendations."

Implement recommended adaptations

Adaptation means a change in the way of doing business. Implementation of an adaptation may therefore require changes in planning, procedures, policies, regulations, legislation, investments, protocols, guidelines, standards, and operational methods. However, implementation does not encompass any change in SFM objectives.

Evaluate adaptation performance

Evaluation is a continual process. Its purpose is to assess whether those adaptations that have been implemented are enabling the achievement of management objectives. Similar to the assessment of options before implementation, evaluation of adaptations after implementation is based on objective criteria or explicit questions (e.g., Is the sustainability of biodiversity at lower risk after implementation of the adaptation?).

Regardless of the acceptability and feasibility of the various adaptation options, some vulnerability will likely remain after implementation. The fundamental question that the decision maker needs to address after implementing and evaluating an adaptation measure or strategy is whether SFM is being achieved and if not, whether the residual SFM

vulnerability is acceptable. If the answer to either part of this question is "yes," managers should monitor the system and periodically re-evaluate. However, if the answer is "no"—or becomes "no" at some subsequent stage —the decision maker might consider whether the adaptation can be modified. If not, the decision maker faces the prospect of modifying one or more of the SFM objectives and reassessing vulnerability, as described below.

Modify adaptations or SFM objectives

In the event that SFM is not being satisfactorily achieved after implementation of the adaptation, then the manager, agency, or organization may want to determine a new course of action. One possibility is to modify the adaptation. Selection of this option takes the organization back to the box labeled "identify or modify adaptation options" in the decision-analysis framework (Figure 4). Another possibility is to modify the SFM objectives, which leads, in turn, to the box labeled "detailed vulnerability analysis." This approach entails modifying the SFM criterion objective and reassessing vulnerability under the new objective.

Acquire new knowledge, learning, and insights

Over time, the emergence of new information may lead to a better understanding of climate change impacts on forests and on SFM objectives. Alternatively, events may occur that affect adaptive capacity or change societal expectations for forests. This new information could necessitate revision of the SFM objectives. In such cases, reassessment of SFM vulnerabilities may be justified. Alternatively, the new information and insights may point toward more efficient and effective adaptation options, necessitating their evaluation and possible implementation.

Perform monitoring

Monitoring is an essential part of the framework for vulnerability assessment (Figure 4). Monitoring involves regularly checking the SFM system to ensure that its objectives are being met (or will be met in the future) under a changing climate.

SCALABILITY OF THE FRAMEWORK

Canada does not have a single, unified SFM system. In fact, there are a large number of SFM systems, which vary with spatial, operational, and organizational contexts. Therefore, the nature of the vulnerability of SFM to various external forces, including climate change, varies, as do potential solutions for incorporating climate change considerations into SFM. Vulnerability assessments are therefore needed at multiple scales (e.g., national, provincial, and forest management unit levels), for different organizational contexts (e.g., national organizations, provincial forest management jurisdictions, industrial leaseholders, forest-based communities, private landowners), and in different locations. The framework that has been presented here is scalable and applicable across these various spatial, operational, and organizational contexts and in different geographic locations.

Photo: Kelvin Hirsch

Photo: Natural Resources Canada

CONCLUSIONS

The vulnerability assessment framework presented here has several features that make it a suitable tool for preparing forest managers to better understand and adapt to climate change. First, the framework provides a comprehensive, integrated approach to adaptation planning that is based on well-established methods for assessing vulnerability to climate change, specifically designed to incorporate climate change considerations into SFM. Second, the framework provides a systematic and structured approach to analyzing vulnerability and making decisions about adaptations that could support the mainstreaming of adaptation. Third, the framework provides an analytical approach that integrates information and knowledge from an array of sources, including scientists, policy makers, and forest managers.

Application of the vulnerability assessment framework described here will aid forest managers in Canada in reducing risks and capitalizing on opportunities related to climate change. It will also enhance their ability to incorporate climate change considerations into SFM. Forest managers may want to use the vulnerability assessment framework detailed in this report for a variety of reasons. In particular, such assessments offer the ability to perform numerous planning and adaptation activities, such as the following:

- to better prepare and plan for future climate change by organizing information so that it is relevant to decision making about adaptation and by mainstreaming adaptation into the decision making process
- to identify critical knowledge gaps
- to explicitly take account of uncertainty
- to assess adaptive capacity and include adaptive capacity in adaptation decisions
- to undertake adaptation in a planned and proactive way
- to monitor adaptations, assess their effectiveness, and modify them if necessary
- to subdivide the complex climate change problem into manageable parts
- to link science, research, policy, and practitioner knowledge in support of planning and decision making related to adaptation
- to develop a common language for analysis, consultation, and discussion

Climate change is expected to continue into the future. Some of its impacts will be incremental, but it will also result in periodic, unanticipated extreme events, such as the recent outbreak of mountain pine beetle. Thus, one of the key principles reflected in the framework is that vulnerability assessment, adaptation, and monitoring should be viewed as an integrated and continual process that becomes mainstreamed into policy, practices, operations, and management planning.

Photo: Kelvin Hirsch

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Photo: Kelvin Hirsch

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GLOSSARY

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

> **Anticipatory adaptation |** Adaptation that takes place before impacts of climate change are observed. Also referred to as proactive adaptation.
>
> **Autonomous adaptation |** Adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. Also referred to as spontaneous adaptation.
>
> **Planned adaptation |** Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state."
> (Parry et al. 2007)

Adaptation options | Potential actions or activities to address or reduce the vulnerabilities identified in a vulnerability assessment.

Adaptation recommendations | A subset of adaptation options, consisting of those options that will benefit sustainable forest management objectives and for which implementation is acceptable and feasible.

Adaptive capacity | "The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" (Parry et al. 2007).

Adaptive capacity assessment | Assessment of (1) the human and institutional resources and capacities (eg., human capital, social capital) available to identify adaptation requirements and to implement adaptation; (2) the structural attributes, properties, and characteristics that affect the ability of a system to adapt (for example, flexibility, rigidity, diversity, liquidity, substitutability); and (3) the factors that impair optimal choices related to adaptation and adaptive capacity requirements (for example, inefficient institutions, critical knowledge gaps, lack of awareness, biased perceptions of risk).

Adaptive management | "A systematic process for continually improving management policies and practices by learning from the outcomes of previously employed policies and practices" (MEA 2005).

Climate | "Climate in a narrow sense is usually defined as the 'average weather', or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. These quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system. The classical period of time is 30 years, as defined by the World Meteorological Organization (WMO)" (Parry et al. 2007).

Climate change impacts | "The effects of climate change on natural and human systems. Depending on the consideration of adaptation, one can distinguish between potential impacts and residual impacts." Potential impacts are "all impacts that may occur given a projected change in climate, without considering adaptation." Residual impacts are "the impacts of climate change that would occur after adaptation" (Parry et al. 2007). In vulnerability assessment, impacts are the result of exposure to climate change and the sensitivity of the sustainable forest management system to a particular level of exposure.

Coupled human–environmental system | A concept commonly used in the resiliency and vulnerability literatures to refer to a group of agents (e.g., government agencies, firms, communities, citizens) with strong linkages to a natural ecosystem (e.g., a forest ecosystem), where the linkages between the human and natural systems are regulated and controlled by institutions.

Exposure | The degree of climate change imposed upon a particular unit of analysis. Exposure may be represented as long-term changes in climate conditions, as well as by changes in climate variability, including the magnitude and frequency of extreme events (McCarthy et al. 2001).

Exposure assessment | Assessment of past, current, and future trends in both climate and climatic variability and the magnitude of change in mean values and variability of climate measures between two time periods for a particular area. Exposure to future climate and climate variability is typically evaluated by means of alternative scenarios of plausible future climates obtained from general circulation models, which are in turn driven by various greenhouse gas emissions scenarios.

Forest impact scenarios | A range of possible future forest conditions that could result under a given climate scenario. Forest impact scenarios include descriptions of changes in (1) processes such as physiological processes, phenological processes and regeneration; (2) the frequency and intensity of biotic disturbances, such as insect outbreaks and diseases, and abiotic disturbances, such as severe weather, drought, and wildfire; (3) ecosystem health and productivity; (4) forest inventory; and (5) forest composition and age-class over the landscape.

Mainstreaming adaptation | Inclusion of climate change considerations in day-to-day decision-making and management on a continuous and ongoing basis.

Scenarios | "A plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined within a 'narrative storyline'" (Parry et al. 2007). Scenarios are not predictions, and they typically do not include prediction errors or likelihoods.

Sensitivity | "The degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise)" (Parry et al. 2007).

Sensitivity assessment | Assessment of the sensitivity or magnitude of a system's potential response to a particular rate and magnitude of change in local climate (including change in mean values and changes in variability and extremes). Sensitivity can be reduced or modified by adaptation.

Sustainable forest management | "Management that maintains and enhances the long-term health of forest ecosystems for the benefit of all living things while providing environmental, economic, social, and cultural opportunities for present and future generations" (CCFM 2008). According to the Canadian Council of Forest Ministers, the criteria for defining and monitoring sustainable forest management in Canada are biodiversity, ecosystem condition and productivity, soil and water, role of the forests in global ecological cycles, economic and social benefits, and society's responsibility.

Sustainable forest management system | A coupled human–environmental system that obtains goods and services from forests and works toward the management of forests in a manner consistent with sustainable forest management (SFM) principles and objectives. SFM systems vary with spatial, operational, and organizational contexts. An SFM system can exist at any scale, including provincial forests, community forests, protected areas, industrial lease areas, and small private woodlots.

Vulnerability | "The degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity" (Parry et al. 2007).

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APPENDIX

The Vulnerability Approach

Vulnerability is the degree to which a system is susceptible to and unable to cope with adverse effects of climate change, including climate variability and extremes. It is "a function of the character, magnitude, and rate of climate change and variation to which that system is exposed, its sensitivity, and its adaptive capacity" (Schneider et al. 2007). Climate change can have both positive and negative effects on forests and on SFM. Therefore, for the purposes of the framework presented in the main document, the term "vulnerability assessment" refers to the identification of both the positive effects of climate change (which might be enhanced by adaptation) and the negative effects (which might be reduced by adaptation).

Four elements are common to modern assessments of vulnerability and adaptation: exposure assessment, sensitivity assessment, adaptive capacity assessment, and adaptation. These terms are defined as follows:

Exposure assessment: Assessment of past, current, and future trends in both climate and climatic variability and the magnitude of change in mean values and variability of climate measures between two time periods for a particular area. Exposure to future climate and climate variability is typically evaluated with alternative scenarios of plausible future climates obtained from general circulation models driven by different greenhouse gas emissions scenarios.

Sensitivity assessment: Assessment of the sensitivity or magnitude of potential response of the system to a particular rate and magnitude of change in local climate (including change in mean values and changes in variability and extremes). Sensitivity can be reduced or modified by adaptation. Climate change impacts are a function of both exposure and sensitivity.

Adaptive capacity assessment: Assessment of (1) the human and institutional resources and capacities available (e.g., human capital, social capital) to identify requirements for adaptation and to implement adaptation actions; (2) the structural attributes, properties, and characteristics affecting a system's ability to adapt (e.g., its flexibility, rigidity, diversity, liquidity, and substitutability); and (3) the factors impairing optimal choices in relation to adaptation and adaptive capacity requirements (e.g., inefficiency of institutions, critical knowledge gaps, lack of awareness, and biased perceptions of risk) (Williamson et al. 2012). Adaptive capacity can be enhanced by investing directly in adaptive capacity assets or by removing barriers that impair optimal investment in adaptive capacity.

Adaptation: Specific actions that are taken to reduce negative effects and risks related to climate change and to increase the magnitude and likelihood of positive effects. Adaptation can take many forms. Anticipatory or planned adaptation includes deliberate actions or activities undertaken to reduce future negative effects (and risks) and to increase future positive effects, in terms of both magnitude and likelihood. Responsive or reactive adaptation includes deliberate actions or activities undertaken to reduce negative effects or enhance positive effects after they have occurred or as they are occurring. Autonomous adaptation refers to spontaneous or automatic (i.e., without conscious or deliberate thought or planning) actions or activities in response to climate or climate change stimuli. Adaptation mainstreaming is the development of processes that allow for the inclusion of climate change considerations in day-to-day decision making.

The Intergovernmental Panel on Climate Change applied a vulnerability assessment approach in its Fourth Assessment report (Parry et al. 2007), and this approach was also applied for Canada's national assessment of climate change impacts (Lemmen et al. 2008). Vulnerability assessment has been undertaken in a broad range of other climate change contexts (Fussel and Klein 2006) and has been used in several forestry and nonforestry

applications (O'Brien et al. 2004; Ford et al. 2006; Reid et al. 2007; Lindner et al. 2010; Johnston and Edwards n.d.).

The foundation for the vulnerability assessment framework presented in the main document is referred to as an "adaptation policy assessment" (Fussel and Klein 2006). It represents the fourth generation of vulnerability assessment methodologies. Figure A.1 is a detailed schematic of the adaptation policy assessment approach, showing the relations among exposure, sensitivity, impacts, adaptive capacity, vulnerability, and adaptation. The levels of impacts (both positive and negative) that a system faces as a result of climate change are related to exposure and sensitivity. Systems that are not exposed and those that are insensitive face a relatively low level of impacts and are therefore deemed to have low vulnerability. However, even in cases where there is potential for large impacts on a system because of high exposure or high sensitivity (or both), high adaptive capacity can reduce the system's vulnerability.

Adaptation is an essential part of the framework shown in Figure A.1. The vulnerability portion of the assessment (exposure, sensitivity, and adaptive capacity) contributes to identification of adaptation requirements. Adaptation actions, in turn, reduce vulnerability by reducing sensitivity and exposure or enhancing adaptive capacity. Therefore, vulnerability assessment and the identification and implementation of adaptations are considered jointly, on an ongoing basis.

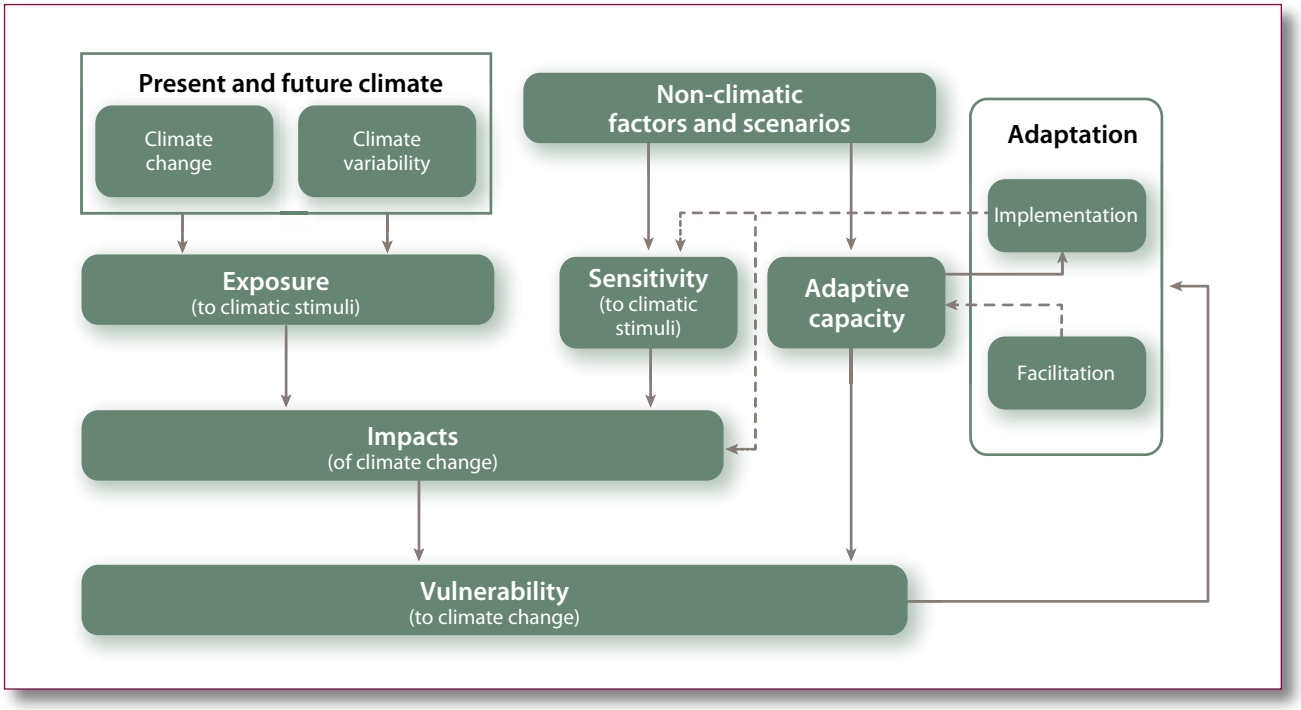

FIGURE A.1 **Detailed schematic for the adaptation policy assessment approach (source: adapted from Fussel and Klein 2006).** The different types of connecting lines represent the various types of interrelationships among the parts of the adaptation policy assessment framework presented here. Solid lines represent direct cause-and-effect relationships. For example, an increase in average temperature in an area will increase exposure. Dashed lines represent the effects of human actions. For example, increased investment in public information about ways of dealing with extreme temperatures (i.e., facilitation) will increase adaptive capacity. Alternatively, it may be possible for people to implement specific adaptation actions to reduce the system's sensitivity to increases in average temperature, which would reduce vulnerability. The dotted line represents a flow of information influencing responses related to adaptation policy. For example, new information about sources of vulnerability will inform the development of adaptation policy.

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