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Criteria and Indicators of Sustainable Forest Management in a Changing Climate: An Evaluation of Canada's National Framework

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Abstract

Sustainability is now woven throughout forest management and policy. Criteria and indicators (C&I) provide a means of defining the concepts of sustainability in the context of forest management and establishing goals to gauge progress. There have been no major research initiatives to determine the implications of climate change for C&I. We evaluated the 46 indicators of the 2003 Canadian Council of Forest Ministers framework. Indicators were evaluated for their relationships with climate, relationships with other indicators, robustness and utility under climate change, and future prospects, including abandonment, improvement, or continued use. An evaluation framework was developed to analyze indicator linkages, direct and indirect climate-change influence, and potential modifications. 12 indicators were considered unaffected by climate change. The remaining 34 indicators were considered to be influenced by climate change. No modification seemed warranted for 23 of these indicators, while modifications for the remaining 11 indicators were recommended. Six new indicators were identified for monitoring forests sustainably under climate change. The difference between action and state indicators had implications for the influence of climate change on indicator effectiveness. State indicators were more prone to declines in their tracking ability, while action indicators were often unaffected, or even improved under climate change, as measured by several key traits of indicator effectiveness. The most prevalent theme in the evaluations was a decline in indicator predictability. We suggest moving from predominantly retrospective analysis to a balance of retrospective and prospective analysis, given that monitoring is inherently backward-looking and the threats and uncertainties of climate change are impending.

Keywords: criteria, indicator, C&I, climate change, sustainable forest management, adaptation, Canada

1. Introduction

The theme of sustainability is now globally woven throughout forest management and policy. Commitments to sustainability and the sustainable development of forests became internationally accepted after the United Nations Conference on Environment and Development (UNCED) in 1992, also known as the Rio Summit, and the statement of *Forest Principles* and Chapter 11 of Agenda 21 of the conference's action plan (UNCED, 1992). A key initiative to emerge from the *Forest Principles* commitments to sustainable development in forestry was the development of criteria and indicators (C&I; UNCED, 1992). C&I provide a means of defining the broad and ambitious concepts of sustainability in the context of forest management and establishing measurable goals to gauge progress towards sustainable forest management (SFM; Wijewardana, 2008). Several international agreements and initiatives for C&I-SFM exist, which combined have involved almost 150 countries. Notable examples include the Montréal Process, the Helsinki Process (now Forest Europe), and the International Tropical Timber Organization Process (Duinker, 2011; Hall, 2001). The use of C&I-SFM to define and measure SFM progress has also been refined and implemented at the local, forest-management-unit level (Duinker, 2001). Local-level applications of C&I include industrial forest management planning, model-forest initiatives, and forest certification standards, such as those provided by the Canadian Standards Association (CSA), the Sustainable Forestry Initiative (SFI), and the Forest Stewardship Council (FSC; Duinker, 2011). There have been two significant national/international-level C&I-SFM initiatives in Canada: the Canadian Council of Forest Minister's (CCFM) national framework of C&I-SFM (CCFM, 1995; 2003) and the Montréal Process and Santiago Declaration (Montreal Process, 1995).

Prior to the formation of the Montréal Process (Montreal Process, 1995), the CCFM initiated a C&I Task Force to develop a national framework of C&I-SFM and meet Canadian commitments to SFM made at the Rio Summit and in the 1992 national forest strategy (CCFM, 1992). In 1995, the CCFM released a national framework of C&I-SFM with six criteria and 83 indicators (CCFM, 1995). The C&I-SFM were first reported on in the 1997 technical report (CCFM, 1997) and then the 2000 national assessment report (CCFM, 2000), and a public review process was initiated soon after in 2001. The revised C&I-SFM, consisting of six criteria and 46 indicators, were released in 2003 and reported on in 2005 (CCFM, 2003; 2006).

C&I-SFM are widely recognized as a valuable science-based tool both to define the full spectrum of values associated with forests and their management and to measure and gauge the degree to which forests are being managed sustainably (CCFM, 2003). There have been many recent studies on the potential improvement of C&I and sustainability indicators (Gough et al., 2008; Rametsteiner et al., 2011; Wijewardana, 2008; Wolfslehner & Vacik, 2011). However, there have been no major research initiatives to determine the implications of climate change for existing national/international frameworks of C&I, and certainly no research on how climate change might influence the utility of C&I-SFM. Canada's national framework of C&I-SFM was developed to have the quality and utility to track SFM progress with confidence. Because significant climate change in Canada is expected during the next century (Intergovernmental Panel on Climate Change [IPCC], 2007), and because climate is a strong driver and determinant of forests and the forest sector (Williamson et al., 2009), it is paramount that C&I-SFM have sufficient robustness to be both meaningful and valid in a changing climate. Consequently, a comprehensive and systematic assessment of the national C&I framework was undertaken to explore its effectiveness and validity under a changing climate (Steenberg et al., 2011b). This paper summarizes an evaluation of each of the CCFM indicators, as defined within the revised 2003 C&I framework (CCFM, 2003), for their suitability in defining and monitoring SFM in a changing climate.

2. Methods

2.1 Key Term Definitions

We define C&I herein as they are used in the Canadian forest sector, and specifically by the CCFM. A criterion is a collection or homogeneous category of values, by which SFM is assessed (CCFM, 1995; Montréal Process, 1995). An indicator is some identified system component that can be objectively and empirically measured to assess the status of a criterion or progress towards a goal associated with the SFM values of a criterion (CCFM, 1995; Duinker, 2001; Prahbu et al., 1999). The CCFM national framework also includes elements, which are simple categories used to organize related SFM values within several of the criteria. For example the biological diversity criterion includes ecosystem, species, and genetic diversity elements. For this analysis it is important to differentiate between indicators and variables. We define variables as alternative ways to measure an indicator. An indicator may have one or many variables, as was evident in the 2006 C&I-SFM assessment. For example, Indicator 1.2.2 (population levels of selected forest-associated species) is tracked using 41 variables (i.e., population levels of 41 species), while the related Indicator 1.2.3 (distribution of selected forest associated species) is represented by only four variables.

There are several types of SFM indicators, in terms of what they measure and track. It is, however, important to delineate the difference between two key groups, which are the action indicators and state indicators. Action indicators track both the quality and quantity of management actions, such as the rate of compliance with soil disturbance standards. State indicators measure the condition or state of a system that is being monitored. One type of state indicator is the condition/response indicator, which tracks the response of phenomena to management actions, such as the population levels of forest-associated species. Another state indicator is the context indicator, tracking variables that cannot be directly influenced by management, such as the contribution of timber products to the gross domestic product (Duinker, 2001).

A key mechanism for analyzing the effects of climate change on the indicators was a set of indicator traits, which have been established to define the characteristics of a valid, relevant, and effective indicator (Duinker, 2001). These traits include measurability, feasibility, responsiveness, relevance, understandability, validity, and predictability. Measurability and feasibility refer to the degree to which a phenomenon can be objectively and empirically measured on a continual basis and how practical, expensive, and obtainable data are to measure an indicator, respectively. More often than not, biophysical indicators are more easily measured than socioeconomic and socio-political indicators. Responsiveness, also called sensitivity, is the degree to which a phenomenon responds to management actions in known ways, and is a vital factor for indicator effectiveness. Relevance is an indicator's relationship to a defined SFM value within a criterion and the insight it provides into the sustainability of that value. Understandability is an obvious trait, as the SFM signal generated by an indicator must be clear and approachable to decision-makers and forest stakeholders. Validity refers to the overall soundness of the science behind an indicator. Finally, predictability is the degree to which the future value or range of an indicator can be confidently forecast. The implications of climate change for these indicator traits are discussed in Section 4.1.

2.2 Evaluation Framework

Table 1. The CCFM 2003 national framework of C&I-SFM

Criterion 1. Biological diversity
Element 1.1. Ecosystem diversity
Indicator 1.1.1. Area of forest by type and age class, and wetlands in each ecozone
Indicator 1.1.2. Area of forest by type and age class, wetlands, soil types and geomorphological feature types in protected areas in each ecozone
Element 1.2. Species diversity
Indicator 1.2.1. The status of forest-associated species at risk
Indicator 1.2.2. Population levels of selected forest-associated species
Indicator 1.2.3. Distribution of selected forest-associated species
Indicator 1.2.4. Number of invasive, exotic forest-associated species
Element 1.3. Genetic diversity
Indicator 1.3.1. Genetic diversity of reforestation seed-lots
Indicator 1.3.2. Status of *in situ* and *ex situ* conservation efforts for native tree species within each ecozone
Criterion 2. Ecosystem condition and productivity
Indicator 2.1. Total growing stock of both merchantable and non-merchantable tree species on forest land
Indicator 2.2. Additions and deletions of forest area, by cause
Indicator 2.3. Area of forest disturbed by fire, insects, disease and timber harvest
Indicator 2.4. Area of forest with impaired function due to ozone and acid rain
Indicator 2.5. Proportion of timber harvest area successfully regenerated
Criterion 3. Soil and water
Indicator 3.1. Rate of compliance with locally applicable soil disturbance standards
Indicator 3.2. Rate of compliance with locally road construction, stream crossing and riparian zone management standards
Indicator 3.3. Proportion of watersheds with substantial stand-replacing disturbance in the last 20 years
Criterion 4. Role in global ecological cycles
Element 4.1. Carbon cycle
Indicator 4.1.1. Net change in forest ecosystem carbon
Indicator 4.1.2. Forest ecosystem carbon storage by forest type and age class
Indicator 4.1.3. Net change in forest products carbon
Indicator 4.1.4. Forest sector carbon emissions
Criterion 5. Economic and social benefits
Element 5.1. Economic benefits
Indicator 5.1.1. Contribution of timber products to the gross domestic product

	Indicator 5.1.2. Value of secondary manufacturing of timber products per volume harvested
	Indicator 5.1.3. Production, consumption, imports and exports of timber products
	Indicator 5.1.4. Contribution of non-timber forest products and forest-based services to the gross domestic product
	Indicator 5.1.5. Value of unmarketed non-timber forest products and forest-based services
Element 5.2. Distribution of benefits	
	Indicator 5.2.1. Forest area by timber tenure
	Indicator 5.2.2. Distribution of financial benefits from the timber products industry
Element 5.3. Sustainability of benefits	
	Indicator 5.3.1. Annual harvest of timber relative to the level of harvest deemed to be sustainable
	Indicator 5.3.2. Annual harvest of non-timber forest products relative to the level of harvest deemed to be sustainable
	Indicator 5.3.3. Return on capital employed
	Indicator 5.3.4. Productivity index
	Indicator 5.3.5. Direct, indirect and induced employment
	Indicator 5.3.6. Average income in major employment categories
Criterion 6. Society's responsibility	
Element 6.1. Aboriginal and treaty rights	
	Indicator 6.1.1. Extent of consultation with Aboriginals in forest management planning and in the development of policies and legislation related to forest management
	Indicator 6.1.2. Area of forest owned by Aboriginal peoples
Element 6.2. Aboriginal traditional land use and forest-based ecological knowledge	
	Indicator 6.2.1. Area of forested Crown land with traditional land use studies
Element 6.3. Forest community well-being and resilience	
	Indicator 6.3.1. Economic diversity index of forest-based communities
	Indicator 6.3.2. Education attainment levels in forest-based communities
	Indicator 6.3.3. Employment rate in forest-based communities
	Indicator 6.3.4. Incidence of low income in forest-based communities
Element 6.4. Fair and effective decision-making	
	Indicator 6.4.1. Proportion of participants who are satisfied with public involvement processes in forest management in Canada
	Indicator 6.4.2. Rate of compliance with sustainable forest management laws and regulations
Element 6.5. Informed decision-making	
	Indicator 6.5.1. Coverage, attributes, frequency and statistical reliability of forest inventories
	Indicator 6.5.2. Availability of forest inventory information to the public
	Indicator 6.5.3. Investment in forest research, timber products industry research and development, and education
	Indicator 6.5.4. Status of new or updated forest management guidelines and standards related to ecological issues

Our approach was to review and evaluate each indicator in the national set for a) its relationships with climate, b) its systemic relationships with other indicators in the set, c) its robustness and utility in the face of climate change, and d) future prospects for the indicator including possible abandonment, improvement, or continued use unchanged. This analysis is a form of applied policy research, which brings with it specific challenges and methodological needs. A particular challenge is the lack of access or repeatability of the analysis (Ritchie & Spencer, 1994), which is certainly true of this study. Because there is a strong reliance on the conceptual abilities of the analysts in applied policy research and in this study, there is a need for explicitness in description of the research methods (Ritchie & Spencer, 1994). Consequently, we developed a three-stage, qualitative evaluation framework for the analysis of the indicators (Figure 1; Appendix A), which was applied to each of the 46 indicators in the 2003 C&I-SFM framework (Table 1; CCFM, 2003). In the evaluation, we attempted to decipher the often complex, uncertain, or ambiguous effects of climate change on indicator functioning and ability to gauge SFM progress.

After evaluating each indicator using the framework, the indicators were assigned to one of four post-evaluation categories: a) uninfluenced indicators, which were found to have no discernible interaction with climate change, either directly or indirectly, b) unmodified indicators, which were found to be either unchanged by their interaction with climate change or where no possible modifications seemed appropriate, c) modified indicators, which may require modification to maintain or enhance their effectiveness under climate change, and d) abandoned indicators, which were found to be degraded by climate change to the point where they were no longer valid or useful. A fifth category was also created for new possible indicators in response to climate change. Recommendations for new indicators could occur in association with each of the four previously mentioned categories.

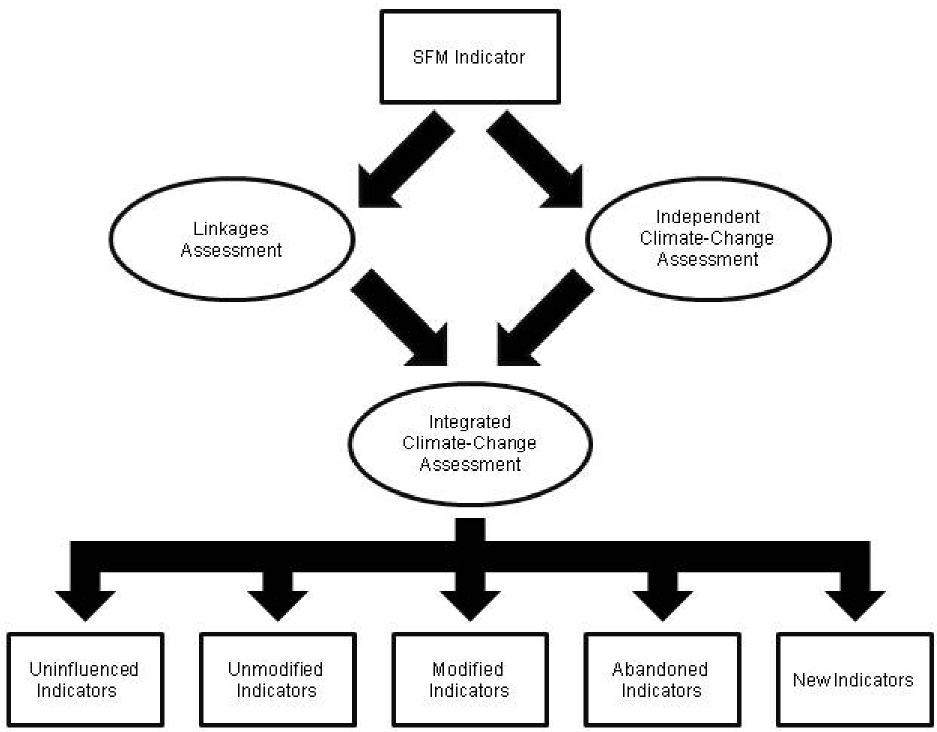

Figure 1. Evaluation framework

The development of C&I-SFM has often been seriously impeded in past initiatives because they failed to address relationships or linkages between indicators and among disciplines (Wolfslehner & Vacik, 2011; Yamasaki et al., 2002). Indicators developed in the confines of one discipline, whether in the biophysical, social, or economic realm, will be insufficient to address adequately the integrated nature of SFM that they are meant to define and measure. It stands to reason that an evaluation of the potential influence of climate change on C&I-SFM should avoid these same pitfalls. We therefore began the indicator evaluations with a linkages assessment to explore the linkages among all indicators prior to the assessment of climate change.

The current CCFM C&I-SFM do not thoroughly address the complex linkages that exist among indicators within the framework. Thus, our goal in the linkages assessment was to ascertain the extensive network of relationships among the indicators of SFM so that these linkages could be incorporated into our climate-change assessments. This was done through critical review and comparison of indicator pairs to gauge the nature of the relationship between them, and whether one was influential over the other. The basis of comparison was both the fundamental indicator design and intent (CCFM, 2003) and the specific variables or processes for which data were collected in the 2005 national assessment (CCFM, 2005), as they were found occasionally to differ. Climate change was not addressed in this assessment, but rather this was a preliminary stage of evaluation prior to the independent and integrated climate-change assessments.

An assessment of the effects of climate change on each individual indicator, independent of its linkages with other indicators, was done to ensure a detailed and uncluttered examination of all possible avenues of effects, prior to the integrated assessment. While the relationships with other indicators may open further possibilities for climate change to influence an indicator, we assumed that these relationships would never reduce or reverse the potential influence of climate change. Thus, the independent climate-change assessment was the logical second stage of evaluation. The assessment consisted mainly of a review of the literature in relevant fields of study.

The final stage of evaluation was the integrated climate-change assessment. Here, the efforts of the two previous assessments were combined to explore both the direct and indirect effects of climate change on the indicators in order to assign indicators to one of the four final post-evaluation categories or create a new indicator. A key focus of the integrated climate-change assessment was the indirect effects of climate change on the indicators through the complex network of interactions among them.

3. Results

In total, there were found to be 12 uninfluenced indicators, 23 unmodified indicators, 11 modified indicators, and no abandoned indicators. We also recommended creation of six new indicators (Table 2). All six of the new indicators were created within the biophysical criteria. The indicator modifications were more evenly distributed, with six of the 20 biophysical indicators modified within Criteria 1 through 4, and five of the 26 social/economic indicators modified within Criteria 5 and 6. It was initially expected that the effects of climate change would have resulted in the abandonment of some of the indicators. However, our project was restricted to the analysis of the influence of climate change alone on indicator effectiveness, and did not address any existing deficiencies in indicator strength. There could conceivably be instances where the combined influence of climate change and existing indicator effectiveness would warrant abandonment.

Given the text length of the unabbreviated results and usual confines of journal publication, it was not possible here to present the full findings of the three-stage evaluation for each of the 46 indicators. Instead, we present a brief summary of the implications of climate change for each of the indicators, organized by criterion. A more-detailed presentation of the findings can be found in Appendix A or in the two original reports (Steenberg et al., 2011a; 2011b).

Table 2. New indicators recommended for inclusion into the C&I-SFM framework

Criterion	**Element**	**New Indicator**
Biological diversity	Genetic diversity	Proportion of tenured forest area with seed transfer guidelines that account for climate change
Biological diversity	Genetic diversity	Connectivity of protected areas
Ecosystem condition and productivity	-	Total area of Crown forest with assisted migration initiatives
Ecosystem condition and productivity	-	Daily average, minimum, and maximum temperature
Soil and water	-	Annual rate, timing, and form of precipitation, by ecozone
Role in global ecological cycles	Carbon cycle	Carbon emissions avoided through product substitution

3.1 Criterion 1 – Biological Diversity

The biophysical indicators within Criterion 1, biological diversity, were highly susceptible to the changing climate, as biological diversity at all scales is intrinsically linked to the surrounding climate. Indicators 1.1.1 and 1.1.2 represent the ecosystem diversity element, tracking forest type, age, and area, and wetlands in and out of protected areas, and were both assigned to the unmodified category. Both of these indicators were broad and encompassing in what was measured in the 2005 assessment, with a total of 20 measured variables (CCFM, 2005). The anticipated effects of climate change on species distribution, natural disturbance regimes, and hydrological processes, as well as the sheer breadth of what was measured by the indicators, suggests that Indicator 1.1.1, and to a lesser degree Indicator 1.1.2, were among the indicators most afflicted by climate change, with a decline in the predictability, responsiveness, and relevance of the Indicators. However, these indicators are at the foundation of SFM monitoring, so developing alternative approaches to measurement to mitigate the deterioration of these indicator traits would be unwise.

Indicator 1.1.2 is highly related to 1.1.1 and vulnerable to all the aforementioned climate-change impacts. However, because its function in signalling progress towards SFM is to yield insight into the ability to protect representative forest areas (CCFM, 2006), we found it to be further compromised by climate change due to the core assumption of biogeographic stability in the protected areas system. Because of this loss of biogeographic stability and the shifting ranges and relative abundance of species, we recommended the creation of an additional indicator to track the connectivity of protected areas. Given the degree to which Indicators 1.1.1 and 1.1.2 are interrelated with other indicators in the framework and the fact that they track physical forest-ecosystem conditions within Canada and its terrestrial ecozones, they represent arguably one of the most fundamental sets of information pertaining to biodiversity. Therefore, we saw no possible justification for abandoning these indicators in light of climate change.

The species diversity indicators were also found to be affected quite extensively by climate change, resulting in the modification of Indicators 1.2.2 and 1.2.4. Indicator 1.2.1 was somewhat anomalous, as the status of forest-associated species that it tracks refers to the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) risk status (CCFM, 2006). Therefore, the indicator's capacity under climate change is dependent on the COSEWIC status assessment and designation process. Fortunately, climate change is being more frequently considered in this process and Indicator 1.2.1 was subsequently assigned to the unmodified category.

Indicators 1.2.2 and 1.2.3 are similar in concept but quite different in terms of what is measured and tracked. Indicator 1.2.2 currently tracks population levels of ten mammal species and 31 bird species, while Indicator 1.2.3 tracks four species with detailed case studies (CCFM, 2006). Consequently, we feel that the decline in predictability, responsiveness, and relevance of these indicators was unacceptable and warranted modification to Indicator 1.2.2, but not to Indicator 1.2.3. Since climate change may cause both increases and decreases in the population levels of some forest-associated species, both directly and indirectly and often in an unpredictable manner, their ability to signal SFM is compromised. Species monitored by Indicator 1.2.2 in the future will need to be either relatively uninfluenced by climate change, or have a climate-change response that is adequately researched and understood. This will certainly result in the abandonment of some of the 41 species currently monitored. The more-focused and in-depth approach to the measurement of Indicator 1.2.3 suggested a smaller decline in the strength of its SFM signal, and it was left unmodified.

Invasive, alien, forest-associated species will likely become more abundant and detrimental to forest ecosystems and the sustainable flow of their resources under climate change. Therefore, Indicator 1.2.4 not only suffered a considerable decline in its predictability, but also an increase in its relevance. The impetus behind the switch to measuring area disturbed rather than the number of species was that it could be more easily aligned with a directional goal statement; the minimization of forest area disturbed by invasive species. Moreover, the mountain pine beetle is an example of how climate change may destabilize the population dynamics of native forest-associated biological disturbance agents. As such, we also modified the indicator to track both native and alien invasive species.

Indicator 1.3.1 offers a relatively simple measure of genetic diversity by assessing the number of parents used for collecting seed of regeneration seed-lots, and as an action indicator, it was largely uninfluenced by climate change and was assigned to the uninfluenced category. However, the rate and magnitude of climate change in Canada may lead to a decline in the genetic diversity of tree species. One potential adaptation to this is adjusting jurisdictional seed-transfer guidelines to promote assisted migration of more southerly genetic resources. This issue has serious implications for the relevance of Indicator 1.3.1, yet the current structure of the indicator does not reflect this. We therefore recommended a new indicator for the Genetic Diversity Element to track seed-transfer updates on public land.

Indicator 1.3.2, another action indicator, has two key components, *in situ* and *ex situ* conservation efforts for native tree species, which were afflicted by climate change in differing ways. The *ex situ* component of the Indicator was relatively uninfluenced by climate change. The *in situ* component shares the same assumption of biogeographic stability as Indicator 1.1.2, and thus was reduced in its ability to monitor SFM progress. We saw no possible modifications that would mitigate the decline in this indicator's effectiveness. However, it is reasonable to assume that many of the *in situ* and especially the *ex situ* conservation efforts will adapt to incorporate the additional threats of climate change. In this case, the current design of Indicator 1.3.2 is sufficient to monitor these potential adaptations.

3.2 Criterion 2 – Ecosystem Condition and Productivity

Indicators within Criterion 2, ecosystem condition and productivity, were the most directly affected by climate change, resulting in recommendations for two modifications and two new indicators. These five biophysical state indicators are also all relatively well researched in the climate-change literature and far more tractable than most of the socioeconomic indicators within Criteria 5 and 6. Therefore, the evaluation of, and recommendations for, these indicators were more in-depth and developed than many of the more conceptual and ambiguous socioeconomic and socio-political indicators.

Indicator 2.1 tracks merchantable volume and was found to increase in relevance from observed and anticipated effects of climate change, but was also expected to decline in predictability and measurability. The SFM signal generated by Indicator 2.1 was slightly diminished, not because of how we interpret growing stock and its relation to SFM in a changing climate (i.e. its relevance), but because of how it is often measured and the predictability of these measurements. The measurement has a reliance on pre-established relationships and processes in forest ecosystems that are based on historically stable climates. Thus, inventory and modelling methods will need to be modified to account for a variable climate. The creation of a new indicator to track temperatures was also recommended because of its importance for phenology, tree growth performance, and forest productivity.

Indicator 2.2, though having numerous interactions with climate change, was not found to be significantly diminished in its effectiveness. Climate change may directly influence forest area through species migration and dieback and indirectly through new afforestation and carbon sequestration policies, which increased the relevance of Indicator 2.2 in a changing climate. Moreover, the proliferation of remote-sensing technologies may improve the feasibility of monitoring the indicator in the future. The decline in predictability was found for nearly every biophysical state indicator, and in this case we felt it did not overly diminish the Indicator's SFM signal and we assigned it to the unmodified category.

Indicator 2.3 greatly increased in its relevance to SFM because of the more frequent and severe natural disturbance events, as is already being observed across Canada. The decline in predictability of Indicator 2.3 was concerning, given the major influence of Indicator 2.3 on other indicators in the C&I framework, though we saw no possible modifications that could mitigate this decline in predictability. However, given the increased relevance of natural disturbance in a changing climate, we did recommend modifying the Indicator to incorporate other major forms of natural disturbance.

Indicator 2.4 tracks forest area disturbed by ozone and acid rain, and was far more linked with anthropogenic emissions from fossil-fuel combustion than the resulting climatic change. However, there was some decline in the predictability of the indicator due to the influence of changing precipitation rates and temperatures with acid rain and tropospheric ozone, respectively. Despite this drop in predictability, we felt that Indicator 2.4 would remain largely unchanged in its ability to signal SFM progress and we assigned it to the unmodified category.

Indicator 2.5 was also left unmodified, but resulted in the recommendation of a new indicator. We surmised that the Indicator experienced major declines in predictability and responsiveness because of the anticipated impacts of climate change. The relevance of Indicator 2.5 to SFM also increased given the vulnerability of forest regeneration to climate change. We felt that the best approach to address the introduced uncertainty and relevance from climate change was to create a new indicator as opposed to modifying the original Indicator 2.5, which was assigned to the unmodified category. The newly created indicator tracks assisted migration initiatives on public land, since this is an adaptation to climate-change impacts on natural regeneration that is growing in relevance. However, assisted migration is still a new and developing science and practice, with many uncertainties (Ste-Marie et al., 2011). Consequently, further research into its effectiveness and appropriateness is needed.

3.3 Criterion 3 – Soil and Water

Criterion 3, soil and water, contains three indicators, the least of the six criteria. Indicators 3.1 and 3.2 are action indicators tracking compliance rates with various standards, and were found to be uninfluenced by climate change. Indicators 3.1 and 3.2, along with Indicator 1.3.1 (another action indicator), were the only biophysical indicators to be uninfluenced by climate change. Some observed and potential climate-change impacts are relevant to Criterion 3, such as changes in decomposition rates of dead organic matter, soil disturbance arising from less frozen-ground conditions, and changes in hydrological processes, but they were not captured by Indicators 3.1 and 3.2.

Indicator 3.3 has considerable overlap with Indicator 2.3, and naturally was influenced to some degree by the effects of climate change on natural disturbance regimes. The most notable effects of climate change on the indicator were a decline in predictability. However, the SFM values associated with Criterion 3 and Indicator 3.3 are the maintenance of soil and water resources, not ecosystem condition and productivity. Therefore, we chose to leave the indicator unmodified and created a new indicator in response to the likely impacts of climate change on hydrological processes. This new indicator may also satisfy some of the current misalignment of the indicator with its described goal of monitoring major changes in water yield, timing, and peak flow (CCFM, 2003).

3.4 Criterion 4 – Role in Global Ecological Cycles

All four indicators in Criterion 4, role in global ecological cycles are within the carbon cycle element, tracking the Canadian forest's contribution in global carbon cycling. This criterion is unique in the framework in that it expressly addresses climate change (CCFM, 2003), and its indicators were all found to track phenomena that can potentially mitigate climate change and were all therefore more relevant in the face of global environmental change. Two out of four indicators were modified, a new indicator was created, and all were influenced by climate change to some degree. Indicators 4.1.1 and 4.1.2 both track the carbon stored in forest ecosystems and are similar in design. As such, they both were subject to the same recommendations for modification. These indicators suffered from the same decline in measurability, and arguably in validity, as Indicator 2.1. Climate change is predicted to affect the physiological growth rate of trees and the productivity of forests, as well as decomposition rates of dead organic matter, which invalidates some of the core assumptions of how we measure net changes in forest carbon. Consequently, Indicators 4.1.1 and 4.1.2 were both assigned to the modified category.

Indicator 4.1.3 tracks carbon stored in forest products and was much more relevant in a changing climate, though we did not modify the Indicator. Instead, given the growing recognition of forest products carbon and the carbon emissions avoided through product substitution to mitigate climate change, we recommended the creation of an additional indicator to track emissions avoided through product substitution. However, it will be important to examine what we classify as forest products in the future measurement of this indicator, considering the growing relevance of bioproducts, biofuels, and other forest-derived products.

Indicator 4.1.4 also increased in relevance because of the contribution of forest-sector emissions to climate forcing by anthropogenic greenhouse gas emissions. Future uncertainty around the magnitude and rate of climate change and society's response, namely the employment of policy tools for emissions reductions, also confounded the predictability of Indicator 4.1.4. However, unlike more complex and inclusive indicators like Indicators 1.1.1 and 2.3, Indicator 4.1.4 is relatively simple and transparent, so we felt no modifications were necessary to maintain its SFM signal.

3.5 Criterion 5 – Economic and Social Benefits

Indicators within Criterion 5, economic and social benefits, track the social and economic benefits derived from forests, and were far more difficult to evaluate in light of climate change. While on average the indicators within Criteria 5 and 6 were less influenced by climate change, it was far more difficult to expose and quantify the full suite of direct and indirect effects of climate change on social systems and the indicators that track them, in comparison to those that track ecological systems (Beckley, 2000). The economic indicators of Element 5.1 were influenced by climate change to varying degrees. Indicator 5.1.1 and 5.1.4 are simple economic measures similar in design that track the contribution of timber products, non-timber forest products, and forest-based services to the gross domestic product (GDP). Indicator 5.1.4 was modified to include the contribution of biotechnologies, bioproducts, and carbon credits to the GDP. Indicator 5.1.1 was similarly modified to include the contribution of bioenergy generated from forest biomass to the GDP. This subsector is increasing in relevance as a low-emissions substitute for fossil fuels in light of climate change.

Indicator 5.1.2 suffered a decline in predictability due to the indirect effects of climate change on the supply of wood fibre. The linear dependence of secondary manufacturing on the supply of primary manufactured products make fluctuations in this indicator easily understandable, despite the likelihood that climate change will influence the flow of primary timber products. Therefore, Indicator 5.1.2 was assigned to the unmodified category.

Indicator 5.1.3 is highly dependent on external factors, especially ones external to the C&I framework and to Canada, which run the gamut from the price of fossil fuels to consumer preferences and trade patterns. These relationships obscured the influence of climate change on quality, quantity, and type of wood available, and subsequently the production, consumption, and trade of timber products, thereby diminishing the SFM signal generated by Indicator 5.1.3. However, Canada has long been the world's biggest exporter of forest products (CCFM, 2006), so monitoring international trade is critical to SFM. Furthermore, Indicator 5.1.3 was found to be highly influential on other socioeconomic indicators within Criterion 5. So while no modifications were deemed appropriate, we were not ready to abandon the indicator and it was assigned to the unmodified category. Indicator 5.1.5 tracks the value of unmarketed forest-based services and products. This indicator has existing challenges in its measurability and feasibility. However, the influence of climate change alone does not warrant any action, and the indicator was left unmodified.

Indicator 5.2.1 tracks the type and distribution of forest tenures on public land, and is an important indicator for the distribution of benefits from the forest sector. The ability of Indicator 5.2.1 to signal SFM progress may be slightly diminished if it does not incorporate emergent societal demand for climate-change mitigation and adaptation on public land. This was largely addressed by the creation of new indicators under Criteria 1 and 2. We did, however, recommend modifying the indicator so that the proportion of tenured area with agreements that specifically address climate change would also be measured. Indicator 5.2.2 tracks the distribution of financial benefits specifically, and was assigned to the unmodified category, as most of the economic impacts of climate change were far removed from the indicator and only marginally reduced its predictability.

Indicators 5.3.1 and 5.3.2 are two of the most influential and important indicators in the framework as they track the flow of timber and non-timber forest products from forest ecosystems in Canada. Both indicators were influenced by climate change but were left unmodified. The anticipated impacts of climate change and the already observed alterations to annual allowable cut (AAC) in response to the mountain pine beetle outbreak meant a considerable decline in the predictability of these indicators. However, these two indicators, Indicator 5.3.1 especially, are at the core of SFM in Canada, and we saw no possible modifications or alternative indicators to alleviate the decline in their predictability. Moreover, because they interact so heavily with the biophysical indicators and are therefore influenced by climate change indirectly, it was hoped that much of the decline in the effectiveness of these two indicators would be addressed by the new and modified indicators within Criteria 1 through 4.

Indicators 5.3.3 and 5.3.4 are two traditional economic indicators used to gauge the economic welfare of an industry. Both indicators are largely unrelated to other indicators in the C&I framework and were both determined to be uninfluenced by climate change. Indicators 5.3.5 and 5.3.6 track employment variables in the forest sector. Indicator 5.3.6 tracks the distribution of income in employment categories and was deemed uninfluenced by climate change. Indicator 5.3.5 sustained a decline in predictability due to short- and long-term fluctuations in employment deriving from climate change. It also increased in relevance in light of emerging subsectors like carbon markets and bioenergy, as well as job creation from assisted migration and research to discover new forest practices and products. Indicator 5.3.5 is also a widely accepted and used indicator of economic and social welfare, so modifications to the indicator would be both unfavourable and unrealistic, despite the influence of climate change on its effectiveness.

3.6 Criterion 6 – Society's Responsibility

Criterion-6 indicators of social responsibility were the most uninfluenced by climate change of all the criteria of SFM. As previously mentioned, these social indicators were far more difficult to evaluate for their interaction with climate change, as all or any effects of climate change were indirect and frequently ambiguous. However, many of these indicators were genuinely independent of climate and climate change and eight of the 13 indicators are action indicators. Several of the indicators were evaluated in groups, which was done not because they were considered less important but because they were closely related and largely independent of climate change.

Indicators 6.1.1, 6.1.2, and 6.2.1 are action indicators that track Aboriginal rights, land use, and traditional knowledge, and were all left unmodified. Indicator 6.1.1 was deemed to be uninfluenced by climate change. Indicators 6.1.2 and 6.2.1 both had some decline in their predictability due to the effects of climate change, most notably tree-line advance in Canada's northern regions and the threats to traditional knowledge arising from environmental change. However, no modifications were considered to be necessary for these two indicators to remain effective SFM signals.

The four socioeconomic indicators used to track forest-dependent community well-being in Element 6.3 were also evaluated jointly. Indicators 6.3.1, 6.3.3, and 6.3.4 were all influenced by climate change in a near-identical fashion. The short- and long-term ecological, economic, and social impacts of climate change will reduce the predictability of these three socioeconomic state indicators. However, these three indicators are well established measures of community well-being and resilience (Beckley, 2000), so it is more than likely that these will remain a vital tool in monitoring SFM progress in relation to society's responsibility in managing the economic and social benefits of forests in Canada as the climate changes. They were therefore all assigned to the unmodified category. Indicator 6.3.2 tracks education attainment levels, and was determined to be uninfluenced by climate change, as it tracks a climatically insensitive phenomenon.

Indicator 6.4.1 tracks satisfaction with the public engagement process in forest management in Canada. The Indicator was almost entirely unrelated to climate change and had no decline in its ability to signal SFM progress. However, the growing public awareness of climate-change issues, especially those that pertain to forest management, may surface more frequently in advisory committee processes and increase the relevance of the Indicator. Indicator 6.4.2 is another action indicator, and tracks compliance rates with SFM laws and regulations, which makes it closely related to Indicators 3.1 and 3.2. There was a very low potential for the indicator to decline under climate change, and it was determined to be uninfluenced.

Indicators 6.5.1 and 6.5.2, evaluated jointly, are action indicators that track the quality and availability of forest inventory data, and did not sustain any declines in their ability to signal progress towards SFM. It seems likely that the indicators will increase in relevance due entirely to their role in the measurement of other major climate-change impacts, especially given recent improvements to inventory capacities with new remote-sensing technologies. However, we still regarded both these indicators as fundamentally uninfluenced by climate change.

Indicators 6.5.3 and 6.5.4 were the only indicators within Criterion 6 where some form of change was recommended. Indicator 6.5.3 is a socioeconomic action indicator tracking investment in the forest sector. The Indicator had a considerable increase in its relevance, largely because of the likelihood for new major research initiatives into climate-change adaptation and mitigation, like Natural Resources Canada's Regional Adaptation Collaborative initiatives (Natural Resources Canada, 2011). We therefore modified the Indicator to also measure investment into climate-change adaptation and mitigation. Indicator 6.5.4 is another broad and encompassing indicator that because of its breadth and relatedness with other indicators was influenced by climate change. Specifically, this action indicator increased in relevance because of the myriad of ecological issues expected and currently arising from climate change. In response to this, we modified the indicator so that the development of new standards and guidelines pertaining to ecological issues would also address those ecological issues caused by the changing climate.

4. Discussion

4.1 Interpreting the Effects of Climate Change on Indicator Effectiveness

Assessing the influence of climate change on an indicator is far more complex than simply determining how the phenomenon tracked by an indicator will be affected. Moreover, assuming that simply measuring and monitoring a phenomenon that is heavily influenced by climate change will continue to be adequate to gauge SFM progress is misleading. Measurability is just one of many traits that are instrumental to indicator effectiveness. To understand and characterize the complex interactions of climate change with the ability of an indicator to track SFM progress, we analyzed the effects of climate change through a set of seven traits of indicator effectiveness (Duinker, 2001). These traits included measurability, feasibility, responsiveness, relevance, understandability, validity, and predictability.

A simple example of the effects of climate change on measurability is the expected decrease in American marten (*Martes americana*) populations (Steventon & Daust, 2009). The smaller marten population, as an indicator, would become physically more difficult to count and less measurable. Conversely, climate change is predicted to lead to more invasive alien species (Dukes et al., 2009), and those more-abundant species would become easier to count, and thus more measurable. Feasibility is inextricably linked to measurability, and is more of a limiting factor for indicator effectiveness, especially at the national level. Any change in the measurability of an indicator caused by climate change will subsequently correspond to a change in feasibility for the same reasons.

Responsiveness may also be used to interpret the effects of climate change on indicators. Moose (*Alces alces*) populations might become far less sensitive to forest management actions due to increasing competition with deer, more parasites, physiological stress, and habitat alteration from more-frequent natural disturbances (Thompson et al., 1998). The cumulative effects of these climatically introduced stressors would mean that the moose population is now far less proportionally affected by forest management activities in its habitat and therefore a poor signal of SFM.

The relevance of an indicator may increase or decrease with climate change. For example, forest-management initiatives for maximizing carbon sequestration and storage are becoming more relevant due to climate change and major mitigation initiatives (Hall, 2002). Moreover, an existing indicator that will be heavily influenced by climate change, such as area of forest disturbed by natural disturbance, will also increase in relevance. A decline in relevance corresponds to a diminishing ability to interpret how changes in an indicator correspond to a given SFM value. Any decline in relevance due to climate change would only arise from a decline in responsiveness.

We have made the assumption that the understandability of an indicator is independent of climate change. Conversely, validity is such a broad and overarching trait of indicator effectiveness that we assumed that most fluctuations in other indicator traits would correspond to a fluctuation in validity. It is a less tangible indicator trait that was found to have less utility in assessing the effects of climate change on individual indicators, but is far more important in initial indicator design.

Predictability is fundamental in the context of SFM, climate change, and adaptive management because it is the expected future range of an indicator by which we derive management goals and indicator targets (Duinker, 2001). Monitoring is inherently focused on the present and past (Duinker, 1989), so the ability to predict, forecast, or model an indicator into the future is vital to gauging whether indicators will be within acceptable ranges or progressing towards desired targets. Climate change is not only a significant driver of change in forest ecosystems and SFM, but is tremendously uncertain. Consequently, the predictability of indicators is highly sensitive to climate change.

Each of the 46 indicators in the C&I framework has existing strengths and weaknesses in these different traits. In our assessment, we focused exclusively on the effects of climate change on these indicator traits, though the current effectiveness of the SFM indicators, independent of climate change, was often a determinant of how an indicator fared in the evaluation.

4.2 Common Patterns in Climate-change Influence on Indicators

As can be expected, there are some major differences for the implications of climate change on biophysical indicators versus social indicators. First, it is important to recognize that developing ecological and economic indicators tends to be a less challenging task than developing social indicators, as they are longer-standing disciplines with many existing systems of data collection and monitoring in place (Bridge et al., 2001). Moreover, the inherent normative nature and political implications of social sustainability indicators further complicate their development (Rametsteiner et al., 2011). Social indicators from Criterion 6, and to a lesser degree Criterion 5, are therefore faced with existing challenges in indicator development and effectiveness (Gough et al., 2008), which will in all likelihood be exacerbated by climate change. The biophysical indicators of Criteria 1 through 4 were heavily affected by predicted and observed climate change, while the influence of climate change on the socioeconomic and socio-political indicators in Criteria 5 and 6 were difficult to assess and, in our assessment, much less pronounced. Also, the vast majority of climate-change influence on the social indicators was indirect, and dependent on linkages with biophysical indicators.

Another key division in the climate-change evaluations was between action indicators, which track the quality and quantity of management actions, and state indicators, which track how forest and forest-related systems react to management action and external drivers. The state indicators were more prone to a decline in their ability to track SFM progress, while the utility of action indicators were often unaffected, or even improved in the face of climate change. It is useful to examine this division through the indicator traits.

Every state indicator declined in predictability to some degree because of climate change. Many of them also had substantive declines in responsiveness and relevance, which often resulted in the modification of the indicator. The action indicators most often had an increase in relevance under climate change, frequently because of the capacity of the actions they track to influence climate-change mitigation or adaptation. However, action indicators were also found to be insufficient in capturing the threats of climate change to SFM values identified by the criterion that contains them. For example, Indicators 3.1 and 3.2 are action indicators designed to track phenomena associated with the SFM values pertaining to water and soil. We know that climate change will affect soil and water to varying degrees (Johnston et al., 2010; Jones et al., 2009), yet both of these indicators were uninfluenced by climate change. This division may emphasize the advanced utility of state indicators in place of action indicators, if possible, despite the propensity for state indicators to decline in effectiveness under climate change.

A general theme of these evaluations was that the C&I most often responded to climate change with a decline in their predictability. This response, though not beneficial for the overall effectiveness of the C&I framework, is far more desirable than a complete lack of response of the indicators. The inherit dependence of forest ecosystems and their management on climate predisposes them to vulnerability to climatic fluctuation. If many of the SFM indicators, especially the biophysical ones, were largely unaffected, it would suggest that the indicators do not fully respond to system variation or are not entirely aligned with the SFM values defined for their respective criteria. This was largely the case for Criterion 3, consisting of two action indicators and a state indicator with low measurability/feasibility. It could also be stated that climate change certainly will make defining and measuring SFM more difficult, but we have no comparable or adequate replacement for C&I-SFM, which are already integrated into many scales and levels of forest management and policy development.

A decline in indicator predictability was in fact the most common outcome for state indicators. Many of these indicators, the biophysical ones in particular, were classified as unmodified in the evaluation. However, it is no surprise to us that the majority of indicators were not modified. They represent fundamental components of forests and SFM that are entirely embedded in the surrounding climate and have no surrogates to replace them as indicators. For example, the growing stock of trees (Indicator 2.1) will be affected by changes in temperature and precipitation, reducing its predictability. However a good surrogate indicator does not exist nor would it be favourable. These declines in predictability occurred because of the uncertainty and variability of future climate change, and rather than necessitating modification to individual indicators, they instead strongly reinforce the need for prospective insight and analysis in applications of C&I-SFM. Current approaches to C&I implementation and monitoring are intrinsically backward-looking. Through measurement of a suite of indicators, we take a snapshot of present conditions in order to monitor trends over time. A key implication of climate change is future uncertainty. Effective C&I implementation will need to draw from forecast modelling and scenario analysis toolsets to address future uncertainty with prospective insight (Duinker, 2011).

A major challenge to the indicator evaluations and especially the indicator modifications pertained to how these national indicators are currently defined and constructed, which we believe also is largely related to issues of spatial scale. Some of the indicators consist of a single objective and measurable variables that are easily aligned with a desired management direction or target – an important attribute of SFM indicators (Duinker, 2001). A prime example of this is Indicator 2.5 (proportion of timber harvest area successfully regenerated). Conversely, Indicator 1.2.2 (population levels of forest-associated species), tracks 41 species of birds and mammals in the national assessment, and is in essence a cluster of indicators. Indicator 6.5.4 (status of new or updated forest management guidelines and standards related to ecological issues), is an exceedingly broad and inclusive indicator that is not easily aligned with a management target.

The above distinctions are important as they heavily influence the type of modifications made to an indicator due to climate change. More specifically, we suggested two types of modifications to the indicators. The first arose when we needed to alter the foundational concepts of an indicator, by making contributions or omissions to the phenomenon tracked by an indicator because of the changing climate. An example of this is the modification to Indicator 6.5.3 to include investment in climate-change adaptation and mitigation in addition to scientific research, industry research and development, and education. The second type of modification arose when we had no need to change what phenomenon an indicator tracks, but instead had to change how the phenomenon is measured. An example of this is again Indicator 2.1, which is currently measured and subsequently modelled under the assumption of a stable climate.

4.3 Indicator Adjustments and Improvement for a Changing Climate

Often the case for indicator modification in this project was founded on existing deficiencies in one or more of the seven indicator traits of effectiveness. The most frequent deficiency appeared to be low understandability, resulting from the broad definition of indicators and 'indicator clusters', as defined in Section 4.2. Again, this is at least partly due to scale, as explicit indicator definition is difficult at the national level given the diversity of Canada's jurisdictions, forests, and SFM values (Hickey & Innes, 2005). Clearly defined, understandable indicators with adequate measurability and feasibility are critical, though of course a challenge, as indicators of SFM strive to monitor incredibly complex systems while at the same time being as simple as possible (Wijewardana, 2008). Another recommended course of action for future C&I framework revision would be to adopt state indicators over action indicators, when feasible. The analysis of action-indicator performance under climate change as well as their interaction dynamics in the linkages assessment suggests that action indicators are not as effective as the state indicators within the national framework of C&I-SFM.

One concept relating to indicator-based monitoring of SFM is that of an early warning system for climate change. For example, climate change, notably warmer winter temperatures, was the catalyst for the mountain pine beetle (*Dendroctonus ponderosae*) outbreak in western Canada (Carroll et al., 2004). However, the abundance of over-mature lodgepole pine (*Pinus contorta*) in the region, a major host species, was an early indicator of vulnerability that was not entirely heeded. This represents a situation where the C&I-SFM, in this case Indicators 1.1.1 and 2.3, have the capacity to serve as an early warning system for climate-change vulnerability and impacts, but only if they are so interpreted. Certainly this will not always be possible because of the tremendous uncertainty associated with future climatic change. However, known climate-change impacts should be incorporated into future national assessment initiatives so that early warnings can be heeded.

An ongoing limitation of the indicators is the lack of, or inability to be linked with, a direction or target. This is a vital attribute of indicators that will likely become more critical under climate change and echoes the need for more prospective insight in C&I-SFM. A considerable threat to the utility of indicators to gauge SFM progress under climate change will be an introduced uncertainty and variability in indicator targets. Furthermore, there may be emergent ecological thresholds that are unanticipated because of the interaction of climate change and management actions (Millar et al., 2007), which further complicates the setting of desirable targets. For example, if reforestation initiatives are focused on a given species mix that is no longer climatically favoured, eventually some key thresholds may be exceeded, resulting in time-lags and potential ecosystem collapse. Established targets may be too close to or beyond these thresholds introduced by climate change. In addition to clear indicator definition, the latter point reinforces the use of prospective analysis in C&I implementation.

5. Conclusions

C&I-SFM are, without question, a key component in the pursuit of SFM. Canadian and international forest and forest-sector stakeholders have embraced them and, using them, tried to determine the degree to which SFM is becoming a reality. Climate change adds considerable complexity and uncertainty to this enterprise. With concerted and coordinated efforts, we can address these complexities and uncertainties in useful ways to improve the capacity to gauge progress in SFM. This study points to a range of improvements that can be made to further the C&I cause. Many of the identified implications of climate change for C&I and subsequent recommendations may also have relevance in C&I applications at the local level (Duinker, 2001). This warrants an independent investigation, not least because of the continuing importance of forest certification and the central position of C&I in certification schemes. A greater degree of uncertainty around potential climate-change impacts at the local level and their implications for management are issues, among others, that may make our recommendations for national-level indicators less applicable at the local level.

It has been established that a failure to address linkages among indicators can lead to deficiencies in the monitoring and assessment of SFM (Wolfslehner & Vacik, 2011). Our evaluation of climate change and C&I-SFM emphasises this point further, and suggests that a failure to address indicator linkages may also reduce the capacity to track the influence of climate change on SFM values. It will also be important in future C&I reviews for the adoption of climate change to acknowledge the participatory nature of indicator development as a process of political negotiation (Rametsteiner et al., 2011), as lack of political commitment has been found to be one of the key challenge in C&I-SFM implementation (Wijewardana, 2008). Stronger links into management and policy decision-making processes will help to guide C&I-SFM forward under the changing climate. Finally, prospective analysis in C&I-SFM implementation will be a critical addition in light of climate change. Monitoring is inherently backward-looking, so prospective insight into the future uncertainty of climate change using C&I will be a stronger tool for defining and assessing SFM.

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References

Bridge, S. R. J., Wright, P., & Rios, R. (2001). Criteria and indicators of sustainable forest management: Relationships between multi-scaled initiatives. *Proceedings of the XXI Sessions of the North American Forest Commission*. Honolulu, HI: Natural Resources Canada.

Canadian Council of Forest Ministers. (1992). *Sustainable forests: A Canadian commitment*. Hull, QC: Canadian Council of Forest Ministers.

Canadian Council of Forest Ministers. (1995). *Defining sustainable forest management: A Canadian approach to criteria and indicators*. Ottawa, ON: Canadian Council of Forest Ministers.

Canadian Council of Forest Ministers. (1997). *Criteria and indicators of sustainable forest management in Canada – Technical report 1997*. Ottawa, ON: Canadian Council of Forest Ministers.

Canadian Council of Forest Ministers. (2000). *Criteria and indicators of sustainable forest management in Canada – National status 2000*. Ottawa, ON: Canadian Council of Forest Ministers.

Canadian Council of Forest Ministers. (2003). *Defining sustainable forest management in Canada – Criteria and indicators*. Ottawa, ON: Canadian Council of Forest Ministers.

Canadian Council of Forest Ministers. (2006). *Criteria and indicators of sustainable forest management – National status 2005*. Ottawa, ON: Canadian Council of Forest Ministers.

Carroll, A. L., Taylor, S. W., Régnière, J., & Safranyik, L. (2004). Effects of climate and climate change on range expansion by the mountain pine beetle. In T. L. Shore, J. E. Brooks, & J. E. Stone (Eds.), *Mountain pine beetle symposium: Challenges and solutions* (pp. 223-232). Victoria, BC: Natural Resources Canada.

Duinker, P. N. (1989). Ecological effects of monitoring in environmental impact assessment: What can it accomplish? *Environmental Management, 13*, 797-805.

Duinker, P. N. (2001). Criteria and indicators of sustainable forest management in Canada: Progress and problems in integrating science and politics at the local level. In A. Franc, O. Laroussinie, & T. Karjalainen (Eds.), *Criteria and indicators for sustainable forest management at the forest management unit level*. Joensuu, Finland: European Forestry Institute.

Duinker, P. N. (2011). Advancing the cause? Contributions of criteria and indicators to sustainable forest management in Canada. *The Forestry Chronicle, 87*, 488-493. http://dx.doi.org/10.1007/BF01868319

Dukes, J. S., Pontius, J., Orwig, D., Garnas, J. R., Rodgers, V. L., Brazee, N., … Ayres, M. (2009). Responses of insect pests, pathogens, and invasive plant species to climate change in the forests of northeastern North America: What can we predict? *Canadian Journal of Forest Research, 39*, 231-248. http://dx.doi.org/10.1139/X08-171

Gough, A. D., Innes, J. L., & Allen, S. D. (2008). Development of common indicators of sustainable forest management. *Ecological Indicators, 8*, 425-430. http://dx.doi.org/10.1016/j.ecolind.2007.03.001

Hall, J. P. (2001). Criteria and indicators of sustainable forest management. *Environmental Monitoring and Assessment, 67*, 109-119. http://dx.doi.org/10.1023/A:1006433132539

Hall, J. P. (2002). Sustainable production of forest biomass for energy. *The Forestry Chronicle, 78*, 391-396.

Hickey, G. M., & Innes, J. L. (2005). Monitoring sustainable forest management in different jurisdictions. *Environmental Monitoring and Assessment, 108*, 241-260. http://dx.doi.org/10.1007/s10661-005-4329-y

Intergovernmental Panel on Climate Change. (2007). *Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.

Johnston, M., Williamson, T., Munson, A., Ogden, A., Moroni, M., Parsons, R., … Stadt, J. (2010). *Climate change and forest management in Canada: Impacts, adaptive capacity, and adaptation options.* Edmonton, AB: Sustainable Forest Management Network.

Jones, J. A., Achterman, G. L., Augustine, L. A., Creed, I. F., Folliot, P. F., MacDonald, L., & Wemple, B. C. (2009). Hydrologic effects of a changing forested landscape – challenges for the hydrological sciences. *Hydrological Processes, 23*, 2699-2704. http://dx.doi.org/10.1002/hyp.7404

Millar, C. I., Stephenson, N. L., & Stephens, S. L. (2007). Climate change and forests of the future: Managing in the face of uncertainty. *Ecological Application, 17*, 2145-2151. http://dx.doi.org/10.1890/06-1715.1

Montreal Process. (1995). *Criteria and indicators for the conservation and sustainable management of temperate and boreal forests: The Montréal Process* (2nd ed.). Hull, QC: Natural Resources Canada.

Prahbu, R., Colfer, C. J. P., & Dudley, R. G. (1999). *Guidelines for developing, testing and selecting criteria and indicators of sustainable forest management*. Jakarta, Indonesia: Center for International Forestry Research.

Rametsteiner, E., Pülzl, H., Alkan-Olsson, J., & Frederiksen, P. (2011). Sustainability indicator development – science or political negotiation? *Ecological Indicators, 11*, 61-70. http://dx.doi.org/10.1016/j.ecolind.2009.06.009

Ritchie, J., & Spencer, L. (1994). Qualitative data analysis for applied policy research. In A. Bryman & R. G. Burgess (Eds.), *Analyzing qualitative data* (pp. 173-194). London, UK: Routledge. http://dx.doi.org/10.4324/9780203413081_chapter_9

Steenberg, J. W. N., Duinker, P. N., Van Damme, L., & Zielke, K. (2011a). *Indicator evaluations. Ottawa, ON: Canadian Council of Forest Ministers*.

Steenberg, J. W. N., Duinker, P. N., Van Damme, L., & Zielke, K. (2011b). *Indicators of sustainable forest management in a changing climate – Final report*. Ottawa, ON: Canadian Council of Forest Ministers.

Ste-Marie, C., Nelson, E. A., Dabros, A., & Bonneau, M.-E. (2011). Assisted migration: Introduction to a multifaceted concept. *The Forestry Chronicle, 87*, 724-730.

Steventon, J. D., & Daust, D. K. (2009). Management strategies for a large-scale mountain pine beetle outbreak: Modelling impacts on American martens. *Forest Ecology and Management, 257*, 1976-1985. http://dx.doi.org/10.1016/j.foreco.2009.02.013

Thompson, I. D., Flannigan, M. D., Wotton, B. M., & Stuffling, R. (1998). The effects of climate change on landscape diversity: An example in Ontario Forests. *Environmental Monitoring and Assessment, 49*, 213-233. http://dx.doi.org/10.1023/A:1005894525278

United Nations Conference on Environment and Development. (1992). *Agenda 21: The United Nations program of action from Rio*. New York, NY: United Nations.

Wijewardana, D. (2008). Criteria and indicators for sustainable forest management: The road travelled and the way ahead. *Ecological Indicators, 8*, 115-122. http://dx.doi.org/10.1016/j.ecolind.2006.11.003

Williamson, T., Colombo, S., Duinker, P., Gray, P., Hennessey, R., Houle, D., … Spittlehouse, D. (2009). *Climate change and Canada's forests: Current and predicted impacts*. Edmonton, AB: Sustainable Forest Management Network.

Wolfslehner, B., & Vacik, H. (2011). Mapping indicator models: From intuitive problem structuring to quantified decision-making in sustainable forest management. *Ecological Indicators, 11*, 274-283. http://dx.doi.org/10.1016/j.ecolind.2010.05.004

Yamasaki, S. H., Kneeshaw, D. D., Munson, A. D., & Dorion, F. (2002). Bridging boundaries among disciplines and institutions for effective implementation of criteria and indicators. *The Forestry Chronicle, 78*, 487-491.

Appendix A

Evaluation Framework

Linkages Assessment

1.1. Which indicators are influencing and influenced directly by the indicator in question? Is the indicator more of a driver of change in other indicators, or being driven by other indicators?

1.2. List the indicators described as 'relevant indicators under other criteria' in the 2003 Criteria and Indicators of Sustainable Forest Management (C&I-SFM). Is there any conflict with the interactions described in Question 1.1?

Independent Climate-change Assessment

2.1. Provide in detail, a description of the expected direct effects of climate change on the indicator, using a broad representation from the literature.

2.2. Given expected changes in Canada's climate, describe if and how the indicator's ability to signal progress towards SFM remains unchanged.

2.3. If an indicator's ability to signal progress towards SFM will be changed, describe if and how the indicator may become worse or better at signalling SFM progress.

Integrated Climate-change Assessment

3.1. What are the key determinants of the indicator (i.e. what causes it to change when it does change);

a) Among other indicators in the C&I framework?

b) Among determinants not within the C&I framework?

3.2. For what other entities is this indicator a key determinant (i.e. when it changes, what other indicators are influenced to change);

a) Among other indicators in the C&I framework?

b) Among determinants not within the C&I framework?

3.3. To what degree can we now, on the basis of extant knowledge, establish how the key determinants interact cumulatively in influencing the indicator?

3.4. Is the indicator largely unrelated to any other, as described by the linkages assessment and evaluation of key determinants? If so, and the indicator was defined as uninfluenced by climate change in the independent assessment, then it can be placed in uninfluenced category.

3.5. Do the indirect effects of climate change via the linkages with other indicators influence the indicator's ability to signal SFM, regardless of which category was assigned in the independent climate-change assessment?

3.6. If the indicator's ability to signal SFM progress remains the same under a changing climate, can we conclude no negative influence and leave it unchanged? These indicators can be placed in the unmodified category.

3.7. If the indicator's ability to signal SFM progress deteriorates when one assumes a changing climate, then what modifications are possible or warranted to improve its ability sufficiently for it to remain among the C&I-SFM? These indicators can be placed in the modified category.

3.8. If no modifications seem possible or warranted, are we ready to recommend abandonment of the indicator? These indicators can be placed in the abandoned category.

3.9. Can we identify any new and closely allied indicators that might suit our needs better under climate change? Are there any other reasons for the creation of an additional indicator?

3.10. Have extant climate change impacts made this indicator more pertinent to SFM? These indicators can be considered for conversion from a supporting to a core indicator (where applicable).

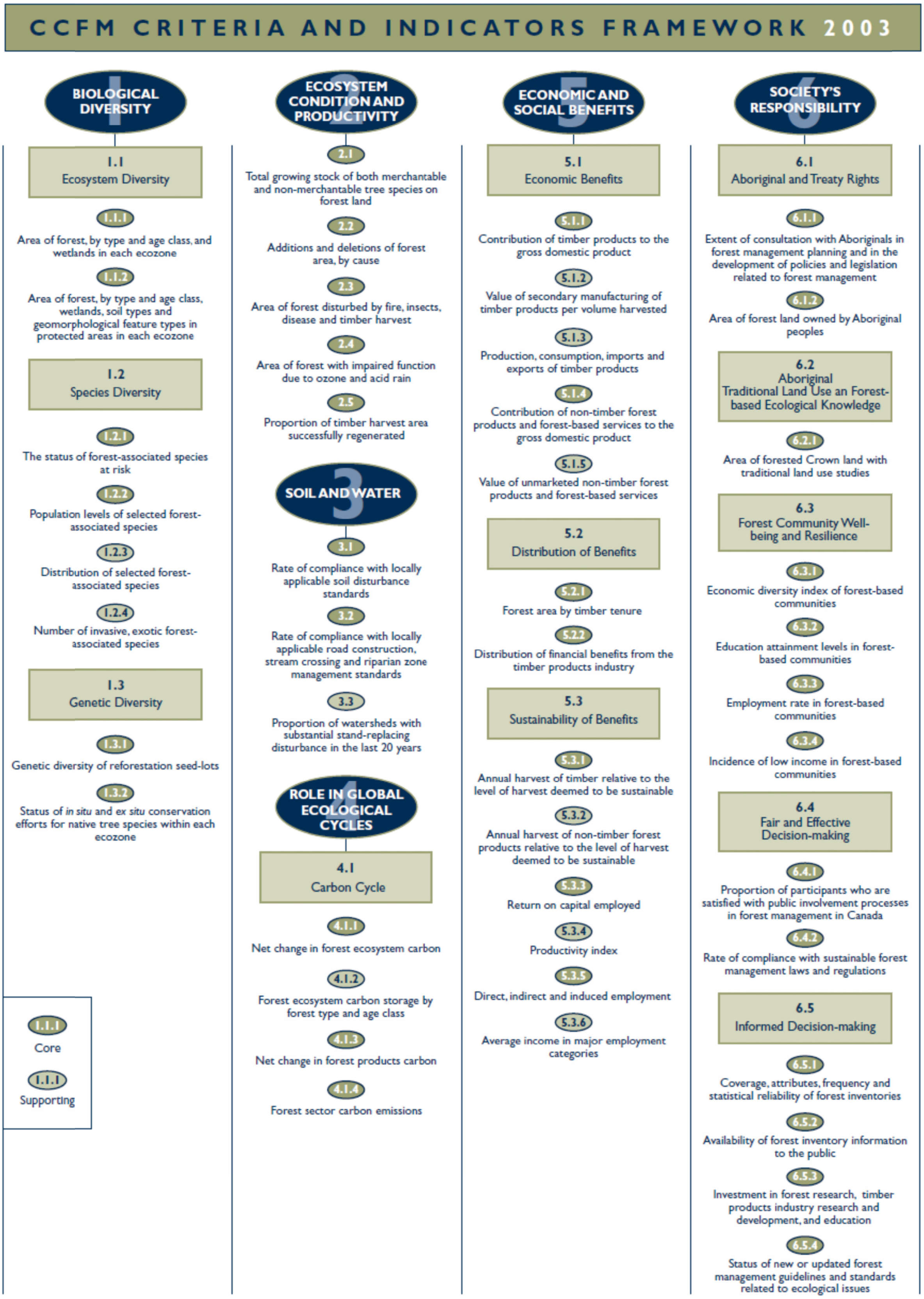

Figure 1. The 2003 national framework of Criteria and Indicators of Sustainable Forest Management taken directly from the Canadian Council of Forest Ministers (CCFM; 2003, p. 22)

Table 2. Abbreviated evaluation results, including indicator number, total number of linkages with other indicators in the framework, keywords illustrating the interaction of the indicator with climate change, main references used during the indicator evaluation, and final evaluation category, respectively

Indicator	Linkages	Climate change keywords	Main references	Evaluation category
1.1.1.	22	Species migration; changes in phenology; more frequent and severe disturbance; tree-line advance; dieback; hydrological change	Burkett & Kusler, 2000; Dale et al., 2001; Hulme, 2005; Danby & Hik, 2007; McKenney et al., 2007; Aitken et al., 2008; Iverson et al., 2008; Hogg et al., 2008; Erwin, 2009	Unmodified
1.1.2.	20	Loss of biogeographic stability; species migration; changes in phenology; tree-line advance; dieback; more frequent and severe disturbance; hydrological change	Franke, 2000; Hall & Farge, 2003; Scott, 2003; Scott & Lemieux, 2005; Danby & Hik, 2007; McKenney et al., 2007; Scott et al., 2007; Hogg et al., 2008	Unmodified & new indicator
1.2.1.	17	Species migration, changes in phenology; more disease and parasites; habitat change; competition with invasive species; Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessment and designation process[1]	COSEWIC, 2001; McCarty et al., 2001; Hannah et al., 2002; Schneider & Root, 2002; COSEWIC, 2004; Thomas et al., 2004; COSEWIC, 2008a; COSEWIC, 2008b; Mawdsley et al., 2009; Thompson et al., 2009; COSEWIC, 2010	Unmodified
1.2.2	27	Species migration, changes in phenology; more disease and parasites; habitat change; competition with invasive species	Thompson et al., 1998; Gitay et al., 2002; Hannah et al., 2002; Schneider & Root, 2002; Thomas et al., 2004; Pounds et al., 2006; Malcom et al., 2006; Mawdsley et al., 2009	Modified
1.2.3.	26	Species migration, changes in phenology; more disease and parasites; habitat change; competition with invasive species	Kelsall, 1984; Bradshaw et al., 1995; Chapin et al., 1998; Thomas, 1998; Chowns, 2003; Matthews et al., 2004; Malcom et al., 2006; Mawdsley et al., 2009; Vitt et al., 2010; Tyler, 2010	Unmodified
1.2.4.	15	More invasive alien and native species; changes in phenology; changes in predation and competition with native species	Fleming & Candau, 1998; Ayres & Lombardero, 2000; Frelich, 2002; Hunter & Mattice, 2002; Logan et al., 2003; Burdvig & Berg et al., 2006; Gray, 2008; Kurz et al., 2008; Dukes et al., 2009	Modified
1.3.1.	6	Species migration; genetic maladaptation; seed transfer guidelines	Cumming & Burton, 1996; Mátyás, 1997; Flemming et al., 2002; Gray, 2005; Millar et al., 2007; O'Neill et al., 2008; McKenney et al., 2009	Uninfluenced & new indicator
1.3.2.	13	Species migration; genetic maladaptation; seed transfer guidelines; loss of biogeographic stability	Mosseler, 1992; Rogers & Ledig, 1996; McCarty, 2001; Flemming et al., 2002; Scott & Lemieux, 2005; Beardmore et al., 2006; Gray, 2005; Groom et al., 2006; Government of Canada, 2009	Unmodified
2.1.	24	Increased metabolic rates; longer growing season; carbon fertilization; soil moisture and nutrient limitations; increases and decreases in forest productivity; more frequent and severe natural disturbance	Chaplin et al., 1995; Braswell et al., 1997; Colombo & Buse, 1998; Peng & Apps, 1999; Dale et al., 2001; Gitay et al., 2001; Schimel et al., 2001; Zhou et al., 2001; Norby et al., 2005; Bunn & Goetz, 2006; Bernier, 2007; Zhang et al., 2008; Friend, 2010; McMahon et al., 2010	Modified & new indicator
2.2.	21	Tree-line advance; dieback; afforestation initiatives	UNFCCC, 2001; Climate Change Action Fund (CCAF), 2003; McKenney et al., 2006; Danby & Hik, 2007; Aitken et al., 2008; Dominy et al., 2010	Unmodified
2.3.	25	More frequent and sever natural disturbance; more salvage harvests; range of natural variability	Fleming & Candau, 1998; Fleming, 2000; Peterson, 2000; Dale et al., 2001; Harper et al., 2004; Pederson, 2004; Carroll, 2006; Hogg & Bernier, 2006; Gray, 2008; Kurz et al., 2008; Flannigan et al., 2009	Modified
2.4.	12	Fluctuations in precipitation rates; photochemical processes in warmer temperatures	Aber et al., 1989; Krzyzanowski et al., 2005; Langner et al., 2005; Sitch et al., 2007	Unmodified

Indicator	Linkages	Climate change keywords	Main references	Evaluation category
2.5.	23	Species migration; changes in seed production and seedling survival; Changes in phenology; climatic variability; dispersal barriers; assisted migration	Noss, 2001; Goodale et al., 2002; van der Meer et al., 2002; Scheller and Mladenoff, 2005; McKenney et al., 2007; Kurz et al., 2008; Johnston et al., 2009; McKenney et al., 2009; Thomson et al., 2009; Xu et al., 2009; Steenberg et al., 2012	Unmodified & new indicator
3.1.	7	Decline of frozen-ground conditions	Spittlehouse & Stewart, 2003; Barrow et al., 2004; Johnston et al., 2010	Uninfluenced
3.2.	7	Hydrological change	Trombulak & Frissel, 2000; Swank et al., 2001; Morrison et al., 2002; Hodgkins et al., 2003; Mote et al., 2003; Dettinger et al., 2004; Spittlehouse, 2005; Payne et al., 2004; Vaidya et al., 2008; Jones et al., 2009	Uninfluenced
3.3.	17	More frequent and sever natural disturbance; hydrological change	Dale et al., 2001; Flannigan et al., 2005; Hogg & Bernier, 2006; Gray, 2008; Hogg et al., 2008; Kurz et al., 2008; Jones et al., 2009	Unmodified & new indicator
4.1.1.	19	Increases and decreases in forest productivity; carbon fertilization; change in decomposition rates; more frequent and severe natural disturbance	Chaplin et al., 1995; Gitay et al., 2001; Schimel et al., 2001; Norby et al., 2005; Bond-Lamberty et al., 2007; Kurz et al., 2008; Flannigan et al., 2009; Slaney et al., 2009; Friend, 2010; McMahon et al., 2010; Stinson et al., 2011	Modified
4.1.2.	19	Increases and decreases in forest productivity; carbon fertilization; change in decomposition rates; more frequent and severe natural disturbance	Schimel et al., 2001; Gillet et al., 2004; Norby et al., 2005; Bunn & Goetz, 2006; Flannigan et al., 2009; Kurz et al., 2009; Slaney et al., 2009; Friend, 2010; MacLean et al., 2010; McMahon et al., 2010; Stinson et al., 2011	Modified
4.1.3.	4	Carbon capture policy; product substitution; changes in decomposition rates	Kurz et al., 1995; Apps et al., 1999; Pederson, 2004; Spittlehouse, 2005; Verburg, 2005; Canadell & Raupach, 2008; Hennigar et al., 2008; Neilson et al., 2008; MacLean et al., 2010	Unmodified & new indicator
4.1.4.	5	Climate forcing; emissions reduction initiatives	Saddler, 2002; Matin et al., 2004; Demerse & Bramley, 2008; Kurz et al., 2008; Flannigan et al., 2009; MacLean et al., 2010	Unmodified
5.1.1.	4	Forest ecosystem change[2]; timber supply fluctuation[2]; global trade fluctuations; forest biomass and bioenergy industries	Dale et al., 2001; Perez-Garcia et al., 2002; Bradley, 2006; Browne & Hunt, 2007; McKenney et al., 2007; Williamson et al., 2008; Yemshanov & McKenney, 2008; Dominy et al., 2010	Modified
5.1.2.	4	Forest ecosystem change; timber supply fluctuation	Dale et al., 2001; Schimel et al., 2001; Perez-Garcia et al., 2002; Stennes et al., 2005; DeLong et al., 2007; Spetic, 2009	Unmodified
5.1.3.	11	Timber supply fluctuation; global trade fluctuations	Sohngen & Mendelsohn, 1998; Irland et al., 2001; Perez-Garcia et al., 2002; Lee & Lyon, 2004; Browne & Hunt, 2007; Kirilenko & Sedjo, 2007; Williamson et al., 2008; Jonsson, 2009	Unmodified
5.1.4.	4	Forest ecosystem change; loss of biogeographic stability; carbon markets; bioproducts and biomaterials industries	United Nations Framework Convention on Climate Change (UNFCCC), 1997; Hauer et al., 2001; Duchesne & Wetzel, 2002; Scott, 2003; Gray, 2005; Browne & Hunt, 2007; Freedman et al., 2009; Anderson et al., 2010a; Anderson et al., 2010b	Modified
5.1.5.	4	Forest ecosystem change; loss of biogeographic stability	Franke, 2000; Scott, 2003; Scott & Lemieux, 2005; McFarlane et al., 2006; Scott et al., 2007; Anderson et al., 2010a; Anderson et al., 2010b; Solano-Rivera, 2010	Unmodified
5.2.1.	9	Forest ecosystem change; public awareness of climate-change issues	Haley & Luckart, 1990; Beckley, 1998; Haley & Nelson, 2007	Modified
5.2.2.	9	Forest ecosystem change; timber supply fluctuation	Perez-Garcia et al., 2002; Kirilenko & Sedjo, 2007; Kurz et al., 2008	Unmodified

Indicator	Linkages	Climate change keywords	Main references	Evaluation category
5.3.1.	31	Forest ecosystem change; timber supply fluctuation; more salvage harvests; fluctuation in annual allowable cut	Peng & Apps, 1999; Volney & Fleming, 2000; Dale et al., 2001; Schimel et al., 2001; Hall, 2002; Perez-Garcia et al., 2002; Barrow et al., 2004; Spittlehouse, 2005; Bernier, 2007; Kirilenko & Sedjo, 2007; McKenney et al., 2007; Aitken et al., 2008; Hogg et al., 2008; Iverson et al., 2008; Lindenmayer & Noss, 2008; Flannigan et al., 2009	Unmodified
5.3.2.	27	Forest ecosystem change; timber supply fluctuation	Irland, 1998; Kerry et al., 1999; Hauer et al., 2001; Duchesne & Wetzel, 2002; Hardy, 2002; McCready, 2004; Gray, 2005; McKenney et al., 2007; Johnston et al., 2010	Unmodified
5.3.3.	5	None	Dale et al., 2001; Kirilenko & Sedjo, 2007; Jonsson, 2009	Uninfluenced
5.3.4.	6	Wood fibre quality	Jozsa & Middleton, 1994; Kennedy, 1995; Nyland, 1996; Francis & Hengeveld, 1998; Parker et al., 2000; Johnston et al., 2010	Uninfluenced
5.3.5.	11	Timber supply fluctuation; growing forest biomass and bioenergy industries; bioproducts and biomaterials industries climate-change innovation	Beckley, 2000; Berndes et al., 2003; Jochem & Madlener, 2003; Kammen et al., 2006; Frankhauser et al., 2008; Martizez-Fernandez et al., 2010	Unmodified
5.3.6.	5	None	Sohngen & Mendelsohn, 1998; Irland et al., 2001; Perez-Garcia et al., 2002; Berndes et al., 2003; Kirilenko & Sedjo, 2007; Freedman et al., 2009; Jonsson, 2009	Uninfluenced
6.1.1.	0	None	Cohen, 1997; Rothman & Herbert, 1997; Duchesne & Wetzel, 2002; Kovats et al., 2003; Ford & Smit, 2004; Karjala et al., 2004; Gray, 2005; Juday et al., 2005; Nuttall et al., 2005; Furgal & Seguin, 2006; McKenney et al., 2007; Kopra & Stevenson, 2008; Adam & Kneeshaw, 2009; Johnston et al., 2010; Tyler, 2010; Vitt et al., 2010	Uninfluenced
6.1.2.	2	Forest ecosystem change	Cohen, 1997; Rothman & Herbert, 1997; Duchesne & Wetzel, 2002; Kovats et al., 2003; Ford & Smit, 2004; Karjala et al., 2004; Gray, 2005; Juday et al., 2005; Nuttall et al., 2005; Furgal & Seguin, 2006; McKenney et al., 2007; Kopra & Stevenson, 2008; Adam & Kneeshaw, 2009; Johnston et al., 2010; Tyler, 2010; Vitt et al., 2010	Unmodified
6.2.1.	1	Vulnerability of Aboriginal traditional land uses to environmental change	Cohen, 1997; Rothman & Herbert, 1997; Duchesne & Wetzel, 2002; Kovats et al., 2003; Ford & Smit, 2004; Karjala et al., 2004; Gray, 2005; Juday et al., 2005; Nuttall et al., 2005; Furgal & Seguin, 2006; McKenney et al., 2007; Kopra & Stevenson, 2008; Adam & Kneeshaw, 2009; Johnston et al., 2010; Tyler, 2010; Vitt et al., 2010	Unmodified
6.3.1.	7	Forest ecosystem change; timber supply fluctuation	Slovic, 1997; Beckley, 2000; Beckley et al., 2002; Natcher & Hickey, 2002; Davidson et al., 2003; Medis et al., 2003; Karjala et al., 2004; Pederson, 2004; Parkins & MacKendrick, 2007; Williamson et al., 2008; Adam & Kneeshaw, 2009; Williamson & Watson, 2010	Unmodified
6.3.2.	5	None	Slovic, 1997; Beckley, 2000; Beckley et al., 2002; Natcher & Hickey, 2002; Davidson et al., 2003; Medis et al., 2003; Karjala et al., 2004; Pederson, 2004; Parkins & MacKendrick, 2007; Williamson et al., 2008; Adam & Kneeshaw, 2009; Williamson & Watson, 2010	Uninfluenced

Indicator	Linkages	Climate change keywords	Main references	Evaluation category
6.3.3.	11	Forest ecosystem change; timber supply fluctuation	Slovic, 1997; Beckley, 2000; Beckley et al., 2002; Natcher & Hickey, 2002; Davidson et al., 2003; Medis et al., 2003; Karjala et al., 2004; Pederson, 2004; Parkins & MacKendrick, 2007; Williamson et al., 2008; Adam & Kneeshaw, 2009; Williamson & Watson, 2010	Unmodified
6.3.4.	6	Forest ecosystem change; timber supply fluctuation	Slovic, 1997; Beckley, 2000; Beckley et al., 2002; Natcher & Hickey, 2002; Davidson et al., 2003; Medis et al., 2003; Karjala et al., 2004; Pederson, 2004; Parkins & MacKendrick, 2007; Williamson et al., 2008; Adam & Kneeshaw, 2009; Williamson & Watson, 2010	Unmodified
6.4.1.	1	Public awareness of climate-change issues	Duinker, 1998; Health Canada, 2005; McFarlane et al., 2006; McGurk et al., 2006; Health Canada, 2010; Martineau-Delisle & Nadeau, 2010	Uninfluenced
6.4.2.	17	None	Spittlehouse, 2005; Nabuurs et al., 2007; McKenney et al., 2009; Carlson et al., 2010	Uninfluenced
6.5.1.	0	None	Rettie et al., 1997; Linder, 2000; Canada's Forest Inventory (CanFI), 2001; Leckie et al., 2002; Leckie et al., 2003; Thompson et al., 2007; Hogg et al., 2008; Wulder et al., 2008; Zhang et al., 2008; Kurz et al., 2009	Uninfluenced
6.5.2.	0	None	Rettie et al., 1997; Linder, 2000; CanFI, 2001; Leckie et al., 2002; Leckie et al., 2003; Thompson et al., 2007; Hogg et al., 2008; Wulder et al., 2008; Zhang et al., 2008; Kurz et al., 2009	Uninfluenced
6.5.3.	8	Forest ecosystem change; timber supply fluctuation; public awareness of climate-change issues; new climate change policies	Grissom et al., 2000; Noss, 2001; Ontario Ministry of Natural Resources (OMNR), 2006; Spittlehouse, 2008; Government of Canada, 2010; Johnston et al., 2010; Natural Resources Canada (NRCan), 2011	Modified
6.5.4.	17	Forest ecosystem change; public awareness of climate-change issues; new climate change policies	Naiman et al., 1993; Swank et al., 2001; Spittlehouse & Stewart, 2003; Lee et al., 2004; Spittlehouse, 2008; Johnston et al., 2009; Johnston et al., 2010	Modified

[1] This indicator is highly dependent on the COSEWIC assessment and designation process and the inclusion of climate change in that process.

[2] Forest ecosystem change and timber supply fluctuation refer to the indirect influence from climate change impacts on the biophysical indicators in Criteria 1 through 4.

References

Aber, J. D., Nadelhoffer, K. J., Steudler, P., & Melillo, J. M. (1989). Nitrogen saturation in northern forest ecosystems: Excess nitrogen from fossil fuel combustion may stress the biosphere. *Bioscience, 39*, 378-386. http://dx.doi.org/10.2307/1311067

Adam, M.-C., & Kneeshaw, D. (2009). *Formulating Aboriginal criteria and indicator frameworks*. Edmonton, AB: Sustainable Forest Management Network.

Aitken, S. N., Yeaman, S., Holliday, J. A., Wang, T., & Curtis-McLane, S. (2008). Adaptation, migration or extirpation: Climate change outcomes for tree species. *Evolutionary Applications, 1*, 95-111. http://dx.doi.org/10.1111/j.1752-4571.2007.00013.x

Anderson, J., Gomez W., C., McCarney, G., Adamowicz, V., Chalifour, N., Webber, M., … Howlett, M. (2010a). *Ecosystem service valuation, market-based instruments, and sustainable forest management: A primer.* Edmonton, AB: Sustainable Forest Management Network.

Anderson, J., Gomez W., C., McCarney, G., Adamowicz, V., Chalifour, N., Weber, M., … Howlett, M. (2010b). *Natural capital: Using ecosystem service valuation and market-based instruments as tools for sustainable forest management*. Edmonton, AB: Sustainable Forest Management Network.

Anderson, R. C., & Lankester, M. W. (1974). Infectious and parasitic diseases and arthropod pests of moose in North America. In J. Bedard (Ed.), *Alces moose ecology* (pp. 23-50). Laval, QC: Les Presses de Université Laval.

Apps, M. J., Kurz, W. A., Beukema, S. J., & Bhatti, J. S. (1999). Carbon budget of the Canadian forest products sector. *Environmental Science & Policy, 2*, 25-41. http://dx.doi.org/10.1016/S1462-9011(99)00006-4

Ayres, M. P., & Lombardero, M. J. (2000). Assessing the consequences of global change for disturbance from herbivores and pathogens. *Science of the Total Environment, 262*, 263-286. http://dx.doi.org/10.1016/S0048-9697(00)00528-3

Barrow, P., Maxwell, B., & Gachon, P. (2004). *Climate variability and change in Canada: Past, present and future*. Toronto, ON: Environment Canada, Meteorological Service of Canada.

Beardmore, T., Loo, J., McAfee, B., Malouin, C., & Simpson, D. (2006). A survey of tree species of concern in Canada: The role for genetic conservation. *The Forestry Chronicle, 82*, 351-363.

Beckley, T. M. (1998). Moving towards consensus-based forest management: A comparison of industrial, co-managed, community, and small private forests in Canada. *The Forestry Chronicle, 74*, 736-744.

Beckley, T. M. (2000). *Sustainability for whom? Social indicators for forest-dependent communities in Canada*. Edmonton, AB: Sustainable Forest Management Network.

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

Berndes, G., Hoogwijk, M., & van den Broek, R. (2003). The contribution of biomass in the future global energy supply: A review of 17 studies. *Biomass and Bioenergy, 25*, 1-28. http://dx.doi.org/10.1016/S0961-9534(02)00185-X

Bernier, P. (2007). *Climate change and forest productivity: Questions abound.* Quebec, QC: Natural Resources Canada, Canadian Forest Service, Laurentian Forestry Centre.

Bond-Lamberty, B., Peckham, S. D., Ahl, D. E., & Gower, S. T. (2007). Fire as the dominant driver of central Canadian boreal forest carbon balance. *Nature, 450*, 89-92. http://dx.doi.org/10.1038/nature06272

Bradley, D. (2006). *Canada biomass-bioenergy report*. Ottawa, ON: Climate Change Solutions.

Bradshaw, C. J. A., Hebert, D. M., Rippin, A. B., & Boutin, S. (1995). Winter peatland habitat selection by woodland caribou. *Journal of Wildlife Management, 54*, 161-168.

Braswell, B. H., Schimel, D. S., Linder, E., & Moore, B. (1997). The response of global terrestrial ecosystems to interannual temperature variability. *Science, 278*, 870-873. http://dx.doi.org/10.1126/science.278.5339.870

Browne, S. A., & Hunt, L. M. (2007). *Climate change and nature-based tourism, outdoor recreation, and forestry in Ontario: Potential effects and adaptation strategies*. Thunder Bay, ON: Ontario Ministry of Natural Resources, Centre for Northern Forest Ecosystem Research.

Bunn, A. G., & Goetz, S. J. (2006). Trends in satellite-observed circumpolar photosynthetic activity from 1982-2003: The influence of seasonality, cover type, and vegetation density. *Earth Interactions, 10*, 1-19. http://dx.doi.org/10.1175/EI190.1

Burdvig, L. A., & Evans, C. W. (2006). Competitive effects of native and exotic shrubs on *Quercus alba* seedlings. *Northeastern Naturalist, 13*, 259-268. http://dx.doi.org/10.1656/1092-6194(2006)13[259:CEONAE]2.0.CO;2

Burkett, V., & Kussler, J. (2000). Climate change: Potential impacts and interactions in wetlands of the United States. *Journal of the American Water Resources Association, 36*, 313-320. http://dx.doi.org/10.1111/j.1752-1688.2000.tb04270.x

Canadell, J. G., & Raupach, M. R. (2008). Managing forests for climate-change mitigation. *Science, 320*, 1456-1457. http://dx.doi.org/10.1126/science.1155458

CanFI. (2001). *Canada's national forest inventory*. Retrieved from https://nfi.nfis.org/home.php?lang=en

Carlson, M., Chen, J., Elgie, S., Henschel, C., Montenegro, Á., Roulet, N., … Wells, J. (2010). Maintaining the role of Canada's forests and peatlands in climate regulation. *The Forestry Chronicle, 86*, 434-443.

Carroll, A. L. (2006). The influence of climate change on the mountain pine beetle: Today's reality or tomorrow's problem. *BC Professional Forester, 13*, 16-17.

CCAF. (2003). *Building on success. Climate Change Action Fund (CCAF) 2002-2003 annual report*. Ottawa, ON: Environment Canada.

CCFM. (2003). *Defining sustainable forest management in Canada: Criteria and indicators 2003*. Ottawa, ON: Canadian Council of Forest Ministers.

Chapin, T. G., Harrison, D. J., & Katnik, D. D. (1998). Influence of landscape pattern on habitat use by American marten in an industrial forest. *Conservation Biology, 12*, 1327-1337. http://dx.doi.org/10.1111/j.1523-1739.1998.96227.x

Chaplin, F. S., Shaver, G. R., Giblin, A. E., Nadelhoffer, K. J., & Laundre, J. A. (1995). Responses of Arctic tundra to experimental and observed changes in climate. *Ecology, 76*, 694-711. http://dx.doi.org/10.2307/1939337

Chowns, T. J. (2003). *State of the knowledge of woodland caribou in Ontario*. Mattawa, ON: Forestry Research Partnership.

Cohen, S. (1997). *Mackenzie Basin impact study: Final report*. Ottawa, ON: Environment Canada.

Colombo, S. J., & Buse, L. J. (1998). *The impacts of climate change on Ontario's forests*. Toronto, ON: Ontario Ministry of Natural Resources.

COSEWIC. (2001). *COSEWIC assessment and update Status Report on the flammulated owl* Otus flammeolus *in Canada*. Ottawa, ON: Committee on the Status of Endangered Wildlife in Canada Secretariat.

COSEWIC. (2004). *Canadian species at risk*. Ottawa, ON: Committee on the Status of Endangered Wildlife in Canada Secretariat.

COSEWIC. (2008a). *COSEWIC assessment and update status report on the polar bear* Ursus maritimus *in Canada*. Ottawa, ON: Committee on the Status of Endangered Wildlife in Canada Secretariat.

COSEWIC. (2008b). *Stay informed: Species at risk in Canada increase in 2010 – The International Year of Biodiversity* (Press Release). Retrieved from http://www.cosewic.gc.ca/eng/sct7/sct7_3_15_e.cfm

COSEWIC. (2010). *COSEWIC Assessment and Update Status Report on the Whitebark Pine* Pinus albicaulis *in Canada*. Ottawa, ON: Committee on the Status of Endangered Wildlife in Canada Secretariat.

Cumming, S. G., & Burton, P. J. (1996). Phenology-mediated effects of climatic change on some simulated British Columbia forests. *Climatic Change, 34*, 213-222. http://dx.doi.org/10.1007/BF00224632

Dale, V. H., Joyce, L. A., McNuly, M., Neilson, R. P., Ayres, M. P., Flannigan, M. D., … Wotton, B. M. (2001). Climate change and forest disturbances. *Bioscience, 51*, 723-734. http://dx.doi.org/10.1641/0006-3568(2001)051[0723:CCAFD]2.0.CO;2

Danby, R. K., & Hik, D. (2007). Variability, contingency and rapid changes in recent sub-arctic alpine tree line dynamics. *Journal of Ecology, 95*, 352-363. http://dx.doi.org/10.1111/j.1365-2745.2006.01200.x

Davidson, D. J., Williamson, T., & Parkins, J. (2003). Understanding climate change risk and vulnerability in northern forest-based communities. *Canadian Journal of Forest Research, 33*, 2252-2261. http://dx.doi.org/10.1139/x03-138

DeLong, D. L., Kozak, R. A., & Cohen, D. H. (2007). Overview of the Canadian value-added wood products sector and the competitive factors that contribute to its success. *Canadian Journal of Forest Research, 37*, 2211-2226. http://dx.doi.org/10.1139/X07-027

Demerse, C., & Bramley, M. (2008). *Choosing greenhouse gas emission reduction policies in Canada*. Drayton Valley, AB: The Pembina Foundation.

Dettinger, M., Cayan, D., Meyer, M., & Jeton, A. (2004). Simulated hydrologic responses to climate variations and change in the Merced, Carson, and American River Basins, Sierra-Nevada, California, 1900-2099. *Climatic Change, 62*, 283-317. http://dx.doi.org/10.1023/B:CLIM.0000013683.13346.4f

Dominy, S. W. J., Gilsenan, R., McKenney, D. W., Allen, D. J., Hatton, T., Koven, A., … Sidders, D. (2010). A retrospective and lessons learned from Natural Resources Canada's Forests 2020 afforestation initiative. *The Forestry Chronicle, 86*, 339-347.

Duchesne, L. C., & Wetzel, S. (2002). Managing timber and non-timber forest product resources in Canada's forests: Needs for integration and research. *The Forestry Chronicle, 78*, 837-842.

Duinker, P. N. (1998). Public participation's promising progress: Advances in forest decision-making. *Commonwealth Forestry Review, 77*, 107-112.

Dukes, J. S., Pontius, J., Orwig, D., Garnas, J. R., Rodgers, V. L., Brazee, N., … Ayres, M. (2009). Responses of insect pests, pathogens, and invasive plant species to climate change in the forests of northeastern North America: What can we predict? *Canadian Journal of Forest Research, 39*, 231-248. http://dx.doi.org/10.1139/X08-171

Erwin, K. L. (2009). Wetlands and global climate change: The role of wetland restoration in a changing world. *Wetlands Ecology and Management, 17*, 71-84. http://dx.doi.org/10.1007/s11273-008-9119-1

Flannigan, M. D., Logan, K. A., Amiro, B. D., Skinner, W. R., & Stocks, B. J. (2005). Future area burned in Canada. *Climatic Change, 72*, 1-16. http://dx.doi.org/10.1007/s10584-005-5935-y

Flannigan, M. D., Stocks, B., Turetsky, M., & Wotton, M. (2009). Impacts of climate change on fire activity and fire management in the circumboreal forest. *Global Change Biology, 14*, 1-12. http://dx.doi.org/10.1111/j.1365-2486.2008.01660.x

Fleming, R. A., & Candau, J. N. (1998). Influences of climatic change on some ecological processes of an insect outbreak system in Canada's boreal forests and the implications for biodiversity. *Environmental Monitoring and Assessment, 49*, 235-249. http://dx.doi.org/10.1023/A:1005818108382

Fleming, R. A. (2000). Climate change and insect disturbance regimes in Canada's boreal forests. *World Resource Review, 12*, 520-555.

Fleming, R. A., Fleming, R. L., & Fleming, I. A. (2002). Life cycles. In H. A. Mooney & J. G. Canadell (Eds.), *The Earth system: Biological and ecological dimensions of global environmental change*. Chichester, UK: John Wiley & Sons Ltd.

Ford, J. D., & Smit, B. (2004). A framework for assessing the vulnerability of communities in the Canadian Arctic to risks associated with climate change. *Arctic, 57*, 389-400.

Francis, D., & Hengeveld, H. (1998). *Extreme weather and climate change*. Ottawa, ON: Environment Canada.

Franke, M. (2000). *Yellowstone after the glow: Lessons from the rire*. Cheyenne, WY: National Parks Service.

Frankhauser, S., Sehlleier, F., & Stern, N. (2008). Climate change, innovation and jobs. *Climate Policy, 8*, 421-429. http://dx.doi.org/10.3763/cpol.2008.0513

Freedman, B., Stinson, G., & Lacoul, P. (2009). Carbon credits and the conservation of natural areas. *Environmental Reviews, 17*, 1-19. http://dx.doi.org/10.1139/A08-007

Frelich, L. E. (2002). *Forest dynamics and disturbance regimes: Studies from temperate evergreen-deciduous forests*. Cambridge, UK: Cambridge University Press. http://dx.doi.org/10.1017/CBO9780511542046

Friend, A. D. (2010). Terrestrial plant production and climate change. *Journal of Experimental Botany, 61*, 1293-1309. http://dx.doi.org/10.1093/jxb/erq019

Furgal, C., & Seguin, J. (2006). Climate change, health, and vulnerability in the Canadian northern Aboriginal communities. *Environmental Health Perspectives, 114*, 1964-1970. http://dx.doi.org/10.1289/ehp.8433

Gillet, N. P., Weaver, A. J., Zwiers, F. W., Flannigan, M. D. (2004). Detecting the effect of climate change on Canadian forest fires. *Geophysical Research Letters, 31*, L18211. http://dx.doi.org/10.1029/2004GL020876

Gitay, H., Brown, S., Easterling, W., & Jallow, B. (2001). Ecosystems and their goods and services. In J. J. McCarthy, O. F. Canziani, N. A. Leary, D. J. Dokken, & K. S. White (Eds.), *Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.

Gitay, H., Suárez, A., & Watson, R. T. (2002). *Climate Change and Biodiversity*. Geneva, Switzerland: Intergovernmental Panel on Climate Change.

Goodale, C. L., Apps, M. J., Birdsey, R. A., Field, C. B., Heath, L. S., Houghton, R. A., … Shvidenko, A. Z. (2002). Forest carbon sinks in the Northern Hemisphere. *Ecological Applications, 12*, 891-899. http://dx.doi.org/10.1890/1051-0761(2002)012[0891:FCSITN]2.0.CO;2

Government of Canada. (2009). *Species at risk public registry*. Retrieved from http://www.sararegistry.gc.ca/sar/index/default_e.cfm

Government of Canada. (2010). *ABDC. Alberta Biomaterials Development Centre*. Retrieved from http://www.albertabiomaterials.com/

Gray, D. R. (2008). The relationship between climate and outbreak characteristics of the spruce budworm in eastern Canada. *Climatic Change, 87*, 361-383. http://dx.doi.org/10.1007/s10584-007-9317-5

Gray, P. A. (2005). Impacts of climate change on diversity in forested ecosystems: Some examples. *The Forestry Chronicle, 81*, 655-661.

Grissom, P., Alexander, M. E., Cella, B., Cole, F. V., Kurth, J. T, Mallote, N. P., … Ward, P. C. (2000). Effects of climate change on management and policy: Mitigation options in the North American boreal forest. In E. S. Kasischke & B. J. Stocks (Eds.), *Fire, climate change, and carbon cycling in the boreal forest* (pp. 85-101). New York, NY: Springer-Verlag. http://dx.doi.org/10.1007/978-0-387-21629-4_6

Groom, M. J., Meffe, G. K., & Carroll, C. R. (2006). *Principles of conservation biology*. Sutherland, MA: Sinauer Associates.

Haley, D., & Luckert, M. K. (1990). *Forest tenures in Canada: A framework for policy analysis*. Victoria, BC: Forestry Canada, Economics Directorate.

Haley, D., & Nelson, H. (2007). Has the time come to rethink Canada's Crown forest tenure system? *The Forestry Chronicle, 83*, 630-640.

Hall, J. P. (2002). Sustainable production of forest biomass for energy. *The Forestry Chronicle, 78*, 391-396.

Hall, M., & Farge, D. (2003). Modelled climate-induced glacier change in Glacier National Park, 1850-2100. *Bioscience, 53*, 131-140. http://dx.doi.org/10.1641/0006-3568(2003)053[0131:MCIGCI]2.0.CO;2

Hannah, L., Midgley, G. F., Lovejoy, T. E., Bond, W. J., Bush, M., Lovett, J. C., … Woodward, F. I. (2002). Conservation of biodiversity in a changing climate. *Conservation Biology, 16*, 264-268. http://dx.doi.org/10.1046/j.1523-1739.2002.00465.x

Hardy, Y. (2002). The Canadian Forest Service: New directions for science and technology. *The Forestry Chronicle, 78*, 57-59.

Harper, K. A., Lesieur, D., Bergeron, Y., & Drapeau, P. (2004). Forest structure and composition at young fire and cut edges in black spruce boreal forest. *Canadian Journal of Forest Research, 34*, 289-302. http://dx.doi.org/10.1139/x03-279

Hauer, G., Williamson, T., & Renner, M. (2001). *Socioeconomic impacts and adaptive responses to climate change: A Canadian forest sector prospective*. Edmonton, AB: Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre.

Health Canada. (2005). *Climate change, extreme weather events, and health effects in Alberta*. Retrieved from http://www.hc-sc.gc.ca/sr-sr/pubs/hpr-rpms/2004-scleros-eng.php

Health Canada. (2010). *Climate change and health*. Retrieved from http://www.hc-sc.gc.ca/ewh-semt/climat/index-eng.php

Hennigar, C. R., MacLean, D. A., & Amos-Binks, L. J. (2008). A novel approach to optimize management strategies for carbon stored in both forests and wood products. *Forest Ecology and Management, 256*, 786-797. http://dx.doi.org/10.1016/j.foreco.2008.05.037

Hodgkins, G. A., Dudley, R. W., & Huntington, T. G. (2003). Changes in the timing of high river flows in New England over the 20th century. *Journal of Hydrology, 278*, 244-252. http://dx.doi.org/10.1016/S0022-1694(03)00155-0

Hogg, E. H., & Bernier, P. Y. (2006). Climate-change impacts on drought-prone forests in western Canada. *The Forestry Chronicle, 81*, 675-682. http://dx.doi.org/10.1139/X08-001

Hogg, E. H., Brandt, J. P., & Michaelian, M. (2008). Impacts of a regional drought on the productivity, dieback, and biomass of western Canadian aspen forests. *Canadian Journal of Forest Research, 38*, 1373-1384. http://dx.doi.org/10.1111/j.1365-2664.2005.01082.x

Hulme, P. E. (2005). Adapting to climate change: Is there scope for ecological management in the face of a global threat? *Journal of Applied Ecology, 42*, 784-794. http://dx.doi.org/10.1111/j.1365-2664.2005.01082.x

Hunter, J. C., & Mattice, J. (2002). The spread of woody exotics into the forests of a northeastern landscape, 1938-1999. *Journal of the Torrey Botanical Society, 129*, 220-227. http://dx.doi.org/10.2307/3088772

Irland, L. C. (1998). Ice storm 1998 and the forests of the Northeast: A preliminary assessment. *Journal of Forestry, 9*, 32-40.

Irland, L. C., Adams, D., Alig, R., Betz, C. J., Chen, C., Hutchins, M., … Sohngen, B. (2001). Assessing socioeconomic impacts of climate change on U. S. forests, wood product markets and forest recreation. *Bioscience, 51*, 753-764. http://dx.doi.org/10.1641/0006-3568(2001)051[0753:ASIOCC]2.0.CO;2

Iverson L. R., Prasad, A. M., Matthews, S. N., & Peters, M. (2008). Estimating potential habitat for 134 eastern US tree species under six climate scenarios. *Forest Ecology and Management, 254*, 390-406. http://dx.doi.org/10.1016/j.foreco.2007.07.023

Jochem, E., & Madlener, R. (2003). *The forgotten benefits of climate-change mitigation: Innovation, technological leapfrogging, employment, and sustainable development*. Paris, France: Organisation for Economic Co-operation and Development.

Johnston, M., Campagna, M., Gray, P., Kope, H., Loo, J., Ogden, A., … Williamson, T. (2009). *Vulnerability of Canada's tree species to climate change and management options for adaptation*. Ottawa, ON: Canadian Council of Forest Ministers.

Johnston, M., Williamson, T., Munson, A., Ogden, A., Moroni, M., Parsons, R., … Stadt, J. (2010). *Climate change and forest management in Canada: Impacts, adaptive capacity, and adaptation options*. Ottawa, ON: Sustainable Forest Management Network.

Jones, J. A., Achterman, G. L., Augustine, L. A., Creed, I. F., Folliot, P. F., MacDonald, L., & Wemple, B. C. (2009). Hydrologic effects of a changing forested landscape – challenges for the hydrological sciences. *Hydrological Processes, 23*, 2699-2704. http://dx.doi.org/10.1002/hyp.7404

Jonsson, R. (2009). *Forest products markets: External drivers affecting Swedish forests and forestry* (Forest Futures Working Report). Alnarp, Sweden: Forest Futures.

Jozsa, L. A., & Middleton, G. R. (1994). *A discussion of wood quality attributes and their practical implications* (Special Publication No. SP-34). Vancouver, BC: Forintek Canada Corp.

Juday, G. P., Barber, V., Duffy, P., Linderhorm, H., Rupp, S., Sparrow, S., … Yarie, J. (2005). Forests, land management and agriculture. In *Arctic Council. 2005. Arctic climate impact assessment: Scientific report* (pp. 1-137). Cambridge, UK: Cambridge University Press.

Kammen, D. M., Kapadia, K., & Fripp, M. (2006). *Putting renewables to work: How many jobs can the clean energy industry generate?* Berkeley, CA: University of California, Berkeley.

Karjala, M. K., Sherry, E. E., & Dewhurst, S. M. (2004). Criteria and indicators for sustainable forest planning: A framework for recording Aboriginal resource and social values. *Forest Policy and Economics, 6*, 95-110. http://dx.doi.org/10.1016/S1389-9341(02)00117-X

Kelsall, J. P. (1984). *Status report on the woodland caribou* Rangifer tarandus dawsoni *and* Rangifer tarandus caribou. Ottawa, ON: Committee on the Status of Endangered Wildlife in Canada.

Kennedy, R. W. (1995). Coniferous wood quality in the future: Concerns and strategies. *Wood Science and Technology, 29*, 321-338. http://dx.doi.org/10.1007/BF00202581

Kerry, M., Kelk, G., Etkin, D., Burton, I., & Kalhok, S. (1999). Glazed over: Canada copes with the ice storm of 1998. *Environmental Science and Policy for Sustainable Development, 41*, 6-11. http://dx.doi.org/10.1080/00139159909604608

Kirilenko, A. P., & Sedjo, R. A. (2007). Climate-change impacts on forestry. *Proceedings of the National Academy of Science, 104*, 19697-19702. http://dx.doi.org/10.1073/pnas.0701424104

Kopra, K., & Sevenson, M. (2008). *Aboriginal community-based criteria and indicators: A localised approach*. Edmonton, AB: Sustainable Forest Management Network.

Kovats, S., Ebi, K. L., & Menne, B. (2003). Methods of assessing human health vulnerability and public health adaptation to climate change. In *Health and Environmental Change* (Series No. 1). Copenhagen, Denmark: World Health Organization, Health Canada, United Nations Environmental Programme.

Krzyzanowski, J., McKendry, I. G., & Innes, J. L. (2006). Evidence of elevated ozone concentrations on forested slopes of the Lower Fraser Valley, British Columbia, Canada. *Water, Air, and Soil Pollution, 173*, 273-287. http://dx.doi.org/10.1007/s11270-005-9072-z

Kurz, W. A., Apps, M. J., Beukema, S. J., & Lekstrum, T. (1995). 20th-century carbon budget of Canadian forests. *Tellus B, 47*, 170-177.

Kurz, W. A., Dymond, C. C., Stinson, G., Rampley, G. J., Neilson, E. T., Carroll, A. L., … Safranyik, L. (2008). Mountain pine beetle and forest carbon feedback to climate change. *Nature, 452*, 987-990. http://dx.doi.org/10.1038/nature06777

Kurz, W. A., Dymond, C. C., White, T. M., Stinson, G., Shaw, C. H., Rampley, G. J., … Apps, M. J. (2009). CBM-CFS3: A model of carbon-dynamics in forestry and land-use change implementing IPCC standards. *Ecological Modelling, 220*, 480-504. http://dx.doi.org/10.1016/j.ecolmodel.2008.10.018

Langner, J., Bergström, R., & Foltescu, V. (2005). Impact of climate change on surface ozone and deposition of sulphur and nitrogen in Europe. *Atmospheric Environment, 39*, 1129-1141. http://dx.doi.org/10.1016/j.atmosenv.2004.09.082

Leckie, D. G., Gillis, M. D., & Wulder, M A. (2002). Deforestation estimation for Canada under the Kyoto Protocol: A design study. *Canadian Journal of Remote Sensing, 28*, 672-678. http://dx.doi.org/10.5589/m02-062

Leckie, D. G., Gougeon, F. A., Walsworth, N., & Paradine, D. (2003). Stand delineation and composition estimating using semi-automated individual tree crown analysis. *Remote Sensing of the Environment, 85*, 355-369. http://dx.doi.org/10.1016/S0034-4257(03)00013-0

Lee, D. M., & Lyon, K. S. (2004). A dynamic analysis of the global timber market under global warming: An integrated modeling approach. *Southern Economic Journal, 70*, 467-489. http://dx.doi.org/10.2307/4135326

Lee, P., Smith, C., & Boutin, S. (2004). Quantitative review of riparian buffer width guidelines from Canada and the United States. *Journal of Environmental Management, 70*, 165-180. http://dx.doi.org/10.1016/j.jenvman.2003.11.009

Lindenmayer, D. B., & Noss, R. F. (2006). Salvage logging, ecosystem processes, and biodiversity conservation. *Conservation Biology, 20*, 949-958. http://dx.doi.org/10.1111/j.1523-1739.2006.00497.x

Linder, M. (2000). Developing adaptive forest management strategies to cope with climate change. *Tree Physiology, 20*, 299-307. http://dx.doi.org/10.1093/treephys/20.5-6.299

Logan, J. A., Régnière, J., Powell, J. A. (2003). Assessing the impacts of global warming on forest pest dynamics. *Frontiers in Ecology and the Environment, 1*, 130-137. http://dx.doi.org/10.1890/1540-9295(2003)001[0130:ATIOGW]2.0.CO;2

MacLean, D. A., Amos-Binks, L. J., Hennigar, C. R., Neilson, E. T., Slaney, G. L., Arp, P. A., … Meng, F.-R. (2010). *Strategies for storing carbon in forests and wood products*. Edmonton, AB: Sustainable Forest Management Network.

Malcolm, J. R., Liu, C., Neilson, R. P., Hansen, L., & Hannah, L. (2006). Global warming and extinction of endemic species from biodiversity hotspots. *Conservation Biology, 20*, 538-548. http://dx.doi.org/10.1111/j.1523-1739.2006.00364.x

Martineau-Delisle, C., & Nadeau, S. (2010). Assessing the effects of public participation processes from the point of view of participants: Significance, achievements, and challenges. *The Forestry Chronicle, 86*, 753-765.

Martinez-Fernandez, C., Hinojosa, C., & Miranda, G. (2010). *Green jobs and skills: The local labour market implications of addressing climate change.* Paris, France: Organisation for Economic Co-Operation and Development.

Matin, A., Collas, P., Blain, D., Ha, C., Liang, C., MacDonald, L., … Rhoades, K. (2004). *Canada's greenhouse gas inventory 1990-2002*. Ottawa, ON: Environment Canada, Greenhouse Gas Division.

Matthews, S. N., O'Connor, R. J., Iverson, L. R., & Prasad, A. M. (2004). *Atlas of climate change effects in 150 bird species of the eastern United States*. St. Paul, MN: United States Department of Agriculture, United States Forest Service.

Mátyás, C. (1997). Genetics and adaptation to climate change: A case study of trees. In B. Huntley, W. Cramer, A. V. Morgan, H. C. Prentice, & J. R. Allen (Eds.), *Past and Future Rapid Environmental Changes: The Spatial and Evolutionary Responses of Terrestrial Biota* (pp. 357-370). Berlin, Germany: Springer-Verlag.

Mawdsley, J. R., O'Malley, R., & Ojima, D. S. (2009). A review of climate-change adaptation strategies for wildlife management and biodiversity conservation. *Conservation Biology, 23*, 1080-1089. http://dx.doi.org/10.1111/j.1523-1739.2009.01264.x

McCarty, J. P. (2001). Ecological consequences of recent climate change. *Conservation Biology, 15*, 320-331. http://dx.doi.org/10.1046/j.1523-1739.2001.015002320.x

McCready, J. (2004). *Ice storm 1998: Lessons learned*. Kelowna, BC: The 6th Canadian Urban Forest Conference.

McFarlane, B. L., Stumpf-Allen, R. C. G., & Watson, D. O. (2006). Public perceptions of natural disturbance in Canada's national parks: The case of the mountain pine beetle (*Dendroctonus ponderosae* Hopkins). *Biological Conservation, 130*, 340-348. http://dx.doi.org/10.1016/j.biocon.2005.12.029

McGurk, B., Sinclair, J., & Diduck, A. (2006). An assessment of stakeholder advisory committees in forest management: Case studies from Manitoba, Canada. *Society and Natural Resources, 19*, 809-826. http://dx.doi.org/10.1080/08941920600835569

McKenney, D. W., Pedlar, J. H., Lawrence, K., Campbell, K., & Hutchinson, M. F. (2007). Potential impacts of climate change on the distribution of North American trees. *Bioscience, 57*, 39-948. http://dx.doi.org/10.1641/B571106

McKenney, D. W., Pedlar, J., & O'Neil, G. (2009). Climate change and forest seed zones: Past trends, future prospects and challenges to ponder. *The Forestry Chronicle, 85*, 258-266. http://dx.doi.org/10.5558/tfc85258-2

McMahon, S. M., Parker, G. G., & Miller, D. R. (2010). Evidence for a recent increase in forest growth. *Proceedings of the National Academy of Science, 107*, 3611-3615. http://dx.doi.org/10.1073/pnas.0912376107

Medis, S., Mills, S., & Yantz, J. (2003). *Building community capacity to adapt to climate change in resource-based communities*. Prince Albert, SK: Prince Albert Model Forest Association Inc.

Millar, C. I., Stephenson, N. L., & Stephens, S. L. (2007). Climate change and forests of the future: Managing in the face of uncertainty. *Ecological Applications, 17*, 2145-2151. http://dx.doi.org/10.1890/06-1715.1

Morrison, J., Quick, M. C., & Foreman, M. G. G. (2002). Climate change in the Fraser River watershed: Flow and temperature projections. *Journal of Hydrology, 263*, 230-244. http://dx.doi.org/10.1016/S0022-1694(02)00065-3

Mosseler, A. (1992). Life history and genetic diversity in red pine: Implications for gene conservation in forestry. *The Forestry Chronicle, 68*, 701-708.

Mote, P. W., Parson, E. A., Hamlet, A. F., Keeton, W. S., Lettenmaier, D., Mantua, N., … Snover, A. K. (2003). Preparing for climatic change: The water, the salmon, and forests of the Pacific Northwest. *Climatic Change, 61*, 45-88. http://dx.doi.org/10.1023/A:1026302914358

Nabuurs, G. J., Masera, O., Andrasko, K., Benitez-Ponce, P., Boer, R., Dutschke, M., … & Zhang, X. (2007). Forestry. In B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, & L. A. Meyer (Eds.), *Climate change 2007: Mitigation. contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 541-584). Cambridge, UK: Cambridge University Press.

Naiman, R. J., Decamps, H., & Pollock, M. (1993). The role of riparian in maintaining regional diversity. *Ecological Applications, 3*, 209-212. http://dx.doi.org/10.2307/1941822

Natcher, D. C., & Hickey, C. G. (2002). *A criteria and indicators approach to community development*. Edmonton, AB: Sustainable Forest Management Network.

Neilson, E. T., MacLean, D. A., Meng, F.-R., Hennigar, C. R., & Arp, P. A. (2008). Optimal on- and off-site forest carbon sequestration under existing timber supply constraints in northern New Brunswick. *Canadian Journal of Forest Research, 38*, 2784-2796. http://dx.doi.org/10.1139/X08-120

Norby, R. J., DeLucia, E. H., Gielen, B., Calfapietra, C., Giardina, C. P., King, J. S., … Oren, R. (2005). Forest response to elevated CO_2 is conserved across a broad range of productivity. *Proceedings of the National Academy Science, 102*, 18052-18056. http://dx.doi.org/10.1073/pnas.0509478102

Noss, R. J. (2001). Beyond Kyoto: Forest management in a time of rapid climate change. *Conservation Biology, 15*, 578-590. http://dx.doi.org/10.1046/j.1523-1739.2001.015003578.x

NRCan. (2011). *Regional adaptation collaboratives*. Retrieved from http://adaptation.nrcan.gc.ca/collab/abosuj_e.php

Nuttall, M., Berkes, F., Kofinas, G., Vlassova, T., & Wenzel, G. (2005). Hunting, herding, fishing, and gathering: Indigenous peoples and renewable resource use in the Arctic. In *Arctic Council. 2005. Arctic climate impact assessment: Scientific report* (pp. 1-88). Cambridge, UK: Cambridge University Press.

Nyland, R. D. (1996). *Silviculture concepts and applications*. New York, NY: McGraw Hill.

O'Neill, G. A., Hamann, A., & Wang, T. (2008). Accounting for population variation improves estimates of the impact of climate change on species' growth and distribution. *Journal of Applied Ecology, 45*, 1040-1049. http://dx.doi.org/10.1111/j.1365-2664.2008.01472.x

Oliver, C. D., & Larson, B. C. (1996). *Forest stand dynamics*. New York, NY: John Wiley & Sons Inc.

OMNR. (2006). *Climate change and MNR: A program-level strategy and action plan*. Retrieved from http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@climatechange/documents/document/198258.pdf

Parker, W. C., Colombo, S. J., Cherry, M. L., Flannigan, M. D., Greifenhagen, S., McAlpine, R. S., … Scarr, T. (2000). Third millennium forestry: What climate change might mean to forests and forest management in Ontario. *The Forestry Chronicle, 76*, 445-464.

Parkins, J. R., & MacKendrick, N. A. (2007). Assessing community vulnerability: A study of the mountain pine beetle outbreak in British Columbia, Canada. *Global Environmental Change, 17*, 460-471. http://dx.doi.org/10.1016/j.gloenvcha.2007.01.003

Payne, J. T., Wood, A. W., Hamlet, A. F., Palmer, R. N., & Lettenmaier, D. P. (2004). Mitigating the effects of climate change on water resources of the Columbia River basin. *Climatic Change, 62*, 233-256. http://dx.doi.org/10.1023/B:CLIM.0000013694.18154.d6

Pederson, L. (2004). *Prince George Timber Supply Area: Rationale for allowable annual cut (AAC) determination*. Victoria, BC: British Columbia Ministry of Forests.

Peng, C., & Apps, M. J. (1999). Modelling the response of net primary productivity (NPP) of boreal forest ecosystems to changes in climate and fire disturbance regimes. *Ecological Modelling, 122*, 175-193. http://dx.doi.org/10.1016/S0304-3800(99)00137-4

Perez-Garcia, J., Joyce, L. A., McGuire, A. D., & Xiao, X. (2002). Impacts of climate change on the global forest sector. *Climatic Change, 54*, 439-461. http://dx.doi.org/10.1023/A:1016124517309

Peterson, C. J. (2000). Catastrophic wind damage to North American forests and the potential impact of climate change. *Science of the Total Environment, 262*, 287-311. http://dx.doi.org/10.1016/S0048-9697(00)00529-5

Pounds, J. A., Bustamante, M. R., Coloma, L. A., Consuegra, J. A., Fogden, M. P. L., Foster, P. N., … Young, B. E. (2006). Widespread amphibian extinctions from epidemic disease driven by global warming. *Nature, 439*, 161-167. http://dx.doi.org/10.1038/nature04246

Rettie, W. J., Sheard, J. W., & Messier, F. (1997). Identification and description of forested vegetation communities available to woodland caribou: Relating wildlife habitat to forest cover data. *Forest Ecology and Management, 93*, 245-260. http://dx.doi.org/10.1016/S0378-1127(96)03940-0

Robinson, D. C. E., Kurz, W. A., & Pinkham, C. (1999). *Estimating the carbon losses from deforestation in Canada*. Ottawa, ON: National Climate Change Secretariat.

Rogers, D. L., & Ledig, F. T. (1996). *the status of temperate North American forest genetic resources*. Davis, CA: University of California Genetic Resources Conservation Program.

Rothman, D. S., & Herbert, D. (1997). The socio-economic implications of climate change in the forest sector of the Mackenzie Basin. In S. J. Cohen (Ed.), *Mackenzie Basin impact study: Final report* (pp. 225-241). Ottawa, ON: Environment Canada.

Saddler, J. N. (2002). *The potential of short rotation forestry on marginal farm land in BC and Alberta to provide feedstock for energy generation and to reduce greenhouse gas emissions*. Edmonton, AB: Sustainable Forest Management Network.

Scheller, R. M., & Mladenoff, D. J. (2005). A spatially interactive simulation of climate change, harvesting, wind, and tree species migration and projected changes to forest composition and biomass in northern

Wisconsin, USA. *Global Change Biology, 11*, 307-321. http://dx.doi.org/10.1111/j.1365-2486.2005.00906.x

Schimel, D. S., House, J. I., Hibbard, K. A., Bousquet, P., Ciais, P., Peylin, P., … Wirth, C. (2001). Recent patterns and mechanisms of carbon exchange by terrestrial ecosystems. *Nature, 414*, 169-172. http://dx.doi.org/10.1038/35102500

Schneider, S. H., & Root, T. L. (2002). *Wildlife responses to climate change: North American case studies*. Washington, DC: Island Press.

Scott, D. (2003). Climate change and tourism and the mountain regions of North America. In *Proceedings of the First International Conference on Climate Change and Tourism*. Djerba, Tunisia: World Tourism Organization.

Scott, D. J., & Lemieux, C. J. (2005). Climate change and protected area policy and planning in Canada. *The Forestry Chronicle, 81*, 696-703.

Scott, D. J., Jones, B., & Konopek, J. (2007). Implications of climate and environmental change for nature-based tourism in the Canadian Rocky Mountains: A case study of Waterton Lakes National Park. *Tourism Management, 28*, 570-579. http://dx.doi.org/10.1016/j.tourman.2006.04.020

Sitch, S., Cox, P. M., Collins, W. J., & Huntingford, C. (2007). Indirect radiative forcing of climate change through ozone effects on the land-carbon sink. *Nature, 448*, 791-794. http://dx.doi.org/10.1038/nature06059

Slaney, G. L., Lantz, V. A., & MacLean, D. A. (2009). The economics of forest carbon sequestration through pest management: Application to forested landbases in New Brunswick and Saskatchewan. *Forest Policy and Economics, 11*, 525-534.

Slovic, P. (1997). Public perception of risk. *Journal of Environmental Health, 59*, 22-25.

Sohngen, B., & Mendelsohn, R. (1998). Valuing the impact of large-scale ecological change in a market; the effects of climate change on U. S. timber. *The American Economic Review, 88*, 686-710.

Solano-Rivera, C. (2010). *Determining the economic value of forests: An economic measure*. Edmonton, AB: Sustainable Forest Management Network.

Spetic, W. C. (2009). *Competitiveness and sustainability: Perspectives from the secondary wood industry of British Columbia, the forest industries of New Zealand, Chile, and Brazil, and the sugarcane-based ethanol industry of Brazil.* (Unpublished Doctoral Thesis). University of British Columbia, Vancouver, BC.

Spittlehouse, D. L., & Stewart, R. B. (2003). Adaptation to climate change in forest management. *BC Journal of Ecosystems and Management, 4*, 1-11.

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

Spittlehouse, D. L. (2008). *Climate change, impacts, and adaptation scenarios: Climate change and forest and range management in British Columbia*. Victoria, BC: British Columbia Ministry of Forests and Range.

Steenberg, J. W. N., Duinker, P. N., & Bush, P. G. (2012). Modelling the effects of climate change, timber harvest, and natural disturbance on the forests of central Nova Scotia. *Annals of Forest Science*. In press. http://dx.doi.org/10.1007/s13595-012-0235-y

Stennes, B., Wilson, B., & Wang, S. (2005). Growth of secondary wood manufacturing in British Columbia, Canada. *Forest Products Journal, 55*, 22-27.

Stinson, G., Kurz, W. A., Smyth, C. E., Neilson, E. T., Diamon, C. C., Metsaranta, J. M., … Blain, D. (2011). An inventory-based analysis of Canada's managed forest carbon dynamics, 1990 to 2008. *Global Change Biology, 17*, 2227-2244. http://dx.doi.org/10.1111/j.1365-2486.2010.02369.x

Swank, W. T., Vose, J. M., & Elliot, K. J. (2001). Long-term hydrologic and water quality responses following commercial clear cutting of mixed hardwoods on a southern Appalachian catchment. *Forest Ecology and Management, 143*, 163-178. http://dx.doi.org/10.1016/S0378-1127(00)00515-6

Thomas, C. D., Cameron, A., Green, R. E., Bakkenes, M., Beaumont, L. J., Collingham, Y. C., … Williams, S. E. (2004). Extinction risk from climate change. *Nature, 427*, 145-148. http://dx.doi.org/10.1038/nature02121

Thomas, D. C. (1998). Needed: Less counting of caribou and more ecology. *Rangifer, 10*, 15-25.

Thompson, I. D., Flannigan, M. D., Wotton, B. M., & Stuffling, R. (1998). The effects of climate change on landscape diversity: An example in Ontario Forests. *Environmental Monitoring and Assessment, 49*, 213-233. http://dx.doi.org/10.1023/A:1005894525278

Thompson, I. D., Maher, S. C., Rouillard, D. P., Fryxell, J. M., & Baker, J. A. (2007). Accuracy of forest inventory mapping: Some implications for boreal forest management. *Forest Ecology and Management, 252*, 280-221. http://dx.doi.org/10.1016/j.foreco.2007.06.033

Thompson, I., MacKey, B., McNulty, S., & Mosseler, A. (2009). *forest resilience, biodiversity, and climate change: A synthesis of the biodiversity/resilience/stability relationship in forest ecosystems*. Montreal, PQ: Secretariat of the Convention on Biological Diversity.

Thomson, A. M., Riddell, C. L., & Parker, W. H. (2009). Boreal forest provenance tests used to predict optimal growth and response to climate change: 2. Black spruce. *Canadian Journal of Forest Research, 39*, 143-153. http://dx.doi.org/10.1139/X08-167

Trombulak, S. C., & Frissell, C. A. (2000). Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology, 14*, 18-30. http://dx.doi.org/10.1046/j.1523-1739.2000.99084.x

Tyler, N. J. C. (2010). Climate, snow, ice, crashes, and declines in populations of reindeer and caribou (*Rangifer tarandus* L.). *Ecological Monographs, 80*, 197-219. http://dx.doi.org/10.1890/09-1070.1

UNFCCC. (1997). Kyoto Protocol to the United Nations Framework Convention on Climate Change. In *Proceedings of the 3rd Conference of Parties*. Buenos Aires, Argentina: United Nations Framework Convention on Climate Change.

UNFCCC. (2001). *The Marrakesh Accords and the Marrakesh Declaration*. Bonn, Germany: United Nations Framework Convention on Climate Change.

Vaidya, O. C., Smith, T. P., Fernand, H., & McInnis-Leek, N. R. (2008). Forestry best management practices: Evaluation of alternate streamside management zones on stream water quality in Pockwock Lake and Five Mile Lake Watersheds in Central Nova Scotia, Canada. *Environmental Monitoring and Assessment, 137*, 1-14. http://dx.doi.org/10.1007/s10661-006-9370-y

van der Meer, P. J., Jorritsma, I. T. M., & Kramer, K. (2002). Assessing climate change effects on long-term forest development: Adjusting growth, phenology, and seed production in a gap model. *Forest Ecology and Management, 16*, 39-52. http://dx.doi.org/10.1016/S0378-1127(02)00049-X

Verburg, P. S. J. (2005). Soil solution and extractable soil nitrogen response to climate change in two boreal forest ecosystems. *Biology and Fertility of Soils, 41*, 257-261. http://dx.doi.org/10.1007/s00374-005-0831-1

Vitt, D. H., Halsey, L. A., & Zoltai, S. C. (2010). The changing landscape of Canada's western boreal forest: The current dynamics of permafrost. *Canadian Journal of Forest Research, 30*, 283-287. http://dx.doi.org/10.1139/x99-214

Volney, W. J. A., & Fleming, R. A. (2000). Climate change and impacts of boreal forest insects. *Agriculture, Ecosystems and Environment, 82*, 283-294. http://dx.doi.org/10.1016/S0167-8809(00)00232-2

Williamson, T., Price, D., Beverly, J., Bothwell, P., Frenkel, B., Park, J., & Patriquin, M. (2008). *Assessing potential biophysical and socioeconomic impacts of climate change on forest-based communities: A methodological case study*. Edmonton, AB: Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre.

Williamson, T., & Watson, D. O T. (2010). Assessment of community preference rankings of potential environmental effects of climate change using the method of paired comparisons. *Climatic Change, 99*, 589-612. http://dx.doi.org/10.1007/s10584-009-9656-5

Wulder, M. A., White, J. C., Hay, G. J., & Castilla, G. (2008). Towards automated segmentation of forest inventory polygons on high resolution satellite imagery. *The Forestry Chronicle, 84*, 221-230.

Xu, C., Gertner, G. Z., & Scheller, R. M. (2009). Uncertainties in the response of a forest landscape to global climate change. *Global Change Biology, 15*, 116-131. http://dx.doi.org/10.1111/j.1365-2486.2008.01705.x

Yemshenov, D., & McKenney, D. (2008). Fast-growing poplar plantations as a bioenergy supply for Canada. *Biomass and Bioenergy, 32*, 185-197. http://dx.doi.org/10.1016/j.biombioe.2007.09.010

Zhang, K., Kimball, J. S., Hogg, E. H., Zhao, M., Oechel, W. C., Cassano, J. J., & Running, S. W. (2008). Satellite-based model detection of recent climate-driven changes in northern high-latitude vegetation productivity. *Journal of Geophysical Research, 113*, G03033. http://dx.doi.org/10.1029/2007JG000621

Zhou, L., Tucker, C. J., Kaufman, R. K., Slayback, D., Shabanov, N. D., Fung, I., & Myneni, R. B. (2001). Variations in northern vegetation activity inferred from satellite data of vegetation index during 1981-1999. *Journal of Geophysical Research, 106*, 20069-20083. http://dx.doi.org/10.1029/2000JD000115