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A Framework for Assessing Vulnerability of Forest-based Communities to Climate Change

T.B. Williamson, D.T. Price, J.L. Beverly, P.M. Bothwell, J.R. Parkins, M.N. Patriquin, C.V. Pearce, R.C. Stedman, and W.J.A. Volney

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Canada

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The map on the cover shows the locations of Canadian forest-based communities. Each dot on the map represents a census subdivision where the forest products industry provides at least 50% of the community's economic base income. The map was prepared by Marty Siltanen and Sue Mayer of the Canadian Forest Service. Data for the map were provided by the Canadian Forest Service's Dave Watson and Statistics Canada census data.

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A FRAMEWORK FOR ASSESSING VULNERABILITY OF FOREST-BASED COMMUNITIES TO CLIMATE CHANGE

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ABSTRACT

This report describes a general framework for and approach to assessing the vulnerability of forest-based communities to climate change and the potentially increased risks associated with such change. Communities that face relatively high levels of exposure to climate change and that are highly sensitive to changes in the composition and productivity of forests and to changes in forest disturbances (e.g., wildfire), or that have relatively low adaptive capacity (because of factors such as individual immobility, low economic diversity, remoteness, or lack of autonomy) will be vulnerable to climate change. This report identifies specific elements that should be considered in assessing vulnerability and outlines a series of steps that researchers or a community itself may follow to systematically determine sources of vulnerability to climate change. The first phase is to engage the community, develop a context for assessment, and obtain data on past and current climate and future climate scenarios. The second phase is to interpret what the anticipated climate changes may mean in terms of the surrounding forests and to determine the resulting social and economic impacts, including changes in local timber supply; employment and income effects; increases in the risk of wildfire; changes in the economic viability of local firms (because of structural change in global markets); changes in forest health, wildlife, fisheries, forest esthetics, water quality and quantity, traditional and cultural activities, and outdoor recreation opportunities; and increases in instability, volatility, and uncertainty in the local economy. The third phase is to measure the local capacity for adaptation. Many factors affect adaptive capacity, including wealth, mobility, education, social networks, trust, institutions, risk perceptions, and natural resource endowments. An important consideration is that the capacity to adapt exists both as a property of individual households and firms and as a general property of the community and the local economy. Therefore, an accurate portrayal of adaptive capacity requires measurement at different levels of aggregation. Adaptive capacity may also vary depending on whether it is assessed over the short term (where assets are fixed) or over the long term (where assets are variable). The framework presented in this document is a tool that communities can use to gather information that will help them identify where they are most vulnerable to climate change.

RESUME

Ce rapport porte sur une méthodologie qui permet d'évaluer la vulnérabilité des collectivités forestières aux impacts du changement climatique et aux risques associés au phénomène. Certaines collectivités sont particulièrement sensibles aux impacts du changement climatique et aux perturbations qui affectent la composition et la productivité de la forêt et qui interfèrent avec les agents responsables des processus de transformation de l'écosystème forestier (p. ex. les feux de forêt). Cette sensibilité particulière peut être due notamment à une faible capacité d'adaptation (« immobilité » relative des résidents, manque de diversité et d'autonomie économique, éloignement, etc.). Ce rapport définit certains des facteurs qui devraient être considérés dans l'évaluation de la vulnérabilité des collectivités forestières et décrit les paramètres que devraient suivre les spécialistes et les responsables locaux pour déterminer de manière systématique les principaux facteurs de vulnérabilité aux impacts du changement climatique. La première phase consiste à mobiliser la communauté pour établir les paramètres contextuels de l'évaluation, et à obtenir des données historiques et prospectives sur le régime climatique de la région. La deuxième consiste à interpréter ce qu'impliquent les effets prévus du changement climatique pour les forêts de la région et à déterminer les impacts sociaux et économiques qu'ils induiront sur divers plans : réserves de matière ligneuse; sources d'emplois et de revenus; augmentation du risque d'incendie forestier; viabilité économique des entreprises locales (changements structurels des marchés mondiaux); santé de la forêt; pêches, valeur esthétique du paysage forestier; qualité de l'eau et volume des réserves; activités traditionnelles et culturelles; activités récréatives; climat économique local. La troisième consiste à évaluer la capacité d'adaptation de la population locale, capacité qui dépend de plusieurs facteurs : prospérité, mobilité et niveau d'éducation de la population, réseaux sociaux, institutions, conception du risque en présence et ressources naturelles à disposition. Une importante considération est la capacité d'adaptation en termes individuels (ménages et entreprises) et collectifs (collectivité et économie locale). Par conséquent, le profil d'adaptabilité exact d'une région forestière donnée nécessite la prise de mesures à divers niveaux d'interaction. Il faut également souligner que la capacité d'adaptation peut varier selon qu'elle est évaluée sur le court terme (valeurs d'actif fixes) ou sur le long terme (valeurs d'actif variables). La démarche décrite dans ce document est un outil dont pourront se servir les collectivités pour recueillir l'information qui les aidera à déterminer les secteurs où elles sont le plus vulnérables aux impacts du changement climatique.

DEDICATION

This report is dedicated to the memory of Mike Waldram. Mike was a visionary and a strong advocate for forest-based communities. This report would not have been possible without Mike's encouragement and support.

PREFACE

Canada's forest-based communities are facing many challenges, and in the past few years, climate change has begun to surface as one of these concerns. One way to improve the capacity of communities to adapt to climate change is to ensure that they have access to information on sources of vulnerability. This document provides a framework for conducting vulnerability assessments for forest-based communities. The framework has been developed to incorporate a range of approaches and sources of information, including local knowledge, expert opinion, and detailed data collection and technical analysis. The framework focuses on assessing the vulnerability that occurs as a result of the impacts of climate change on forests. It is important to recognize that climate change will affect communities in other ways that are not included in the framework. For example, climate change may have direct implications in terms of health, community infrastructure, and risks of extreme weather. Also, climate change may affect other industries and natural resources such as the agriculture industry, the tourism industry, and ground and surface water resources. In addition, communities are affected by many forces that are not related to climate. These aspects are not directly considered here, but a vulnerability framework could potentially be expanded to cover these areas. This document focuses on the assessment of forest-based communities' vulnerability to climate change, and is the result of a joint initiative of the Canadian Model Forest Network and the Canadian Forest Service.

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INTRODUCTION

The impacts of climate change are expected to be higher for some segments of society than for others because of geographic location; the degree of association with climate-sensitive environments; and the unique economic, political, and cultural characteristics of particular areas (McCarthy et al. 2001; Dolan and Walker 2004). In Canada rural areas and resource-based communities are of particular concern (Standing Senate Committee on Agriculture and Forestry 2003). This report develops a general framework and approach for understanding the vulnerability of forest-based communities to climate change.

Forest-based communities will of course be affected by the same general impacts as non-forest-based communities. Examples of such general impacts include health effects, impacts on infrastructure, and exposure to extreme weather events. Over and above these general impacts, forest-based communities may be affected by climate change in the following specific ways (among others), because of their connections to climate-sensitive forests:

- Residents of forest-based communities generally have strong ties to the surrounding landscape, and changes in this landscape may affect their activities and values.
- Forest-based communities are located close to forests and residents may therefore be subjected to greater risks of property loss, job disruptions, travel disruptions, health impacts, and evacuation threats through changes in the frequency of wildfire.
- The forest industry supports the economy of many forest-based communities, but the supply of raw materials (wood from the forest) may be affected by climate-related factors.
- The forest industry is export oriented, and local economies may be affected by structural changes in global markets resulting from global climate change.

Adaptation has the potential to reduce the negative impacts and increase the benefits of climate change. It also has the potential to reduce the hazards and risks associated with climate change. However, knowledge of local vulnerability is a key requirement for successful adaptation (McCarthy et al. 2001). In essence, vulnerability depends on the extent of *exposure* of the system to climate change (i.e., the amount of climate change that is expected to occur in an area, the extent of changes in climate variability, and the extent of change in the frequency of extreme weather), the *sensitivity* of natural and human systems to climate change, and the *capacity* of those systems to adapt. Hence, an assessment of system vulnerability requires an understanding of each of these components at appropriate scales.[1] The US National Assessment Synthesis Team (NAST 2001; Parson et al. 2003) noted an increasing need to assess the vulnerability of human systems to climate and climate change. The Third Assessment report of the Intergovernmental Panel on Climate Change (IPCC) suggested that "Quantitative assessment of the sensitivity, adaptive capacity, and vulnerability of natural and human systems to climate change, with particular emphasis on changes in the range of climatic variation and the frequency and severity of extreme climate events" is a "high priority for narrowing gaps between current knowledge and policymaking needs" (McCarthy et al. 2001, p. 17). Similarly, the Stockholm Environment Institute has noted, "It is essential that we have a common conceptual framework that has been operationalized in indicators and measures. Beyond that, several case studies that demonstrate what a high-quality assessment would look like would be very valuable" (Kasperson and Kasperson 2001).

[1] A more detailed definition of vulnerability suitable for application to forest-based communities is provided in the section entitled "What is vulnerability? (below)."

For various reasons, Canada's capacity to assess the vulnerability to climate change of forest-based communities is low. First, the prediction of changes in climate and biophysical responses is a challenging area of research, characterized by uncertainty and continuing experimentation. Extending the results of these projections to an assessment of socioeconomic impacts adds to the challenges of quantifying vulnerability. Second, although many large-scale (global to regional) projections of ecological impacts have been attempted, relatively little has been done to generate assessments at scales relevant to forest managers and communities. Third, knowledge of the factors contributing to the resilience of natural and human systems and of the adaptive capacities of these systems is incomplete. Fourth, there exists a general lack of understanding of the processes involved in social risk construction[2] and of how the features of social systems and the characteristics of particular types of risks influence community perceptions and behavioral responses. Fifth, there is a lack of understanding of the roles of property rights configurations, entitlements, methods of governance, policy processes, and institutional structures in relation to promoting or constraining adaptive capacity and resiliency. Finally, systematic, integrated assessment tools are lacking. This study attempts to address all of these gaps.

WHAT IS VULNERABILITY?

A community is considered vulnerable to climate change if there is some probability of adverse consequences (i.e., the community is exposed and sensitive) that exceeds the community's capacity to adapt (McCarthy et al. 2001). These three elements (i.e., exposure, sensitivity, and adaptive capacity) are common to most definitions of climate change vulnerability (see Dow 1992; Adger and Kelly 1999; McCarthy et al. 2001; Luers et al. 2003). Vulnerability is, however, considered in different contexts, and the definition of vulnerability may vary to some degree depending on the context.

Kelly and Adger (2000), Brooks (2003), and Dolan and Walker (2004) have summarized the various definitions of vulnerability that have previously appeared in the literature. The Intergovernmental Panel on Climate Change (IPCC) described vulnerability as follows:

> Vulnerability is a function of the *sensitivity* of a system to changes in climate (the degree to which a system will respond to a given change in climate, including beneficial and harmful effects), *adaptive capacity* (the degree to which adjustments in practices, processes, or structures can moderate or offset the potential for damage or take advantage of opportunities created by a given change in climate), and the *degree of exposure* of the system to climatic hazards. Under this framework, a highly vulnerable system would be a system that is very sensitive to modest changes in climate, where the sensitivity includes the potential for substantial harmful effects, and for which the ability to adapt is severely constrained. Resilience is the flip side of vulnerability—a resilient system or population is not sensitive to climate variability and change and has the capacity to adapt (McCarthy et al. 2001, p. 89; italics added for emphasis).

This view of vulnerability has two main distinguishing characteristics. First, vulnerability is viewed as an end point. That is to say, a system is considered vulnerable if the potential net impacts, after adaptation, are predicted to be particularly high. Second, this view of vulnerability encompasses or incorporates the causative factors (i.e., the hazards or particular risks), system sensitivities, and system properties that influence adaptive

[2] Social construction is a formulation employed within some areas of sociology to emphasize the way in which social institutions and social life generally is socially produced rather than naturally given or determined" (Jary and Jary 1995). Social risk construction, therefore, is the processes and interactions that occur that ultimately lead to some socially determined perception of risk as opposed to a scientifically based, value free and objective measure of risk.

capacity. However, the IPCC perspective also has some gaps in terms of its potential application in forest-based communities. For example, it does not explicitly take into account how the characteristics of climate hazards might influence peoples' response to them. In addition, the IPCC view assumes that if adaptive capacity is high, adaptive response will also be high. This assumption may not always hold true, as individual or community variables may play an important role in mediating the relationship between capacity and action.

Another definition of vulnerability comes from the natural hazards literature. This perspective considers the causative factor (the hazard in question) and vulnerability as independent entities (Kelly and Adger 2000; Brooks 2003). Within the hazards literature, vulnerability is defined as the existence of one or more properties of a particular human system that determine its ability to adapt or cope in general terms. However, the severity and likelihood of particular hazards have no bearing on system vulnerability. This perspective is similar to that presented in the social science literature on community well-being and community capacity. Community capacity is defined as "the collective ability of a group to combine various forms of capital within institutional and relational contexts to produce desired results or outcomes" (Beckley et al. 2002; Flora and Emery 2006). Desired results or outcomes may be to successfully respond to or cope with external and internal stresses, to create and take advantage of opportunities, and to meet the diverse needs of residents (Kusel 2001).

For the purposes of the assessment framework described here, a specific definition of vulnerability was developed. This definition expands on the previously quoted IPCC definition (McCarthy et al. 2001) in several ways. First, following Smit and Pilifosova (2002), the scope has been broadened to include exposure, sensitivity, and adaptive capacity to present-day climate-related hazards as well as those associated with future climate change. Second, following Davidson et al. (2003), social and economic factors that might help in understanding individual and community responses to current and future risks have been considered. Such factors (e.g., perceptions of risks or hazards and public reluctance to change cherished community economic and social institutions) may be based at least in part on lack of information about the probability, magnitude, and local manifestations of climate change. These factors may mediate the relationship between the potential for adaptive response (based on community capacity indicators) and the adaptive response itself. Too much or too little investment in adaptation may also occur in cases where there is potential for external economies (i.e., rational individual choices and behavior resulting in social costs that are not accounted for in individual decisions), governance structures aimed at providing optimal levels of public goods are lacking or inadequate (e.g., to prevent, protect against, or control the occurrence of hazards), or institutional failure occurs (i.e., local institutions fail to adjust or redefine themselves in response to changing external conditions and circumstances, perhaps because of poor leadership). Hence, for the purposes of the assessment framework for forest-based communities, we have defined vulnerability as follows:

> In the context of a forest-based community, vulnerability is a function of the *sensitivity* and degree of *exposure* of social, ecological, and economic systems to climate hazards (both present and in the future), and *adaptive capacity*. A highly vulnerable community is one where the economic, social, and ecological systems are sensitive to climate hazards, where sensitivity includes the potential for substantial harmful effects, and where the ability to adapt is severely constrained. Adaptive constraints may result from one or more of: limited capacity, misperception of risk, and weak or inflexible institutions.

This definition focuses on potential negative impacts as sources of vulnerability for forest-based communities. It should be noted, however, that climate change may have positive impacts or may create opportunities for communities. Thus, in addition to looking at sources of vulnerability, communities should be aware of the possibility of positive impacts. Adopting measures to exploit the positive effects of climate change is also a legitimate form of adaptation.

ASSESSMENT FRAMEWORK AND APPROACH

This document presents a framework for linking information from multiple sources that can be used to better understand sources of vulnerability to climate change within forest-based communities.[3] In principle, vulnerability assessment should be holistic, viewing the system of interest in its entirety rather than focusing on specific symptoms or components. Such an approach is necessary because climate change is likely to have multiple effects on a forest-based community. If, however, an assessment is intended to cover only a portion of a system, this should be clearly stated at the outset.

The remainder of this section describes the elements and features of the proposed assessment framework for forest-based communities. The framework and approach described here focus on the impacts of climate change on forests, the resulting impacts on communities, and the adaptive capacity of communities. As recommended above, the framework attempts to be holistic in considering how these various aspects contribute to a community's overall vulnerability. However, it does not consider potential impacts on other economic sectors (e.g., agriculture or tourism), on water resources, on public health, on municipal infrastructure, or on building requirements, nor does it take into account changes in the risks associated with extreme weather events. It is also important to acknowledge that the future of most rural communities is and will continue to be affected by an array of nonclimatic socioeconomic trends (e.g., trade rules, demographic trends, globalization, urbanization, and the emerging knowledge economy). Therefore, any assessment based on this framework should recognize sources of vulnerability outside the forest sector and should acknowledge that many nonclimatic factors will affect the community concurrent with climate change.

Sensitivity of Forest-Based Communities to Climate Change

To understand and assess the vulnerability of forest-based communities to climate change, it is first necessary to identify the various ways by which such changes may affect these communities. A starting point for this process is to identify the ways in which individuals, businesses, property owners, landowners, and the community at large are sensitive to current climate and climate variability (Ford et al. 2006).

The vulnerability of forest-based communities to climatic factors results from complex interactions among atmospheric processes (i.e., weather), the forest ecosystem, and socioeconomic systems within and outside the communities of interest. Spatial scales range from meters (for individual organisms) to a few square meters or hundreds of square kilometers (for vegetation communities and ecosystems) to the national or global scale. Temporal scales range from the time needed for an "extreme event" to occur (e.g., a "once-in-200-years flood" or a catastrophic forest fire) to the multiple generations required for climatic shifts that affect global resources and human populations. The design of a vulnerability assessment framework and its application in specific community contexts requires an understanding of the key processes and systems affecting community vulnerability and how these systems and processes are linked (Figure 1).

[3] The framework described in this document is based in part on the results of an expert workshop hosted by the Canadian Model Forest Network in Edmonton, May 27 and 28, 2004. Workshop participants are listed in the acknowledgments section.

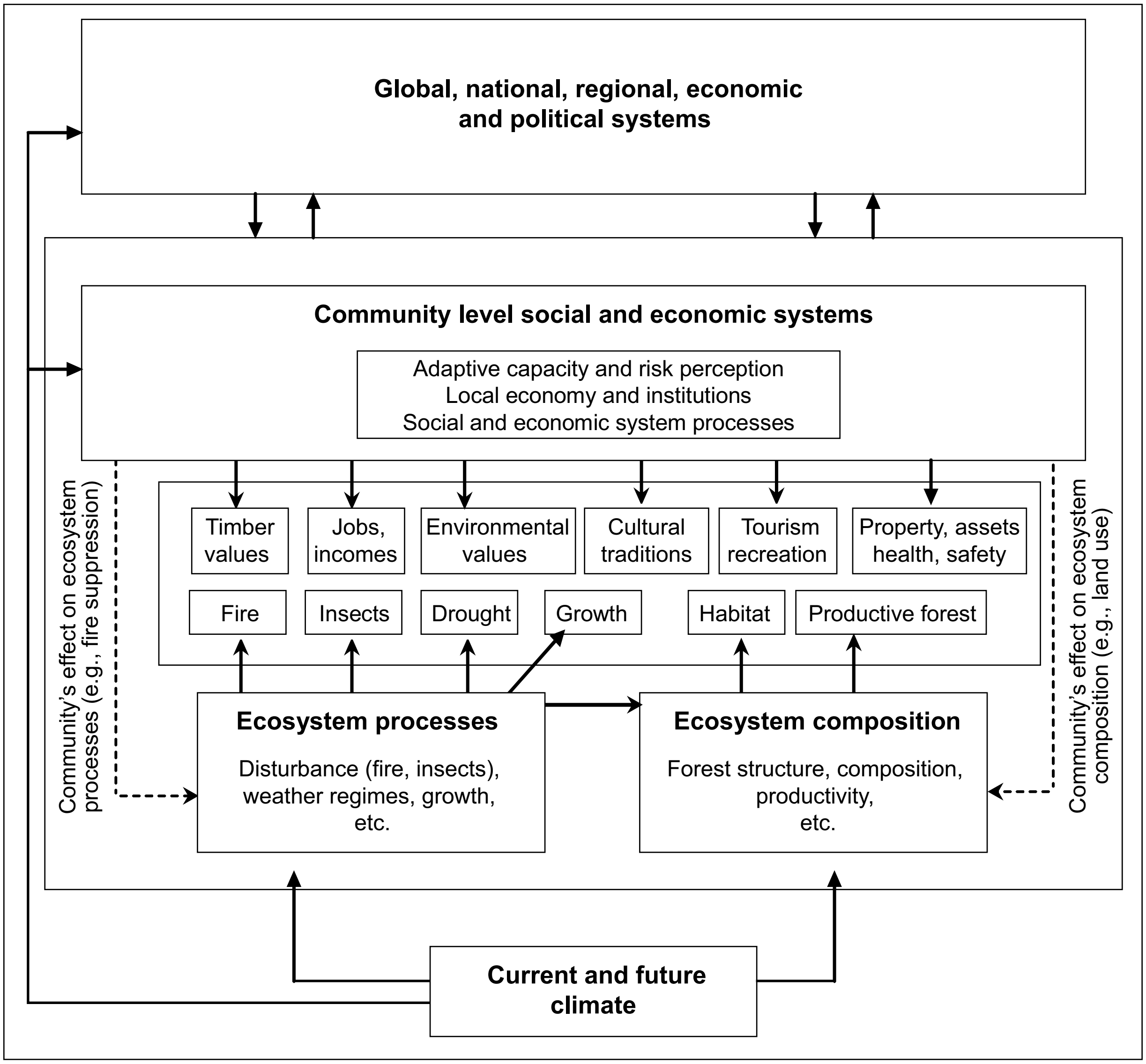

Figure 1. Pathways for forest-based community impacts to climate change.

There are three main ways by which changes in climate and climate variability may affect forest-based communities. First, climate has direct biophysical effects on the composition and processes of ecosystems. Such changes may have important implications for the availability and productivity of the forest resources upon which the community relies. Second, climate change may have direct impacts on community residents, through its effects on health, community infrastructure, and the heating and cooling requirements for buildings, as well as through changes in risks associated with extreme weather. Third, changes in global markets for forest products may occur as a result of changes in global timber supply caused by climate change (Sohngen et al. 2001; Perez-Garcia et al. 2002). More specifically, climate change is expected to result in an increase in global timber supply and a general restructuring of global supply and demand. This global market restructuring may have implications for manufacturers of forest products in Canadian forest-based communities, which generally rely on export markets for the sale of their products. The vulnerability assessment framework developed in this report focuses on the first and last of these three pathways.

Assessment Framework

Smit and Pilifosova (2003) developed a general conceptual framework for vulnerability assessment. Later, Ford and Smit (2004) and Ford et al. (2006) applied the general framework to Arctic communities. For the current study, a similar framework was adopted and tailored for application to forest-based communities (Figure 2). This framework follows from the definition of vulnerability set out in the previous section. In particular, the vulnerability of forest-based communities to climate change results from exposure to climate, the sensitivity of the forest ecosystem and of the community's social and economic systems, various socioeconomic scenarios, global trends in the markets for forest products, and the community's adaptive capacity. Aspects pertaining to exposure and sensitivity to climate change were discussed briefly in the previous section. Examples of factors affecting adaptive capacity include human capital, entrepreneurial leadership, level of economic diversification, efficiency and productivity of firms, levels of social capital, and the degree to which institutions do or do not constrain adaptation. Another consideration comprises the level of awareness and general perceptions of climate-related risk. Many of these factors are linked, and all contribute in some way to the assessment of vulnerability. The various components of the vulnerability assessment framework are described in more detail below.

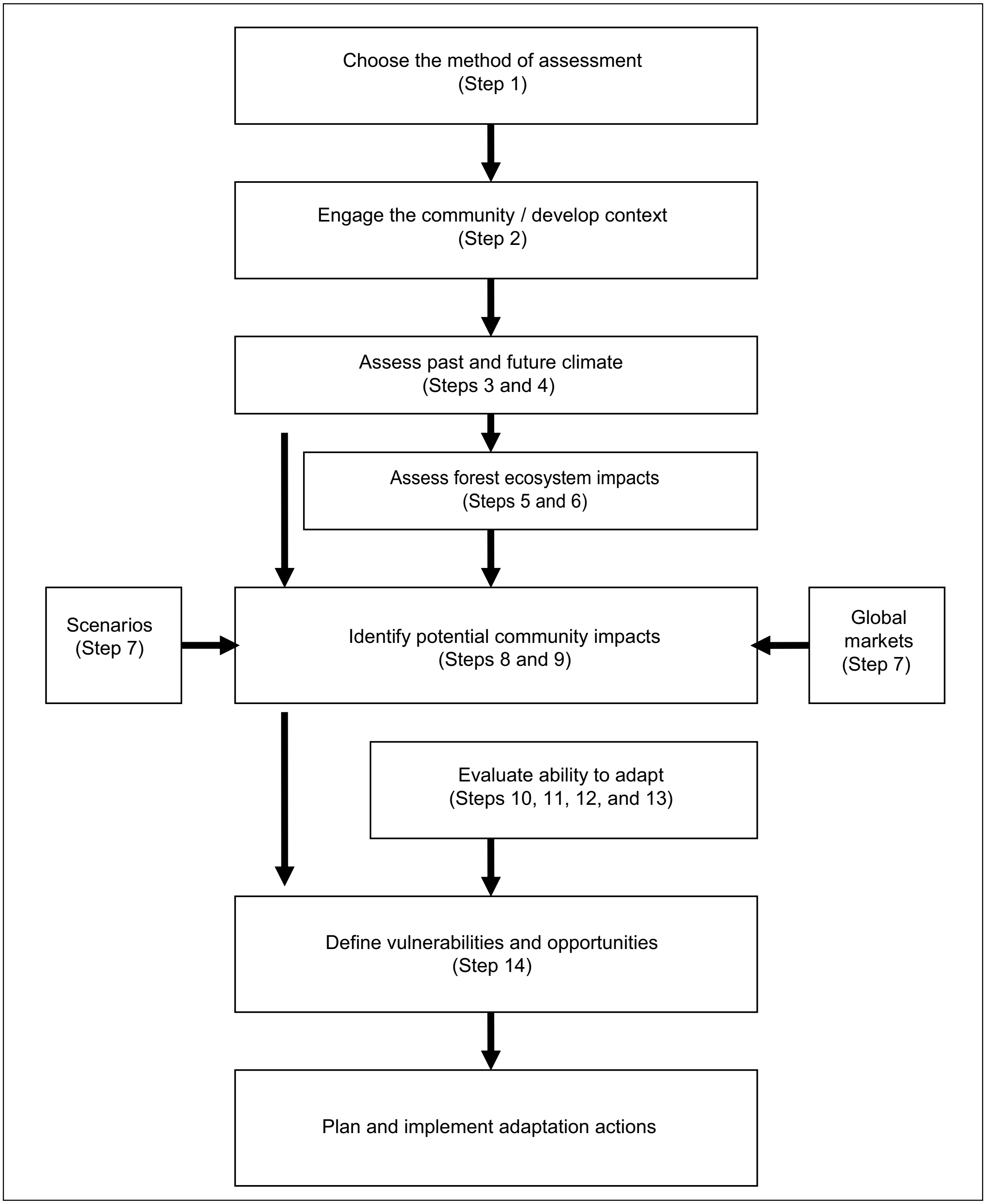

Figure 2. Conceptual model for vulnerability assessment of forest-based communities.

Scope and Approach for the Vulnerability Assessment

The main purpose of this report is to identify and describe the components of a vulnerability assessment framework and then outline a structured approach for conducting an assessment using the framework. Methodological options for vulnerability assessment are discussed in more detail in the next section.

The following steps are recommended as an approach to conducting a vulnerability assessment based on the framework described above.

Step 1 Decide on an assessment method according to need, technical capacity, and available funding.

Step 2 Develop a general community profile, including an overview of the community and areas of sensitivity to current climate and climate variability.

Step 3 Obtain information about current climate and climate variability and any impacts that may be related to recent climate change. Obtain information about how households, landowners, firms, and the community in general are affected by current climate and climate variability and about any measures that have been taken to adapt to current climate and climate variability.

Step 4 Obtain information about future climate (i.e., at least three [and up to six, if possible] different climate scenarios) for the area where the community is located.

Step 5 Assess possible ecosystem effects (e.g., change in vegetation or productivity) under each climate scenario.

Step 6 For each scenario, assess possible changes in wildfire (or other potential damaging disturbances such as drought, insects, and disease) in the area.

Step 7 Obtain information about global, national, and regional trends in social, economic, and political factors that may affect the community.

Step 8 Combine the information obtained in steps 4, 5, 6, and 7 and assess the potential impacts of climate change on the local economy.

Step 9 Assess the various climate scenarios in terms of possible environmental damage (e.g., forest health, wildlife, fisheries, esthetics, water levels, level and quality of outdoor recreation activities).

Step 10 Assess the adaptive capacity of the community.

Step 11 Assess the general level of social capital in the community.

Step 12 Assess perceptions of the risks and general levels of awareness of issues related to climate change (among both individuals and community leaders); determine if there are significant differences between local perceptions and expert opinion (or technical assessments) and the reasons for any such differences.

Step 13 Determine if there are important institutional barriers to adaptation.

Step 14 Summarize the results and prepare an overall assessment of factors that may contribute to the community's vulnerability to forest effects related to climate change.

More detailed descriptions of the various components identified above and why they are important for vulnerability assessment are discussed in more detail in the following sections.

METHODOLOGICAL OPTIONS FOR ASSESSMENT

As noted in the previous section, Step 1 of a vulnerability assessment is to assess methodological options and decide on an approach. We do not advocate a specific methodology for data collection and analysis of which there are many. These include data collection and analysis, data collection and modeling, analogs and literature reviews of impacts (e.g., review of detailed assessments conducted for similar types of communities, to allow comparisons with one's own community), surveys of local residents using structured questionnaires and representative samples of the population, workshops and focus groups (for example, see Brklacich and Woodrow 2007; Reid et al. 2007), interviews with local stakeholders, leaders, local experts, and households (for example, see Ford et al. 2006; Reid et al. 2007), and subjective assessment based on the opinions of technical experts (obtained using interviews or surveys). Any combination of these approaches might be used in a particular location, depending on the availability of resources for conducting the assessment, the level of detail required, and the levels of spatial and temporal resolution required by a decision maker. Some communities may prefer to rely on local knowledge and perceptions about impacts and vulnerability, whereas others may decide to commission an integrated assessment based on intensive data collection, modeling, and science-based technical analysis. The most comprehensive and effective approach involves the integration of both local knowledge and science-based methods (e.g., modeling, data collection, analysis) through all steps of the vulnerability assessment (Jones 2001; Mackinson 2001; Dolan and Walker 2004; Keskitalo 2004; Schröter et al. 2005; Kloprogge and Van Der Sluijs 2006).

PROVIDING CONTEXT THROUGH A COMMUNITY OVERVIEW

Step 2 of the process involves preparing a general description of the community concerned, to provide context for the subsequent assessment and to begin to identify areas where the community may be sensitive to climate change and climate variability. The following items, among others, should be included in the community description:

- description of the town site and surrounding area;
- description of the town's origins, its historical development, and its connection to the surrounding forest;
- description of the community's population in terms of demographic characteristics (e.g., population by age group), seasonality, and historical trends;
- lists of local organizations and events, retail businesses, facilities, modes of transportation access (e.g., road, rail, air, water), and community leaders, and description of the community's role within the larger region;
- description of the local economy (including description of the key sectors, supported by data on sales, exports, employment, and income by sector where possible) and important issues that are affecting it;
- description of the local government;
- description of the ways in which community members are involved in forest management and land-use policy and planning;
- discussion of contemporary issues facing the community;
- discussion of vulnerability to current climate and to climate variability and the ways in which governments, households, firms, and landowners are already addressing these issues;

- anecdotal observations of environmental change that can be tied to recent climate change or other causes and identification of local areas and resources where the community may be particularly sensitive to future climate change.

Much of this information may be available in community documents, such as official community plans, economic development plans, local chamber of commerce documents, and marketing information. Local leaders and long-time residents can often be additional important sources of information. The Census of Canada (through Statistics Canada) is a reliable source of demographic data at the census division and census subdivision levels, the latter generally corresponding to municipalities.

LOCAL CLIMATE

Understanding Local Climate and Its Current Influence

Understanding vulnerability begins with determining how the local community is affected by current climate and climate variability (Ford et al. 2006). Climate is a naturally defining characteristic of a region; for example, the climate of Port Alberni, British Columbia, is distinct from that of The Pas, Manitoba, and this difference results in an entire range of social, cultural, and economic differences between the two communities. Because many of the people who reside in resource-based communities spend substantial amounts of time outdoors, they may have an innate understanding of the local climate, which could lead to greater awareness of climatic changes before statistically significant trends appear in historical records. Step 3 of the process is to gather information and data about the current climate and its influence on a community.

Climate is also the primary factor determining the development of vegetation and soils. Hence, it strongly influences the characteristics, vegetation, and productivity of local ecosystems and the occurrence of natural disturbances (e.g., wildfire, insects, disease, storms, floods, and droughts). Climate therefore has a strong influence on local culture, the local economy, the types and levels of risks that producers (e.g., corporations, landowners) and residents face, and people's general quality of life. As noted previously, people who depend on climate-sensitive resource industries (such as forestry and agriculture) for their livelihoods tend to understand climate and recognize their vulnerability to current climate and climate variability.

Residents of rural resource-based communities are already experiencing the impacts of climate change. For example, the major outbreak of mountain pine beetle in the interior of British Columbia is at least partially attributable to a series of exceptionally mild winters (Carroll et al. 2004). Other local observations in this area include shorter winters, bird species not previously observed in the region, and shallower snow packs (Frenkel 2005).

Obtaining historical climate data for the area surrounding a community and collating these with anecdotal observations from local residents, if possible, can serve three purposes. First, such information will provide a more precise understanding of the local climate and its relationship to local culture, norms, and traditions. Second, it will help to confirm whether the climate of the local area has in fact changed in recent years. Third, it will help in determining how the community is vulnerable to current climate and climate variability.

Monthly data on temperature, precipitation, and other variables are now available for local climate stations in Canada from the Meteorological Service of Canada. Other agencies, including the Canadian Forest Service, have used these and other data to develop climate summaries for specific regions and time periods.

Characterizing the climate of a region generally requires temperature and precipitation data for an extended period. For most regions of Canada (except for the far north and higher elevations in the west) daily records extend back to 1900. Hence, characterizing the local climate for the 20th century is generally feasible. Monthly averages are sufficient to determine long-term trends, although daily data are needed to assess changes in variability (an analysis that would usually be carried out by a climatologist or knowledgeable statistician). Monthly data can be summarized by season and graphed for easier interpretation. In the northern hemisphere, the seasons are generally defined as winter (December to February), spring (March to May), summer (June to August), and fall (September to November).

Climate Scenarios

McCarthy et al. (2001) predicted with high certainty that mean global temperatures will increase in the coming decades and suggested that, regardless of human action in the immediate future, the effects of climate change will persist for centuries. Along with the increase in mean global temperatures, precipitation, humidity, and cloudiness are also expected to increase. Globally averaged surface air temperatures are forecast to increase by 1.4°C to 5.8°C by the year 2100 (Houghton et al. 2001; McCarthy et al. 2001), a rate of change that is unprecedented, at least in the past 200 000 years. However, the future rate of change is likely to differ greatly for different regions of the planet, with some regions possibly becoming cooler relative to present-day climatic means, at least over the short term. Another general prediction is that the frequency and intensity of extreme weather and climatic events will increase in many regions. As such, projected increases in precipitation may not be evenly distributed throughout the year. Rather, precipitation may occur in the form of more frequent intense storm events, which will result in high runoff levels and increased risks of flooding (Trenberth et al. 2003). Higher temperatures will increase evapotranspiration. Thus, in some regions, there is a greater likelihood of prolonged droughts (Hogg and Bernier 2005). Thus the magnitude and nature of future climate change will vary by community. Step 4 of the assessment process is to obtain information on future climate scenarios at a scale that is relevant to the community.

Hengeveld (2006) reviewed the current state of climate change science, reporting that mean global surface temperatures increased by about 0.7°C during the 20th century, with 0.4°C to 0.5°C of this change occurring since 1970. During the latter period, nighttime minimum temperatures over much of the land surface of the northern hemisphere increased at approximately double the rate of daytime maxima (Stone and Weaver 2002; Jones and Morberg 2003). Some regions—notably the northern regions of Canada and Siberia—have warmed more than the average, while the eastern United States and Canadian maritime regions may have cooled slightly (Przyblak 2002; Robinson et al. 2002). Logan and Price (2004) reported an average warming of about 2°C for Alberta during the 20th century.

Historical precipitation trends are much less clear, because spatial and temporal distributions are characteristically much more variable than those for temperature. Available data suggest recent increases of 0.5%–1.0% per decade in mean annual precipitation on land in the mid- to high-latitude regions of the northern hemisphere, with slight decreases in the subtropics (New et al. 2001; Frich et al. 2002; Milly et al. 2002; Trenberth et al. 2003). The Atlantic hurricanes of 2004–2005 and a general trend of increasing storm damage over the 1990s and into the 21st century tend to confirm the anticipated increase in storm intensity as the heat stored in the atmosphere gradually increases (Frich et al. 2002; Milly et al. 2002).

Much of the evidence confirming or explaining these observed trends is based on model simulations of global climate, (i.e., general circulation models or GCMs). These models are also the basis for predicting that the observed trends are likely to continue into the coming decades, given past and projected increases in anthropogenic greenhouse gas (GHG) emissions to the atmosphere. The global atmosphere is a huge and exceedingly complex system, composed of many interacting, often chaotic, physical and biological processes. The most sophisticated, fully coupled GCMs are still gross simplifications of the global atmosphere, but they are the best tools available. Such models are used every day as the basis for weather forecasts, which most people involved in outdoor activities recognize as imperfect but do not entirely ignore. The reality is that weather forecasting has improved enormously since the 1960s, almost entirely through improved understanding of the atmospheric processes captured in GCMs.

The predicted effects of increases in concentrations of GHGs on global climate have a solid scientific basis. The explanations for recent observed climate trends, and scenarios of future climate change, are based largely on the inclusion of GHG forcing (i.e., increases in atmospheric concentration of GHGs) in GCM physics. Therefore, the GCMs provide a plausible basis for projecting future climate although the complexity and potential importance of feedback processes (e.g., changes in cloudiness affecting the global radiation balance and changes in vegetation cover influencing uptake and release of natural sources of carbon dioxide [CO_2], methane [CH_4], and other GHGs) must be recognized. GCM projections are also subject to substantial uncertainty, which can be traced to two basic sources: limitations in the accuracy of the models (as previously discussed) and uncertainty about predictions of changes in the concentrations of atmospheric GHGs. These predictions are based on global demographic and economic projections for various regions of the globe (see Nakćenović et al. 2000).

The GCMs remain the primary means for beginning to assess the possible effects of climatic change on ecosystems and human infrastructure. Different GCMs project different temperature increases for specific regions of the world. There is, however, some general agreement among the models, including a consensus that greater warming will occur over land than over the oceans and also that greater warming is to be expected closer to the poles. Projected increases for mid-continental North America are therefore relatively large. Examination of the results from three GCMs combined with two commonly used GHG emission scenarios (A2 and B2, as described in Nakćenović et al. 2000) suggests possible increases of 4°C to 8°C in nighttime minimums and 2°C to 6°C in daytime maximums by 2100 for mid-continental North America. The magnitude of future climate change will vary significantly from region to region across Canada.

Warmer temperatures will promote greater evaporation of water from lakes and vegetation and higher humidity, which will in turn lead to increased precipitation. Although the GCMs vary widely in both the magnitude and the spatial distribution of their forecasts, the general projection is for an increase in mean annual rainfall of about 1% to 2% per degree of warming (Hengeveld 2006). This change may result in fewer but more intense precipitation events (Trenberth et al. 2003). Indeed, many of the potential risks due to climate change result from changes in the frequency and intensity of such events, because it is these extremes, rather than changes in the mean values, that are likely to drive the most serious impacts on human communities and natural ecosystems. By their nature, many extreme events are aperiodic and very localized, so they are difficult to capture with current models. Nevertheless, GCM outputs provide important information that can be used to estimate changes in extreme events, including significant increases in the frequency and intensity of heat waves, which cause intense heat stress and threats to health; increased occurrence of intense storms in the mid-latitudes, with storm tracks shifting to higher latitudes (e.g., Atlantic hurricanes reaching the Canadian maritime coast); more frequent extreme flows in large rivers such as the Fraser, the Nelson, and the St. Lawrence; and more intense El Niño events, causing warmer drier summers and milder winters (particularly in western Canada).

Climate data encompass both point-based data (for specific climate stations) and gridded data (estimated from observations made at climate stations), as well as historical time series, climate normals (averages calculated over specified 30-year periods), and scenarios of past and future climate developed from GCM simulations.

Substantial research has been conducted over the past 5 years on how best to interpret and utilize the information provided by GCMs. Most current-generation GCMs operate on global grids of very coarse resolution; for example, individual grid cells are as large as 400 km^2 at the equator. Most methods of interpreting GCM outputs at a local scale involve some form of calibration against historical observations and some form of "down-scaling" to make the simulated data more applicable to a particular location or small region.

The IPCC (Houghton et al. 2001) proposed that simulations of the impacts of climate change should be based on a suite of GHG emissions scenarios, each of which would represent a plausible future "story" of human population change and economic growth. These are known as the special report on emissions scenarios (or SRES) (Nakćenović et al. 2000). The various groups working on GCMs around the globe have all been expected to carry out simulation experiments "forced" by some or all of these SRES scenarios.

Price et al. (2004) described a comprehensive database of interpolated climate change scenarios covering North America at a resolution of approximately 10 km. Sets of monthly data for the period 1961–2100 were compiled for each of two key SRES emissions scenarios (A2 and B2), as simulated by each of three different GCMs: the Canadian CGCM2, the UK Hadley Centre HadCM3, and the Australian CSIRO[4] Mk 2 GCM. (Similar data are currently being prepared for the US NCAR PCM[5].) Each GCM simulation was referenced to the 1961–1990 period by calculating the monthly averages for this 30-year period and then expressing all of the simulated values as changes from these monthly averages. In the case of temperature variables, the changes were reported as temperature differences, whereas for other variables (precipitation, humidity, solar radiation, and wind speed), the changes were reported as ratios relative to the 1961–1990 means. These derived data (differences and ratios) could then be applied to *observed* means for 1961–1990 at the same location to estimate the projected changes in each variable according to each GCM simulation.

In addition to the scenario data, historical time series of monthly temperature and precipitation data extending back to 1901 have been developed and are available on the same grid-cell basis (Price et al. 2004). The combination of these historical observations with the down-scaled GCM scenario data allows the creation of future scenarios that are strongly tied to the known spatial characteristics of North American climate.

Use of the data described here requires some caution. The scenarios developed for a particular vulnerability assessment must not be considered predictions, particularly when they focus on a single point location, since it is by no means certain that any single scenario will capture reality. The future is, by definition, uncertain, and the further a projection extends into the future, or the more closely a projection is tied to a particular location, the greater the uncertainty. Climate scenario data should therefore be considered to represent plausible alternative futures, none of which will actually happen but any of which *could* prove similar to reality.

[4] CSIRO = Commonwealth Scientific and Industrial Research Organization.
[5] NCAR = National Center for Atmospheric Research, PCM = Parallel Climate Model.

Impacts on Forest Composition and Productivity

Step 5 of the assessment is to assess the impacts of future climate change on forest composition and productivity. Communities and community residents derive a wide range of goods (e.g., timber) and other benefits (e.g., recreation, amenities, conservation values) from forests (Davidson et al. 2003). Depending on a forest-based community's location, climate change may have small to large impacts on the health, structure, and productivity of the surrounding forest ecosystems (Singh and Wheaton 1991; Burton and Cumming 1995; Saporta et al. 1998; McKinnon et al. 2004), and the stream of benefits may thus be altered (positively or negatively or both) over time. Understanding the sensitivity and response of the forest to future climate change is therefore an important component of a vulnerability assessment. Several approaches exist for assessing ecosystem sensitivity and potential responses to future climate change, including capturing local knowledge, monitoring, and modeling. These three methods are described below.

Capturing Local Knowledge

Capturing local knowledge through stakeholder participation has an important role in local vulnerability assessment (Dolan and Walker 2004; Kloprogge and Van Der Sluijs 2006; Keskitalo 2004) and in environmental and risk assessment in general (Duffield et al. 1998; Huntington 2000; Usher 2000; Jones 2001; Mackinson 2001; Riedlinger and Berkes 2001; Corburn 2002). In fact, much of what is known about the importance of climate change at the community level has emerged from local observations and knowledge. Over recent decades, such observations have contributed to an increasingly coherent picture of the reality of changes in climate and the local social and economic significance of such changes; they have also raised awareness of the potentially greater impacts of anticipated future changes.

A commonly recognized feature of the climate change issue from the perspective of community analysis is the scientific uncertainty associated with assessing impacts at local scales. At the same time, though, there is potential for those impacts to be significant. Relatively high values at risk may invite or, in some cases, demand decisions or action. Kloprogge and Van Der Sluijs (2006), building on the concept of post-normal science introduced by Funtowicz and Ravetz (1992, 1993, 1996), referred to this situation as a post-normal science problem. The post-normal science problem of climate change has potentially significant socioeconomic impacts for which decisions and action may be needed urgently. There is, however, significant scientific uncertainty and a general scarcity of hard facts to guide decision makers, who must rely on the best available knowledge and information; in other words, "hard value commitments" must be made on the basis of "soft facts". Of course, science must continue to contribute to the development of a knowledge base for decision making in response to climate change, but science in and of itself is not sufficient. For the assessment of issues such as the impacts of climate change at the community scale, scientific knowledge must be augmented by local knowledge and subjective assessment.

Local stakeholders can contribute knowledge to a vulnerability assessment in several ways. For example, they can describe local conditions and provide personal observations about recent climate changes and their effects. Local stakeholders may also be the best source of creative thinking about mechanisms and processes through which projected climate changes might affect a local area. In addition, local stakeholders are usually the best source of information about the capacity of local institutions to adapt.

Other authors have reinforced the view that local knowledge is necessary for vulnerability assessments. Dolan and Walker (2004), for example, suggested that local knowledge is needed to provide local context to scientific research.

Schröter et al. (2005) suggested that obtaining local knowledge through stakeholder participation increases the accuracy of assessments and ensures that assessments are more locally relevant and more acceptable to local decision makers. Keskitalo (2004) suggested that vulnerability assessments that incorporate processes for capturing local knowledge are generally more reflective of local culture, lifestyles, and work activities. Jones (2001) indicated that local knowledge is often required to identify thresholds and is also needed for the identification, assessment, and implementation of adaptation measures. Once thresholds have been defined by local stakeholders, the probabilities of exceeding the thresholds can be derived, and these probabilities then become the basis for decisions regarding the need for adaptation measures. Shackley and Deanwood (2003) identified local knowledge and stakeholder input as essential for constructing social and economic futures. As will be discussed in a later section, socioeconomic scenarios also provide important context for community-level assessments of vulnerability to climate change.

This section considers the impacts of climate change on the forests in the area of interest. Local knowledge is important for understanding these impacts, but it is also needed for a number of additional aspects of vulnerability assessment, including assessment of local social and economic impacts and adaptive capacity, identification of community thresholds, and development of socioeconomic scenarios associated with future conditions in the area.

Monitoring

Programs aimed initially at understanding particular ecosystems have in some cases continued long enough to provide hard evidence of the impacts of climate change. In several western European countries, for example, amateur and professional botanists have recorded leaf-flushing and flowering dates for numerous plant species for more than a century. Recent work, notably in Germany, has used this type of information to demonstrate significant increases in the average length of the growing season. Within managed forests, permanent sample plots provide records of tree growth rates over decades or longer. These data can be useful for reconstructing productivity responses to historical climate. More recently, intensive field study programs (e.g., the Long Term Ecological Research [LTER] Network in the United States [http://lternet.edu/] and BOREAS [http://www-eosdis.ornl.gov/BOREAS/bhs/BOREAS_Home.html]; see also Sellers et al. 1995, 1997) have provided much information about ecosystem functioning, as well as information for calibrating models. Changes in wildlife populations have been monitored over extensive periods. All of this information has yielded insights into the effects of both natural and human pressures. In the north, continuing study of the Churchill polar bear (*Ursus maritimus*) herd (a major tourist attraction), coupled with meteorological and satellite observations over more than 20 years, has clearly shown that climatic factors affect bear behavior and survival, and there is now mounting evidence that Arctic warming is already endangering this population of polar bears and the ecosystems they inhabit (Stirling et al. 1999, 2004).

For a country as large and as sparsely populated as Canada, long-term monitoring is expensive and often does not attract enough interest for systematic funding. However, the NatureWatch program (http://www.naturewatch.ca/english/) facilitates the collection of phenology data by local volunteers. The program has four components: PlantWatch, IceWatch, FrogWatch, and WormWatch. The web site explains why it is important to collect such data and describes how they should be obtained and recorded. In rural communities, local monitoring programs run by responsible volunteers may in time provide highly significant data for the community that could not be obtained in any other way. For example, much of the attention on climate change in northern Canada originated with local reports, supported by scientific interpretation.

Modeling

Ecosystem models are a means of assessing the sensitivity of forests to climatic change. Over the past 5 years, much research effort in Canada has been invested in developing ecosystem process models that will be suitable for interpreting both small-scale and large-scale impacts. In principle, an ecological model that has been tested (i.e., calibrated and validated) at a few sites where natural processes (e.g., survival and growth of a particular tree species) have been studied in great detail should be applicable over a wider range of sites. Ideally, such tests will have been carried out under a complete range of environmental conditions so that the model can be used with confidence over a large region. In practice, however, the sheer numbers of important processes, species, and sets of environmental conditions makes it impossible to cover every combination. Furthermore, it is unlikely that any existing ecosystem model can accurately represent present-day forests. When it comes to assessing the impacts of climate change, the uncertainty inherent within any ecological model must be combined with the uncertainties in future climate—including limitations in the GCM used to generate climate projections and the unknown possibilities for a future world that may affect the climate in ways we cannot anticipate.

In the Canadian rural context, one of the key challenges is accounting for spatial variability, which results from the variety of soil types and climatic gradients encountered, which are in turn caused by latitude, elevation, and continentality (distance from the coast). Soils vary in terms of their structure, water-holding capacity, and nutrient content over relatively small distances, so the variability is enormous.

The application of any ecosystem model, even over a relatively small region such as a township or forest management agreement area, requires "spatial data," including climatology, information on soils and vegetation cover, forest inventory data, and records of age distribution, fire history, and previous management. Methods of assessing spatial variability include various mapping and data interpolation methods, as well as use of aerial photography and satellite imaging. Geographic information systems (GIS) represent an important tool in compiling and managing spatial data sets.

Empirical Forest Productivity Models

The empirical growth and yield models used in forest management are statistical models derived from observed data. The data are collected at sample plots over periods of years or decades and are then used to define relationships between site conditions and stand-level productivity for individual species in a particular area. Such models are relatively accurate when applied to forest stands similar to those for which they were calibrated, but they tend to yield inferior estimates when applied outside the range of the original measurements, where climatic conditions are often different. Hence, a stand-level growth and yield model developed for, say, black spruce growing in northern Alberta may be inaccurate in predicting the growth of black spruce at a site in western Ontario. This suggests that regional growth and yield models developed in the past may not be appropriate for estimating forest yields in the future, when temperatures are anticipated to be generally warmer and soil moisture conditions different. This is not to say that growth and yield models have no value for predicting forest productivity under climate change. For one thing, it may be possible to develop "climate modifiers" that can be applied to existing yield tables to correct them for the effects of climate change. In addition, growth and yield models are crucial in the testing and validation of other "climate-sensitive" models that may be developed and applied over larger regions. Moreover, careful assessment of the effects on site productivity of spatial climatic gradients (e.g., due to differences in latitude and elevation) can be a useful analog for estimating the effects of climate warming.

Process Models

Process models make projections on the basis of a mathematical representation of the processes that drive vegetation responses to environmental factors. Observed relationships (i.e., at the scale of interest) may be used to test the success of a model, but they are not used in creating the model. Conversely, within a process model, there are often representations of smaller-scale "empirical" processes. Taking the growth and yield example just described, stand-level productivity could be estimated by calculating the net conversion of solar energy to carbohydrate in photosynthesis and allocating a portion of this to wood production, based on a knowledge of plant growth and the constraints imposed by water, temperature, and nutrient supply. However, the representation of leaf-level photosynthesis in such a model is usually based on laboratory studies of leaf biochemistry, which can be measured (or observed) but not fully explained without knowledge of molecular interactions within plant cells. The objective is to make the representation of processes appropriate for the scale of application of the model.

If appropriate funding is available, we advocate the use of process models to assess the impacts of climate change on forests (for a review, see Lindner et al. [2002]). There are many models to choose from, each with particular strengths and weaknesses. Some examples of process models used for investigating ecosystem response to various future climate scenarios in Canada include the Integrated BIosphere Simulator (El Maayer et al. 2001; Kucharik et al. 2000), and the Photosynthesis and Evapotranspiration model (Aber et al. 1997). Depending on the range of questions being asked, it may be appropriate to use several models. In addition to performing simulations with multiple models, it is also important to try "driving" each of them with different climate change scenarios (i.e., as created by different GCMs and forced by different scenarios of GHG emissions).

A process-based ecosystem model typically produces diagnostic output for a number of important indicator variables, including several that can be related to everyday observations (if not, the model will be of little value). The important indicators can be split into three main groups: species composition, productivity, and carbon stocks.

Of these three indicators, species composition and how it changes with a changing climate may be of the greatest interest to the most people. It provides a direct link to what can be observed "on the ground," and it may also allow comparisons with existing vegetation types in other regions. For example, one plausible outcome of global warming is that droughts will become more frequent in regions that already have limited water resources, such as the southern edge of the boreal forest in Alberta and Saskatchewan. In these regions, more frequent or more intense droughts would likely cause trees to die back repeatedly, which could lead to the general decline and possible disappearance of the forest ecosystems. If these conditions persist, tree cover in these regions will eventually be replaced by grassland. In the Prairie provinces, therefore, substantial areas of forest currently dominated by pines and aspen can be expected to be replaced by seminatural grasslands that closely resemble the short-grass ecosystems found on the prairies before agricultural conversion. Of course, there may also be a tendency for grassland to be quickly converted to agricultural use, but this is something that the model would not be able to recognize.

Foresters are familiar with assessing site productivity as a basis for predicting long-term timber yields and determining management regimes. The indicators used in forest management, such as the site index (SI)[6] and the mean annual increment (MAI),[7] are determined relatively easily in the field. They are, however, difficult to estimate in a process model because the relationship between net primary productivity (NPP)[8] and a measure such as SI is complex. Researchers at the Canadian Forest Service's Laurentian Forestry Centre in Québec have been working on this problem with the StandLEAP model (Raulier et al. 2000; Bernier et al. 2001, 2002). They have achieved good agreement between process-based estimates of tree height and diameter at breast height for stands of balsam fir and sugar maple at sample plots in the province of Quebec and have also tried to extend this model for boreal species in Saskatchewan and Alberta. Accounting for the effects of water stress in the western provinces has proved challenging, however, and further research is required.

[6] Stand height at a specified age.
[7] Merchantable timber production ($m^3\ ha^{-1}\ y^{-1}$).
[8] Net growth of live plant biomass over a specified period, such as a year.

Changes in annual wood production generally follow changes in NPP, but the relationship is not simple, because it varies with seasonal and interannual changes in climate. The correlation with NPP also shifts as tree growth accelerates from the seedling stage, gradually reaches a maximum around the middle of the typical stand life span, and then slows down again. With these caveats taken into account, however, many ecosystem models are able to simulate NPP (often split into aboveground and belowground components), and the simulated NPP values can be interpreted as approximate projections of general trends in future wood production.

Effects on Susceptibility to Wildfire and Forest Health

Step 6 involves assessing the effects of climate change on disturbance and on forest health.

Wildfire

Climate change may affect the susceptibility of forests to wildfire (Flannigan et al. 2005), and increases in the incidence and intensity of wildfires may increase the associated risk to communities. A community's wildfire risk consists of two parts: the susceptibility of the community to a significant fire event[9] (including the probability or likelihood of such an event) and the expected impacts if the community does experience a significant fire event.

Susceptibility to wildfire varies across the landscape that surrounds a community. This spatial variation is due to complex interactions among variables that influence fire spread. As a result, some areas will be far more likely to burn than others. It is generally possible to classify the area around a community in terms of relative likelihood of a wildfire according to either expert judgment or sophisticated modeling.

The potential impacts of a fire event are also subject to spatial variation. For example, the impacts of a fire next to a residential development will differ from those of a fire in a productive forest area that supplies the local mill or one in a noncommercial forest that provides important wildlife habitat. The location of a fire will determine whether its impacts are direct or indirect and whether they occur over the short or long term.

Assessing a community's overall wildfire risk requires linking spatial variation in the impacts of fire to spatially explicit burn susceptibilities. For this purpose, fire impact zones around and within a community can be described to account for spatial variations in fire impacts. These zones can be defined to reflect major land-use divisions and forest values in the area and the main determinants of fire (i.e., fuels, topography, climate), as well as fire management capabilities. As is the case for burn probability mapping (Parisien et al. 2005), fire impact zones can also reflect predicted future conditions associated with changes in socioeconomic variables, land use, or fire mitigation activities.

Describing a Community's Fire Experience and Assessing Its Impacts

A community can be said to experience a significant fire event if the fire, or portions of it, are located within jurisdictional boundaries that define the community itself or within land-management boundaries that define surrounding landscape areas used by the community's social and economic systems. A community's fire experience will be determined by the impacts of the fire, which in turn will depend on the location of the fire in relation to the community itself and the surrounding landscape. For example, fires that occur in forested areas immediately adjacent to the community can be expected to cause structural losses (i.e., direct short-term impacts), whereas fires in productive forest areas surrounding the community may affect timber supply and/or recreational values (i.e., longer term impacts). Table 1 lists some of the factors that affect forest-based communities' sensitivity to wildfire.

[9] A significant fire event is any fire that reaches a final size ≥ 200 ha. A fire < 200 ha in size may conceivably have significant impacts on a community, but almost all historical wildfire–community interface situations in Canada have been associated with fires that far exceeded 200 ha. These large, intense fires are difficult to control and therefore have the greatest potential for extensive ecological, economic, and social consequences.

Table 1. Factors contributing to a community's sensitivity to wildfire

Category of impacts	Critical factors
Economic impact	
Structural losses	Site-level building materials and configuration
	Community morphology
Nonstructural losses	Timber supply
	Infrastructure
	Employment and revenue
Social impact	
Health impacts	Demographic factors
	Exposure
	Mobility
Community capacity	Resources
	Services and infrastructure
	Planning
Ecological impact	
Direct impacts on susceptible habitat	Endangered species, wildlife populations
Indirect ecological impacts	Water quality, aesthetics, forest use, and erosion

The spatial location of a fire in relation to the community and other variables, such as prevailing wind patterns, also influence a community's fire experience. For example, fires that are positioned between the community and the path of prevailing winds will cause smoke-induced human health impacts that may not occur with fires positioned elsewhere on the landscape.

Fire impact zones can provide a basis for evaluating the type of fire experience that can be expected if a fire burns a given area of the landscape surrounding a community. Land-use zones can be used as an initial template for defining fire impact zones. However, it may be necessary to subdivide the land-use zones to reflect other determinants of fire impacts. The community itself can also be divided into zones to reflect potential impacts associated with fires that occur in different sections of the interface zone (i.e., the boundary between the community and the surrounding flammable forest).

The complexity and sophistication of fire-impact evaluations within a zone will depend on data availability and time limitations. Simple evaluations could involve the use of existing data and expert opinion for qualitative estimates of impacts, whereas more complex evaluations could involve a combination of methods, including data collection, statistical modeling, and survey techniques.

Assessing Changes in Fire Risk Associated with Predicted Future Conditions

Predicted changes in future climate and land cover can be incorporated into impact assessments to estimate a community's wildfire risk. Wildfire susceptibility maps are created from a variety of data inputs, including vegetation (fuels), topography, fire ignition patterns, fire-size distributions, and fire weather. Many of these environmental conditions can be expected to change under predicted future climate scenarios.

Baseline susceptibility maps for an area can be compared with maps produced from inputs that have been altered to reflect predicted future conditions associated with climate change. Similarly, future fire impacts within each zone of a study area can be reassessed by altering the zone boundaries to reflect predicted future changes in socioeconomic conditions, ecological factors, and values and attitudes, as well as changes related to mitigation activities (e.g., fuel management around structures) or changes in fire-suppression capabilities.

Forest Health

Forest pests, including insects, pathogens, weeds, and vertebrates, directly affect forest productivity. Together with other biophysical agents, they can interact to create impacts far in excess of their individual effects (Volney and Hirsch 2005). When considered from a socioeconomic perspective, these impacts can ultimately change the relationships that forest-dependent communities have with forests. In effect, pests can determine the course of community development through the nature of the forests they damage and the vegetation types that develop after outbreaks. The current mountain pine beetle outbreak in central British Columbia is an example of such a process that is now under way. Climate change may modify the rates at which pests affect forests. Moreover, there is always some risk that an altered climate will shift pest dynamics to a new equilibrium state that cannot be foreseen. Enough is known about native pests, however, that abrupt shifts can generally be anticipated; as such, long-term management interventions can be implemented to adapt to these events and reduce the risk of catastrophic changes in ecosystem behavior (Volney and Mallett 1998).

Quantifying the impacts of interactions among pests and of pests with other disturbance agents is currently the purview of modeling, because experience with these interactions is limited. Nevertheless, the risk is real and the losses can be astronomical. For example, the effects of fire in the wake of catastrophic insect outbreaks may be dramatic. The specific impacts depend on the forest ecosystems affected, the type of fire season that occurs following pest-induced tree mortality, and the spatial and vertical structure of the stands attacked. The outcome of these interactions is also highly dependent on the specific weather events occurring before and during the individual fire and pest events, as well as the climatic regime prevailing at the time.

Numerous pests are known to affect native forest trees, but they affect forest stands differently at various stages of development, in different habitats, in different ecozones, and under different management regimes. To deal with this complexity in the context of modeling impacts of climate change, a universal framework for assessing the effects of pests is required. Such a framework has already been developed for plantation pests (Volney et al. 2005) and might be adapted for forest stands more generally. The framework accounts for multiple disturbances over the life of stands, but does not explicitly model interactions related to disturbances, nor does it specifically model climate change. However, the effects of climate change could be evaluated by considering probabilities and impacts for ecozones where current conditions mimic the future climates of the subject area.

Socioeconomic Scenarios

Scenario analysis is a method for examining alternative futures given a variety of hypothetical or expected changes to current conditions (i.e., scenarios). The purpose of scenario analysis (Step 7) is to improve decision making by considering the implications of different management options or external influences before policies are changed or future external events unfold.

Socioeconomic scenarios are an important component of vulnerability assessments (Yohe et al. 1999; Lorenzoni et al. 2000; Berkhout et al. 2002; Shackley and Deanwood 2003). There are four main reasons for developing socioeconomic scenarios as part of climate vulnerability assessment at the community level:

- To provide a basis for understanding vulnerability to climate impacts in the context of other socioeconomic forces affecting a particular community: A community's vulnerability to climate and climate change may be less important than its vulnerability to some other economic pressure. Alternatively, other factors may exacerbate the degree to which the community is vulnerable to climate effects.
- To provide a baseline for assessing potential net economic impacts of climate change: One way of assessing the sensitivity of the local economy to climate effects is to evaluate future economic activity under different climate scenarios and compare these to the level of economic activity that might be expected without climate change (i.e., the baseline). Assessing net impacts often involves comparing various scenarios to a baseline situation. However, in many cases the baseline itself is evolving over time. Socioeconomic scenarios provide information about expected trends in the baseline.
- To provide sector-specific outlooks for locally important industries: For example, climate change can be expected to affect the markets for agricultural and forest products at global, national, and regional scales. Changes in supply and demand at these levels may have important implications for production, profitability, employment, prices of local goods, and land use at the local level.
- To provide a structured approach for obtaining expert local knowledge about the future of the community: Scenario development usually involves obtaining information and feedback from local experts and stakeholders.

The development of scenarios usually begins with a brainstorming process to identify key factors, driving forces, and critical uncertainties facing the community. This activity results in alternative "stories" about the future (Bell 1997). This method emerged to address some of the limitations of quantitative and formal modeling methods. For example, econometric and statistical modeling techniques often ignore important qualitative factors, and they perform poorly in modeling nonlinear impacts that result from nonlinear processes (Bell 1997). Economic models have limited accuracy over long periods, especially when there are fundamental structural changes in social constructs (driven by changes in institutions, policy, technological change, and other factors). Qualitative scenario development, on the other hand, provides a useful means of communicating and exploring ideas about how complex changes in a community's external environment will affect it and the implications of different community-level responses. Scenario storylines are generally broad in scope. They can incorporate assessments of how certain unmeasurable or difficult-to-predict factors will affect the community over time. Thus, the development of qualitative storylines using a scenario development approach allows a community to develop a vision of the future that accounts for complex changes in the external environment, that is applicable over the long term, and that is locally relevant.

Developing socioeconomic storylines that are relevant at the community level presents some challenges. The best approach is to consult with local stakeholders, local experts, and possibly outside experts to capture their knowledge, views, and opinions about the future of local industries, the factors that are likely to affect further economic development in the community, and the ways in which climate change may affect competitiveness or create new economic opportunities. This can be done formally through a structured scenario-planning process or informally through open-ended interviews with local business leaders. Modeling and data collection can support a local scenario planning process. However, as previously noted, the limitations of any model's ability to provide credible estimates of a community's long-term economic development must be recognized.

Numerous authors have described formal methods and approaches to developing qualitative scenarios, including Godet (1987), Wilson (1978), and Bell (1997). Berkhout et al. (2002) described approaches for scenario development in the context of climate change assessment, identifying two broad categories of possible approaches: normative and exploratory.

With normative approaches, a single future desired state for the local economy is described, and pathways, local strengths and weaknesses, and institutional factors that enable or constrain social agents from making the changes necessary to reach the future state are identified and described.

Exploratory scenario approaches are more common. They also tend to be more complex, detailed and time consuming. According to Berkhout et al. (2002), an exploratory scenario analysis is based on four underlying principals: recognizing that past trends do not provide a basis for projecting the future, accepting that the future cannot be predicted with certainty but that "exploring" possible futures can inform local decision making, accepting uncertainty and recognizing that any number of different futures could occur, and acknowledging that local knowledge and input from local stakeholders are fundamentally important for successful storyline development.

In an exploratory scenario analysis, several possible futures are identified. For example, this type of analysis for a particular community could generate four future scenarios (or storylines), each defined in terms of a unique combination of assumptions about future economic and environmental conditions. The criteria differentiating the scenarios are defined by the participants. In many cases, they are features outside the control of the local community (e.g., assumptions about global economic development, global climate change, degree of integration of the global market, global distribution of income, degree of political harmony, rates of technological change, or population change). The implications of each scenario for the local economy are then identified and described through structured or facilitated discussions (e.g., focus groups or workshops) with local experts. Participants in these discussions can determine the implications for the local economy by identifying strategic opportunities and sectors at risk, describing the community's capacity to adapt to external changes, and identifying the local changes and improvements needed to achieve the vision described in a particular storyline.

A potential source of vulnerability to climate change in resource-based communities is the local economy.[10] Assessing impacts on the local economy as a source of vulnerability is exceedingly complex, for several reasons. First, a changing climate will affect the economy at multiple scales (global, national, regional, and local). The economy of a forest-based community is usually linked to global markets and will therefore be sensitive to changes in global timber supply caused by climate change and to the resulting restructuring of global markets, changes in trade patterns, and potential changes in the ability of local firms to access export markets.

[10] Climate change can affect both extractive industries (such as the forest industry) and nonextractive industries (such as tourism). An assessment of the economic impact of climate change should consider impacts on all climate-sensitive sectors.

A second source of complexity is the long time frame over which climate change effects will occur and the variability of impacts over time. There is not necessarily a one-to-one relationship between the magnitude of climate change over a particular time period and the magnitude of impacts. The impacts in a particular sector may be relatively small initially (say, over the next 20–30 years) but may increase drastically as thresholds are reached and exceeded or if changes occur that exceed the adaptive capacity of firms within the community. This problem is further complicated by the many other factors that are likely to affect a community's economy over time, such as technological change, globalization, population growth, changes in tastes and preferences, and institutional change, all of which may occur concurrently with climate change. As such, it may be difficult to assess the impacts of climatic trends alone. If non-climate-related pressures increase, communities will become increasingly stressed, their resources may be increasingly devoted to dealing with these issues, and fewer resources will be available to address problems arising as a result of climate change.

A third complicating factor is that the effects of climate change on various sectors in a particular geographic area (such as agriculture, forestry, and tourism) may differ with respect to direction (positive or negative) and magnitude. The net effects within the community are potentially offsetting, but only to the extent that there is institutional capacity to efficiently redirect resources from one production sector to another. This suggests the need for a holistic approach that considers both the economic impacts for all industrial sectors and the ability of the economy to adapt. However, current capacity to carry out such holistic economic assessments in Canada is limited.

A practical, simplified approach for assessing economic impact involves focusing on the areas where the local economy will be most sensitive to climate change, which will vary from one community to another. This approach involves deciding on the breadth of the analysis, in terms of considering how changes in economic systems at higher levels will affect the economic system of the community; the overall time frame of the analysis and the specific prediction periods (e.g., 10-year, 30-year and 60-year periods); the sector or combinations of sectors to be examined; and the methodological approach to be used.

The remaining discussion in this section focuses on methods for assessing community-level economic impacts. The models discussed here are those typically used to evaluate the implications for community employment and income of changes in local forest industry production and exports (resulting from climate-change-related factors).

Regional Economic Impact Assessment

Climate change can result in spatially concentrated changes (or impacts) that have consequences for economic agents and institutions. Regional economic impact assessment (Step 8) involves identification and quantification of these impacts at the regional level, to enable decision makers to make informed judgments of whether a particular impact is acceptable relative to existing conditions (Davis 1990). In other words, an economic impact assessment serves as a guide in decision making (Loomis 1993).

The scale of analysis has important implications for the interpretation of results. For example, changes that are considered "transfers" at the provincial level may be considered "impacts" at the regional or community level. Also, whereas economies at larger geographic scales may be able to absorb and adjust to the shocks associated with climate change, the economies of smaller forest-dependent communities may be less able to adjust; as a result, local economic impacts may be relatively larger.

Regional Economic Impact Methodology

Determining local economic impacts or changes resulting from climate change requires some knowledge of the "preshock" state of the local economy. Such knowledge can be amassed by collecting sector-specific baseline information and data on production, value of shipments, capital stocks (i.e., replacement value or current value of industrial capital), exports, payments to factors of production (e.g., labor, capital, and natural resources), levels of activity, and transactions between sectors. Anecdotal and locally based information can provide valuable insights about historical trends and factors that have contributed to the current situation.

The type of information needed depends on the extent of the intended analysis. Some census data are readily available from Statistics Canada, at minimal cost, including census indicator profiles (e.g., median income, employment, median dwelling value, and education attainment), national and provincial economic accounts, and national and provincial input–output tables. Custom regional census tabulations and information on sector activity are also available from Statistics Canada, at a higher cost.

General equilibrium (GE) models are commonly used in economic impact analysis. When this type of model is used for this purpose, detailed information on economic activity and sector linkages (technical coefficients and elasticities) is required. As previously discussed, such data are not generally available at the regional or community level; however, a variety of techniques exist for creating detailed regional economic databases. The approaches can be classified into three categories: synthetic, survey, and hybrid (Richardson 1985). The top–down synthetic approach involves mathematical scaling of provincial input–output coefficients; although inexpensive and less time consuming than the other methods, this type of modeling is also less reliable. The bottom–up survey approach involves collection of primary data on industry transactions; this method is considered the most reliable but is expensive and time consuming. The hybrid method involves synthetic scaling and targeted collection of primary data to improve reliability. Patriquin et al. (2002) provided a more detailed discussion of these methods in the context of regional analysis in Canada.

Economic Impact Models

GE models are standard tools for assessing the economic impacts of proposed industrial projects, major events, issues concerning international trade, and changes in domestic government policy (Miller and Blair 1985; Pyatt and Round 1985). Every sector of an economy is linked to other sectors, whether directly through transactions (purchases and sales) or indirectly through competition for labor, capital, and land used in industrial production. GE models account for sector linkages and offer a more complete picture of the impact that one sector can have on other sectors and on the overall economy of a region.

Two theoretical streams exist within the GE approach: fixed-price approaches (input–output [I–O] and social accounting matrix [SAM]) and flexible-price approaches (computable general equilibrium [CGE] models). Each approach is valid under certain circumstances. In some cases, the I–O or SAM approach can be used to form a building block for the more flexible CGE approach. The general features of these two modeling approaches are compared in Table 2.

Table 2. A snapshot comparison of model features

Model features	I-O/SAM	CGE
Frequency of use	Common	Rare
Complexity	Simple	More complex
Data requirements	Low	Medium
Role of prices	Fixed	Endogenous
Role of technology	Fixed	Not necessarily fixed
Supply of inputs	Excess capacity	Constraints possible
Time frame	Extreme short term	Variable
Sector impacts	Unidirectional	Multidirectional
Theoretical structure	Linear	Nonlinear

Note: I-O = input output, SAM = social accounting matrix, CGE = computable general equilibrium.
Source: M.N. Patriquin, Canadian Forest Service, Edmonton, Alberta, personal communication 19 July 2007.

Fixed-price models, such as I–O and SAM models, are the most common GE tools, but they are also the most restricted in terms of the scope of analysis that can be undertaken, their rigidity, and the nature of their underlying assumptions (which are sometimes considered overly simplistic). For example, I–O models do not account for competition among economic sectors for land, labor, and capital; thus, factor inputs (e.g., labor, raw materials, and capital) are assumed to be available without limit. However, these and other fixed-price approaches remain popular because of ready availability of data (at the national and provincial level) and low cost. Flexible-price models, such as the CGE models, are less common (because of the more demanding input requirements and higher cost of development), but they overcome many of the limitations of the fixed-price approaches.

Several authors have compared fixed-price and flexible-price approaches in various types of natural-resource-based and forest-dependent regional economies, including Alavalapati et al. (1996), Seung et al. (1997), Partridge and Rickman (1998), Alavalapati and Adamowicz (1999), Alavalapati et al. (1999), Patriquin et al. (2002), and Patriquin et al. (2003). These studies have shown that CGE techniques can provide valuable information about the potential impacts of changes in natural resource management. These models are not commonly applied at the regional scale, but there is general agreement that they provide unique insights not available with the more widely applied fixed-price techniques.

Some important limitations of economic impact models should be noted, especially with respect to how they can be applied in evaluating the impacts of future climate change. GE models are, in general, static, and the technical coefficients embodied within them are fixed with respect to time. These models assume that knowledge and technologies are the same in comparisons of two different states (e.g., two different time periods). Also, these models generally assume that resources such as capital stocks are fixed. Climate change, however, is a long-term process, and because conditions change, it is inevitable that knowledge, technologies, and capital stocks will change over the time scales for which economic impact assessments are conducted. Therefore, the results of economic models that consider the impacts of climate change cannot be considered predictions. Rather, they indicate the relative sensitivities of certain areas within the economy and the general nature of economic impacts. If anything, they may overstate the magnitude of particular impacts because the models do not incorporate adaptation or new investment.

Impacts on Landscape Values

The effects of climate change on the surrounding landscape may affect the inhabitants of forest-based communities. People who reside in forest-based and other natural-resource-based communities often place a high value on the environmental attributes of the surrounding forest landscape. These environmental features, attributes, and values contribute to a person's "sense of place" or attachment to a particular community (Stedman 1999), but they may be at risk because of climate change. These values are often considered in the form of various "use values" (e.g., outdoor recreation activities), "nonuse values" (e.g., existence values, bequest values, option values), and environmental services (e.g., clean air and water, healthy ecosystems, and esthetically appealing landscapes). These values vary from location to location and in relation to distance from the centre of a community. Step 9 of the process is to assess how climate change might impact the community as a result of changes in the surrounding landscape.

The following general step-by-step approach can be used to gain an understanding of the degree to which climate change over various time frames might affect these values:

1. Identify valuable and climatically sensitive environmental features.

General categories of such features include the following:

- overall health of the surrounding forest ecosystem
- protected areas and special sites that are important to the community, where plant communities may be particularly sensitive to climate change
- water and fisheries
- wildlife
- scenic quality, outdoor recreation, and landscape features that are important for tourism

2. Map these values on the landscape around the community.

GIS software or web-based mapping tools might be useful for community-level mapping of valued natural resource features around the community (for one example, see http://www.greenmapping.org). The identification of natural resource features or assets surrounding the community usually requires some form of consultation with the community (Brown 2005). In some cases, local land-use planning reports may be a useful resource.

3. Assess the potential impacts on each value under alternative climate scenarios.

The method of assessment of impacts will depend on needs and resources. A community-based approach could include consulting with local experts to develop a list of climate-sensitive environmental features; developing informal maps showing the location and distribution of these values over some defined region around the community; determining potential risks to these values from climate change over time; and conducting workshops, focus groups, interviews, and surveys to determine and rank the importance of potential impacts. A more technically oriented approach might involve a combination of surveys, modeling, and GIS mapping. Brown (2005) described a survey methodology for ascertaining the spatial distribution of environmental values, and Rutherford et al. (1998) and Chuenpagdee et al. (2001) have described a methodology that can be used to interpret community preferences for potential environmental damages caused by climate change.

Indicators of Adaptive Capacity

An important component of vulnerability assessment is measurement of the adaptive capacity of economic and social systems (Step 10).

McCarthy et al. (2001) suggested that adaptive capacity is determined by technology, social capital, resource availability, human capital, institutional decision-making capacity, and public perceptions of climate change events. Similarly, Brooks (2003), Adger et al. (2004), and O'Brian et al. (2004) all used a definition of social sustainability that emphasizes not only the impacts or damages to social systems that might result from climate change, but also the characteristics of a system that allow it to cope with change. These authors recognized that the vulnerability of a human system goes beyond direct climate-related impacts to include the current state of social systems and dynamic political and institutional processes at both micro and macro levels.

In their study of the agricultural sector of Canada, Smit and Pilifosova (2001) identified the determinants of adaptive capacity to climate change as economic wealth, technology and information skills, infrastructure, institutions, social capital, and equity. More recently, Adger et al. (2004) identified a larger number of indicators such as wealth, inequality, educational commitment, isolation of rural communities, quality of basic infrastructure, political influence, willingness to invest in adaptation, and various environmental sustainability measures. These indicators are used for country-level comparisons to identify large regions across the globe with higher or lower levels of adaptive capacity.

In similar ways, the literature on hazards (e.g., Tobin 1999), health promotion (e.g., Goodman et al. 1998), and resource-dependent communities (e.g., Kusel 2001) identifies the characteristics of communities that would allow them to withstand more generic threats or shocks such as an earthquake or an economic downturn. Especially in the literature relating to resource-dependent communities, there is an important transition away from thinking in terms of community stability toward a focus on the social processes and capacities of local communities as important components of their long-term adaptability and hence viability.

Community-Based Approach

Beckley et al. (2002) described an indicator-based approach to community-level assessment of adaptive capacity. Borrowing from Kusel (2001), they defined community capacity as "the collective ability of a group (or community) to combine various forms of capital within an institutional context to produce desired results or outcomes" (Beckley et al. 2002, p. 7). Forms of capital represent the range of assets available within communities to pursue specific outcomes, such as the following:

- natural capital: natural resources and environmental services such as clean air and water
- human capital: the skills, education, and health of individuals, all of which contribute to the skill base and economic performance of the community
- economic capital: the local industrial base, physical infrastructure such as roads and buildings, and financial capital such as organizational budgets and household savings
- social capital: the relationships among community members that contribute to collective action

Flora and Emery (2006) developed a broader framework for assessing community capacity for adaptation, which incorporated natural capital, cultural capital, human capital, social capital, political capital, financial capital, and built capital.

This capital-based (or asset-based) approach to vulnerability assessment provides a useful framework for organizing some measures of adaptive capacity in relation to climate change into "suites" of indicators. The breadth of these indicator suites conveys the complexity of adaptive capacity concepts and the need for comprehensive, long-term studies to understand them. One of the challenges in this regard is to identify a subset or core list of indicators for assessing some of the key aspects of adaptive capacity at the community level without becoming overly simplistic. The framework may be further refined through local-level indicators research with community members (Parkins et al. 2001). Through workshops and survey research, project participants can identify the specific indicators that are most relevant to their community's goals and aspirations and can then relate these back to the organizing framework.

It is also important to acknowledge the more dynamic aspects of adaptive capacity. Some authors refer to the importance of considering the processes inherent in adaptation. These aspects are embodied within institutional and organizational arrangements, which can be combined with assets (or stocks of capital) to produce various outcomes. Adaptive capacity can be facilitated or constrained by institutions and their associated rules, norms, standards, and governance structures (Adger and Kelly 1999). The important topic of institutions and governance is discussed in more detail in a later section of this document.

Adaptive Capacity of a Community's Economic System

Climate change can affect a community's economic system through changes in prices of locally produced goods and services (e.g., as a result of price changes in export markets); changes in the availability, quality, and cost of local natural resources; and increases in financial uncertainty (e.g., through increased variance in supply of inputs and potentially increased variance in input and product prices). The magnitude of the net economic impacts on forest-based communities will ultimately depend on the ability of the economic systems within these communities to adapt to these changes.

The economic system within a community comprises the following entities: firms, investors (or owners of firms), workers, landowners (or providers of natural resource inputs) intermediate suppliers, and local consumers (i.e., located within or closely associated with the community). These various agents are interconnected through and may be regulated by various institutions (e.g., markets, governments, property rights). The community's economic system is also connected to other economic systems at higher or lower levels.

Adaptive Capacity of Individual Firms

Firms are at the core of the economic system, because they purchase inputs, convert these inputs into products, and then market and distribute the products to consumers. Firms in forest-based communities operate within complex and rapidly changing economic milieux. Adaptive capacity can be viewed as the ability of individual firms to respond (or adapt) to external forces and economic signals and to remain in business. In the short term, business decisions are constrained by the fact that some inputs (such as a firm's capital stock) are fixed. The fixed nature of these inputs means that options for adaptation in the short term are limited. Over the long term, all inputs (including capital) are variable, and a different set of adaptation strategies might be possible. Thus, in assessing the adaptive capacity of firms, it is necessary to differentiate between short-term and long-term adaptation capacities.

The few studies that have examined the effects of climate change on global timber markets have suggested that the impacts on producers in North America (and particularly in Canada) will tend to be negative (Sohngen et al. 2001; Perez-Garcia et al. 2002). These negative impacts will result from a general increase in timber supply in global markets, which is anticipated to result in lower relative prices. In the short term, firms can adapt to lower relative prices by changing their output and lowering their costs. However, once prices fall below average variable costs, a firm will usually shut down. Thus, the difference between average prices and average variable costs at the firm level provides a measure of the firm's capacity to adapt to price changes in the short term.

Another adaptation option for firms is to attempt to reduce average variable costs by increasing efficiency. The capacity of firms to adapt in this way depends on the availability of some "slack" that will permit efficiency improvements in the short term and the firm's capacity to incrementally improve the technology of its fixed capital stock.

Another potential impact of climate change is a change in resource availability or input cost (or both). In locations where climate change has negative effects on resource supplies, negative impacts on the local economy are possible. A potential adaptive strategy of firms to increases in the cost of wood inputs is to substitute inputs in the production process. For example, if the price (or availability) of wood inputs increases relative to labor costs, a firm might be able to substitute labor for wood inputs within the production process (e.g., hire more specialized workers or provide training to increase product recovery per cubic meter of wood). The degree of flexibility that a firm has in input substitution is determined by the firm's current technology.

In the long-term, capital is not fixed. Firms may respond to lower prices and to changes in resource costs and availability by shutting down or relocating, by increasing plant size (assuming that economies of scale exist), or by investing in new technologies. The adaptive capacity of firms in this regard can be evaluated by assessing the potential for cost savings through increasing plant size (economies of scale), changing input proportions (e.g., through substitution), and adopting new technology (which is a function of both the availability of technology and the innovative capacity of firms).

Adaptive Capacity of the Local Economy

The previous paragraphs discussed the adaptive capacity of firms, but adaptive capacity can also be considered from the point of view of the entire economic system. Economic diversity may be an important determinant of the adaptive capacity of a community's economy (Oinas and Lagendijk 2005). Although the term *diversity* is well known in biological science, the concept is relatively new to social scientists. In fact, social scientists originally borrowed the theory and concepts from the biophysical sciences in efforts to define and measure economic diversity through indices (Siegel et al. 1995).

Economic diversity and diversification are frequently cited as indicators for, or strategies in, regional economic development initiatives (Conroy 1975; Ashton and Pickens 1995; Horne and Haynes 1999). For example, economic diversity plays a prominent role in the Foothills Model Forest Local Level Indicators Initiative (Foothills Model Forest 2004), the Alberta government's Northeast Slopes Integrated Resource Management Pilot Program (Regional Steering Group for the NES Strategy 2001), and the Canadian government's Western Economic Diversification Program (Western Economic Diversification Canada 2006).

Economic diversity, and its possible role in regional development, is not as straightforward as many assume. Much effort has focused on measuring diversity and the relationships (if any) among diversity, stability, growth, and resilience (Kort 1981; Dabalen and Goldman 1994; Wagner and Deller 1998; Imbs and Wacziarg 2003). These studies have suggested that economic diversity and diversification are commonly discussed with respect to regional economic development, but found no consensus on the appropriate method to measure diversity or how it relates to stability, sustainability, growth, and resilience. Furthermore, there are few studies specific to Canadian community development issues.

It has been suggested that specialization contributes to efficiency and growth and that a diversified industrial structure contributes to stability, stronger innovation performance, and greater adaptive capacity (Oinas and Lagendijk 2005). Portfolio theory (Zerbe and Dively 1994), suggests that in terms of a community's economic development path there may be trade-offs between maximizing production and economic growth in the short term (through specialization) and maximizing adaptive capacity (through diversification).

Social Capital

Social capital refers to relationships and networks among individuals, organizations, and community leaders. Social capital is an asset or resource both for individuals within communities and for communities as collective entities. Social capital contributes to the ability of individuals and communities to adapt to change in general (Matthews 2003; Franke 2005) and to climate change in particular (Adger 2003). Step 11 involves assessing a community's social capital.

Interpersonal trust contributes to the formation and maintenance of social capital. The creation of networks and the generation of trust are consequences of processes that occur over time and that require social investment. Other types of social variables may be closely related to the formation of social capital. One example is attachment to place (Stedman 1999). Matthews (2003) noted that "communities are stronger when their residents identify with them and express commitment to them." The degree of participation in community events and interest in politics are also viewed as important indicators of a community's social capital. Social capital may be a vital resource for communities that are addressing climate change because it represents "resources and support" to individuals and groups within communities (Matthews 2005).

Social capital can be characterized in various ways. Individual social capital refers to an individual's personal network. The size, density, and diversity of networks can vary from one person to another, as can the frequency and intensity of contacts between an individual and his or her network (Franke 2005). Individuals may have weak ties (acquaintances) or strong ties (close friends and relatives) to others in their personal networks. The types of positions held by people within an individual's network may affect the kinds of support to which the individual has access.

People obtain a wide variety of supports from their social networks, including information (for example, about health, employment, finances, technology, and travel), emotional support, financial support, assistance in finding employment, a place to stay in times of crisis, assistance with vehicle repairs or home renovations, and child or pet care. Information about typical levels of social capital for individuals within a community can be obtained through surveys of a representative sample of the local population.

Social capital also exists at higher levels of aggregation. For example, a community's collective social capital is measured in terms of the numbers of organizations in a community, the numbers of members that these organizations have, and the level of interconnection among organizations (Franke 2005). In addition, community leaders have social networks that may benefit the overall community. A high level of social capital in a community contributes to adaptive capacity because it supports collective action by the community. It also contributes to actions or decisions that determine overall community health and well-being. Information about numbers of organizations, about intra- and inter-organizational networks, and about the networks of community leaders can be obtained through interviews with community leaders, from community web sites, or from documents such as local chamber of commerce documents and community profiles.

Risk Perception

The perception of risks by individuals and by the community contributes to vulnerability assessment in two distinct ways. First, an understanding of public perception of risks can provide valuable local information that complements technical risk assessments and leads to a more holistic understanding of the "real risks" associated with climate change. Second, as already noted, certain features or characteristics of climate-related risks or the risk perceivers themselves (i.e., individuals, communities, or policy actors) will result in underestimation or overestimation of the risks of climate change (Davidson et al. 2003; Stedman et al. 2004; Williamson et al. 2005). Underestimation of risk tends to result in inadequate adaptation, causing individuals and communities to be relatively more vulnerable because of failure to take actions or measures to mitigate some of the negative impacts. Thus, underestimation of risk contributes to vulnerability.

The study of risk perception is growing in prominence in the social sciences (for example, see Slovic 2000). The study of climate change as a risk issue is also increasing. Perceptions of risk are usually studied by psychometric research methods. McDaniels et al. (1996) and O'Connor et al. (1999) have applied this approach to assessing perceptions of ecological risk associated with global change. Stedman et al. (2004) considered the perceptions of Canadian policy actors in relation to climate change risk. Williamson et al. (2005) looked at Canadian forestry experts' perceptions of climate change risk in relation to forest ecosystems and forest-based communities. Step 12 of the assessment involves developing an understanding of peoples' perceptions of climate risk and analyzing the information in the context of its implications relative to peoples' willingness to adapt.

Risk Perceptions of Individuals

For the most part, perceptions of risk are studied at the individual level. Those who perceive the presence of risk or vulnerability are more inclined to act in ways that will mitigate the risk or reduce the vulnerability. Alternatively, if risks are misperceived, individuals may overinvest or underinvest in adaptive measures. Actions that should be undertaken may be neglected (even if the individual has sufficient capacity to adapt). Alternatively, actions that should be avoided may be undertaken (which results in wastage of resources). Knowledge of how members of forest-based communities perceive climate risk will be an important predictor of community adaptation. Moreover, this understanding can also promote better dissemination of information and greater community discussion about the risks associated with climate change.

Individual risk perceptions are typically measured in terms of attitudinal domains (or risk characteristics) such as controllability, dread, and predictability. People's preferences for certain types of risks can be strongly affected by these characteristics. Levels and types of concern may also be influenced by other factors, including the following:

- current employment (the degree to which a person's employment could be affected by certain risks, or by policies to mitigate or reduce risk may influence that person's perceptions of risk)
- community capacity (strong community capacity and institutions may act to "buffer" an individual's perceptions of risk)
- exogenous factors (e.g., an individual's knowledge of assistance programs to overcome effects of climate-related hazards may affect perceptions of risk)
- sources of information regarding climate change and the social networks in which people are involved
- beliefs about causation and connection related to global climate change
- individual characteristics (such as age, sex, education, and income)

A great deal of research and theory has examined the relationship between individual risk perception and behavior. The rational actor approach, which assumes a rational, atomistic view of individual risk perception (Golding 1992; Renn 1992), is based on the following important assumptions (The Presidential/Congressional Commission on Risk Assessment and Risk Management 1997): that people have the correct information available to help them make decisions; that people can process such information in an unbiased way (i.e., free of biases related to personal experiences, cultural background, and other factors); that people are willing and able to expend the time and energy to weigh all possible information and the costs and benefits of all behavioral responses; and that individual perceptions and decisions matter, such that individuals' well-being is determined by their own decisions rather than by outside forces.

The psychometric approach, made famous by Slovic (1992), explores the various reasons for deviations between people's subjective assessment of risk and purely objective, science-based technical risk assessment. Three main reasons have been established for these potential deviations. First, people's preferences for specific qualitative features of risk (e.g., dread, controllability) play a role in how their perceptions are formed. Second, individual risk perceptions may simply be incorrect. Tversky and Kahnemen (1974) noted that people often employ heuristic tools or take cognitive shortcuts to simplify complex risk issues, but these processes can lead to systematic errors in a person's ultimate perception of risks. According to this view, perceptions are not motivationally based but rather are the outcomes of poor information processing, based on, for example, memories of certain events. This view, though limited, begins to incorporate contextual factors that may affect individual perceptions. The third potential source of deviation is the fact that in some cases, subjective risk assessments (from personal, local observation and experience) are correct while technical assessments are unclear or even wrong (because of missing data or incomplete information). These personal observations and experiences may contain information that is not readily available or not collected in a scientific or technical risk assessment.

Risk Perceptions of the Community

Much previous research on a community's risk perceptions associated with climate change has simply aggregated the responses of individuals within the community. We disagree with this approach. The aggregate risk perceptions of individual community residents may be very different from community-level perceptions of risk, a distinction similar to that between individual and collective social capital, described earlier. This difference may be important in terms of how communities approach adaptation. Flint (2004) defined community risk perception as a collective expression of risk based on a commonly understood threat or harm. However, collective expressions are qualitatively different from the aggregation of individual responses (see also Fitchen et al. 1987; Wolfhorst and Krannich 1999). Conventional (individual-based) approaches to risk perception tend to focus on a fairly narrow perspective of the object of risk (i.e., the individual and those about whom he or she cares deeply). Individuals weigh the costs and benefits of reducing the harmful consequences of particular threats (as described earlier), using rational actor approaches, psychometrics, or cultural perspectives. In contrast, Wolfhorst and Krannich (1999) noted that community risk perception involves risks to the community as a whole (e.g., risk to community well-being). This implies a broader object of risk. Community response then involves action to protect the community, reduce community-level impacts, and reduce risk of losses or damages at the community level. As well, a broader set of less tangible community values may be at play than is the case for individual risk. Short (1984), for example, described risks to the "social fabric" in terms of trust among members of the community, social capital, community capacity, and faith in institutions (and the smooth social functioning that results from these). These aspects are, in some respects, similar to what economists refer to as public goods.

Because a community's collective perceptions can be shown to be qualitatively different from aggregations of individual perceptions, vulnerability assessments must also consider processes for social construction of risk at the community level. When people share a common experience in a particular place and come together to solve problems for the good of the community, community action is said to occur (Kemmis 1990; Wilkinson 1991). One clear example of this is the development of a community policy, reflecting the collective belief that community well-being is more than the sum of the well-being of individual community members.

Institutions and Governance

A potentially important contributing factor for assessments of the vulnerability of forest-based communities to climate change is weak, inefficient, or out-of-date institutions (Adger and Kelly 1999). Step 13 of the process is to assess institutions. Institutions represent the set of rules, customs, norms, and standards that guide economic, social, and political choice and behavior. They define rights and responsibilities, and guide or set boundaries on decisions by individual households, firms, government agencies, landowners, and organizations. In the context of climate change, institutions provide the incentives, rules, mechanisms, tools, and means to motivate and direct adaptation. Institutions that are effective and efficient and that entitle communities to the resources needed for adaptation will contribute to the adaptive capacity of forest-based communities. Conversely, institutions that limit access to the resources necessary for adaptation will constrain or reduce adaptive capacity.

What makes this topic difficult to address in the context of a community vulnerability framework, however, is that institutions are complex, widespread, interconnected, amorphous, abstract, and ingrained in the day-to-day lives of the community. They derive from a society's values, its history and culture, its system of government, and its economic system. It is therefore difficult to address this topic and to draw conclusions about potential institutional failure as a source of vulnerability through empirical measurement or any systematic analytical method. Nevertheless, institutions are fundamentally important for adaptation because they define and determine property rights and entitlements to the resources required for adaptation by individuals and by communities (Adger and Kelly 1999).

Climate change will increasingly require institutions that are forward looking; flexible, adaptive, and responsive to change; efficient (i.e., able to reallocate resources quickly and efficiently); and able to account for differences in the nature and magnitude of the impacts of climate change at local levels (i.e., more decentralized).

Several different types of institutions may need to be considered in the vulnerability assessment of a forest-based community. For example, institutions that guide and determine natural resource management and availability and land use around the community may affect the ability of firms within the community to adapt. These institutions may vary by sector (e.g., forestry, agriculture), so sector-specific assessments may be required. Providing more direct community access to an area's natural resources may be beneficial for the community and for determining how resources are locally managed in response to local climate changes.

Finally, it is important to acknowledge that climate change will affect socioeconomic systems at multiple scales (local, regional, provincial, national, and international). A given community's socioeconomic system is embedded within a larger network of socioeconomic systems, and communities are connected to these higher-level socioeconomic systems through institutions. Institutions will thus constitute an important determinant of the degree to which climate impacts are passed from one level to another. Institutions also determine the distribution of entitlements, rights, and powers at various scales of decision making. Therefore, an understanding of climate change impacts at higher scales, as well as the implications for possible institutional changes affecting the linkages and relationships of a community to higher-level systems, may be required for a more complete picture of a particular community's vulnerability.

Thus, a community-level vulnerability assessment should consider the current institutional setting of the community and should identify particular features or characteristics of the institutional context that may pose barriers to adaptation or limit in some way the general capacity to adapt. The following are some of the questions that will help to define a community's institutional context:

- Does the community have sufficient control, autonomy, or influence in areas where it has a direct interest in promoting planned adaptation measures (e.g., land-use change or economic development)?
- Does the community have sufficient resources for adaptation (e.g., revenues, knowledge, and skills)?
- Are the institutions that will primarily influence community adaptive capacity under climate change flexible, efficient, forward-looking, and responsive?

- Do households have sufficient information to adapt?
- Do decision makers have sufficient information to adapt?
- Do institutions allow for managing risk and uncertainty at the community level?
- Are community interests adequately addressed in public policy and decision making in the areas of forest protection, forest management, forest tenure, and land use?

OVERALL ASSESSMENT

The final step of the assessment (step 14) is to organize and summarize the information collected in the previous steps, to provide a basis for drawing conclusions about the extent and causes of vulnerability in the community.

For the purposes of organizing and summarizing the information on forestry-related sources of vulnerability, the community may want to address the following specific questions:

1. Past and current climate: impacts and adaptation
   (a) Impacts on forests
   - Is there evidence that the climate has already started to change in the geographic area of interest?
   - Is there evidence of local impacts on the surrounding forest or environment?

   (b) Social and economic impacts
   - Do the current climate and current climate variability have social and economic implications for the community?

   (c) Current adaptation
   - How does the community deal with current climate and climate variability?
2. Future climate: impacts and adaptation
   (a) Potential climatic impacts on forests
   - What are the best-case and worst-case scenarios in terms of changes in forest ecosystems over time?
   - What are the best-case and worst-case scenarios in terms of changes in wildfire risk (for the forests and for the community) over time?
   - What are the best-case and worst-case scenarios in terms of forest health, insect and disease infestations, and landscape esthetics affecting forests surrounding the community?

   (b) Potential social and economic impacts
   - How will climate change affect the supply of raw materials and other goods and services of importance to the community that are derived from the forests surrounding the community over time?
   - How will climate change affect the local economy over time?
   - How will climate change affect environmental quality, environmental services, and environmental values (e.g., water and fisheries, wildlife, scenic quality and outdoor recreation opportunities, tourism, protected areas, rare and unique ecosystems, traditional and cultural activities) over time?

   (c) Community's capacity to adapt
   - Are there significant factors that may limit the capacity of households, firms, and social and economic systems within the community to adapt to climate change?
   - Does the community have strong and active social networks?

- Are there significant institutional barriers to adaptation?
- In cases where climate change has the potential to increase risk, are households, firms, and organizations aware of these increased risks?

Answers to these questions will give individuals, business leaders, and municipal governments a more informed view of forest-related vulnerabilities to current climate and a better sense of whether vulnerability will increase or decrease over time. This exercise will also help individuals and communities to identify significant factors that are contributing (or that may contribute in the future) to their vulnerability, and hence allow them to begin the process of adaptation.

SUMMARY AND CONCLUSIONS

The goal of this report was to present a framework for assessing some of the ways in which forest-based communities may be vulnerable to climate change. The vulnerability assessment framework described here focuses on the impacts of climate change on forests, the resulting impacts on communities, and the adaptive capacity of those communities. The framework attempts to be holistic with respect to how these various aspects contribute to a community's overall vulnerability. The report does not discuss the assessment of other types of impacts (e.g., on agriculture and tourism, water resources, public health, municipal infrastructure, or building requirements), nor does it discuss the assessment of changes in risk associated with extreme weather events. We acknowledge that the future of rural communities is and will continue to be affected by an array of non-climatic socioeconomic trends (e.g., trade rules, demographic trends, globalization, urbanization, and the emerging knowledge economy). It is suggested that any vulnerability assessment include the development of future socioeconomic scenarios to allow the community to put the impacts of climate change into context with broader socioeconomic changes. Therefore, an assessment using this framework should recognize sources of vulnerability outside the forest sector and should acknowledge that many other non-climatic factors will affect the community concurrently with climate change.

The purpose of the vulnerability assessment described in this document is not necessarily to provide a single value of vulnerability that somehow integrates all of the information described in the assessment framework. Rather, the goal is to systematically identify and assess potential sources of vulnerability and the relative magnitude and timing of factors that contribute to vulnerability. The vulnerability assessment framework and approach described here should assist communities in anticipating and managing change and increasing their level of preparedness.

The approach to vulnerability assessment presented here may be a useful tool that communities can use in anticipating and planning for the risks and impacts (positive and negative) resulting from climate change. Some potential applications of this framework include building awareness at the community level, contributing to municipal or regional planning processes, contributing to forest management policy and planning, contributing to the development of risk management strategies, identifying institutional barriers to adaptation, and identifying program requirements for adaptation.

A number of caveats should be noted. The framework and approach are not intended to be prescriptive in terms of identifying specific adaptation measures. Communities themselves are in the best position to identify and implement specific adaptations. The technical methods described here are not intended to replace local knowledge in deciding how best to respond to climate change. Nor can carrying out an assessment completely identify or eliminate risks to the community. Finally, the framework for vulnerability assessment provided in this report is not intended as a cookbook approach. Communities are diverse, and each has its own needs and resources available for assessment. This diversity makes it difficult to define a single mechanistic approach that is universally applicable. A more general approach is required. The framework presented here identifies and describes various factors and considerations that may contribute to a particular community's vulnerability, but it is up to each community to determine which factors are relevant to its own situation and which methods are most appropriate for obtaining information on various possible sources of vulnerability.

The capacity to understand and assess the future impacts of climate change on biological resources and the consequent impacts on social and economic systems at locally relevant scales is advancing rapidly. Moreover, concepts and methods that support improved assessments of community capacity are improving. These increased capacities and data availability create opportunities for developing a more informed view of the vulnerability of forest-based communities in the future. At the same time, a community may decide that a costly and detailed technical assessment is not required. If so, the framework described here can also be applied using only local knowledge and expert opinion.

Climate change has potential consequences for forest-based communities in Canada. Future climate change may increase hazardous risks (e.g., wildfire, severe weather); change the level and type of economy that can be sustained in communities over time; and affect the health, functioning, appearance, and structure of ecosystems surrounding forest-based communities. Impacts to communities will be diverse, complex, interactive, and cumulative. Moreover, impacts to communities will be both acute and chronic in nature. The requirement for adaptive capacity in communities will increase under climate change.

Adaptation can help to reduce the magnitude of climate change impacts; however, before adapting, communities need a basic understanding of how they may be vulnerable. This report provides a basis for beginning to make decisions and choices. It provides and describes a systematic approach and framework for assessing forest-based community vulnerability to climate change. The framework focuses on past and future climates, forest ecosystem effects, wildfires, impacts on the local economy that might occur as a result of change in surrounding forests, and measuring adaptive capacity. The framework is intended to be a tool that communities can use to assist them in identifying where they are most vulnerable to future climate change.

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